

# Energy Planning: A Sustainable Approach

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## 1. Introduction

Energy system is currently based on a large fossil fuels dependence. It is a centralised model that have allowed a strong economic development in the last century, but that is showing a number of inconveniences which are turning it more and more unsustainable. Fossil fuels depletion, environmental damage and territorial unbalance caused by centralised energy model are significant factors to change energy structure, integrating new resources and modifying the way we use them. It is necessary to make compatible socio-economic development with a sustainable energy model, environmental respectful and that could generate local wealth. The key issue is to address current model towards a more balanced system based on the exploitation of renewable resources.

Therefore, planning decisions concerning energy system cannot be consider under one specific criterion. Different implications, apart from energetic, such as environmental or socioeconomic matters, derived from changes on energy development and from the seek of sustainability, make it unavoidable to use tools and techniques that could take into account such multiplicity.

In this way, this chapter summarizes current trends in energy planning when social and environmental issues have to be considered. This kind of approach have to be set in order to foster renewable energies development, mainly at regional level, by establishing strategies to reach, in the long term, an energy system more sustainable and mainly based upon autochthonous resources.

Current energy planning models, related to sustainable development processes, are described and analyzed. The importance of multicriteria decision techniques, Delphi surveys and SWOT analysis, which are the most referred approaches on literature, is highlighted, and a deep review of such methodologies is presented.

Successful combinations of these methods are also enlightened. Hybrid models as those using SWOT analysis and Delphi techniques, or Delphi techniques as a support of a Multicriteria Decision Making analysis, are specified and best examples are shown. Finally, a number of best practices are also presented, looking into their main drawbacks and advantages.

## 2. Sustainable approach to energy planning

Energy sector configures a strategic area inside territorial socio-economic system. On one side, energy supply constitutes a basic service for citizen's daily life and, on the other hand it represents a fundamental item on progress and economic development. This is the reason

why energy policies and planning process have traditionally intended to assure energy supply on optimal conditions of security, quality and price.

In the past, national energy planning aimed to determine the infrastructure investment program to be carried out in a defined time period. However, on the new legal frame, most of the energy planning is recommended, being respectful with private enterprise, and reserving as binding planning only great energy transport infrastructures.

In spite of above mentioned, inconveniences derived from current energy model imply the need to drive energy system toward more sustainable levels, establishing strategies to encourage energy diversification and solid commitment with renewable energies. In this context, planning processes became essential to fix European, national and even regional targets and to foster the involvement of public and private actors in objectives attainment.

Following this philosophy, the European Commission issued on 1997 the communication called "Energy for the future: renewable sources for energy. White Paper for a community strategy and action plan" establishing a European target of 12 percent for the contribution of renewables on year 2010 (Comision Europea, 1997). Attainment of this target at European level required strategies and commitments at national level, as they were established in the Spanish Renewable Energies promotion plan in 1999 (IDEA, 1999), subsequently revised as the new Spanish Renewable Energies Plan in 2005 (IDEA, 2005), and is definitely requiring strategies and actions at regional level.

As the "planning chain" is deployed, new energy planning models have to be developed. It must be taken into account that decisions concerning energy system cannot be consider any longer under one specific criterion. Different implications, energetic, environmental or socioeconomic, derived from changes on energy development make it unavoidable to use tools and techniques to deal with such multiplicity.

### 3. Renewable energy planning methodologies: basic tools

Different techniques have been traditionally used for renewable planning purposes at regional level. In this section, techniques currently used for energy planning purposes are analysed, focusing on those ones related to sustainable development processes and regional level scope. As we will highlight, multicriteria decision techniques, Delphi surveys and territorial energy planning constitutes the most referred approaches on literature.

#### 3.1 Multicriteria decision techniques

Multicriteria decision techniques were developed profusely in the 60's. Classic methods come from that decade, when Goal Programming and ELECTRE (Elimination and choice translating reality) method were proposed. On the 70's new methods and refinements of existing ones were developed, and finally on the 80's support from computer sciences has allowed a fast growth in applications and results from multiple criteria decision making (MCDA) techniques (Barba-Romero & Pomerol, 1997).

In general, all multicriteria decision aid techniques are based on the identification of a number of alternatives ( $A_1, A_2, \dots, A_m$ ); the selection of assessment criteria, ( $C_1, C_2, \dots, C_n$ ); and determination of results of the assessment of each alternative,  $A_i$ , for each one of the criteria. Resulting matrix,  $[a_{ij}]$ , common to all MCDA methods, is usually called Decision Matrix (Fig.1).

MCDA techniques are being successfully used in many different planning processes. Although there are many different MCDA methods (optimisation, goal aspiration or outranking models), steps to be followed are similar in all of them:

1. Problem definition
2. Identification of alternatives
3. Criteria selection
4. Decision matrix elaboration
5. Weights assignment
6. Prioritization, and
7. Decision making

		Criteria					
		$C_1$	$C_2$	...	$C_i$	...	$C_n$
Alternatives	$A_1$	$a_{11}$	$a_{12}$		$a_{1i}$		$a_{1n}$
	$A_2$	$a_{21}$	$a_{22}$				
	...						
	$A_i$	$a_{i1}$			$a_{ij}$		$a_{in}$
	...						
	$A_m$	$a_{m1}$			$a_{mi}$		$a_{mn}$

Fig. 1. Decision Matrix diagram in a MCDA process

This kind of methodology is often currently used by different environmental Agencies in the US and Europe to tackle planning processes implementation (Linkov et al. 2004). The authors reveal that, despite of the fact that decision process implementation is often based on physical modelling and engineering optimisation schemes, Agencies are beginning to implement formal decision analytical tools, especially multicriteria decision analysis, in environmental decision making. They also highlight the relation between MCDA general steps, as described above, and general planning processes.

Under energy scope, the need to consider environmental, technological and social factors on energy planning has encouraged the use of multicriteria decision techniques. Among different MCDA techniques, AHP (Analytical Hierarchy Process), PROMETHEE (Preference ranking organization method for enrichment evaluation) and ELECTRE method have been widely used in energy planning, in accordance with data compiled and published in mid 2000's (Pohekar and Ramachndran, 2004).

ELECTRE method is based on the outranking relations established between each pair of alternatives. Concordance matrix and discordance matrix are then elaborated to generate a selection or a ranking of the different alternatives. It has been successfully used for renewable energy planning (Beccali et al. 2003). An action plan was assessed for the diffusion of renewable energy technologies at regional scale, using a multicriteria approach with twelve evaluation criteria

ELECTRE has also been utilised to elaborate a new energy strategy for Crete Island (Georgopoulou et al. 1997). It is advocated by these authors the use of MCDA techniques to select alternatives energy policies at regional level, mainly on high renewable resources regions. MCDA tools utilisation allows, in these cases, to take into account the environmental dimension, as well as technical, economical and political criteria. However, it is also emphasized the fact that we are dealing with "decision aid" techniques far from

“decision making” techniques and, in this sense, the application of one of these methods only represents one of the steps to follow.

Other authors take advantage of AHP as community decision support on energy projects implementation (Nigim et al. 2004). MCDA has been used by a workgroup in Canadian Waterloo region, to determine priorities among five different renewable energy projects by means of six criteria that assessed both impacts and project feasibility. A process based upon group participation was developed, and results were successfully compared with those generated by a linear programming tool. Nigim et al. analyse the strong dependency between decision aid methods used, and expert opinion made to assess the hierarchy elements weight. They consider that, finally, MCDA tools have to depend on intangible aspects and subjective opinions of involved people, and they propose the use of objective criteria, as net project value, to minimise this point.

On the other hand, the use of PROMETHEE methodology is also rising. Cavallaro presents a multicriteria integrated system to assess sustainable energy options that has PROMETHEE technique as the basis of its development, and applies it to the Italian Messina region (Cavallaro, 2005). It is important to highlight that, in this case, net flow (defined as difference between positive and negative flow) is used to reach a complete outranking among alternatives.

Furthermore, a combination of MCDA methods, either in parallel or sequentially applied, may also be a proper selection in energy planning. Different combination uses that include AHP along with PROMETHEE; AHP along with TOPSIS (technique for order preference by similarity to ideal solutions); and AHP along with GP (goal programming) are described in research literature (Loken, 2007). Loken also advocates the suitability of MCDA methods as planning tool in local energy system, where several energy sources and several energy carriers are involved.

A recent review of the published literature on sustainable energy decision-making (Wang et al., 2009) shows a great applicability of MCDA methods for sustainable energy decision-making. The review concludes that AHP is the most popular comprehensive method among MCDA techniques and that fuzzy set methodology has been increasingly applied to deal with qualitative criteria and vagueness inherent to the information. Referring to criteria selection, it has been observed that efficiency, investment cost, CO<sub>2</sub> emission and job creation are the most common criteria in the technical, economic, environmental and social scenarios. The investment cost locates the first place in all evaluation criteria and CO<sub>2</sub> emission follows closely because of more focuses on environment protection.

### 3.2 Delphi techniques

Delphi techniques have also been a popular tool for preparing forecasts and planning purposes. Landeta acknowledges that, since its first application up to current applications in a huge diversity of fields such as higher education, public health, information systems, production sector analysis or political options assessment, the technique has been refined and adjusted to different uses (Landeta, 1999).

In recent years, it is being used as an effective method in long term planning related to sustainable development. In this sense, it is suggested the use of two scenarios constructed by means of a Delphi expert-based survey (Shiftan et al. 2003). Other authors propose the utilisation of Delphi, assisted by a web-based survey, combined and supported by a geographical information system (GIS) to promote sustainable development in development countries (Popper and Dayal, 2002).

### 3.3 Territorial and rural energy planning methods

Participatory approaches for energy planning implementation are being extensively used in rural areas and development countries. P.M. Williams reflected on the use of traditional strategic planning methods for designing sustainable development strategies, and advocated changing the model to “strategic architecture” instead of “strategic plan”, in order to plan the things to be done today to modify the future (Williams, 2002). He also emphasized the process more than contents and actors more than the structure.

Participation is an essential item in these processes. In this sense, a paradigmatic example is the rural energy development planning in India that has been referred to by Neudoerffer et al., who verify that energy programmes launched by Indian government have got a limited success due to the lack of mechanism to assure the implication of final users, and present the main conclusion of a research project to develop planning methodologies and tools to facilitate public participation (Neudoerffer et al. 2001). Other authors also highlight the importance of participation techniques to implement, in a successful way, energy plans and projects at rural areas (Anderson and Doig, 2000).

The case of Jaén province (Terrados et al. 2007), also confirms the suitability of this kind of approaches when society implication is essential. Authors conclude that management tools used in territorial strategic planning processes, especially SWOT (Strengths Weaknesses Opportunities and Threats) analysis, can be successfully used by public administrations as proper tools to search and select strategies that may help them in the redesigning of the regional energy system.

### 3.4 Other techniques

Apart from above mentioned techniques, optimisation methods such as EFOM (energy flow optimisation model) have been used to support planning processes (Cormio et al. 2003). In this case, authors executed several simulations on the Apulia region energy system, in Italy, to prove the suitability of combined cycle installations, wind energy and biomass exploitation as environmental friendly technologies to be promoted.

Other techniques, concerning energy model generators, are being currently used for the purpose of strategic energy planning and decision making. This is the case developed at Basilicata region, in Italy, where a MARKAL models generator was used to obtain medium-term strategies and climate protection policies (Pietrapertosa et al. 2003 and Salvia et al. 2004). They implemented a MARKAL model specific for the region in order to assess the contribution of local energy systems to the achievement of national targets.

## 4. Renewable energy planning methodologies: combined models

Combination of SWOT analysis and Delphi techniques has been successfully used in planning processes related with local and regional development. L.V. Zwaenepoel proposes an approach based in an initial SWOT analysis and a later use of the Logical Framework analysis that make use, as inputs, of SWOT analysis outcomes. The process includes, inside SWOT methodology, an expert survey in order to reach a consensus prior to launch the Logical Framework analysis (Zwaenepoel, 2005).

We can also consider as a combined model the one presented by Carlos Benavides who applies it to Strategic Planning at Universities. In this case, a round of talks to experts is utilised as a support process in SWOT matrix elaboration (Benavides & Quintana, 2004).

There are other hybrid models using Delphi techniques as a support of a Multicriteria Decision Making analysis. It can be highlighted contributions by Aragonés, called PRES II Multiexpert methodology (Aragonés, 1997), and also by Curtis, who proceeded with an eighty experts Delphi panel to assign weights on twenty attributes of an ecosystem that was evaluated by means of MCDA (Curtis, 2004).

Another type of combination arisen in the last years is the integration of fuzzy methodologies with expert opinion and MCDA techniques. Recently it has been presented the case of the renewable energy planning for Istanbul by using an integrated fuzzy-AHP methodology (Kaya & Kahraman, 2010). In this methodology, the weights of the selection criteria are determined by pairwise comparison matrices of AHP, and fuzzy logic is successfully applied to model the uncertainty and vagueness of the judgments of expert and decision makers who are unable to provide exact values for the criteria.

## 5. Best practices

In this section a selection of three best practices of sustainable energy planning applications is presented.

The first one is related to regional energy planning through classical strategic planning tools and shows the advantages of the use of SWOT analysis in the design of a new energy system. The second one is an application of Multicriteria decision techniques (MCDA), based on Electre III procedure, to assess an action plan for renewables diffusion in Sardinia. And the third one is an application of a combined methodology, using SWOT, Delphi and Promethee techniques, for sustainable energy planning in the south of Spain.

### 5.1 The strategic plan for Jaén province

Elaboration of the Strategic Plan for Jaén province began with the commitment of the Provincial Government in the project. On 1997, Provincial authorities formally approved the proposal to elaborate an Strategic Plan to foster territorial development. Since this proposal, a negotiation process started, among most relevant institutions, in order to shape the initial idea, to establish the structure and to define organization and project terms.

Both, Provincial Government and University of Jaén, took the lead of the project and created a Foundation called "Strategies for economic and social development of Jaén province" that took charge of the whole project management. This was the starting point for most relevant institutions at provincial level to join to the newly created Foundation and collaborate in the ambitious project of territorial strategic planning.

A sequentially phased program was established (Figure 2), trying to assure on one hand the technical consistency of the Plan and, on the other hand, the massive participation of provincial community. Technical consistency was pursued through a diagnosis phase based upon expert working groups, and the implication of the community was addressed by means of a collective participation phase specifically designed to encourage participation in working tables. Political implication and commitment was also pursued. In this way, an approval phase, where each political institution assumed its compromise with plan execution, was finally carried out.

At the beginning of the Diagnosis Phase, a series of technical expert groups were appointed in each of the technical areas to be addressed by the Strategic Plan. One of these groups was responsible to analyse territory status within the area of Infrastructures, Energy, Urban Development and Environment. It was constituted in December of 1998, including

representation from University, Energy Agency and Provincial Government. Group members maintained up to twenty two working meetings along the whole process and they elaborated first, during four months, an initial report that was issued and presented publicly.

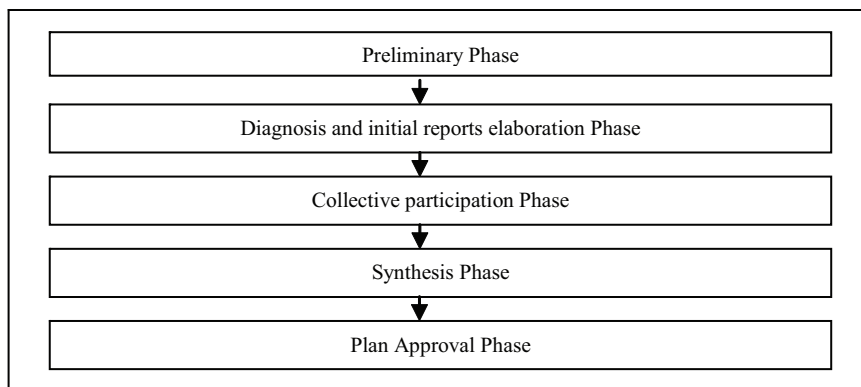


Fig. 2. Strategic plan development phases

Afterwards a Collective Participation Phase began, and the technical report was put under later discussion to allow collaborators, who voluntarily had become involved in the reflection process, to analyze it and to contribute new ideas to the debate. Finally the technical group reprocessed the initial report, collecting the contributions and the suggestions of the collaborators, incorporating new proposals, clarifying some of the existing ones, and omitting those that were not considered pertinent. The final document concerning the energy area was approved in the month of March of 2000.

It is important to emphasize that the work sessions followed an interdisciplinary method, where ideas exposed by anyone of the group members were submitted to different scientific and/or technical interpretations from any other scope. In this way, results were enriched by the manifold approaches under which the proposals were analyzed.

The diagnosis of the energy system was structured through a SWOT matrix (Figure 3), in which were shown the weaknesses, strengths, threats and most relevant opportunities than must be faced by the provincial energy system. This kind of analytic tool is often used in participatory planning approaches, although it was originally developed for strategic planning in business and marketing purposes. It must be taken into account that SWOT is only a tool, and has to be based on a sound knowledge of the present situation and trends.

SWOT analysis for energy allowed to establish, as the following step, problems that had to be faced by the energy area, as well as the suitable strategies that could overcome such problems. For this purpose, a problems tree was elaborated, arranging in form of family tree the main weaknesses of the provincial energy system, grouping them under the headline of: "Centralized energy system, incomplete, hardly respectful with the environment and with scarce autochthonous resources utilization".

Directly derived from that problems tree, it was depicted an objectives tree that allowed the obtainment of strategies and performance lines routed to the solution of detected problems. This objectives tree structured strategies under the general mission of: "To improve the energy efficiency and the energy supply conditions as local development and environment

conservation element". Finally, in third place, they were presented each one of the strategic projects designed to reach the previously outlined objectives.

Despite of the fact that the most usual tools in energy planning are based on multicriteria decision analysis techniques, that have demonstrated their effectiveness in a significant amount of situations, the use of SWOT analysis in the development of the Strategic Plan permitted a correct comprehension of the provincial energy situation and served as a basis for objectives and strategies proposal. In fact, the use of SWOT analysis encouraged the discussion and criteria contrast among group members in the elaboration process of the sectors of the matrix as well as in the subsequent review for the development of the problems tree and objectives tree. This quality, already commented by some authors (Pickton & Wright, 1998), favoured the elaboration of the diagnosis and the interdisciplinary coherence.

<p><b>STRENGTHS</b></p> <p>F.1 High solar radiation</p> <p>F.2 Large amount of agricultural and industrial biomass</p> <p>F.3 High exploitation of hydroelectricity in Guadalquivir river basin</p> <p>F.4 Great tradition in solar energy research and development</p> <p>F.5 Existence of the Energy Management Agency of Jaén province</p> <p>F.6 High value of natural heritage, that favours clean energies development</p>	<p><b>WEAKNESSES</b></p> <p>D.1 Lack of fossil energy resources</p> <p>D.2 Limited installed power for electrical generation</p> <p>D.2 Insufficient infrastructure for natural gas distribution</p> <p>D.4 Low sensitiveness to energy saving</p> <p>D.5 There is no individual awareness for Renewable Energy utilisation</p> <p>D.6 Buildings are not constructed with bioclimatic criteria</p> <p>D.7 Renewable energy business sector is weak</p> <p>D.8 Low quality of electricity on determined areas</p> <p>D.9 Absence of financial mechanisms to endeavour RES penetration</p> <p>D.10 Dependency of an unique high voltage injection to the provincial electricity network</p>
<p><b>OPPORTUNITIES</b></p> <p>O.1 Existence of industrial sectors suitable for installing Cogeneration processes</p> <p>O.2 Suitable climate for the successful application of bioclimatic criteria</p> <p>O.3 Existence of applicable funds to invest in Energy System development</p> <p>O.4 Existence of susceptible areas for wind energy development</p> <p>O.5 Existence of subsidies to electricity production with Renewable sources in the new Spanish electrical market</p>	<p><b>THREATS</b></p> <p>A.1 Progressive environmental deterioration</p> <p>A.2 Excessive dependency on fossil fuels</p> <p>A.3 Risk of energy resources price increase</p>

Fig. 3. SWOT matrix for energy

Along the Synthesis Phase, the Strategic Plan was structured as a deployment of Promotion Programs, Performance Lines and Strategic Projects. Project definition included, in most of the cases, the quantification of the objective goals (Table 1). Among these objectives it can be highlighted the followings: the installation of 100 MW of power in plants electrical generation with biomass; to reach 1 MW of PV grid connected installed power; to obtain the annual installation of 10.500 m<sup>2</sup> of thermal solar panels; or to reach 50 MW installed in Wind Energy systems.



STRATEGIC PROJECTS	Goal to meet
015. Extension of Natural Gas transport and distribution network	80% of population
016. To increase the capacity of the high and medium voltage electricity grid, to guarantee supply and industrial development	-
019. Exploitation of biomass resources for the installation of electricity generation plants	100 MW
020. Installation of cogeneration plants in thermal energy consuming industrial sectors	130 MW
021. Establishing of the necessary structures for the complete exploitation of agricultural and forest residues	Y/N
022. Establishing of the necessary structures for the energy exploitation of residues from cattle raising and industry	Y/N
023. Wind energy planning of Jaén province	50 MW
024. Promotion of solar photovoltaic grid-connected systems	1 MW
025. Promotion of energy crops in marginal lands	-
121. Legal normative to encourage domestic solar water heating systems in new buildings	10.500 m <sup>2</sup>
122. To increase the use of isolated PV systems for the electrification of rural housings and facilities	Y/N
123. Application of energy saving and efficiency criteria in buildings	-
124. To encourage the recovery of small hydraulic plants	Rehab. Plan
125. To transform AGENER into the Provincial Energy Agency	Y/N
145. Installation of a second 220 kV injection to electricity transport grid	Y/N
146. Improvement of the electrical distribution grid to increase supply quality	TIEPI = 2,11
154. Diffusion and training campaigns in energy saving and Renewable energies	Y/N
155. Research and technological development institute dedicated to exploitation and conservation of natural resources	Y/N

Table 1. List of strategic projects and goals defined

The quantification, in terms of energy, of the specifically set Strategic Plan goals, lead us to foresee an electricity yield of 1.226 GWh from renewable sources. It is interesting to check that this figure match with the extrapolation to provincial level, using the population as extrapolation ratio, of the Spanish and Andalusian objectives set by the respective energy plans.

The energy diagnosis of the Plan (Almonacid et al. 2000), concluded fixing as long-term high-priority items the energy diversification, fundamentally based in Natural Gas and autochthonous Renewable Resources, the improvement of gas and electricity networks, the political and social awareness to drive an environment-respectful energy development, and the research and education on Renewable Energy matters.

## 5.2 Application of the ELECTRE method to assess an action plan for RES diffusion.

In this best practice, presented in 2003 by Professors M. Becalli, M. Cellura and M. Mistretta (Becalli et al. 2003), an application of the multicriteria decision-making methodology is used

to assess an action plan for the diffusion of renewable energy technologies at regional scale. They consider that this methodological tool gives the decision-maker considerable help in the selection of the most suitable innovative technologies in the energy sector, according to preliminary fixed objectives, and they show the results of a case study carried out for the island of Sardinia.

The aim of such case study is to select the most suitable technologies in a Renewable Energies diffusion plan for the Sardinia region. They have previously selected a set of technologies of energy conversion and saving, which are associated with their diffusion in Sardinia, and afterwards Electre III method is used. In this method, the criteria of the set of decisional alternatives are compared by means of a binary relationship, defined as 'outranking relationship', are more 'flexible' than the ones based on a multi-objective approach.

### **Selection of alternatives (actions)**

A total amount of fourteen actions were initially selected. The list comprised actions related to solar energy, wind energy, hydraulics, biomass, animal manure, energy saving and CHP.

### **Definition of evaluation criteria**

Twelve evaluation criteria were defined to deal with technical, political, economics and environmental aspects, as follows:

1. Target of primary energy saving at regional scale
2. Technical maturity, reliability
3. Consistence of installation and maintenance requirements with local technical know-how
4. Continuity and predictability of performance
5. Cost of saved primary energy
6. Sustainability according to greenhouse pollutant emissions
7. Sustainability according to other pollutant emissions
8. Land requirement
9. Sustainability according to other environmental impacts
10. Labor impact
11. Market maturity
12. Compatibility with political, legislative and administrative framework

### **Definition of three decisional scenarios**

Selected criteria were weighed in accordance with three different scenarios: the 'environmental-oriented' scenario (with a preference toward actions generating the lowest environmental impacts); the 'economy-oriented' scenario (with a preference toward actions involving the highest economical and social benefits); and the 'energy saving and rationalization' scenario (with a preference toward actions addressed to energy saving and a rationalization of global energy system).

### **Outranking with Electre III procedure**

Finally, the outcome of the Electre III procedure gives us the final order for each decisional scenario. In each order a best actions area is defined as the area within which the best alternatives are placed for both distillations. These alternatives represent the actions that fulfil the objectives that the decision-maker has fixed.

In the environmental scenario, actions concerning domestic solar water heaters; wind energy; hydro plants in existing water distribution networks; Building insulation; High efficiency lighting; and High efficiency electric, belong to such area.

### 5.3 Application of a combined methodology for regional energy planning at a Spanish region

On the basis of the analysis of planning techniques already made in previous sections, it can be deduced that all of the three methodologies have significant advantages and useful contributions for the sketching of strategies and action lines for renewable energies development. Therefore, we can infer that a combination of those methods, in order to take advantage of their positive characteristics, will lead us to strengthen the effectiveness of the results, complementing their main virtues.

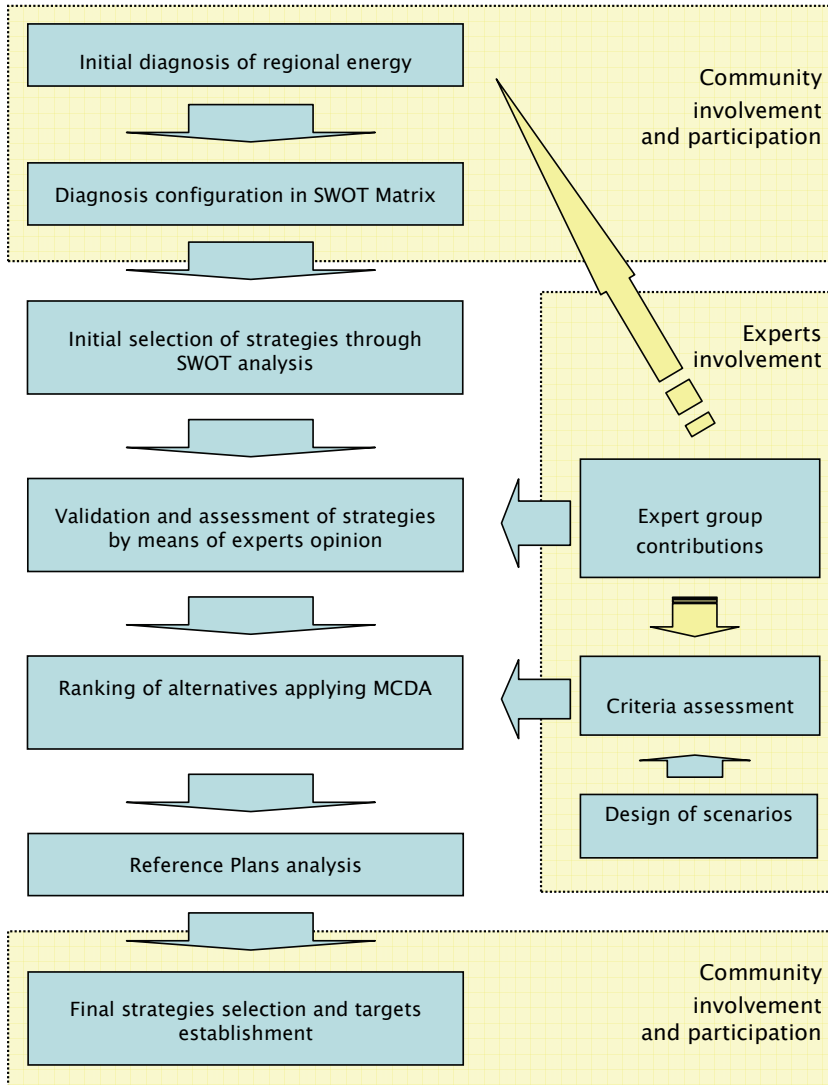


Fig. 4. Scheme of proposed RES planning process

The new approach, proposed by Terrados et al., combines advantages from the three techniques commonly used in regional energy planning: multicriteria decision techniques, expert opinion and SWOT analysis.

For this, the basic structure consists of seven phases:

1. Initial diagnosis of regional energy system
2. Diagnosis configuration as SWOT Matrix
3. Initial selection of strategies through SWOT analysis
4. Validation and assessment of strategies by means of experts opinion
5. Ranking of alternatives applying MCDA
6. Reference Plans analysis
7. Final strategies selection and targets establishment

This scheme is also useful to assure the involvement of stakeholders in the planning process. Figure 4 illustrates the whole framework and shows by means of dark lines the main path, and by means of dotted lines the expected contributions of experts and social community.

The methodology has been applied to Jaén province, a southern Spanish region whose energy system is currently mainly dependant on fossil fuels (Terrados et al. 2009). It was pursued the definition of a series of strategies for renewable energies development and the establishment of energy targets to be achieved in year 2010.

### **SWOT analysis**

First of all, a diagnosis of the provincial energy system was accomplished. Such diagnosis was structured through a SWOT matrix where strengths, weaknesses, opportunities and threats were identified. Deployment of SWOT analysis, comparing the different sectors of the matrix, allowed us to define a set of possible strategies that were segregated on 28 defined actions.

### **Delphi survey**

Following SWOT analysis application, an expert survey, based on Delphi technique, was performed. In this case the number of experts to participate was limited by the characteristics of the matter to study. We needed to contact experts on renewable energies in general, and who should also know about provincial reality. Such limitation would meant to reject Scientifics who were specialized only on a determined renewable resource and were unable to develop a forecast on the rest of sources and, on the other hand it also would meant to reject renewable energies researchers who were unaware of our regional situation.

Thirteen experts were initially selected, and nine of them finally got committed in the process. They represented the main Institutions, Organizations and Enterprises connected with provincial energy field (University, Energy Administration, Provincial Energy Agency, Electrical distribution Company, Andalusian Energy Agency, Andalusian Institute of Renewables, Andalusian Development Institute and Ecologist Associations).

The questionnaire sent in the first round considered twenty eight actions to be executed, and experts were required to assess, in one hand, the relevance of those actions for renewable energies development and, on the other hand, to estimate the target to be met by the action (power installed, number of installations, ...) by year 2010. They were also required to propose additional actions.

As a result arising from the first round, all of the actions were judged very positively with ten alternatives above four points (on a 1 to 5 scale) and another fifteen alternatives above three points. A high degree of consensus was also achieved. Referring to the estimation of targets, discrepancy among experts was higher. A second round was then accomplished.

Consensus among experts was increased both in valuation of alternatives and in target estimation. Variation factor decreased, in a widely manner, and consensus suitable level was judged as appropriate.

### Multicriteria analysis

Finally, a Multicriteria analysis was performed in order to fix priorities among alternatives. A set of ten criteria were initially defined to be assessed in each of the alternatives. Later, an eleventh criterion was added to incorporate results from Delphy analysis into MCDA. In this way, assessment provided by experts survey was consider as an additional criterion.

		Criteria										
		1	2	3	4	5	6	7	8	9	10	11
Type		MÁX	MÁX	MÁX	MÁX	MIN	MIN	MIN	MÁX	MIN	MAX	MÁX
Alternative	1	2,107	4	2	5	50,1	0,08	4	1,75	1442	4	4,52
	2	2,107	4	2	4	50,1	0,08	4	1,75	1442	4	4,09
	3	2,007	3	1	4	50,1	0,08	3	1,75	1442	3	4,27
	4	2,007	3	1	5	50,1	0,08	3	1,75	1442	3	3,76
	5	2,007	2	2	5	73	0,61	3	1,75	1503	3	3,45
	6	2,007	3	2	4	73	0,61	3	1,75	1503	3	3,19
	7	2,007	3	2	4	73	0,61	3	1,75	1503	3	3,42
	8	2,007	3	2	4	73	0,61	3	1,75	1503	2	3,39
	9	0,076	4	3	4	25	0,04	2	1,75	240,9	3	3,67
	10	0,096	4	3	4	25	0,04	2	1,75	151,4	3	3,77
	11	0,076	4	3	4	25	0,04	3	1,75	62,02	3	4,1
	12	0,344	5	1	3	11,6	0,025	4	0,30	601	1	3,33
	13	0,502	5	2	3	9	0,1	2	0,30	1202	3	3,69
	14	0,502	5	2	3	9	0,1	2	0,30	1202	4	4,11
	15	0,416	5	5	4	75	0,4	1	1,02	13222	3	3,91
	16	0,416	5	5	4	75	0,4	1	1,02	13222	3	4,29
	17	0,416	4	5	4	60	0,4	2	1,02	6611	4	3,38
	18	0,416	4	5	4	60	0,4	2	1,02	6611	4	3,74
	19	0,416	4	4	4	60	0,4	2	1,02	6611	3	2,97
	20	0,143	5	5	4	17,98	0,147	1	1,12	729,8	3	4,63
	21	0,143	4	4	4	17,98	0,147	1	1,12	472,2	3	4,81
	22	0,143	4	4	4	17,98	0,147	2	1,12	472,2	3	4,91
	23	0,143	3	3	4	17,98	0,147	2	1,12	472,2	3	4,31
	24	0,645	2	1	4	26	0,19	3	1,12	2524	3	3,57
	25	0,631	4	3	3	18,06	0,08	2	0,30	871,5	3	3,21
	26	0,631	5	2	3	18,06	0,08	5	0,30	871,5	3	4,09
	27	2,007	3	2	3	27,36	0,94	4	1,75	1442	3	2,89
	28	2,007	2	1	3	27,36	0,94	3	1,75	1442	3	2,89

Table 2. Decision matrix of MCDA phase

Therefore, up to eleven criteria were defined, grouping them in four different categories:

*Technological criteria*

1. Total primary energy saved
2. Maturity of technology
3. Technical know-how of local actors
4. Continuity and predictability of resource

*Environmental criteria*

5. Sustainability according to CO<sub>2</sub> emissions
6. Sustainability according to other emissions (SO<sub>2</sub>, NO<sub>x</sub>)
7. Sustainability according to other impacts (noise, visual impact, landscape, ...)

*Socio-economic criteria*

8. Job creation
9. Financial requirements
10. Compatibility with local, regional and national policies

*Delphi criterion*

11. Expert valuation

Each of the alternatives was quantified in every one of the criteria to obtain the Decision Matrix (table 2), and PROMETHEE method was selected to perform multicriteria decision analysis. Incoming (positive) and outgoing (negative) fluxes were calculated and prioritisation of alternatives was established in three different scenarios. Flux diagram concerning environmental scenario is presented in fig 3.

Multicriteria analysis allowed us to establish three different priority levels. Fourteen alternatives were set as A priority, six were set as B, an eight were set as C.

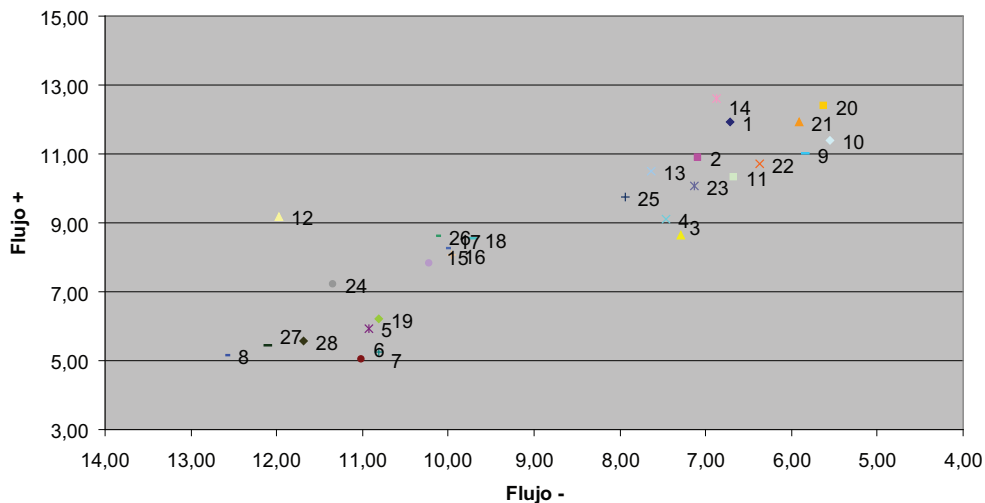


Fig. 5. MCDA process: flux diagram for environmental scenario

### Strategies selection and targets establishment

Final actions selected and energy targets to be met are shown on table 3. For the purpose of the energy plan, the whole set of twenty eight strategies was selected including the group of alternatives that were worse appreciated and that should become lower level priority actions.

Action	2010 Target
Installation of comb. cycle pw. stat. (10-15 MW) fuelled by Olive oil industry res.	75 MW
Installation of comb. cycle pw. stations (10-15 MW) fuelled by Olive pruning res.	30 MW
Installation of gasification-based pw. stat. (10-15 MW) fuelled by Olive prun. res.	20 MW
Installation of gasification-based pw. stat. (10-15 MW) fuelled by wood ind. res.	8 MW
Installation of Biogas plants fuelled by Olive oil industry residues (5 - 10 MW)	10 MW
Installation of Biogas plants fuelled by cattle wastes (5 - 10 MW)	6,5 MW
Installation of CHP plants for the exploit. of water treat. station biogas (0,5-2MW)	1,5 MW
Installation de Biogas plants fuelled by urban residues (1-5 MW)	2,5 MW
Installation of biomass domestic heating systems	980 Unit
Installation of biomass heating systems at educational centres	60 Unit
Installation of biomass heating systems at industry and services	510 Unit
Hydro plants on existing and future dams (10 - 30 MW)	160,0 MW
Small hydro plants on waterfalls and watercourses (0,5 - 10 MW)	58,5 MW
Refurbishing of old hydro plants (0,25 - 5 MW)	7,0 MW
Domestic isolated PV systems (2 - 5 kW)	0,5 MW
Isolated PV systems in farming applications (2 - 5 kW)	0,6 MW
Domestic grid connected PV systems (2 - 5 kW)	0,50 MW
Grid connected PV systems at comp. and public administrations (30 - 100 kW)	3,00 MW
Large grid connected PV systems (200 kW - 1000 kW)	2,00 MW
Single-family domestic solar-thermal heating systems installation	10.500 Unit
Communities domestic solar-thermal heating systems installation	10.200 Unit
Solar-thermal heating systems installation at Hotels and services sector	11.300 Unit
Solar-thermal heating systems installation at Industry	5.500 Unit
Solar-thermal gas hybrid installations (2 - 20 MW)	12,0 MW
Low-power isolated wind systems (5 - 250 kW)	2,0 MW
Wind farms (5 - 30 MW)	70,0 MW
Energy crops exploitation in combustion cycles	2,5 MW
Biofuel generation through energy crops	2,89

Table 3. List of actions selected and energy targets

Final result of such process presents 472 MW of power installed in year 2010, by means of twenty strategies concerning electricity generation with renewable resources, leading to an annual production of 1.630 GWh out of the region. Concerning thermal production, target is fixed in 253,46 ktep through eight strategies mainly focused on biomass and solar thermal.

## 7. Conclusions

Energy planning processes under sustainable development criteria have made extensive use of Multicriteria Decision techniques, where environmental criteria have been incorporated

in the assessment, and also experts' opinion methods and techniques derived from territorial strategic planning.

The analysis of these methodologies and tools is useful to highlight their main advantages and to harness them in the proposal of combined planning methods involving different approaches.

Multicriteria decision analysis (MCDA) tools utilisation allows, in the case of sustainable energy planning processes, to take into account the environmental dimension, as well as technical, economical and political criteria. However, it is important to consider the fact that we are dealing with "decision aid" techniques far from "decision making" techniques and, in this sense, the application of one of these methods only represents one of the steps to follow.

Delphi techniques, that imply the participation of a number of experts, have also been a popular tool for planning purposes. In most of the cases expert opinion has been part of a broader methodology. The use of multicriteria decision analysis combined with expert judgement provides us with a sounder result, strengthening subjective group opinion with objective data analysis. Furthermore, current software applications are allowing planners to perform simulations and sensibility analysis in a quicker and easier way. This characteristic can be useful to value the result robustness.

Finally, methodology based on SWOT analysis for the diagnosis of the energy system assured a comprehensive outline of regional energy situation and a complete set of strategies deployment. SWOT methodology will allow us to arrange energy system diagnosis in accordance with a matrix basis (strengths, weaknesses, opportunities and threats) and will also be used to generate strategies for improving current situation.

These methods allow us to establish development strategies concerning mainly renewable resources, quantifying and ranking them. And, on the other hand, these methods are easily interrelated with collective participation techniques that may assure, as a key factor to success, the involvement of the community in regional planning process. Three issues can be highlighted as the most important for planning success purposes: community participation, interdisciplinarity and SWOT methodology.

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## **Paths to Sustainable Energy**

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The world's reliance on existing sources of energy and their associated detrimental impacts on the environment- whether related to poor air or water quality or scarcity, impacts on sensitive ecosystems and forests and land use - have been well documented and articulated over the last three decades. What is needed by the world is a set of credible energy solutions that would lead us to a balance between economic growth and a sustainable environment. This book provides an open platform to establish and share knowledge developed by scholars, scientists and engineers from all over the world about various viable paths to a future of sustainable energy. It has collected a number of intellectually stimulating articles that address issues ranging from public policy formulation to technological innovations for enhancing the development of sustainable energy systems. It will appeal to stakeholders seeking guidance to pursue the paths to sustainable energy.

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