Evaluation of Renewable Energy Sources Exploitation at Remote Regions, using Computing Model and Multi-Criteria Analysis: A Case-Study in Samothrace, Greece

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Abstract-The exhaustion of conventional energy reserves (diesel, coal, gas etc.), coupled with environmental impacts, influence seriously sustainability aspects of the whole planet, both from an economic as well as an environmental point of view. The use of renewable energy resources for electricity generation is being promoted by most countries. The originality of the present study is that the exploitation of Renewable Energy Sources (RES) based not only on economical criteria, which derived from a HOMER software tool, but also on environmental, social and technical criteria using Multi-Criteria Analysis (MCA) for their evaluation. In this paper, a case study for the island of Samothrace, Greece is analyzed. Samothrace has a high potential for energy resource exploitation (mainly Wind and Solar), but has social acceptance problems because of its socioeconomic and environmental situation. The evaluation proposed help to select the most suitable alternatives.

KeywordsMulti-criteria Analysis; Exploitation; Renewable Energy Sources; Complementary evaluation.

1. Introduction

Energy demand is one of the biggest problems worldwide, with enormous implications for the environment, economy and development. The exploitation of Renewable Sources of Energy in the last few years aims not only towards less dependence on traditional fuels, but also protection of the environment. RES have to overcome environmental, socioeconomic, technical, and institutional barriers. However, environmental impacts of renewable energy facilities are rather localized and include extensive land use, landscape alteration, visual change of rural life, noise, etc [1, 2].

The complex issues of RES render the choice between different exploitation proposals a complicated task. Energy planning processes must appreciate the energy demand situation in the region and aim for the satisfaction of future needs, according to many constraints and factors. The aim of this paper is the analysis and development of a multilevel decision-making structure, utilising multiple criteria for energy planning and exploitation of Renewable Sources of Energy at the regional level. A multi-criteria analysis process is usually adopted in order to face complex economic, environmental, and developmental problems [3].

HOMER (Hybrid Optimization Model for Electric Renewables) is a modelling tool that facilitates design of standalone electric power systems [4]. In this paper, the first step is the pre-feasibility study, which was realized using the HOMER software. The second step is the use of decision-making tools under multiple criteria approach intended to aid the decision maker in the creation of a set of relations between various alternatives. The purpose of this study is to propose the most suitable decision among all the alternatives in energy planning and exploiting renewable energy sources at the isolated regions. The novel idea in this paper focused on the combination of multi-criteria decision analysis (MCDA) with the HOMER software. The energy modelling software cannot dwell the multi-dimensionality of the sustainability goals and the complexity of socio-economic and environmental issues. The MCDA analysis is generally accepted that they give the most efficient and satisfactory solution in energy planning. The use of the proposed procedure aims the multidimensional decision-making process regarding the choice of RES for energy supply in isolated regions. A case study for the island of Samothrace, Greece is analyzed, with presentation of the study area and description of the selection criteria, application and results.

2. Methodology

2.1. Energy planning

Energy planning intends to determine the optimal mix of energy sources to satisfy a given energy demand. In the past, energy planning was guided only by technical and economic criteria. Today, the major difficulty is the multi-faceted nature of the problem. We need to take into account the quantitative (economic, technical), but also qualitative (environmental, social) criteria [5]. Specifically for a isolated region that disposes RES, the quantitative criteria for its exploitation concerning the particularities of region acquire distinguished importance.

In this work, a detailed technoeconomic analysis was realized using HOMER software. Useful information about the different computer tools that can be used to analyze the integration of renewable energy there are in the recently reviews by Connolly et al. and Manfren et al. [6, 7]. HOMER (Hybrid Optimization Model for Electric Renewables) is a modelling tool that facilitates design of standalone electric power systems. Many investigators have used Homer in order to find the optimum hybrid system [8-11]. Analysis with HOMER requires information on resources, control methods, energy storage medium and economic constraints. HOMER calculates the total NPC using the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{1}$$

where$C_{ann,tot}$ is the total annualized cost (€/yr), CRF is the capital recovery factor, i is the interest rate (%) and Rproj is the project lifetime (yr). The CRF is given by

$$CRF = \frac{i(i+1)^{R_{proj}}}{(i+1)^{R_{proj}} - 1} \tag{2}$$

HOMER defines the levelized COE as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}} \tag{3}$$

where$C_{ann,tot}$ is the total annualized cost ($/yr), $E_{prim,AC}$ is AC primary load served (kWh/year), $E_{prim,DC}$ is DC primary load served (kWh/year), $E_{grid,sales}$ is total grid sales (kWh/year).

The simulations with Homer, give only technoeconomic results. In order to considerate and the qualitative criteria, a multi-criteria decision analysis (MCDA) system developed. The results, which derived from Homer, are used as input parameters in the MCDA system. The combination of the two parts, Homer and MCDA system, is capable of facing the complicated problem.

2.2. Procedure definition

This methodology gives considerable information to the decision-maker to estimate the energy from RES that can be produced in the studied area, according to preliminary objectives. This procedure is addressed to give the initial elements to map out strategies for the best RES exploitation in a region, which fits demand and supply according to the many constraints and factors.

In any case, the aim is not only to ensure that local needs are met, but also to examine the possibility to produce the maximum possible energy from RESs. Concluding alternative scenarios can be derived from the goal set identified by the decision-maker, with regard to the environmental, social, economic, and technical restrictions. The procedure consists of the definition of set actions to be assessed in the methodology development. It is fundamental because the selected actions have to synthesize the state of the art, as regards environmental, socio-economic, technical issues at different levels of intervention. In this manner, the decision makers can have a complete framework of different performances of planning alternatives (Figure 1).

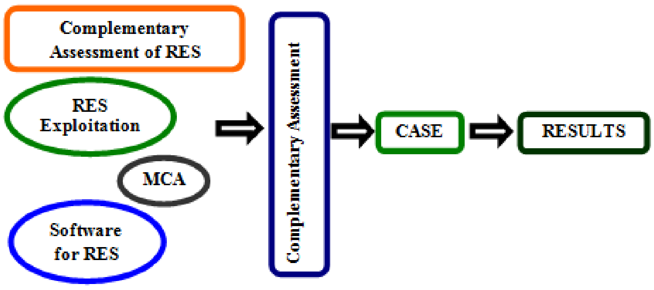

Fig. 1. The decisions analysis for regional energy planning.

The preliminary step is to formulate a set of criteria to eliminate inappropriate regions of RES development and to identify the appropriate regions for RES facilities location. More precisely, the approach involves:

- The procedure of define a series of criteria in order to eliminate the inappropriate areas.
- The identification of the appropriate sets of criteria using previous experience with the intention to limit the number of criteria.
- The grouping of these criteria according to the type of regions' characteristics.
- The definition of the weights for each group of criteria and for each individual criterion within these groups [12].

A MCDA system is based on a methodology with the main objective of development of RES exploitation maps. The procedure aims to propose a system that can be used to produce an overall RES potential map for the Region under study. This can be described as a regional-scale decision support system. There are two main steps in the proposed methodology:

1. Identification of criteria capable of describing the various constraints related to wind facilities installations as first RES. (Table. 1)

2. Translation of these criteria into a map.

The system is based on a GIS platform, taking advantage of its spatial calculation and visualization capabilities. The overlay of maps representing competing land use activities based on the constraints and various special protection subject areas leads to the identification of areas suitable for wind energy facilities installation. Consequently, the total area of the case study region is reduced by competing land-use requirements like industrial and residential areas and transportation infrastructure. The wind energy potential for the remaining areas is calculated based on the density of wind generators per unit area (Km^2), as defined by the Special Framework of Regional Planning and Sustainable Development for Renewable Energy, Ministry of Environment, Greece, 2010.

Table 1. Definition criteria for the elimination of inappropriate areas for Wind facilities installation

Environmental constraints criteria	**Landuse criteria**
1. Special protection area 2. Airports 3. Hilly forests 4. High-voltage lines 5. Landslide risk 6. Nature parks 7. Large common rural landscapes 8. Industrial landscape units 9. Urban landscape units 10. Rural landscape units with heritage value 11. Linear features with heritage 12. View shed of classified monuments	1. Industrial landscape units 2. Urban landscape 3. Proximity to roads 4. Proximity to railroad 5. Heritage landscapes 6. Highly sensitive landscapes and territories 7. Large common rural landscapes

To evaluate the capacity of land areas for grid-connected photovoltaic (PV) power plants, an MCDA method integrated with GIS is proposed. It is thus possible to obtain continuous suitability maps, and to provide an optimal framework for the integration of the environmental, economic, and social factors that affect land suitability for a specific use.

These maps show the best locations for the installation of new renewable energy facilities. They are produced in accordance with GIS procedures specially designed for the creation of specific criteria and attribute maps, the pair-wise comparison of criteria, the selection of global relative weights for each criterion, and criteria aggregation. All the procedures are contained within the GIS platform [13].

The MCDA system adopted for the selection of geographical locations for the installation of renewable energy facilities concerns Wind, Photovoltaic (PV), and Hydro and Biomass RESs. The system combines multi-criteria analysis and the analytic hierarchy process with geographical information systems (GIS) technology [14]. In addition, MCDA methodology is used to identify the geographic distribution of economically exploitable biomass and hydropower potential using remote sensing and GIS [15, 16].

In conclusion, we now know the alternatives to be evaluated for the possibility of RES exploitation. More precisely, wind potential related to the optimal area disposed for wind power production, potential from optimal sites of grid-connected Photovoltaic power plants. Last step it contains an assessment of best alternatives or different combinations for RES exploitation in the region.

3. Description of Evaluation Criteria

After evaluation of theoretical potential derivate from RES exploitation, related to area disposable in the region, we select criteria to determinate the RES and the degree of its exploitation in depth time and aiming the max penetration of RES in an energy mix. The process to select criteria for best exploitation of RES in a region needs the following requirements:

- Compatibility with environmental and ecological constraints.
- Compatibility with economical, political, legislative, and financial situation at regional level.
- Compatibility with the local socioeconomic conditions.
- Consistency with the technical conditions.
- Constraints, which there are in the investigated area.

The following criteria are identified (Table 2). The criteria chosen for this study can be classified in five groups: economic, environmental, social, technical - technological, and others criteria. These can be subdivided into factors, which are those attributes of the land area that best characterize the suitability of an alternative in reference to the activity.

3.1. Economic criteria

Investment cost. Manifest of all costs, such as purchasing equipment, installations, connections to the central grid and roads construction, engineering services, legislative authorisation, and unforeseen work.

Net present cost (NPC). The total net present cost of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

Operation and maintenance costs. The total operation and maintenance cost of the system is the sum of the operation and maintenance costs of each system component.

3.2. Environmental criteria

Greenhouse gas (GHG) emission reduction. Energy production is the biggest cause of GHG emissions. RES exploitation is an essential means of mitigation of GHG emissions. This constitutes several criteria for the reduction of six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) because they have a direct impact on human life and an indirect impact on society [17, 18].

Table 2. Groups of criteria.

Economic criteria	**Environmental criteria**	**Social criteria**	**Technical technological criteria**	**Others criteria**
Investment cost	Land use	Job creation	Efficiency	Safety
Net present cost (NPC)	Visual impact	Social benefits	Availability	Reliability
Operation and maintenance cost	Greenhouse gases (GHG) emission reduction	Social acceptability		

Land use. The land required for the RES facilities and the land required for energy supply systems with biomass. The surrounding landscape and environment are strongly affected by the land occupied by energy installations. Land use can also be a social criterion to evaluate the energy system [19].

Visual impact. RES production systems require a larger use of land compared to conventional sources. Consequently, the visual impact of the RES facilities can be substantial, and capable of prompting negative public reactions [20].

3.3. Social criteria

Social acceptability. The opinions related to the energy systems of the local population regarding the hypothesized realization of the projects under review. It is extremely important since the opinions of the population and pressure groups may heavily influence the amount of time needed to complete an energy project. Social acceptance is not expressed as a measurable figure [21].

Job creation. Energy supply systems employ many people during their life cycles, from construction and operation until decommissioning. The energy systems are closely related to the society. Societies, in which energy systems were established, based their development and prosperity on them for many decades. Sustainable energy systems create more jobs for people and improve their living quality. In the MCDA process of local governments, the job-creating ability of energy systems is considered and selected to evaluate their contributions [3].

Social benefits. These criteria express the social progress in the local regions by introducing an energy project, especially in the less developed regions. Social benefit is also a qualitative criteria and not expressed as a measurable figure [21].

3.4. Technical - technological criteria

Efficiency. Refers to how much useful energy that can be obtained from an energy source. This is measured by the efficiency coefficient, which is the ratio of the output energy to the input energy.

Availability. An important criterion of the evaluation of energy systems is the availability of energy sources that supply the system: either traditional fuels (solid, liquid, gas) or renewable sources (wind, sun, hydrodynamic, biomass etc.).

3.5. Others criteria

Safety. Continuous changes in technology, environmental regulation, and public safety concerns make the analysis of the safety of energy systems more and more demanding. The safety of energy systems is vital to society, national development, and people's lives [21].

Reliability. Reliability of energy systems is the capacity of a device or system to perform as designed and its resistance to failure [21].

4. The Regime Method

Energy planning is a field very conducive to MCDA methods. Many applications of MCDA methods for energy planning problems have been published in recent decades. The aims of multi-criteria decision-making methods are generally:

- To aid decision-makers in consistency,
- to uniquely use data and transparent assessment procedures,
- to increase the efficiency of the decision processes.

The proposed methodology is based on the Regime method. The following paragraphs will describe the steps, which characterize the Regime methodology in detail. Regime is a MCDA qualitative method based on the possibility of partial compensation among the different criteria, which affect the evaluation of the various policy alternatives. MCDA qualitative methods are used when some or all data are not available in quantitative terms, and qualitative criteria and measurements must be applied.

Decision makers are frequently faced with circumstances where the information in the performance matrix, or about preference weights, consists of qualitative judgements. Regime is a partially compensatory method, which allows some degree of compensation among criteria. Regime is also a discrete method, that is, which compares a finite set of alternatives. It can use binary, ordinal, categorical and cardinal (ratio and interval rate), and mixed information. Qualitative information is transformed into quantitative in order to be analyzed more easily. It is a concordance analysis, meaning that it is based on pair wise comparison between alternatives according to some chosen criteria in order to establish a rank between them. Regime uses an impact matrix and a set of weights as input. The first gives information about the impact of the alternatives in relation to the chosen criteria. The weights express the (politically determined) relative importance of the criteria. The impact matrix indicates the performance of each alternative according to each of the chosen criteria.

As well as Electre and Promethee, Regime is a concordance method. Pair wise comparison between the set of alternatives according to each criterion are carried out. For each pair of alternatives i and k, the criteria are selected, for which alternative i is better or equal to alternative j. We call the set of these the criteria concordance set. The criteria according to which an alternative j is worse or equal to alternative i is called the discordance set. Then, the alternatives i and j are ranked by means of the concordance index C_{ij}, that is, the sum of the weights attached to the criteria according to which alternative i is better or equal to alternative j. Then the concordance index C_{ji} is calculated, which is obtained by summing up the weights of the criteria according to which alternative j is better or equal to alternative i.

Finally, the net concordance index is calculated subtracting C_{ji} from C_{ij} ($ì_{ij} = C_{ij}-C_{ji}$), which is positive if alternative i is preferred to alternative j. It must be noted that, since in most cases only ordinal information is available on the weights, but not trade−offs the net concordance index only indicates whether an alternative is preferred to another, but not by how much. Since sometimes it is not possible to obtain a complete ranking of the alternatives using only ìij's sign, a performance indicator p_{ij} is formulated for the criterion i with respect to the criterion j, which indicates the probability that an alternative is preferred to another one, that is, that the net concordance index is positive: p_{ij}=prob (ìij>0). Using the performance indicator, an aggregate probability index can be defined, which indicates the performance score: Next, we define an aggregate probability measure, which represents the performance score:

$$p_i = \frac{1}{I-1}\sum_{j\neq i} p_{ij} \tag{4}$$

where i is the number of chosen alternatives. p_{ij} and of pi are estimated using a specific probability distribution of the set of feasible weights. Regime is a relatively easy method to use, provided that one can have access to user−friendly software. However, it presents the same difficulties of many other MCDA methods: the determination of alternatives, criteria and weights entails a high degree of subjectivity although at the same time this subjectivity can also be made more explicit by the same implementation of the method. Regime is a useful instrument to support a policy process. It offers a structure that helps to gather information on the different impacts of alternative policies. Using the software, the ranking process becomes easy.

The most important difficulty is the determination of the weights, because it is very difficult to reach a consensus among the stakeholders on that and is mainly a political problem rather than a technical one. Similarly, to the other MCDA methods, Regime can be used to assess the sustainability of alternative policy options. In fact, the criteria used in the analysis can represent and include aspects from the three dimensions of sustainability, that is, the environmental, the social and the economic one. As all MCDA methods, Regime helps to structure the evaluation process and the information gathering. The most important advantage of Regime is that it can use different types of information. This flexibility is very important with real world cases, where there is complexity and many data are not available in quantitative terms [22].

5. Case Study

5.1. Area of study

Samothrace (40°29′N, 25°31′E) is a small Greek island situated in the northern Aegean Sea (Fig. 2). The island is 17 km long, covers an area of 180.364 square and has a population of 2723 (2001 census). Its main industries are fishing and tourism. The island presents big tourist development during the summer months (59360 visitors in 2008) due to its appreciable natural resources. According to Fantidis et al. [23] the expected load consumption profiles is shown in Fig. 3.

Fig. 2. Location of the Samothrace Island.

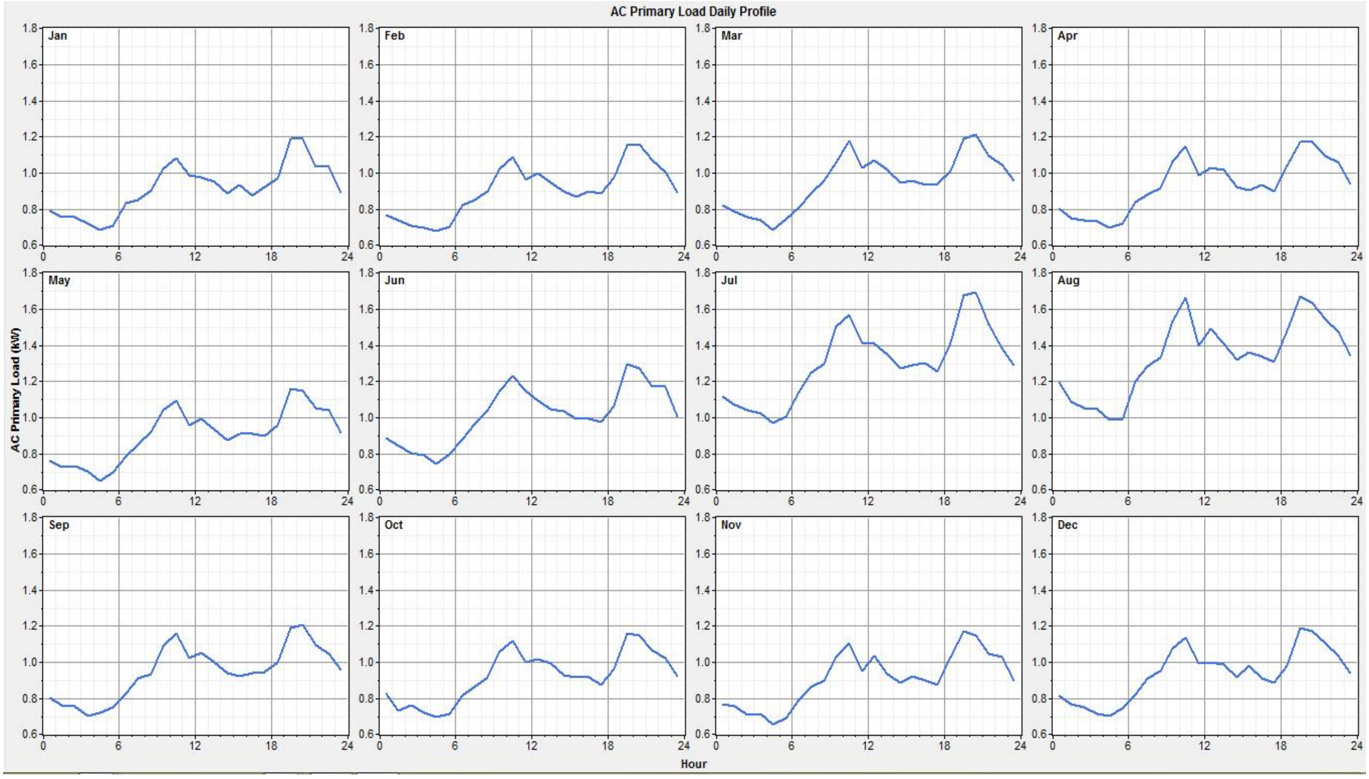

Fig. 3. Expected yearly load consumption profile in Samothrace.

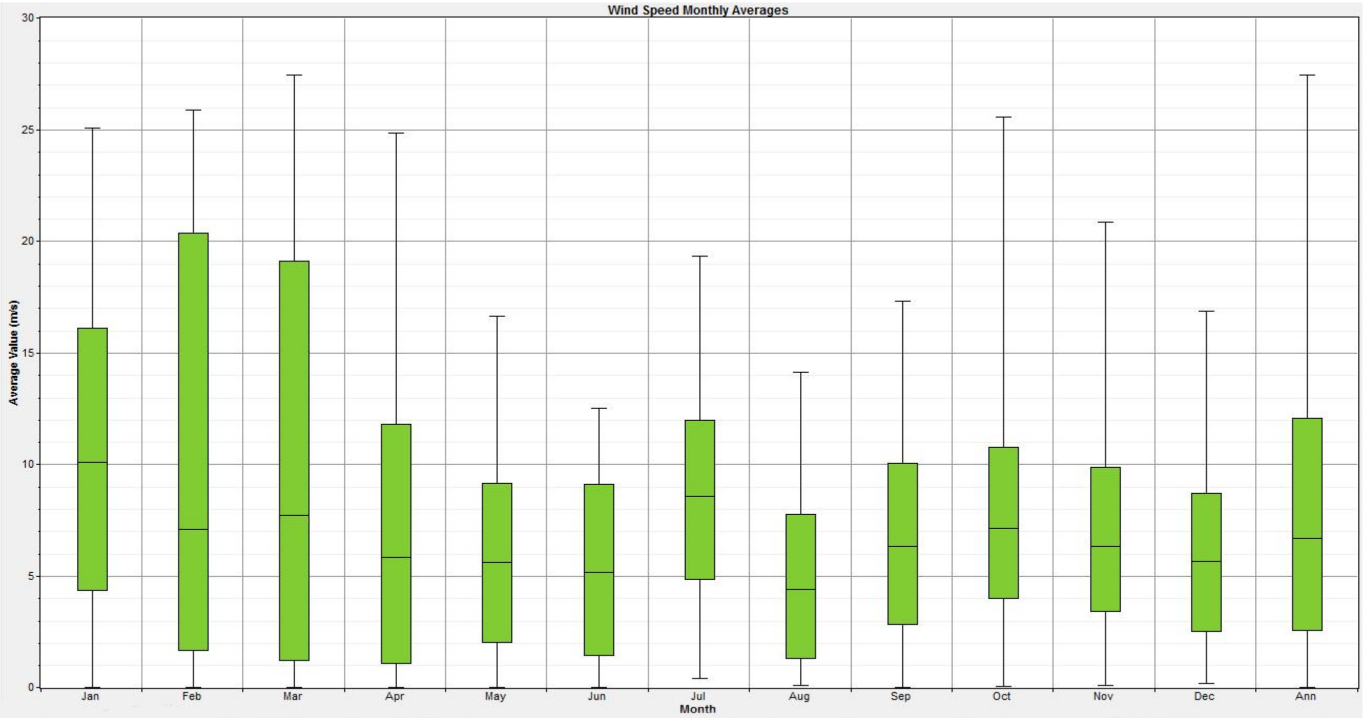

Fig. 4. Monthly average wind speeds in Samothrace.

5.2. Meteorological data and performance

The performance of a hybrid Wind-PV system is strongly dependent on the climatic conditions and accurate weather data in a targeted location is essential. The CRES is a source for these data [24]. CRES (Centre for Renewable Energy Sources and Saving) is the Greek national entity for the promotion of renewable energy sources, rational use of energy and energy conservation.

The average monthly and yearly wind speeds at this location are given in Fig. 4. In the present study, wind turbine of 330 kW from Enercon is used (Table 3). Calculated power curve of the Enercon E33 wind machine according to the constructor is shown in Fig. 5. Enercon E33, has 33.4 m rotor diameter and hub height equal to 50 m [25].

The average daily solar radiation and the average daily clearness index at Samothrace are given in Fig. 6. The derating factor was taken as 0.9 and PV panels are rotated about both horizontal and vertical axes so that the sun's rays are always perpendicular to the surface. Each of the utilized PV modules has a rated power of 280 W and the shown in Table 4 specifications [26]. Table 5 shows the technical data for the inverters [27].

The system control parameters used in this investigation are summarized in Table 6. The project life time has been considered to be 25 yr and the annual real interest rate has been taken as 6%. The cost data of the PV panels, wind machine, batteries, and power converter considered in this study, were collected from market and literature research and are depicted in Table 7 [8, 28, 29, 30].

Numerous simulations for various scenarios have been made by considering different combinations of wind generators and PV panels with battery restore. Based on the HOMER modelling, the optimum PV-battery, wind-battery, and hybrid wind-PV-battery system for the Samothrace are given in Table 8. It is revealed that the hybrid wind-PV-battery system is the most economic feasible system.

Table 3. Wind turbines specifications

Item	**Specification**
Manufacturer	Enercon
Rotor diameter	33.4 m
Hub height	50 m
Number of blades	3
Blade material	GRP (epoxy resin)
Swept area	876 m^2
Rotational speed	Variable, 18 – 45 rpm
Cut-out wind speed:	28 – 34 m/s
Quantity	9 (Wind–PV–Battery mode) 23 (Wind –Battery mode)

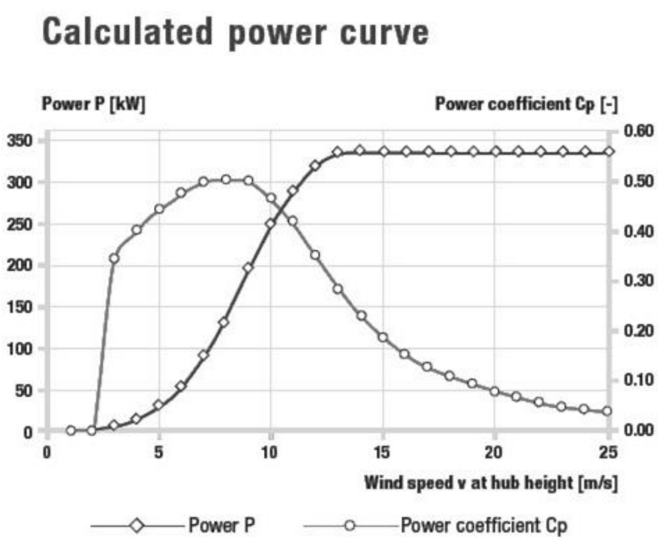

Fig. 5. Enercon E-330 wind turbine power curve.

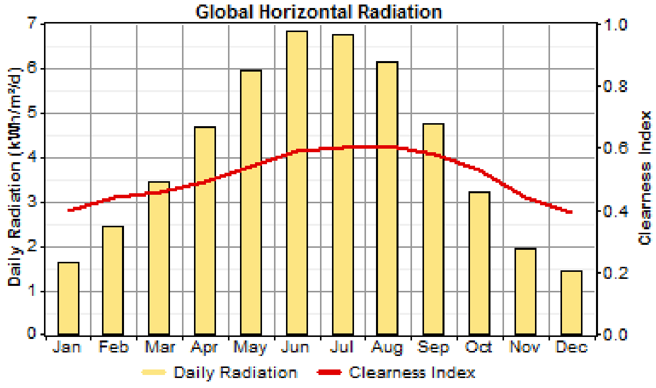

Fig. 6. Monthly variation of global radiation and monthly average daily clearness

Table 4. PV module specifications

Item	**Specification**
Manufacturer	Exiom Solution
PV module type	Mono-Si
Module number	EX-280M
Nominal efficiency	14.5%
PV module rating	280 W
Maximum power voltage	36.8 V
Maximum power current	7.61 A
Open circuit voltage	43.8 V
Short circuit current	8.52 A
Dimensions	1956×992×45 mm
Weight	26 kg
Quantity	6071 (Wind–PV–battery mode) 18928 (PV–Battery mode)

Table 5. Inverter specifications

Item	**Specification**
Manufacturer	SMA solar technology
Module number	Sunny Mini Central7000TL
Rated output power (@230 V, 50 Hz)	7000 W
Maximum output current	31 A
Efficiency	97.7 %
Dimensions (W×H×D)	468×613×242 mm
Weight	32 kg
Quantity	214 (Wind–PV–Battery mode) 443 (Wind–Battery mode) 185 (PV–Battery mode)

Table 6. Constraints used in software Spinning reserve inputs in software

Parameters	Value
Minimum battery life	N/A
Maximum annual capacity shortage	10%
Percent of annual peak load	0%
Percent of hourly load	5%
Percent of hourly solar output	50%
Percent of hourly wind output	50%

Table 7. Components of the hybrid system analysis

Characteristics	**PV module**	**Wind turbine**	**Battery**	**Converter**
Model	Typical	Enercon E-330	Hoppecke 20	Typical
Power	1 kW	330 kW	Nominal voltage: 2V	1 kW
Life time	25 year	25 year	Lifetime throughput 8518kWh	25 year
Price	3500$/kWp	264000$/turbine	1500$/battery	400$/kW
Replacement	3500$/kWp	210000$/turbine	1000$/battery	250$/kW
Maintenance	3$/kW	5280$/turbine	10$/battery	1$/kW

Table 8. The comparisons among the optimized hybrid options

Options	PV (MW)	Enercon E-330	Battery Hoppecke 20	Converter (MW)	Initial capital (X$10^3$$)	Operating cost (X$10^3$$/year)	Total NPC (X$10^3$$)	Cost of energy ($/kWh)
Wind–PV–battery	1.7	9	3800	1.5	14626	142	16447	0.236
Wind–battery		23	6800	3.1	17512	282	21128	0.305
PV–battery	5.3		8000	1.3	31070	268	34496	0.497

5.3. Application of the REGIME multiple criteria evaluation method

The present section elaborates on the application of the above methodological framework in the problem at hand. As long as alternatives have been already defined (Wind, PV, combination Wind-PV), evaluation criteria are considered. The evaluation criteria are presented in Table 9. Based on the alternatives criteria proposed, the impact matrix has been constructed (Table 10). Elements of this matrix reflect the benefit of each alternative RES with respect to each criterion. The benefit matrix is the main input into the REGIME multiple-criteria evaluation method.

Moreover, the priorities of these criteria are considered (Table 11) reflecting the relative importance of each criterion according to socioeconomic factors, high potential of energy resources, environmental issues of the island and technical-technological relative to energy sources. Results obtained by the multi-criteria evaluation are shown in Fig. 7. According to these results, the combination of Wind-PV-battery is the best followed by Wind-battery and PV-battery.

Table 9. Evaluation criteria

a/a	**Criterion**	**Criterion description**	**Measurement scale**	**Criterion direction**
K1	Economic benefits for the region	Express the economic progress made in the region by RES exploitation	- - - / + + +	Benefit
K2	Employment in the energy sector	Increase of employment during construction and operation period of RES facilities	Ordinal	Benefit
K3	Creation of development	Theroleofenergy systemsasdevelopment poles of the greater region	- - - / + + +	Benefit
K4	Land used	Land used for RES facilities	- - - / + + +	Benefit
K5	Social acceptability	Express the opinion for the RES development by the local population	Ordinal	Cost
K6	Environmental quality	Impact on the environmental quality	Ordinal	Cost
K7	Visual impacts	Visual disturbance by the RES facilities on the landscape	Ordinal	Cost
K8	Impacts on flora/fauna	Impacts related to RES facilities operation	- - - / + + +	Cost
K9	CO_2, SO_2, NO_x emissions	CO_2, SO_2, NO_x mitigation potential	Ratio	Benefit
K10	Efficiency	Useful energy obtained from energy source	Ratio	Benefit
K11	Safety	Public safety	Ordinal	Benefit

6. Conclusion

In the present study, a techno-economic feasibility of stand-alone, renewable energy systems to meet the electricity requirements of a typical small island of Greece was investigated. HOMER was used for the analysis, and viability was determined based on NPC and COE. From this study, it is clear that the optimized Wind-PV-Battery hybrid system is more cost effective compared to Wind-Battery or PV-Battery systems for the load with 10% annual capacity of shortage.

However, such problems are multidimensional in nature, requiring an integrated approach to problem solving which takes into account, economic, social, environmental, and other aspects. In such a framework, multi-criteria evaluation has proved to be a useful tool, as such studies need to take into consideration both quantitative and qualitative aspects. The established framework, which is based on the REGIME method, highlights the main procedural characteristics of decision-making and adopts an analytical approach with respect to the optimal exploitation of RESs. It was shown that, due to the multi-faceted nature of RESs and the specific difficulties associated with the coexistence of diverse activities in certain areas, their exploitation is best promoted through a step-by-step approach. Results obtained by the multi-criteria evaluation show that the wind-PV-battery system is the most efficient RESs in the region under consideration, followed by wind-battery and PV-battery systems, according to the evaluation criteria which used.

Table 10. Impact matrix

AlternativesCriteria	**Wind-P/V**	**P/V**	**Wind**
K1	+ + +	++	+ +
K2	+ + +	+	+ +
K3	+ +	+ +	++
K4	3	1	2
K5	2	2	1
K6	2	2	2
K7	2	2	1
K8	2	2	2
K9	3	2	2
K10	3	2	1
K11	3	2	2

Table 11. Priorities of criteria used

Criteria Priorities	**Groups of criteria**
Social criteria	K2, K5, K4
Economic criteria	K1, K3,
Environmental criteria	K6, K7, K8, K9
Technical- technological criteria	K10
Others criteria	K11

Table 12. Priorities of criteria used

Criteria Priorities	**Groups of criteria**
Social criteria	K2, K5, K4
Economic criteria	K1, K3,
Environmental criteria	K6, K7, K8, K9
Technical- technological criteria	K10
Others criteria	K11

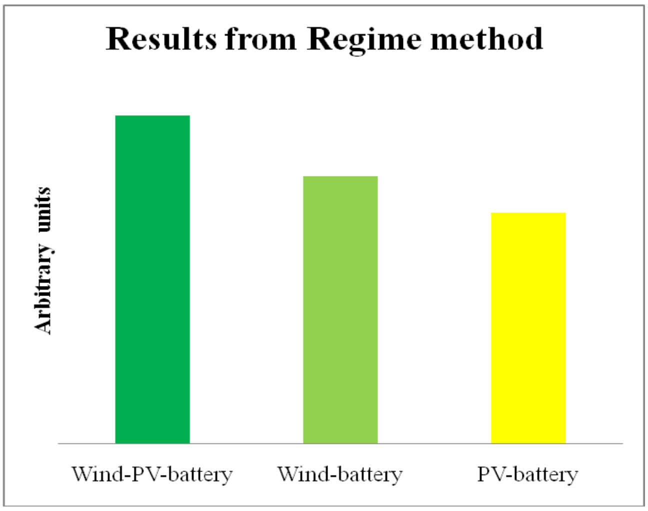

Fig. 7. Results by use of the REGIME method.

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