Different regional scenarios of renewable energies analyzed with the use of Analytic Network Process

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Abstract: In March 2007 Europe Union fixed strong environmental objectives for all its members, and for the 2020 it will be required a reduction of 20% of energy consumption, a 20% quota of energy consumption obtained by renewables and a 20% reduction of greenhouse gases. The Piedmont Region administration lunched a roadmap either for the industrial side that for the civil one, but our Region has several territory scenario strongly linked with the geomorphology and many technical solutions can't be used as a standard. With this work our aim is to make a comparison of the most used renewables technology in our territory like biomass, hydroelectric and photovoltaic with a multi-criteria analysis. The paper shows the application of Analytic Network Process (ANP), a multi-criteria technique, according to complex network, in order to select the most sustainable solution for the different scenario. The models enable all the elements of the decision process to be considered, namely technological factors, environmental aspects, economic costs and social impacts, and to compare them to find the best alternative. All the data used in the model are taken from public sources and the required elaboration were self-made.

Keywords: *Multi-criteria analysis, Renewable energy, Analytic Network Process.*

1. Introduction

In the last years the Piedmont Region started to considered the energies from renewable sources as a priority in the new government energy policies. As a result a deep study was conducted based on economics and technological models, to realize a strategic energy document useful for the sectorial demand and supply, forecasts of the trends of input-output items, and a list of actions, collecting several measures voted to fulfill the main aims of the energy plan [1]. This plan is addressed to reach the main goal of a 20 – 20 – 20 scenery (energy saving, production from renewable sources, reduction of greenhouse emissions), according to the many constraints and factors. To fully comply these needs could be useful the adoption of a multicriteria approaches in the selection of the most appropriate actions among all the available alternatives. The selection of the alternative options derives from the goal set identified by the decision – maker, with regard to the technical, economic and environmental spheres. Different multicriteria methods have been developed during the last 30 years for providing support to decision makers facing conflicting, or not so clear, decision situations. Recent literature surveys have shown that Multi-Criteria Decision Analysis has been used in energy planning [2,3], with some cases dealing with the comparative assessment of energy scenarios [4,5]. This paper presents a decision support approach, called Analytic Network Process [6], for energy planning application. The investigation takes place on a case study of different renewable energy technologies provision for local government in Italy, taking as its base the area of Piedmont, a region placed in the north-western part of the country.

2. Methodology

2.1. The ANP

The ANP model consists of control hierarchies, clusters and elements, as well as interrelations between elements [6,7]. The ANP allows interactions and counter-interactions between clusters to be studied and supplies a network structure that is able to connect clusters and elements in any manner in order to obtain priority scales from the distribution of the influence between the elements and clusters. The ANP requires a network structure to represent the problem, as well as a pairwise comparison to establish the relationships within the structure. The analytical tools provided by the ANP are very useful to support the decision making process; nevertheless, it is always important to supply a great deal of information or many experts to the model in order to arrive at a better solution. The literature in the ANP field is quite recent and some publications can be found in strategic policy planning [8], market and logistics [9], economics and finance [10] and in civil engineering [11], while research activity on territorial and environmental assessment is still poor [12,13,14,15]. From the methodological point of view, the model can be divided into several main stages as follow: Step I: Development of the structure of the decision-making process; Step II: Pairwise comparison; Step III: Supermatrix formation; Step IV: Final priorities.

2.2. Case study

2.2.1. Application of the Analitic Network Process to energy planning in Piedmont

This work presents an application of the ANP for the selection of the most suitable technologies in a RET (renewable energy technologies) diffusion plan for the Piedmont Region [1]. A group of technologies of energy conversion has been chosen in order to asses environment, energy and economic effects, which are associated with their actual and future (2020) diffusion in Piedmont. This set has been further restricted to macro technologies oriented to renewable resource use. Table 1 shows the selected alternatives/actions.

2.2.2. Definition of evaluation cluster

Aside the cluster filled with the alternatives a diffusion process of an innovative technology needs the following requirements: a) consistence with the local energy demand predictions, required to confirm or reject the expectations of lasting development for the considered improvement; b) affinity with the local economic and technical condition, which derives on the local capacity of managing the innovation both at financial and technical levels; c) compatibility with the political, legislative and administrative situation; d) compatibility with the actual environmental and ecological constraints. Agreeing with the above considerations, 13 criteria are identified and collected under 3 macro criteria as shown in Table 2.

2.3. Description of the criteria for the analysis

Regional scale objective of primary energy saving (A): It is an estimation of the amount of primary energy that a given action allows to save. This saving can be estimated by means of reduction of final energy consumptions, under the same operating conditions. This criteria is defined as the awaited annual saved energy in the potential scenario [1], which derives from fossil fuels, as ktep/year.
Technical reliability, maturity (B): It is fundamental based on the state of the art of the applied technology. The judgment is expressed by means of a score included within the range [1,5]. A level order is applied, with increasing preference from 1 to 5, as follows: 1. Laboratory level; 2. Pilot plants, where the demonstrative goals is correlated to the experimental one, referring to the operating and technical conditions; 3. Improvements are still possible; 4. Theoretical limits of efficiency are near to be reached; 5. A very efficient technology.

Table 1. List of the selected actions to be diffused

Number	Energy source	Technologies/actions	Macro technologies
1	Hydraulic energy	Hydro plants in derivation schemes Hydro plants in existing water distribution network	Hydro plants
2	Biomass energy	Electric power from solids biomass Electric power from liquids biomass Electric power from biogas Biofuels CHP plants fed by biogas CHP fed by solids biomass CHP fed by liquids biomass	Biomass
3	Solar energy	PV roofs: grid connected system generating electric energy	PV
4	Solar energy	Solar water heating for large demands at low levels of temperature Domestic solar water heaters	Solar water heaters
5	Geothermal energy at low enthalpy	GSHP, SGV, GWHP, plants that use lakes and drainage basin water to fed the circuit	Geothermal
6	Wind energy	Wind turbines (grid connected)	Wind turbines

Number of installation and maintenance requirements with local technical know-how (C): It is a qualitative comparison between the complexity degree of the considered technology, and the capacity of local actors of assure an appropriate support. The following qualitative scale is used: 1. Inadequate technical background for installation and maintenance; 2. Moderate technical background for installation and maintenance; 3. Good technical background for installation and maintenance.

Efficiency and predictability of performances (D): It is very important to know if exist a pattern of not continuous operational conditions. This situation is often strongly linked to the specific technology and does not indicate a factor of unreliability. Obviously when malfunctioning conveys toward condition of unpredictability, it could be a sign of weakness. The following scale of judgment is used for the evaluation: 1. Erratic and not constant operation; 2. Probable but not constant operation; 3. Probable and constant operation.

Impact on the local employment (E): The estimation of potential labor, due to employment of RET, was not possible using literature data, mostly due to a lack of information at Italian regional and national levels. This value was obtained for every technology [1,5] as the difference between the awaited installed power at the minimal energy scenario and the potential one [1]. Where 1 is the lowest grade and 5 the highest.

Regional economic incentives (F): Is the criteria that takes in consideration how much the generated electricity is paid with the economic incentives. It is a reference index expressed in €/MWh.

Affinity with political, legislative and administrative situation (G): The national normative promotes several innovative strategies of energy saving and conversion. The different strength of these national incentives represents a judgmental element among different alternative interventions. The examined criterion assesses the qualitative relevance of the above actors, and the policy of public information. The overall value judgment is expressed in the following way: 1. Lacking; 2. Middle; 3. High.

Market opportunity (H): This criterion evaluates the market availability and the status in the penetration process of a given technology, materials and services associated with the considered action. The adopted scale is the following: 1. Market availability of the technology for more than 10 years; 2. Market availability of the technology for less than 10 years; 3. Start of market availability; 4. Pilot plants; 5. Not present on the market at least in an experimental stage.

Scheduled lines of research (I): In the Regional energy plan every technology has several research fronts [1],this information is used to create a qualitative index [1-3] where 1 represent the lowest grade of active research channels and 3 the highest.

Sustainability reported to greenhouse pollutant emissions (L): The criteria is taken in consideration to measure the equivalent emission of CO_2, which will be avoided by the examined action in the potential scenario at 2020. Therefore it is a reference index expressed in kt of reduced CO_2.

Sustainability reported to greenhouse pollutant emissions (M): Pollutants taken in consideration are divided in the following categories: a) air emissions mainly due to combustion process; b) liquid wastes, which are associated mainly with secondary products; c) solid wastes, which are generated during the life cycle of actions. Category and volume of emissions, and costs associated with wastes treatment are considered. To obtain a synthetic index, the score is expressed through the following qualitative ranks: 1. Very high emissions, each category is relevant; 2. High emissions, at least two category are relevant; 3. Middle emissions, at least one category is relevant; low emissions, all the emissions category are insignificant or do not exist.

Estate requirement (N): This is probably one of the most critical factors for the intervention site, especially when the human activities are relevant factors of environmental pressure. Some technologies requires strong demand of and this could determinate an economic losses, which are proportional to the specific value of site and the possible attendant alternative needs. For the large scale of proposed actions it is difficult to perform specific evaluation and a mean index is assessed as m^2/kW of installed power. Local scale evaluations could describe better drawbacks or possible benefits, but this is not the scope of the present work.

Sustainability reported to other environmental impacts (O): In this criteria are evaluated all the relevant impacts like landscape, acoustic emissions, electro-magnetic interference, bad smells and microclimatic change. The synthetic judgment is expressed through the following rank: 1. Very high intensity; 2. High intensity impacts; 3. Middle intensity impacts; 4. Low intensity impacts; 5. Not existing impacts. All the scores, obtained from the application of the criteria to each action, are grouped in the table below (Table 3).

2.4. The network model

This model consists of elements grouped into cluster. The elements of a cluster can be related to elements of another cluster or to elements of the same cluster (feedback). The alternatives form an additional cluster.

Table 2. Groups of criteria

Technological criteria	Economic and social criteria	Environmental and energy criteria
Regional scale objective of primary energy saving	Impact on the local employment	Sustainability reported to greenhouse pollutant emissions
Technical reliability, Maturity	Regional economic incentives	Sustainability reported to other pollutant emissions
Number of installation and maintenance requirements with local technical know-how	Affinity with political, legislative and administrative situation	Estate requirement
Efficiency and predictability of performances	Market opportunity	Sustainability reported to other environmental impacts
	Scheduled lines of research	

Table 3. Synthesis of evaluation of alternatives, according to the fixed criteria.

Alternatives	A	B (1-5)	C (1-5)	D (1-3)	E (1-4)	F (€/MWh)	G (1-3)	H (1-5)	I (1-3)	L (kt)	M (1-4)	N (m2/KW)	O (1-5)
Hydro plants	272	5	5	2	2	220	3	1	1	844.7	4	-3.8	2
Biomass	-70.2	4	4	1	2	180-280	1	4	2	2089.8	2	-80.5	3
PV	26.6	2	2	1	1	251-402	2	4	2	82.7	4	0.0	4
Solar water heaters	67.2	4	4	1	1		1	2	3	196	4	0.0	4
Geothermal	30.5	3	3	2	4	200	1	5	1	53.6	4	0.0	5
Wind turbines	30.3	4	2	1	3	300	1	5	1	94.1	4	-10.0	3

2.4.1. Determination of the network.

In ANP, numerical data can be represented graphically and thus show the influence pattern of the network. This step is essential for the further development of the process because if all the complexity of the real-world case study is to be transferred to the model, it is fundamental to accurately identify the influences of some elements upon others based. The risk is that if one influence is not identified, the model will not take it into account and some valuable information will be lost. The decision model was built with the help of the Super Decisions v 2.0.8 software (www.superdecisions.com). Fig. 1 shows the relationships among the clusters.

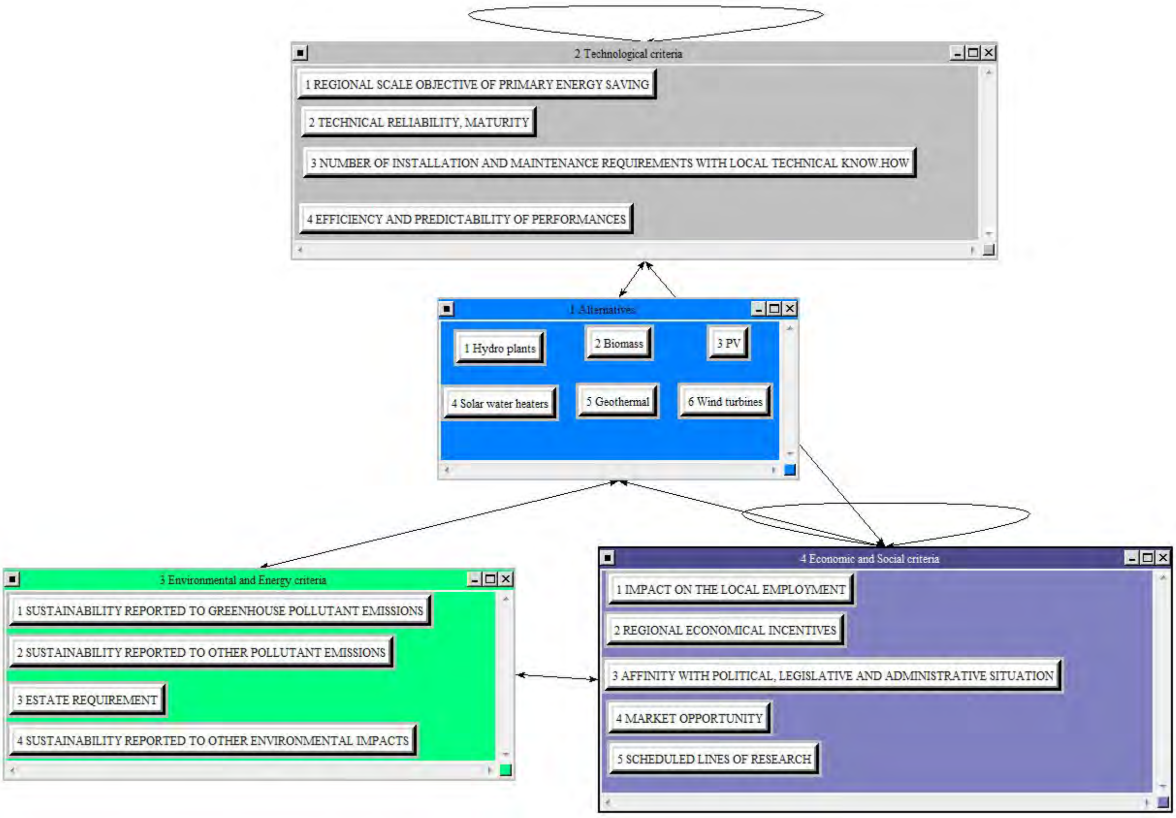


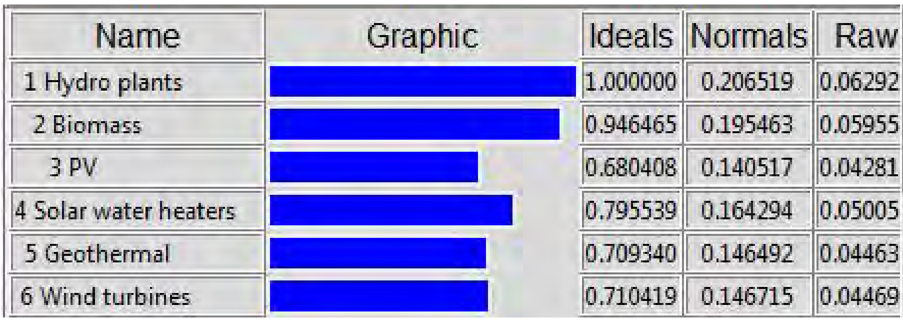
Fig. 1. ANP model scheme with inner and out dependencies.

2.4.2. Determination of element and cluster priorities

This stage includes all the steps of the ANP model. The first step consists of assigning priorities to related elements in order to build the unweighted supermatrix. For this end, each node is analyzed in terms of which other node have influence upon it; then the corresponding pairwise comparison matrices of each cluster are generated in order to obtain the corresponding eigenvectors. As in the case study different node from different clusters have influences on one cluster the unweighted matrix is nonstochastic by columns. All clusters that exert any kind of influence upon each group have to be prioritized using the corresponding cluster pairwise comparison matrices [16]. The value corresponding to the priority associated with a certain cluster weights the priorities of the elements of the cluster on which it acts (in the unweighted supermatrix), and thus the weighted supermatrix can be generated.

2.4.3. Calculation of the limit matrix and resulting prioritization.

By raising the weighted supermatrix to successive powers the limit matrix is obtained. The results of the model are shown in Fig.2.



Name	Graphic	Ideals	Normals	Raw
1 Hydro plants		1.000000	0.206519	0.06292
2 Biomass		0.946465	0.195463	0.05955
3 PV		0.680408	0.140517	0.04281
4 Solar water heaters		0.795539	0.164294	0.05005
5 Geothermal		0.709340	0.146492	0.04463
6 Wind turbines		0.710419	0.146715	0.04469

Fig. 2. Final results where the Raw *column gives the priorities from the limiting supermatrix, the* Normals *column shows the results normalized for each component and the* Ideals *column shows the results obtained by dividing the values in either the normalized or limiting columns by the largest value in the column.*

2.4.4. Phase of evaluation of results

Fig. 2 shows the results obtained with model of the study. The “best” alternative is the one with the “highest” score. The alternative selected by the model as the best options is the hydro plants technology, which is the action with the best behavior throughout the execution process, from project formulation to final score. The result shows the great complexity of the problem. In ANP the priorities are effected by the influences among clusters.

3. Discussion

It is clear that the results obtained from the model must be read in the correct way. Even if the model selected an action amongst the others it does not meaning that technology is always the preferred solution. Indeed the meteorology monitoring of the past few years has shown that precipitation in the Region are not so plentiful to allow a full energy production from the installed hydro plant. Nothing let us believe that this situation will change in the nearest future. So the second and the third actions could be very interesting in a planning situation, both biomass and solar water heaters are good potential technology. Biomass contains a big potential that could be express both in electricity and thermal power. At the same time solar water heating, even if a well know technology, could be implemented in more efficiency ways as the research in the optimization of thermal transformation proceeds.

4. Conclusions

An ANP model is applied in order to asses groups of actions focused on the implementation of several RET innovative technologies voted to use energy renewable resources. The introduction of a multicriteria approach makes a decisional process more flexible and transparent. In this case study 13 evaluation criteria grouped in 3 cluster have been defined, in order to increase the flexible approach to the decision-making. From the obtained results is clear as the RET represent in all forms a strong response to the limits imposed for the 2020 scenario.

References

[1] V.A., Relazione programmatica sull’energia 2009, Regione Piemonte, 2009.

[2] Hobbs B.F., Meier P., Energy decisions and the environment: a guide to the use of multicriteria methods. Dordrecht: Kluwer Academic Publishers, 2000.

[3] Diakoulaki D., Antunes C.H., Martins A., MCDA and energy planning, in: Figueria J., Greco S., Ehrgott M., editors, Multi-criteria decision analysis: state of the art surveys. New York: Springer, 2005, pp. 859-98.

[4] Jones M., Hope C., Hughes R., A multi-attributive value model for the study of UK energy policy, J. Oper Res Soc, 1990, 41:919-29.

[5] Pan J., Rahman S., Multiattribute utility analysis with imprecise information: an enhanced decision support technique for the evaluation of electric generation expansion strategies. Electr Power Syst Res, 1998, 46:101-9.

[6] Saaty T.L.,Vargas L.G., Decision making with the Analytic Network Process – Economic, Political, Social and Technological application with Benefits, Opportunities, Costs and Risk., Springer Science + Business Media LLC, 2006, pp. 1-20.

[7] Saaty T.L., Theory and Applications of the Analytic Network Process. RWS Publications, Pittsburgh, 2005.

[8] Ulutas, B.H., Determination of the appropriate energy policy for Turkey. Energy, 2005, 30 (7), pp. 1146-1161.

[9] Agarwal A., Shankar R., Tiwari M.K., Modelling the metrics of lean, agile and leagile supply chain: an ANP-based approach. European Journal of Operational Research, 2006, 173 (1), pp. 211-25.

[10] Niemura M.P., Saaty T.L., An analytic network process model for financial –crisis forecasting. International Jpurnal of Forecasting, 20 (4), 2004, pp. 573-87.

[11] Neaupane K.M., Piantanakulchai M., Analytic network process model for landslide hazard zonation. Engineering Geology, 2006, 85 (3-4), pp. 281-94.

[12] Promentilla M.A.B., Furuichi T., Ishii K., Tanikawa N., Evaluation of remedial countermeasures using the analytic network process. Waste Management, 2006, 26 (12), pp. 1410-1421.

[13] Bottero M., Lami I.M., Lombardi P., 2008, Analytic Network Process. La valutazione di scenari di trasformazione urbana e territoriale, Alinea: Firenze, 2008.

[14] Bottero M, Mondini G., An appraisal of analytic network process and its role in sustainability assessment in Northern Italy, International Journal of Management of Environmental Quality, 2008, 19 (6), pp. 642- 660.

[15] Wolfslehner B., Vacik H., Evaluating sustainable forest management strategies with the Analytic Network Process in a Pressure-State-Response framework. Journal of Environmental Management, 2008, 88 (2), pp. 1-10.

[16] Saaty T.L., Decision making with independence and feedback: the analytic network process. Pittsburgh: RWS Publications, 2001.