ELSEVIER

Energy Policy 33 (2005) 235–244

ENERGY POLICY

www.elsevier.com/locate/enpol

A multicriteria approach to evaluate wind energy plants on an Italian island

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Abstract

The decision-making process regarding the choice of alternative energy is multidimensional, made up of a number of aspects at different levels—economic, technical, environmental, and social. In this respect multicriteria analysis appears to be the most appropriate tool to understand all the different perspectives involved and to support those concerned with the decision making process by creating a set of relationships between the various alternatives. The main aim of this paper is to make a preliminary assessment regarding the feasibility of installing some wind energy turbines in a site on the island of Salina (Aeolian islands—Italy). Thus, a multicriteria method will be applied in order to support the selection and evaluation of one or more of the solutions proposed. Having analysed the local environmental conditions and its energy profile, four wind turbine configurations were postulated as options. These options were then appraised by comparison against a family of criteria and calculations were performed using a multicriteria algorithm to rank the solutions, from the best to worst. The option at the top of the ranking refers to the installation of a plant of 150 kW and this emerged as the right *compromise* between the costs of realization, local energy requirements and the need to conserve the area and the environment especially in view of the high/medium-bracket tourism business on the island. The sensitivity analysis performed subsequently backed up the findings. As this work demonstrates, multicriteria analysis can provide a valid tool to aid decision making for achieving targets relating to more sustainable green energy.

Keywords: Multicriteria; Wind energy; Renewable energy sources

1. Introduction

Renewable energy sources (RES) catalysed the interest of the public and the institutions at the beginning of the 1970s when they were known as *complementary* (and therefore subordinate to fossil fuels). Rather than being a "reality" in industrial terms they represented the "hoped for" solution in the search for an alternative energy supply as a consequence of the oil crisis. During these years, decision makers and energy planners mainly concentrated their efforts on the development of econometric models aimed at interpreting and analysing the interrelations between energy and the related economic sector. In that phase of economic development modelling was oriented towards increasingly accurate forecasting of future movements in energy demand and at analysing the technological options for the most efficient energy production.

In the 1980s interest in the RES started to fade and this can be attributed to the stabilization of the oil market and the record minimum price for crude recorded in that period (Lorenzoni, 1997, p. 5). The low price for crude led energy producing companies to intensify their investments in the fossil fuel sector.

In the early 1990s, when the 1973 crisis seemed a distant memory, the energy problem cropped up again. This time it was connected above all to its impact on the environment in global and local terms and thus renewable energy recaptured the attention of politicians and decision makers. This intense attention directed towards the environment gave priority to those RES that would have a minimal impact not only on the environment, but also on health and the quality of life. Therefore, this growing awareness of the environmental problem partially modified the traditional decision making structure in the energy field. Indeed, the need to insert strictly environmentally related considerations into

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0301-4215/$ - see front matter
doi:10.1016/S0301-4215(03)00228-3

energy planning resulted in the adoption of multicriteria decision models. Various studies have been developed to illustrate the potential applications of this approach: for the evaluation of energy options when compared to a set of criteria and in order to make the choices clearer (Siskos and Hubert, 1983; Roy and Bouyoussou 1986; Georgopoulou et al., 1998; Goumas and Lygerou, 2000; for the assessment of geothermal energy projects (Goumas et al., 1999); for the siting of power plants (Barda et al., 1990); and for the evaluation of energy strategies for small islands (Cavallaro, 1999).

The central aim of this work is the application of a multicriteria method to aid the evaluation of a number of energy solutions regarding the installation of wind turbines. Accordingly, the first part of this work introduces the aspects related to methodology while the second illustrates the application of a case study on the island of Salina (Italy) followed by a discussion of the results obtained from this analysis.

2. Multicriteria evaluation approach

The use of decision making tools under a multicriteria approach are intended to aid the decision maker in the creation of a set of relations between various alternatives. A decision support system can be defined as an interactive system that is able to produce data and information and, in some cases, even promote understanding related to a given application domain in order to give useful assistance in resolving complex and ill-defined problems. Decision making processes are analysed from different viewpoints and the implementation of analytical methods and models and support tools must take into consideration not only the organizational structure in question, but also the procedures, processes and the dynamics of the decision makers involved. At the core of classic decision making tools lies the idea that for any given problem there is only one solution (the optimum). In Roy's opinion a *decision procedure* is not a valid one if it is based on the principle of discovering pre-existing truths or on mathematical convergence (the decision will reach an optimum) (Roy, 1985, 1996). The final solution according to Roy is a *creation* rather than a *discovery* (Roy, 1985, 1990). Thus the main objective of a *Multiple Criteria Decision Aid* (MCDA) is to build or create a support tool for decision makers that conforms to their objectives and priorities (a constructive or creative approach) (Roy, 1990, p. 28). The "ideal" solution, the option that performs best for *all* the criteria selected, is difficult to achieve. Therefore it is necessary instead to find a compromise from among the different hypothetical solutions. It is for this reason that a choice resulting from MCDA is "justified" and not "optimum".

We outline below the main steps relating to the formulation of a multicriteria problem:

(1) *Defining the nature of the decision.* Here the problem is to come up with, as an end result, an order of merit of admissible actions ranking them from the best to the worst (ranking of alternatives). The actions are compared and grouped into classes of equivalence, after which they are sorted partially or completely in accordance with the model of preferences.
(2) *Selecting potential actions.* The decision making procedure under MCDA normally involves making a choice between different elements that the decision maker examines and assesses via a set of criteria. These elements are part of an overall set of *actions or alternatives*.
(3) *Defining a set of criteria*. The criteria represent the tools which enable alternatives to be compared from a specific point of view. It must be remembered that the selection of criteria is of prime importance in the resolution of a given problem, meaning that it is vital to identify a coherent family of criteria and not just any set of criteria whatsoever (Bouyssou, 1990, pp. 58–68).
(4) Once the set of criteria and the alternatives have been selected then the *payoff matrix* is built. This matrix tabulates, for each criterion–alternative pair, the quantitative and qualitative measures of the effect produced by that alternative with respect to that criterion. The matrix may contain data measured on a cardinal or an ordinal scale.
(5) *Aggregation of preferences and comparison of criteria: outranking relations*. Under this procedure comparisons are first of all made between all pairs of admissible actions to obtain binary relations and then these results are grouped together.

Energy planning involves making many value judgements regarding technical, socio-economic, and environmental issues. Therefore, reaching clear and unambiguous solutions may be very difficult. It is from this difficulty that the need arises to develop a tool for resource planning and management. Such a tool should enable the policy maker to draw up a series of alternatives (based on a variety of, often conflicting, viewpoints) and to choose the best "compromise", i.e. the one held to be the most acceptable. The work involved in seeking a compromise solution requires an adequate assessment method and there are many multicriteria methods available that appear to be admirably suited to handle this task. The most important belonging to MCDA are the following: the ELECTRE family developed by Roy B. and his co-workers, PROMETHEE (Brans), ORESTE (Pastijin and Leysen), MELCHIOR (Leclercq), QUALIFLEX (Paelink), REGIME (Hinloopen, Nijkamp, Rietvald), MACBETH

(Bana e Costa, Vansnick), N-TOMIC (Massaglia and Ostanello) (Maystre et al., 1994, pp. 15–16). Often these methods require a decision maker to assign preference weights to the attributes involved in the decision process. Therefore, it is desirable to use an MCDA approach that has minimal dependence on preference weight input.

3. Fuzzy-sets and the NAIADE method

In this paper the NAIADE method (Munda et al., 1994, 1995; Munda, 1995; software developed by JRC UE, Ispra-VA) has been used. This method may include crisp, stochastic, and fuzzy information regarding the measurements, relative to the performance of the alternatives n with respect to the criteria gm, without using traditional weighting of criteria. Through the specifications of the preferences relating to the criteria and the minimum requisites of acceptance, NAIADE generates an order of merit of the various alternatives (problem of type γ) (Roy, 1990, p. 32) and also enables an analysis to be carried out of the "conflict" between the various interest groups and the formation of possible coalitions concerning the various alternatives proposed. The method lends itself well to the resolution of problems of environmental-energy management characterized by various degrees of imprecision of the variables taken into consideration.

The multicriteria evaluation method is based on the comparison of pairs of alternatives. This comparison is based on user preferences for each criterion, defined as *preference relations.* These establish, for each criterion, by how much one passes from truth to non-truth in the affirmation that one alternative is better than another. The method is based on fuzzy binary relationships that will be used to model different possible situations of preference or of equality. On the basis of the fuzzy relationships, membership functions are built according to a set of equations. Subsequently, given the information of the various performances of the alternatives for each criterion, it becomes necessary to aggregate these evaluations for the purpose of considering all the criteria simultaneously. The index $\mu^*(a,b)$ gives the value of the intensity of the preferences of one alternative over another in the whole set of criteria (Munda et al., 1995). The asterisk indicates the fuzzy preference relations (much better, better, approximately equal, equal, worse, much worse). The information relative to the diversity of the preferences among the single relations, according to each criterion, is expressed by the *index of entropy* $H^*(a,b)m$ (Munda, 1995). Lastly, the *truth indexes* τ for each pair of alternatives **a** and **b** are built by a linguistic operator in order to verify, according to the majority of criteria, by how much **a** is better than, indifferent to, or worse than **b** (Munda, 1995). An in-depth explanation of NAIADE together with a complete description of the multicriteria method and procedure (with all its formal properties and its application to various real-life cases) can be found in the literature (Munda, 1995; Haastrup et al., 1998; Fabbri, 1998).

Once the global values of the intensity of preferences, $\mu^*(\mathbf{a},\mathbf{b})$, and the relative entropies $H^*(\mathbf{a},\mathbf{b})m$ have been obtained then an iterative process is carried out and the indexes ϕ^+ and ϕ^- are calculated for each action. The ϕ^+ is the positive outranking flow and it expresses how an alternative a is outranking the others it is based on how much alternative a wins. The negative outranking (ϕ^-) flow expresses how an alternative a is outranked by the others, it is weakness of a (Brans and Mareschal, 1998, p. 8). For further details see Bouyssou and Perny (1990).

The ascending and the descending ranking with respect to these indexes are obtained and the *final ranking* is derived as a result from their intersection.

4. Wind turbine technology by means of multicriteria decision support: a case study of an island

As outlined briefly above, the evaluation approach used in this analysis is applied to a case study in the part that follows. First of all, the general characteristics of the site will be described in order to then illustrate the alternatives proposed and the results obtained.

4.1. Site characteristics and location

Salina is part of the Aeolian Archipelago (Italy). The islands around Sicily present a great diversity of natural habitats probably as a result of a combination of factors related to their climate and their geographical nature and position. These features, which are extremely rare in the Mediterranean, have influenced the biological and human colonization that is characteristic and peculiar to the small islands of Sicily.

The island's geographical position is latitude 38°37′00″ North and longitude 2°26′30″ East (Mount Mario). It is trapezoidal in shape and has a surface area of 26.75 km^2. The distance from East to West is about 7 km and about 5 km from north to south. The steep volcanic cones, Fossa delle Felci (962 m) and Monte dei Porri (860 m), are two of the highest peaks of the archipelago, and they are separated by a deep valley called Valdichiesa (290 m). The island is rugged in its overall appearance with a coastline characterized by high cliffs. Its climate is arid, due to the scarcity of rainfall, the average annual temperature is approximately 18.2°C and average annual humidity is 71%. The prevailing wind directions are north westerly (maestrale) and south easterly (scirocco).

4.2. Economic aspects

In the past, the prevailing economic activities were agriculture and fishing. The level of agricultural activity has varied; influenced by fluctuations in the population. The fishing industry, with few exceptions, has been in decline and as the slump still endures its contribution to the local economy is rather limited.

Economic activity on the island of Salina is concentrated almost exclusively around tourism and connected activities. The local workforce is mainly employed in residential construction work in winter and in tourism during the summer season. As a consequence of this other traditional areas of economic activity have been almost totally abandoned. An awareness of the factors linked to the local economy is essential in order to appreciate the phenomena connected with energy production and consumption.

4.3. Electrical energy production and consumption

Each of the Aeolian islands is equipped with an autonomous diesel power station for the production of electricity and therefore none are linked up to the mainland grid. These plants have a high industrial production cost (higher than the national grid) mainly due to the cost of transporting fuel from the mainland and other factors relating to the infrastructure that affect the production efficiency of the plant. Production and distribution is handled by local businesses with the exception of some islands (Salina, Vulcano, Stromboli, Panarea, Filicudi and Alicudi) where ENEL (the largest electricity company in Italy) operates directly.

All of the energy produced goes onto the small local grids to which almost all residential and commercial buildings are connected. The costs of producing energy from traditional sources are much higher on the small Sicilian islands compared to costs for the mainland. The companies providing energy production and distribution services are lossmakers but the shortfalls are adjusted for via a contribution fixed by CIP (Comitato Interministeriale Prezzi the cross-ministry pricing commission which fixes prices and charges for certain indispensable goods and services, including energy) and paid out by the "Cassa Conguaglio per il Settore Elettrico". The latter is a division answerable to the Ministry of Industry which was created to harmonise the national system of charges in order to ensure that users on the islands are subject to the same prices and conditions as mainland users.

The losses arise from selling kWh at the same price as that charged by ENEL for the whole country; the price charged for electricity is considerably lower than the production and distribution costs borne by the abovementioned local electricity suppliers. The financial support provided by the State is designed to bridge the gap created between the amounts paid by customers and the actual costs sustained by the production companies on the islands. In Italy, in common with the rest of Europe, the reform of the energy market is getting underway and this process should lead to liberalization of the electricity sector. It is not yet clear whether the system of liberalization will be extended to the small local grids on the minor islands or whether the abovementioned system of subsidies will remain in force. It should be noted that whilst this type of subsidy lowers production costs on the islands to make them equal to mainland costs it inevitably creates a distortion of the market in microeconomic terms: the system of subsidies designed as such unfairly favours energy production from traditional sources and thereby acts as a barrier to the spread of renewable energy sources (EC-DG XII, 1997). Were the energy production market to be free from subsidies or, at the very least, were these to be applied to renewable energy sources, then energy production from renewable sources could already be competitive in many of the small Sicilian islands.

Such high production costs from traditional sources make the use of renewable energy sources even more attractive.

The trend for annual energy consumption on the island of Salina is one of continuous growth; mostly due to the increase of tourism. Currently, the installed power is 3700 kW (two 900 kW generators, three 500 kW and one 400 kW). As far as energy produced is concerned, measurements taken are (year 2000): January 540 MWh, February 430 MWh, July 710 MWh and August 900 MWh. Total consumption has risen from 5670 MWh in 1990 to 6610 MWh in the year 2000. Fig. 1 shows the movements in consumption over a 12-month period. It is easy to see that the growth in consumption begins around June and reaches a peak in August and subsequently decreases sharply until mid-September and then stabilizes at a more or less constant level of consumption until June of the following year. Fig. 2 presents two curves depicting typical daily electric loads

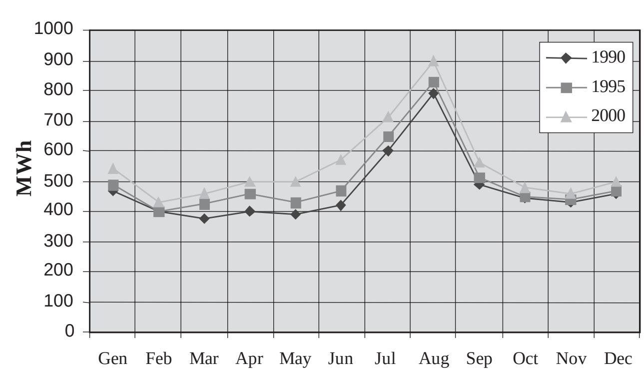


Fig. 1. Energy consumption (1990–2000). Source: our elaboration—Interenergy, 2002, "Studio di fattibilità per interventi di sviluppo delle RES presso l'isola di Salina".

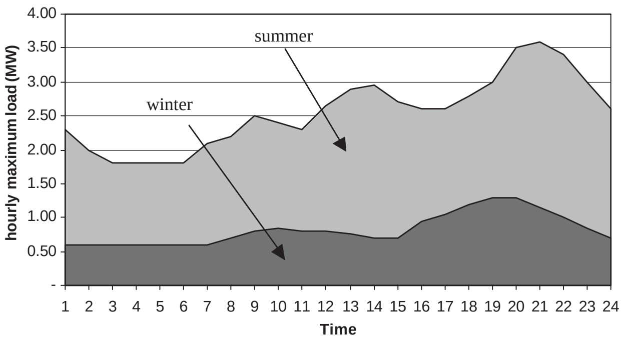


Fig. 2. Daily electric load curves for a typical summer/winter day. Source: our elaboration—Interenergy, 2002, "Studio di fattibilità per interventi di sviluppo delle RES presso l'isola di Salina".

for the island of Salina, one for a typical winter day and the other for a summer day. The two curves show markedly different summer and winter patterns. In both seasons however, the peak loads are recorded between the hours of 20:00 and 21:00. As this is a small tourism-oriented island community with no industry and only a few shops, restaurants and bars there is a big difference in electricity consumption between the tourism season in summer and a typical winter day when only residents are on the island.

4.4. Wind resource assessment

As the literature reveals, in general wind energy potential is available virtually anywhere in which there are sites with an annual average wind speed of around 5–5.5 m/s, measured at a height of 10 m. However, the potential that can be exploited in reality is highly dependent on a series of factors of a meteorological, orographic, environmental, technical and financial nature. Furthermore, the assessment of the production capacity of specific plants and related technical and economic estimates requires data regarding wind speed and direction of a certain statistical significance acquired through systematic recordings made around potential sites over a period of 1 yr or more. In general, the theoretical energy production of a plant installed in a specific site is calculated on the basis of the site's anemologic characteristics and the performance capability of the wind energy equipment employed.

Amongst the most important calculations of recorded anemologic data, the simple and cumulative frequency distributions of wind speed are of specific interest. These are interpreted via Weibull and Rayleigh probability models (Walker and Jenkins, 1997, pp. 8–10). The cumulative frequency distribution, (also known as the "duration curve"), enables identification of the number of hours (in terms of hours/year) in which a given speed is exceeded. Fig. 3 shows this curve relating to the site which is the subject of this study. An awareness of the seasonal movements of available energy is fundamental for a correct preliminary analysis of the technical and economic feasibility of a wind energy plant to be integrated with a local electric system.

4.5. Alternatives proposed

Out of all the anemological data recorded and processed the most significant are the wind speed frequency distributions—simple and cumulative—which are interpreted using the Weibull and Rayleigh probability models.

Table 1 contains the most important meteoclimatic parameters that are useful in calculating producible energy. Naturally, the most important parameter is wind speed, which from the data extracted measured on an annual basis is around 4.8 m/s.

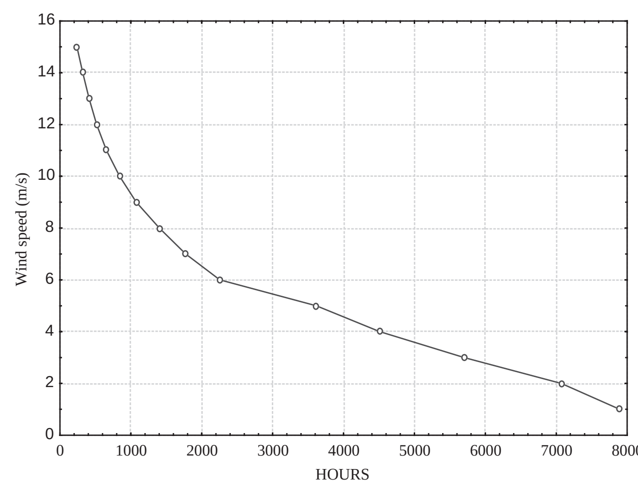


Fig. 3. Cumulative wind speed distribution.

Table 1
Site conditions

Project name	PROES
Project location	Salina-ME
Annual average wind speed (m/s)	4.8
Height of wind measurement (m)	10.0
Wind shear exponent[a] (dimensionless)	0.16
Wind speed at 10 m (m/s)	4.8
V_{max} (m/s)	34.7
Scale A[b]	5.42
Shape k[b]	2
Median	4.5
Average atmospheric pressure (kPa)	89.1
Annual average temperature (°C)	18

[a] Wind shear exponent is a number expressing the rate at which the wind speed varies with the height above the ground. A low exponent corresponds to a smooth terrain while a high exponent reflects a terrain with sizeable obstacles. The w.e. ranges from 0.10 to 0.25 (User manual RETScreen, 2000).

[b] Weibull parameter.

All of the alternatives considered are based on the use of wind turbines. The solutions proposed are the following:

4.5.1. Plan "A" (wind 150 kW)

The proposal is to design and install a medium power wind turbine. The turbine (made by Nordex model number N 27/150) would have a nominal power of 150 kW with a rotor diameter of 27 m and hub height of 30 m.

4.5.2. Plan "B" (wind five 15 kW)

This forecasts installation of five low power turbines of 15 kW each; giving a total power installation of 75 kW. Such small-sized turbines have a three-bladed rotor of approximately 8 m in diameter that are borne by a steel tubular structure of around 18 m in height. This type of turbine has a low visual impact due to its limited rotor diameter and therefore is better suited than other types for installation in sites where the landscape has a high value, as is the case of small islands.

4.5.3. Plan "C" (wind two 150 kW)

This option is based on installation of two medium power (150 kW) turbines so as to guarantee a reasonable energy level in optimum wind conditions.

4.5.4. Plan "D" (PV + wind five 15 kW)

This is a hybrid plant consisting of a small photovoltaic plant of 30 kW_p together with the five 15 kW turbines already described in option "B".

4.6. Identification and selection of criteria

The criteria are the tools that enable alternatives to be compared from a specific point of view. Undoubtedly, selecting criteria is the most delicate part in formulating the problem facing the decision maker, and thus it requires the utmost care. The number of criteria depends more on the availability of both quantitative and qualitative information and data.

4.6.1. Economic and technical criteria

These criteria refer to the costs that must be borne in order to realize the various projects included in each strategy and to guarantee the supply of energy. These factors are of special interest to State authorities.

- *Investment costs*. This criterion includes all costs relating to: the purchase of mechanical equipment, technological installations, construction of roads and connections to the national grid, engineering services, drilling and other incidental construction work. According to specific data provided by the renewal energy section of the Ministry for the Environment, the total average investment required to realize a working wind energy plant in Europe amounts to approximately 1032.90 EURO/kW of installed power. In Italy the estimated cost of installation ranges from a minimum of 852.15 and a maximum of 1291.14 EURO/kW depending on whether it is sited on level terrain or complex ground. In our case we are dealing with an island, therefore the costs are much higher compared to ones on the mainland, estimated costs of the 150 kW turbines are 1549 EURO/kW and 2324 EURO/kW for the 15 kW turbines. Investment cost is measured in thousands of EURO.
- *Operating and maintenance costs*. This criterion includes all the costs relating to plants, employees' wages, materials and installations, transport and hire charges, and any ground rentals payable. The cost of maintenance amounts to approximately 2% of the total investment cost. It is expressed in thousands of EURO.
- *Energy production capacity*. This quantifies the total energy generated by plants and is measured in MWh/annum. To estimate the producible energy was used RETScreen™ International Energy Software.[1]
- *Savings of finite energy sources*. This refers to the amount of fossil fuel currently used by the diesel power plant to produce electricity that could be saved. According to data provided by the local energy producer, around 0.226 kg of fuel (diesel) is required to produce 1 kWh of electricity. It is measured in tons/annum.
- *Maturity of technology*. Measures the degree of reliability of the technology adopted as well as how widespread the technology is at both national and European level. This is appraised using a qualitative measure.
- *Realization time*. This measures the time to realize and put into operation the plants designed. It is expressed in number of months.

4.6.2. Environmental criteria

These criteria refer to protection of the environment and to the principle of *sustainability*:

- *CO_2 emissions avoided*. This refers to the amount of CO_2 emissions avoided as a result of the production of the proposed plants. In Italy, CO_2 emissions, for the typical production mix of electricity, are around 0.58 kg/kWh_{el}. However, because the plants in question are not very efficient this figure rises, reaching as much as 0.65 kg. It is measured in tons/per annum.
- *Visual impact*. This reflects the visual nuisance that may be created by the development of a project in a

[1] RETScreen™ International is an integrated renewable energy project analysis software. It was devised by the Canadian Government at their Natural Resource and Energy Diversification Research Laboratory.

Table 2
Evaluation matrix

		Alternatives			
		"A" wind 150 kW	"B" wind five 15 kW	"C" wind two 150 kW	"D" PV30 kW + five 15 kW
Criteria					
Investment cost	Thousands of Euros	232.4	174.3	464.8	391.2
Operating and maintenance costs	Thousands of Euros	4.6	3.4	9.2	7.8
Energy production capacity	MWh/yr	About 320	About 80	About 640	About 114.5
Fuel savings	ton/yr	72.3	18	144.6	35.3
Technological maturity	Qualitative	Good	More or less good	Good	More or less good
Realization times	No. months	About 12	About 12	About 18	About 18
CO_2 emissions avoided	ton/yr	208	52.1	416	82
Visual impact	Qualitative	Moderate	Moderate	Bad	More or less bad
Acoustic noise	dB	36.4	39.4	42.4	39.4
Impact on ecosystems	Qualitative	More or less bad	Moderate	More or less bad	Moderate
Social acceptability	Qualitative	Bad	Moderate	Bad	More or less bad

specific area. The landscape of the different sites, the distance from the nearest observer, the type and size of plants to be installed and the possibility to integrate them with their surroundings must all be considered when evaluating the various alternatives proposed. Such a criterion is evaluated in qualitative terms.

- *Acoustic noise*. Noise can generally be classified according to its two main sources: aerodynamic and mechanical. Aerodynamic noise is produced when the turbine blades interact with the eddies caused by atmospheric turbulence. Mechanical noise is generated by the rotor machinery such as the gearbox and generator. Noise could be reduced by better-designed turbine blade geometry and by careful choice of operating conditions. In Italy, the noise levels emitted by wind turbines must be lower than 45 dB in the proximity of houses. In the cases we analysed, the sites accommodating plants are at such a distance (300 m more or less) from residential areas as not to cause any nuisance. The *sound pressure level* (Walker and Jenkins, 1997, pp. 79–80) is used to measure the noise levels at the homes of residents. This criterion is measured in dB.
- *Impact on eco-systems.* This refers to the potential risk to eco-systems caused by production of the various projects included in the strategies and is evaluated in qualitative terms. The potential disturbance to fauna caused by wind turbines (a factor of moderate importance) relates to isolated incidents where birds collide with the rotor blades. It seems that although migrating birds are well able to cope with these obstacles, they do present some problem for predatory species of birds. (For further details refer to the Danish Ministry of the Environment and Energy, 1998).
- *Social acceptability*. Expresses the index of acceptance by the local population regarding the hypothesized realization of the projects under review. This criterion is extremely important since the opinion of the population and of pressure groups may heavily influence the amount of time needed to go ahead with and complete an energy project. Therefore it is vital to garner public opinion at an early stage, prior to assessing the feasibility of the project.

4.7. Evaluation matrix

Table 2 shows how the various alternatives perform on the basis of the various assessment criteria. As far as clean energy production is concerned, the highest values are recorded for the plants with greater power generating capacity, i.e. alternative "A" and above all "C", and they show the best performance compared to the other alternatives.

However, in terms of costs the highest values occur for alternative "C" in which the design and installation of two medium power turbines is envisaged and in "D" (hybrid system) that includes a small PV generator of 30 kW_p, the cost of which heavily affects the total cost of this option. Thus, the alternatives "A" and "C", which at first glance would seem the most efficient in technical and economic terms.

The fuel saved and CO_2 emissions avoided are linked closely to the production capacity of plants and consequently benefit options "A" and "C". Although there are no tools to measure unequivocally and precisely the visual impact of the forecast changes to the landscape,[2] the opinion of the local population was

[2] It is possible to prepare a photomontage and show it to a sample of subjects for them to state their visual perception of the projects.

sought on this matter. In relation to the observer's angle of vision, option "C" (two turbines proposed) and "D" (PV plant in addition to the turbines) intrude more on the landscape compared to the other options. As stated previously, noise disturbance is not a problem because the plants are distant from residential areas. Nonetheless, option "C" is slightly noisier (42.4 dB) than the others. The findings for impact on eco-systems revealed that options "A" and "C" impinged more than the others due to the larger rotor diameter and greater hub height of their turbines, thereby increasing the risks of collision with avifauna.

The strength of multicriteria analysis lies in its ability to simultaneously evaluate a number of alternatives in relation to a multiplicity of viewpoints and to produce results that take into consideration any eventual trade-offs between the values examined.

5. Results

Once the calculations have been carried out, using the data shown in the evaluation matrix an iterative process is then activated, calculating for each plan the indices ϕ^+ and ϕ^-. In relation to these indices partial rankings are obtained and the final order is derived from their intersection. The first one, based on *better* or *much better* relations, via an index that goes from 0 to 1 indicates how much "better" ***a*** is in comparison to all the other alternatives. The second one, which is based instead on *worse* or *much worse* relations via an index that goes from 0 to 1, indicates how much "worse" ***a*** is compared to all the other alternatives.

As already stated, the final order of merit for all the alternatives (from the best to the worst) is obtained as a result of the procedure described above. As can be seen in Table 3, solution "A" presents the best compromise followed by "B", "C" and finally "D". However, the latter turns out to be incomparable with "B" and "C". Alternatives are said to be incomparable when the final results reveal that one option compared to another is ranked higher in one ranking and lower in another. In the final order of merit option "A" is prized above all others and this is due in part to its cost being more contained, compared to its energy production capacity and consequent saving of fossil fuels, and in part to a more modest overall environmental impact. Option "A" also comes out on top in technological terms, as this is now tried and tested, and thus reliable, as well as being relatively easy to install. If the turbine is well integrated into the environment, visual perception is not seriously affected. This option emerges as the right compromise between costs, energy production capability, resource savings and alterations to the landscape.

Alternative "D", although yielding reasonable energy production margins, comes at the bottom of the ranking, very far below the other options. This is because of the elevated cost of investment, which is partly attributable to the PV, and its higher environmental impact .

It is also possible to calculate the indexes of truth (Table 4) for each pair of alternatives and in accordance with the majority of criteria in order to verify whether X is better than, indifferent to, or worse than Y.

In addition, a sensitivity analysis was carried out to test the robustness of the results obtained in order to verify any changes in ranking obtained by varying the parameter α, which represents the minimum threshold for the index of preference credibility. A low value for α implies a high level of uncertainty in the information used for the evaluation whilst high values of α account for those values showing strong preference intensity or indifference between one alternative and another, i.e. in all cases in which the information is reasonably certain. Table 5 shows the data relating to the three distinct cases and it is evident that when the value of α remains below the threshold of 0.40 the result does not change much and therefore the ranking in Table 3 is fairly stable. As this value gradually rises to around 0.80 (0.90) the result varies since it alters the reference framework.

Table 3
Final ranking

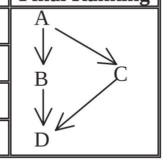
ϕ^+		ϕ^-		**Intersection Final Ranking**
0.78	**A**	0.32	**A**	
0.67	**C**	0.55	**B**	
0.59	**B**	0.61	**C**	
0.19	**D**	0.74	**D**	

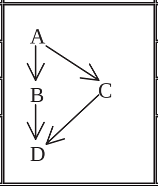
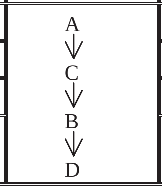
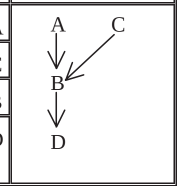
Table 4
Indexes of "truth"

	X is better than Y	X and Y are indifferent	X is worse than Y
A,B	0.8586	0.0000	0.0000
A,C	0.6736	0.1231	0.2783
A,D	1.0000	0.0000	0.0000
B,C	0.8485	0.0000	0.7419
B,D	0.5363	0.3817	0.0000
C,D	0.7385	0.0000	0.0000

6. Conclusion

The exploitation of wind energy has passed the basic research stage as well as the pilot study phase and has now reached a fairly consolidated initial level of commercialization. In the future economies of scale will

Table 5
Sensitivity analysis

$\alpha = 0.40$					$\alpha = 0.70$					$\alpha = 0.90$				
ϕ^+		ϕ^-			ϕ^+		ϕ^-			ϕ^+		ϕ^-		
0.55	A	0.17	A		0.19	A	0.04	A		0.03	C	0.01	A	
0.42	C	0.32	B		0.15	C	0.07	C		0.03	A	0.01	C	
0.32	B	0.34	C		0.06	B	0.10	B		0.01	B	0.02	B	
0.06	D	0.51	D		0.01	D	0.19	D		0.00	D	0.03	D	

enable costs to be reduced further and technological improvements to be made, thus wind energy could become more widespread on the energy market. From a commercial point of view, a wind energy production plant positioned in a site with good wind levels or on a small island is a highly attractive and realistic option nowadays. This work has therefore attempted to test the soundness and strength of multicriteria analysis as a means to serve energy planners as an unambiguous tool for decision making. This approach was held to be useful in view of the peculiarities of the site, arising from the highly sensitive character of the environment and natural landscape together with the local population's unwillingness to accept changes to these. Assessment procedures and energy planning may appear complex because of the number and diversity of the items to evaluate, the uncertainty of data and conflicts between interested parties. As this work demonstrates, multi-criteria analysis can provide a technical-scientific decision making support tool that is able to justify its choices clearly and consistently, especially in the renewable energy sector.

The results of the analysis show option "A" (one 150 kW turbine) to be the winner over the other hypothesized alternatives: "B" (five 15 kW turbines), "C" (two 150 kW turbines) and "D" (option "B" plus a 30 kW_p PV plant). Option "A" emerged as being the right *compromise* between the need to contain costs of realization, the local energy requirements and the need to conserve the area and the environment, especially in view of the high/medium-bracket tourism business on the island. A sensitivity analysis was also performed to test the robustness of the results by verifying any change in rankings resulting from variations made to parameter α. No changes in results occurred whilst parameter was kept below the threshold of 0.40 and therefore the ranking in Table 3 is fairly stable. As the value gradually increases to around 0.80 then the result shows a tendency to vary. Future advances are anticipated in research work to check the results obtained under this method by comparison with the results achieved by applying PROMETHEE, an alternative multicriteria method.

In conclusion, this work demonstrates that the approach is both a useful and workable means to deal with multidimensional energy issues where part of the input data (qualitative) is perhaps ill-defined and not easy to measure. Additional refinements and revisions could stimulate ideas for energy applications in other settings on a regional or national scale.

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