A COMPARATIVE ANALYSIS BASED ON ANALYTIC NETWORK PROCESS FOR SELECTION OF A MINI WIND STATION PLANT

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ABSTRACT

In our modern life, human life is increasingly dependent on energy. The growth in population has a direct impact on energy requirements. To address the pollution problem, green sources of energy like solar, hydropower, wind, tidal, biogas, wave energy, etc. are being encouraged. Of these green sources, the usage of wind as a source of energy is increasing in different parts of the globe due to rapid technology advancement. Wind energy utilization is also becoming competitive compared to traditional sources of energy. Projecting wind-power plants depends on the amount of power that the plant can support. The chosen project needs to be evaluated in consideration of *different criteria* when determining the potentiality of wind-power. 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 context 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 mini wind energy turbines*. A multicriteria method based on Analytic Network Process (ANP) will be applied in order to support the selection and evaluation of one or more of the solutions proposed.

Keywords: ANP, Mini Wind Energy Plant, Renewable Energy Sources, Decision Support System

1. Introduction

The increase in negative effects of fossil fuels on the environment has forced many countries, especially the developed ones, to use renewable energy sources. On the 9th of March 2007, the European Council decided a fixed goal of 20% contribution of the renewable energy sources (RES) on the total European electric energy production in 2020. In order to reach such an ambitious goal, all the European countries are adopting different support policies for encouraging installations of RES-based generation systems

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(Campoccia *et al.*, 2009). Environmental friendly renewable energies are divided into six main categories according to their source: geothermal energy, hydraulic energy, wind energy, wave energy, biomass solar energy which can be converted to electrical energy (see Table 1). Therefore, electrical energy can be obtained from these renewable energies by using different applications. However, to produce electrical energy from wind energy wind turbine and from solar radiation via solar cells are more popular applications than others (Ozdamar *et al.*, 2005). In particular, important reasons responsible for the rapid development of wind energy utilization include its cleanliness, job creation, abundance in nature, no physical boundaries, affordability, inexhaustibility, environmentally friendly and its elegancy (Rehman, 2004).

Table 1. Energy produced by RES-systems in the EU-27 (Elaboration from Nomisma Energia, Data from Eurostat).

RES-based technology	Energy produced in 1997 (GW h)	Energy produced in 2005 (GW h)	Variation in the period 1997–2005 (GW h)	Percentage variation in the period 1997–2005
Biomass	28,835	81,474	52,639	8.1
Geothermal	3956	6614	2658	5.0
Hydro	273,959	264,949	- 9010	-0.4
Mini-Hydro	37,179	39,107	1928	0.6
Photovoltaic	41	1457	1416	12.1
Wind	7330	69,424	62,094	11.2

Definitely, currently the fastest developing energy source technology is **wind energy**. Because wind energy is renewable and environment friendly, systems that convert wind energy to electricity have developed rapidly. Unique features of wind energy have caused increasing demands for such resources in various countries. In order to use wind energy as a natural resource, environmental circumstances and geographical location related to wind intensity must be considered. Different factors may affect the selection of a suitable location for wind plants. These factors must be considered concurrently for optimum location identification of wind plants (Azadeh, *et al.* 2011).

The aim of this paper is to propose an **integrated approach** for the best selection of mini wind plants based on the Analytic Network Process and incorporate the most relevant *indicators* of wind plants. Implementation of the proposed approach would enable energy policy makers to select the best possible wind power plant with the lowest possible costs.

In our study we focused our attention on min wind energy systems because in the coming years they will have more development opportunities, thanks to the development in the turbines field, which provides the opportunity to meet any need and thanks to the simplified legislation in terms of bureaucrancy and encouraged by the economic point of view this type of installation.

2. Energy management and Multi-criteria decision making approach

Several studies have been carried out on power plant evaluation, electricity production and energy planning. Some of them focus on particular types of power plants like those based on renewable energy resources (Georgopoulou et al., 1997), some others use outranking methods like ELECTRE (Beccali et al., 2003; Buchanan and Vanderpootenb, 2007) and some others focus on economic (Diakoulaki and Karangelis, 2007; Kaldellis and Kavadias, 2007; Kaldellis et al., 2005), environmental (Beer, 2007) or technological aspects (Cook and Green, 2005) of power generation. Several methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations are employed for energy planning decisions. We note traditional single criteria decision making is normally aimed at maximization of benefits with minimization of costs (S.D. Pohekar et al., 2004). So different studies apply Multi-

Criteria Decision Making (MCDM) techniques. These methods are gaining popularity in sustainable energy management. In fact when evaluating a composite problem such as the one mentioned above, one has to make trade-offs between the several criteria involved in the assessment of the overall situation. Multicriteria analysis should be applied in order to solve problems of this kind. So, the techniques provide solutions to the problems involving conflicting and multiple objectives. The methods can provide solutions to increasing complex energy management problems. The methods help to improve quality of decisions by making them more explicit, rational and efficient. Multi-criteria decision making (MCDM) methods deal with the process of making decisions in the presence of multiple objectives. A decision-maker is required to choose among quantifiable or non-quantifiable and multiple criteria. The objectives are usually conflicting and therefore, the solution is highly dependent on the preferences of the decision-maker and must be a compromise. In most of the cases, different groups of decision-makers are involved in the process. Each group brings along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise.

Among the MCDM methods one of the most popular is the *Analytical Hierarchy Process,* a well known methodology developed by Prof. Saaty. The AHP is a methodology that supports compensatory multicriteria decision making by aggregating alternatives performances against criteria to an overall indicator (Saaty, 1980). Bad performances against one criterion can be compensated by good performances against other criteria. The verbal terms of Saaty's fundamental scale of 1–9 is used to assess the intensity of preference between two elements. One of the major advantages of AHP/ANP is that it calculates the inconsistency index as a ratio of the decision maker's inconsistency and randomly generated index. This index is important for the decision maker to assure him that his judgments are consistent and that the final decision is made well. The inconsistency index should be lower than 0.10 (Saaty, 1992).

Several papers incorporate AHP for energy conservation promotion (Kablan, 2004), natural resource and environmental management (Zhu and Dale, 2001), energy resource allocation (Ramanathan and Ganesh, 1995) and several other aspects of the energy sector (Vaidya and Kumar, 2006) but there is no application that analyzes the aim of our study. The essence of our process is the decomposition of a complex problem into a network with objective, criterions and sub-criterions, and decision alternatives. Elements are compared in pairs to assess their relative preference with respect the other element. In particular, in this work we will use the Analytical Network Process (ANP) that is a generalization of the Analytic Hierarchy Process (AHP) to evaluate different types of mini wind power plants available, regarding their overall impact on the living standard of local communities and to select the optimum plant.

3. Methodology proposed for selection of the best mini wind plant

In recent years the technologies exploited in turbines under 20 kW have reached the highest levels thanks to the experience gained working at higher power turbines. The highest result has been that of dramatically lowering the operating threshold of these turbines making them effective even in low wind speed scenarios. Turbines with different powers and wide operating range have been developed: they work several thousand hours per year. These turbines are usually used off-grid, with a battery system to store energy. They may be connected directly to the local grid (net metering), or feed small grids, pumping systems and electric fences.

From the viewpoint of incorporating qualitative factors in the location decision, the most widely used technique is a weighted approach in which various important but diverse factors like proximity to customers, business climate, legislation, tax incentives and other supporting factors are rated on a weighted scale and combined into an aggregate score.

This paper proposes most important factors in selecting the location and type of mini wind plants. A set of technical, geographical and social factors for location optimization of wind plants are considered. A network structure for the proposed model has been considered to extend the selected regions that are studied as well.

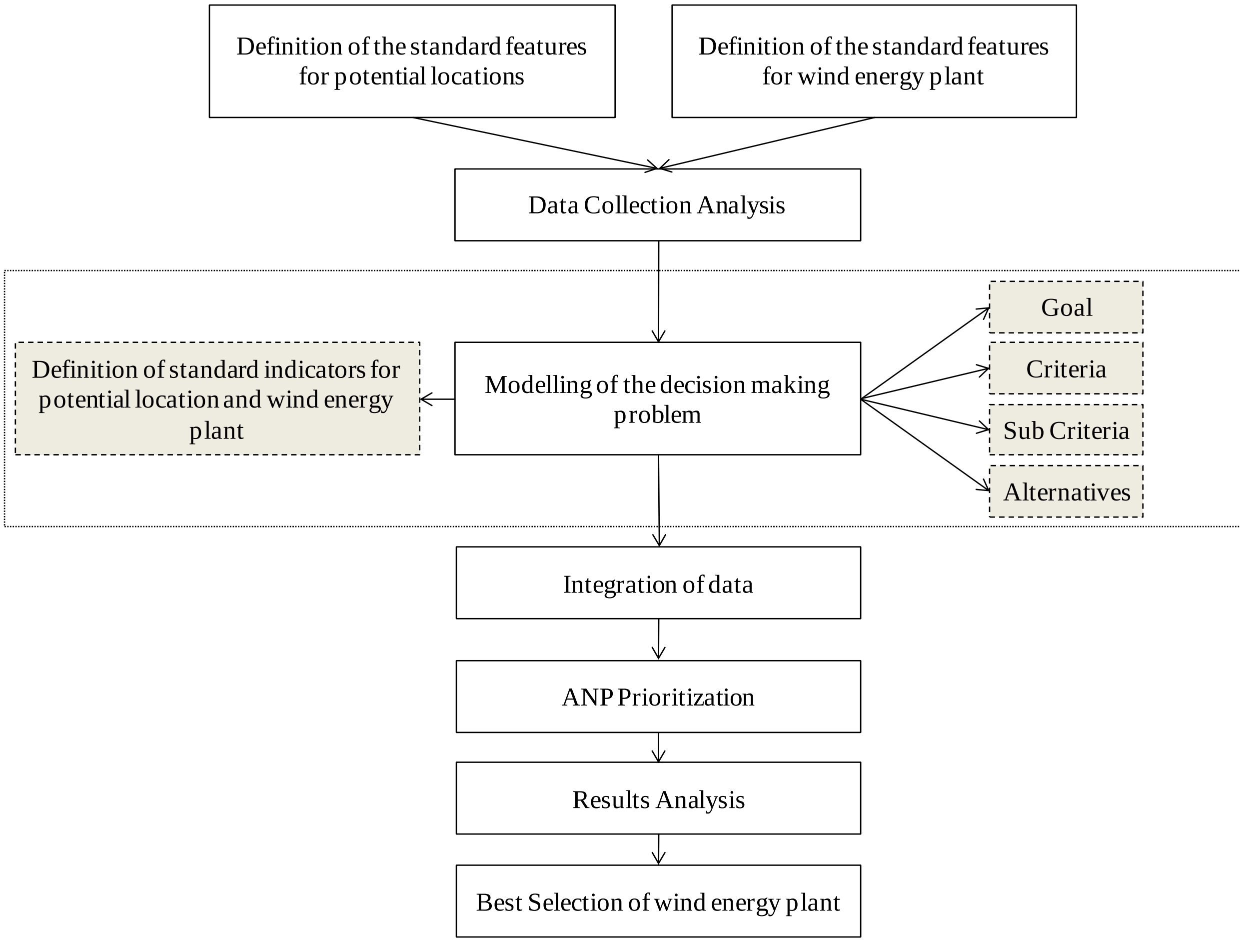


Figure 1: Methodological Approach

3.1 Technical features to install a small wind energy plant

In the field of microgeneration from renewable sources, mini **wind turbines** (below 50 kW) represent an interesting opportunity for public local administrations and private small- and medium-scale companies, as well as farms and tourism facilities.

The mini wind turbines produce a limited impact on the environment based on following major factors:

- occupation of the territory;
- changes to landscape;
- noise;
- electromagnetic interference;
- interference and migratory bird life;
- energy production to be placed directly on the local network (positive impact);
- availability of power directly next to the local load centers (positive impact);
- emissions avoided by replacing a portion of thermal plants (positive impact).

Of these factors, only the first two can somehow be considered particularly significant and reliable.

We can note that there are two major types of wind turbines: vertical and horizontal axis. The classical ones, with the blades turning and tail used to place them perpendicular to the direction of the wind, are horizontal. In the other type, instead, the rotor rotates around a vertical axis through a helical or by the presence of arms, which capture the wind from any direction. Therefore, they do not need to orient themselves but also take advantage of the disturbance.

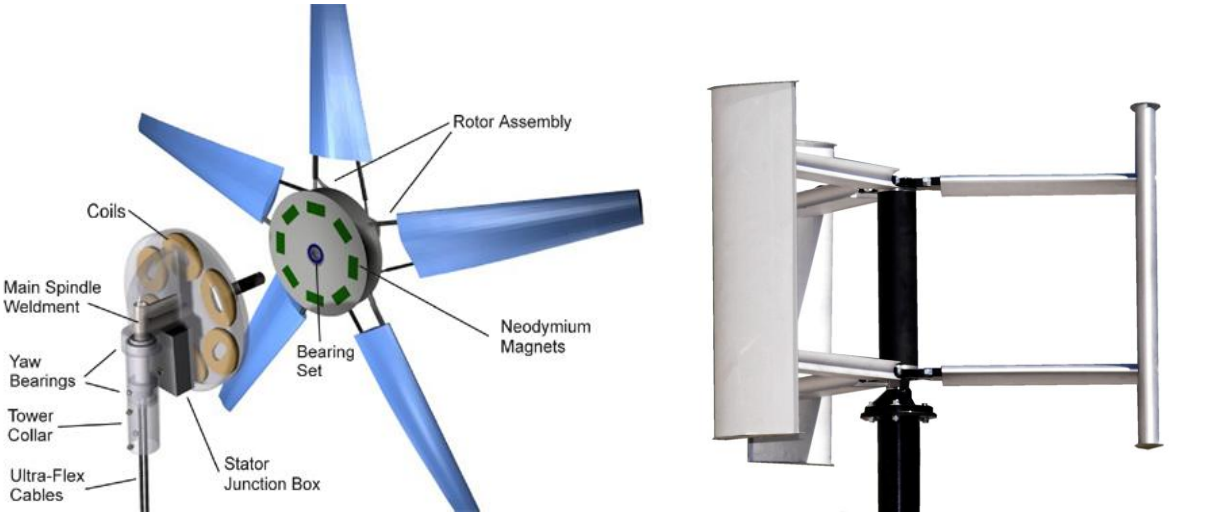


Figure 2: An example of mini wind turbine (horizontal axis- vertical axis)

Worldwide there are about 150 producers of small wind turbines, but not all have the same reliability and technology. There are many technical solutions. To install a mini wind turbine it is necessary to take into account important factors. In fact, the mini turbines are complex and expensive machines.
To choose the best plant for a mini wind turbine it is necessary to consider:

- A careful assessment, able to identify features of the land with the best turbine on the market. The main factor to consider is the amount of energy to be obtained from the turbine. From this point of view, we note that the choice of the exact positioning of mini-turbines, both in plains and in altitude (about 10 meters above the barriers) should be evaluated carefully, since it strongly influences on the amount of energy that the machine can produce. The exact placement should also take account of the distance from the point of connection, since increasing the length of cables also increases the cost of burying cables and electrical losses.
- Analysis of the wind: wind measurement by the anemometer is recommended except in cases where previous measurements or other elements (wind farms in the surrounding area for example) confirm its presence.

The theoretical power available in the fluid of the section "S" perpendicular to the wind direction is:

$$P_t = (S\ v)\ (½\ \rho\ v^2) = ½\ \rho\ v^3\ [W] \qquad (1)$$

where:
ρ = air density (generally 1.225kg/m^3);
V = wind speed.

To estimate potential wind resources in the first approximation it is necessary to estimate the maximum power per unit surface:

$$p_{max} = 0{,}37\ v^3\ [kW/m^2] \qquad (2)$$

$$e_{max/year} = 0{,}37\ v^3\ (n°\ hours/year)\ [kWh/m^2\ year] \qquad (3)$$

The power extracted from wind resource by means of a wind turbine increases with the area swept by the blades (thus increasing length) and wind speed also depends on air density, weather conditions depending on the characteristics of the site.
The wind turbines:

- start with the wind varying from 2 to 4 m / s (speed cut-in);
- are equipped with a power control when the wind speed reaches the order of 10-14 m / s (speed of cutting or nominal).
- taken out of service when the wind speed reaches values around 20-25 m / s (rate cut-off).

The estimated annual energy capability of the plant to be undertaken can be made by considering a value of 1500 to 2000 average hours of operation per year.
The feasibility study of a plant must ensure that the cost / income is adequate to the expectations of the future producer. The cost elements that are considered are:

- Cost of wind turbine;
- Cost of additional work;
- Cost planning;

It is also necessary to consider the following costs:

- Operating costs;
- Maintenance costs;
- License fee;

The costs are compared with the revenue arising from:

- Sale of electricity;
- Savings (avoided cost) of electricity;
- Sale of Green Certificates;
- Income from other incentives.

4. ANP model for the analysis of feasibility of a mini wind turbine

In this paragraph we will propose a decision-making model based on ANP for the analysis of the feasibility of a mini wind farm. The study was developed jointly with a research and expert team. We have considered three different mini-turbines, as homogeneous as possible to allow immediate, comparison between the different models proposed. The power classes and mini turbines considered are (see Table 2, 3 and 4):

- Power 1.0 kW – Plant 1;
- Power 3.5 kW – Plant 2;
- Power 5 kW – Plant 3.

Table 2. Power 1.0 kW

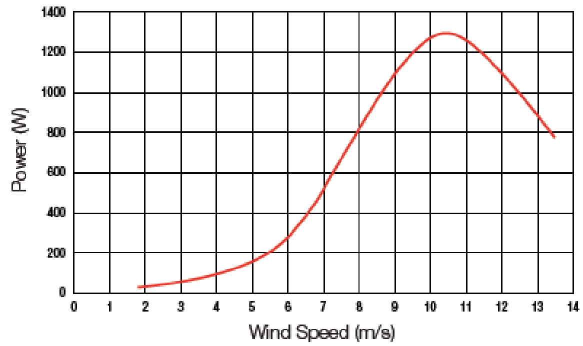
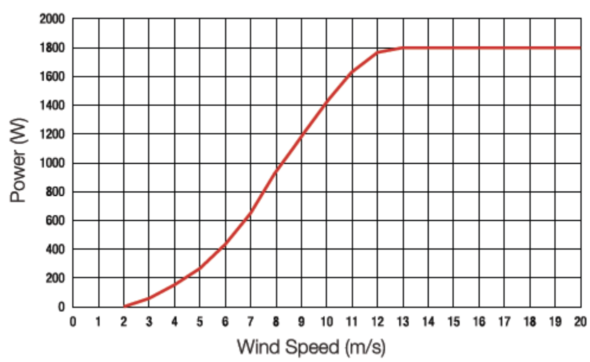
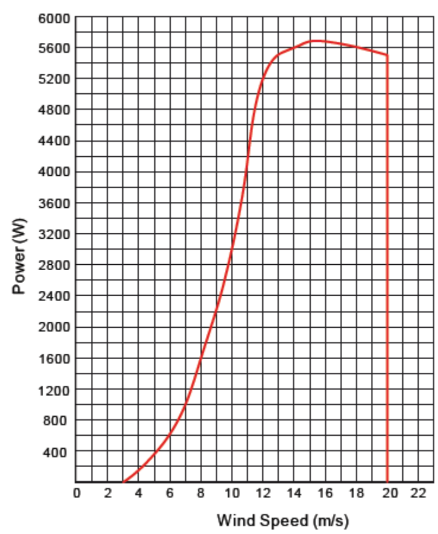
MODEL	Power 1.0 kW – Plant 1
	
Nominal power (W)	1000 W
Voltage	48 V
Rotor Diameter (projected area) m	2 mt
Number of blades	3
Total blades weight (kg)	21 kg
Blade lenght	2 m
Blade components	Glass fibre - Polyester
Min. start wind speed	1,8 m
Rated wind speed (m/s)	8,5 m/s
Survival wind speed	45 m/s
Rotation speed (rpm)	400 g/m
Direction	Self-oriented, no rudder
Nacelle Material	Aluminum
Connection	On-Grid & Off-Grid
Sound level (dBA) (12m/s wind speed)	30 dBA
INSTALLATION PRICE (approximate valuation	**35.000,00 €**

Table 3. Power 3.5 kW

MODEL	Power 3.5 kW – Plant 2
	
Nominal power (W)	3,5 kW
Rotor Diameter (projected area) m	4 m
Number of blades	3 - Chistera
Weight	300 kg

Blades swept area	12,6 m2
Type	HAWT
Total blades weight (kg)	25 kg
Blade lenght	2,5 m
Operation speed	2,5 m/s
Rated wind speed (m/s)	12 m/s
Max wind speed	180 km/h (50 m/s)
Yaw control	Self-oriented, no rudder
Sound level	35dBA @ 12 m/s
Connection	On-Grid & Off-Grid
On Grid	Inverter Aurora Power One 230 VAC, 50 Hz,single phase or equivalent
Off Grid	Inverter XTM Stüder 230 VAC, 50 Hz, single phase or equivalent
Blade components	Glass Fibre / Polyester
Nacelle Material	Aluminum
Nacelle cover	ABS Thermoformed
Fixings	Stainless steel
Tower	Conical shape. 11mt. high (ITI 1.8 HO) e 14m high (ITI 3.5 HO), galvanized steel painting on request
INSTALLATION PRICE (approximate valuation)	**30.000,00 €**

Table 4. Power 5 kW

MODEL	Power 5 kW – Plant 3
	
Nominal power (W)	5 kW
Nominal speed (m/s)	12 m/s
Max wind speed	25 m/s
Survival wind speed	60 m/s
Maximum wind speed (tested in a wind tunnel)	1.8 m/s
Cut out wind speed	3 m/s
Rated rotational spedd	350 g/m / 350 rpm
Max. rotational speed	580 g/m / 580 rpm
Number of blades	3
Rotor Diameter (projected area) m	4.09 m

Blade lenght	2.02 m
Blade components	FRP fiber reinforced plastic
Generator model	CA Tri phase
Braking system	Electromagnetic braking system control
Type	Downwind rotor
Yaw control	Passive
Weight	120 kg
Controller	Protection controller for generator
Grid-tied inverter	120/240 VAC, 50/60 HZ (optional)
Tower	12 m (optional) / 12 m (optional)
INSTALLATION PRICE (approximate valuation)	**23.000,00 €**

An estimate of the wind resource based on a survey of air speed is not always possible for its long duration and its high cost (approximately € 12,000). We have therefore proposed a model by making an estimate based on consultation of the wind atlas. We have considered:

- maps of the wind of the Lazio Region (ITALY) and especially the Lower Lazio (see Appendix – Location A, B and C);
- 2000 average hours of operation per year;
- Wind-power curve for each plant.

In Table 5 we made an estimate of the potential of the resource (we used the equations 2 and 3).

Table 5. Summing up location and plant features
(*) *Estimation for Generator set on pole 9 feet high in places at 200m above sea level*

Location	Altitude	Wind mean speed	p_{max} [kW/m^2]	$e_{max/year}$ [kWh/m^2 year]	
A	25 m	6 m/s	79,92	159,840	
B	50 m	6,5 m/s	101,61	203,222	
C	70 m	7,5 m/s	156,09	312,187	
	Nominal Power	Wind speed for p_{max}	4 m/s (*)	5 m/s (*)	7 m/s (*)
PLANT 1	1.0 kW	10 m/s	247 Kwh	481 Kwh	1.200 Kwh
PLANT 2	3.5 kW	12 m/s	743 Kwh	1.443 Kwh	3.600 Kwh
PLANT 3	5.0 kW	14 m/s	1.800 Kwh	3.439 Kwh	8.220 Kwh

For this kind of plant a payment of 0.30 € kWh for a period of 15 years is expected. This fee provides a rapid payback periods.

- Revenues from all-inclusive rate: about 7,800 €/year for fifteen years;
- Saving power: about 4000 €/year;
- Payback period: 4 years
- Useful life of the system: more than twenty years.

We highlighted three main value added policies: (1) optimizing costs; (2) obtaining social benefits; and (3) ensuring the sustainability of these opportunities also by reducing environmental impacts. Thus, these general strategies have been decomposed in criteria and sub criteria. Here below (Table 6 and Table 7) a description is proposed.

Table 6. Cluster and Sub Criteria list

Cluster	Sub Criteria
C1. TECHNICAL CLUSTER	S1. Energy/year kWh S2. Efficiency S3. Safety S4. Wind Mean Speed S5. Power (kW) S6. Project Development
C2. ENVIRONMENTAL CLUSTER	S7. Landscape S8. Land use S9. Flora and Fauna S10. Electromagnetism S11. Noise S12. Pollution emission
C3. ECONOMIC CLUSTER	S13. Investment Costs S14. Payback Period S15. Service Life S16. Maintenance Costs
C4. SOCIAL CLUSTER	S17. Social Benefits S18. Job Opportunity S19. Urban Planning - License

Table 7. Sub Criteria details

Sub Criteria	PLANT 1	PLANT 2	PLANT 3
S1	Low	Medium	High
S2	Good	Good	Good
S3	Good	Good	Good
S4	Low	Low	Medium
S5	Low	Low	Medium
S6	1 year	> 1 year	1-2 year
S7	Not relevant	Not relevant	Relevant
S8	Not relevant	Not relevant	Relevant
S9	Not relevant	Not relevant	Not relevant
S10	Not relevant	Not relevant	Not relevant
S11	Not relevant	Not relevant	Not relevant
S12	Not relevant	Not relevant	Not relevant
S13	Very High	High	High
S14	Good	Good	Good
S15	Good	Good	Good
S16	< 5000 working hours	< 5000 working hours	> 5000 working hours
S17	Good	Good	Significant
S18	Good	Good	Significant
S19	Not relevant	Not relevant	Not relevant

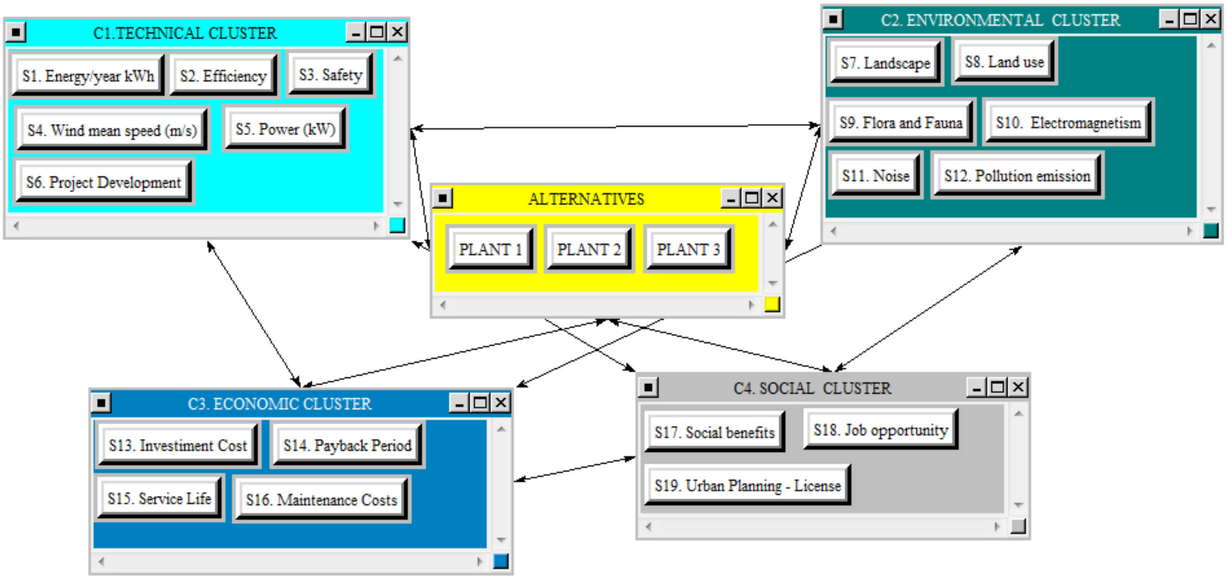


Figure 3: The ANP Model

A consistency analysis has been carried out for all clusters in the proposed network; the calculation always showed CI (consistency Index) values lower than 0,1 which represent the maximum tolerable value. Thus, results supplied by the model are consistent with judgments in the network.
Then, the final alternative ranking shows that "PLANT 2" represents the optimal choice as it is characterized by an ideal priority vector value of 1,000 by comparing with 0,493 and 0,442 for "PLANT 1" and "PLANT 3" respectively. Moreover, as reported in Table 8, results show priority vectors. In details the most important parameters to analyze for feasibility of installing mini wind energy turbines are S6, S8, S13, S14, S15, S17 and S18.

Table 8. Priority Vector

Name	Priority Vector
S1. Energy/year kWh	0.07584
S2. Efficiency	0.13123
S3. Safety	0.05327
S4. Wind mean speed (m/s)	0.01463
S5. Power (kW)	0.00820
S6. Project Development	0.71684
S7. Landscape	0.21007
S8. Land use	0.47056
S9. Flora and Fauna	0.07984
S10. Electromagnetism	0.07984
S11. Noise	0.07984
S12. Pollution emission	0.07984
S13. Investment Cost	0.51094
S14. Payback Period	0.15051
S15. Service Life	0.19187
S16. Maintenance Costs	0.14668
S17. Social benefits	0.54463
S18. Job opportunity	0.28142

S19. Urban Planning - License	0.17395

Definitely the ANP model allows to indentify quantitatively critical areas and specific activities.The model can be used to identify the most appropriate solutions to produce electricity without polluting emissions with absolutely favorable effects on environment; to limit the construction of power lines to better protect the rural landscape, to define skilled jobs for the construction, maintenance and management; to encourage local economic development allowing exploitation of local inexhaustible energy resources as the wind.

5. Conclusions and Results

Because fossil fuels pollute environment fast and their sources are limited, wind energy with an abundant potential is a minor production cost, should be given much more importance in meeting energy demands. Research done on this subject shows that wind-power is and will be one of the most emphasized energy sources. Italy has a large potential for renewable energy sources that its total energy needs from wind energy can be fulfilled

Environmentally friendly benefits of wind power plants make them very desirable as an alternative source of energy. Hence, determination of the optimum locations for use of this resource is a vital decision. Generally, blow wind as a primary tool is used for determining the optimum locations for power plants.

The final results of the proposed model can be used as an effective tool for policy makers to select the most efficient wind plants with the lowest possible costs.

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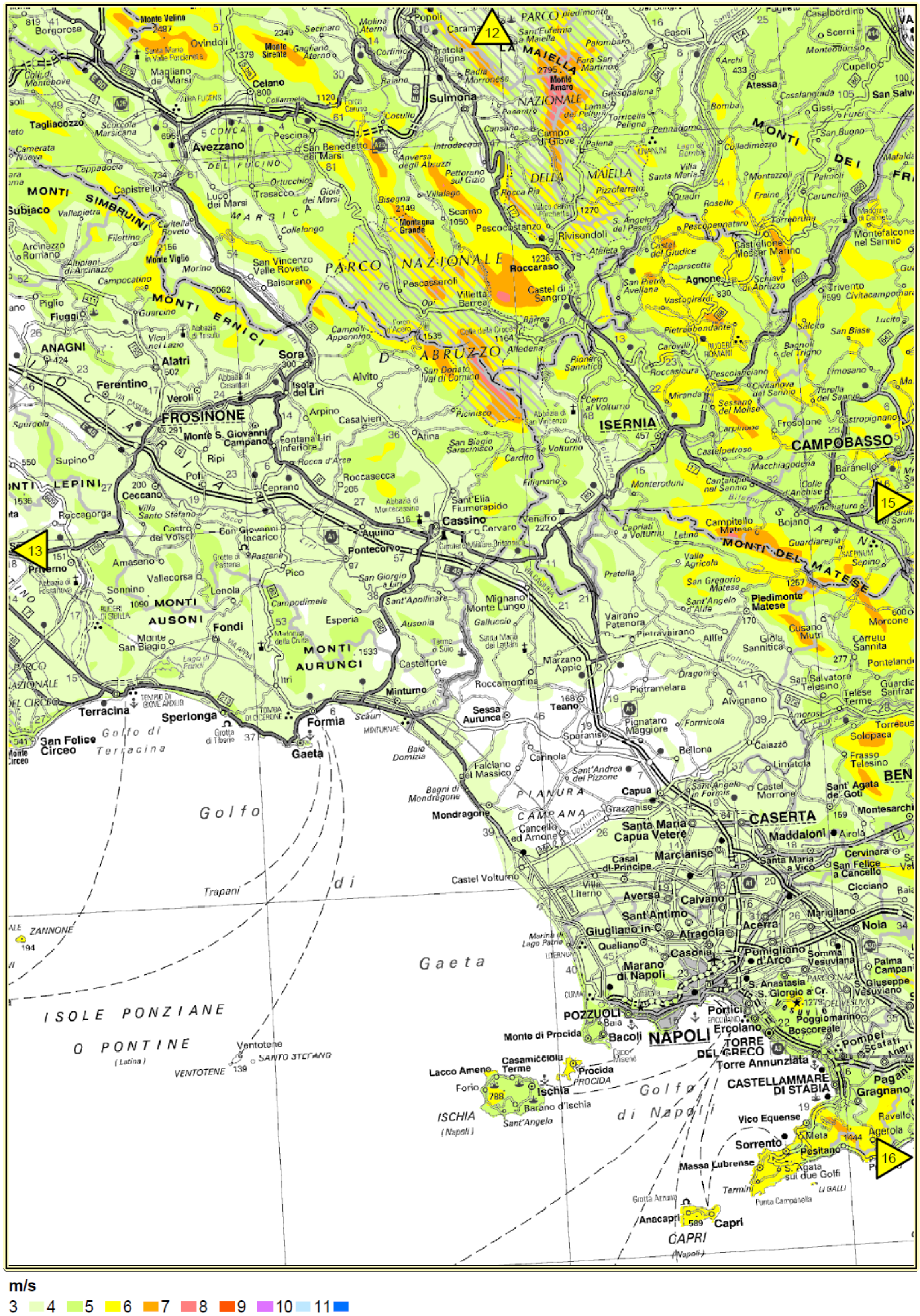
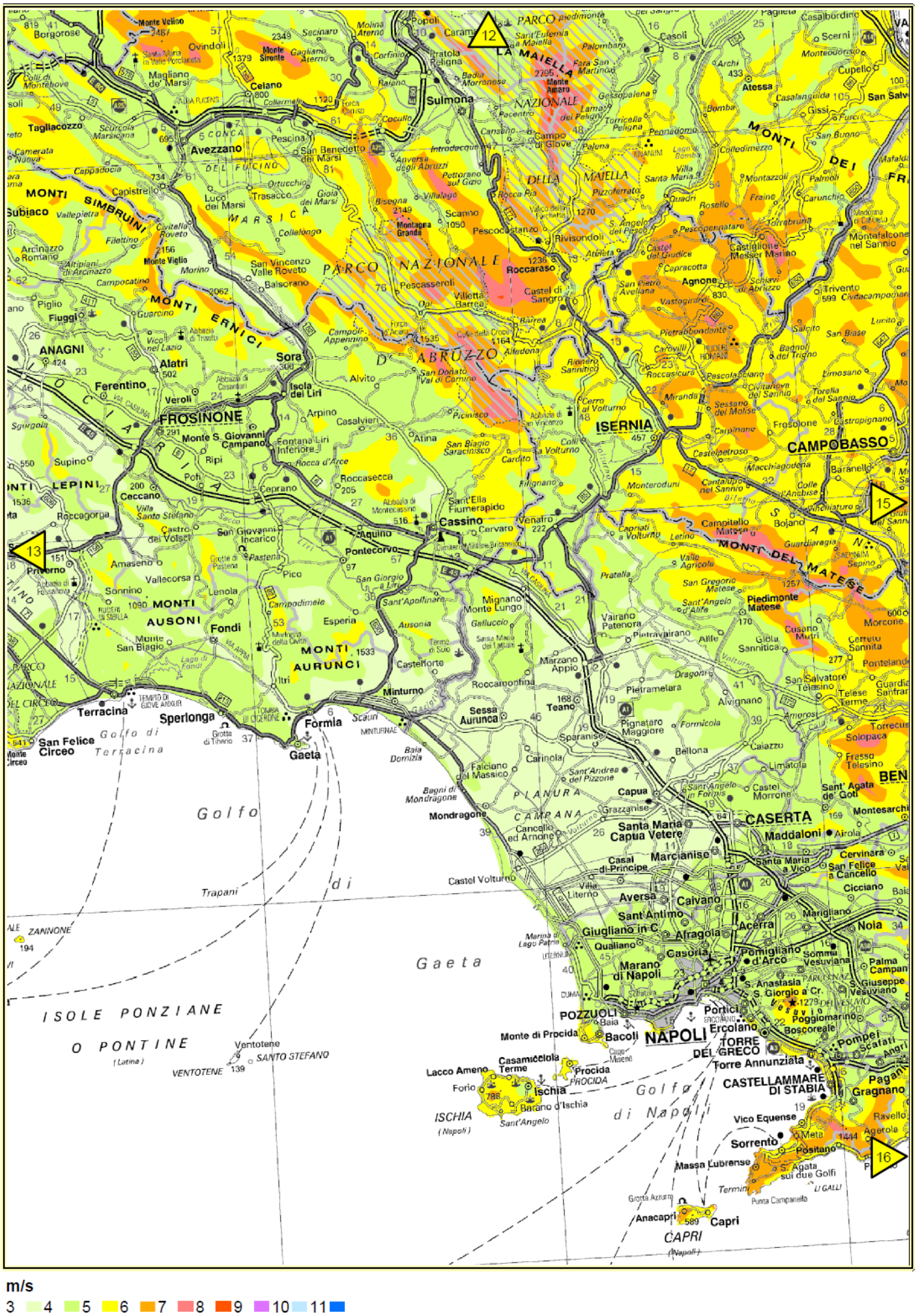
Scale 1:750.000 - Map of the annual mean wind speed at 25 m above sea level



Scale 1:750.000 - Map of the annual mean wind speed at 50 m above sea level



Scale 1:750.000 - Map of the annual mean wind speed at 70 m above sea level