Selection of Photovoltaic Solar Power Plant Investment Projects - An ANP Approach

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Abstract—In this paper the Analytic Network Process (ANP) is applied to the selection of photovoltaic (PV) solar power projects. These projects follow a long management and execution process from plant site selection to plant start-up. As a consequence, there are many risks of time delays and even of project stoppage.

In the case study presented in this paper a top manager of an important Spanish company that operates in the power market has to decide on the best PV project (from four alternative projects) to invest based on risk minimization. The manager identified 50 project execution delay and/or stoppage risks.

The influences among elements of the network (groups of risks and alternatives) were identified and analyzed using the ANP multicriteria decision analysis method. After analyzing the results the main conclusion is that the network model can manage all the information of the real-world problem and thus it is a decision analysis model recommended by the authors. The strengths and weaknesses ANP as a multicriteria decision analysis tool are also described in the paper.

Keywords—Multicriteria decision analysis, Analytic Network Process, Photovoltaic solar power projects.

I. INTRODUCTION

INVESTMENT projects in photovoltaic solar power plants are becoming more and more promising and popular in Spain. Spain has very good conditions for the development of solar power systems due mainly to the high mean daily radiation (amount of mean daily radiation per land surface unit) and the high number of sunny days in most parts of the country. For this reason, the Administration and companies working in the sector are developing policies and investing in photovoltaic solar power systems. A photovoltaic solar plant, also known as a solar power farm, consists of a number of photovoltaic solar panels placed in a specific site with the purpose of selling the generated energy to the contracting electricity supply company. The amount of energy generated ranges between 3 MWp (Megawatt peak) and 50 MWp

Conventional power plants like nuclear or combined-cycle power plants require important investments only affordable to

big power supply companies. By contrast, the investment required in the development of solar power plants is considerably lower and thus affordable to smaller companies or individual investors. For this reason, many companies smaller than the big electricity supply companies are starting to position in this market and are investing in solar power.

The present paper analyzes the problem for the managing board of an important solar power investment company to establish a priority order among different projects for the development of a photovoltaic solar power plant. The company of this case study is a medium-sized company traditionally devoted to the installation and maintenance of power systems for the big power supply companies, but which has recently entered the market of power generation through the development, maintenance and exploitation of solar power plants.

The decision problem presented here is highly complex because in addition to economic profitability, the risks involved in the development, construction, execution and maintenance of the plant are relevant factors in the decision making process. Therefore the priority value assigned to each project depends on the economic profitability and execution time of the projects. Investment companies that execute the project and further exploit the installations cannot have their resources inactive while waiting for the corresponding construction approval and execution permits, which may get delayed, or depend on long negotiations with the power supply company.

A solar power plant project, from the very first stage of selection of the plant site and land survey, to the last stage of implementation and start-up of the plant, follows a long process that involves obtaining the required construction permits and authorizations (Table I), negotiating with the different stakeholders (land owners, local and government authorities, power supply companies), complying with complex legal regulations, as well as solving the technical problems related to the construction of the plant and the distribution of the energy generated. This management process for the obtaining of the required construction and execution permits and development of the plant makes projects that can be very profitable at the exploitation stage be also very risky due to unexpected project execution delays or even project stoppage.

TABLE I
DIAGRAM OF THE REQUIRED CONSTRUCTION AND EXECUTION PERMITS AND
LICENSES

	PRELIMINARY ISSUES	FINAL ISSUES
Local administration	Construction license	Business Activity License
Electric grid manager	Electric grid connection point	Final connection to the grid. Contract
Competent Body Autonomous Regions	Administrative approval. Provisional registration in the Register of Production Facilities in special Regime	Certificate of plant Start-up. LV certificate Registration in the Register of Production Facilities in special Regime
Public Tax Administration	Registration in EAT (Economic Activity Tax)	Business Activity Code

This paper presents a decision-making method based on the Analytic Network Process (ANP) [1], [2] that may help the managing board of a company of this kind to solve the following decision-making problem: "Given a number of photovoltaic power investment projects that are known to be profitable for the company, establish project priority based on project risk levels and execution time delays."

The procedure proposed here allows identifying, weighting and estimating the risks involved in the development of solar power projects, and establishing priorities based on this risk analysis. For that, a network-based ANP model has been used in the study. The resulting data and the overall process have been analyzed on the basis of the time devoted by the decision maker and his degree of satisfaction with the analysis procedure and the final results.

The rest of the paper is organized as follows. Firstly, Section II introduces the Analytic Network Process. Then, Section III describes the decision making process and Section IV presents the main conclusions derived from this research and future works.

II. BACKGROUND OF ANP

ANP represents a decision making problem as a network of criteria and alternatives (all called elements), grouped into clusters. All the elements in the network can be related in any possible way, i.e. a network can incorporate feedback and interdependence relationships within and between clusters. This provides a more accurate modelling of complex settings. The influence of the elements in the network on other elements in that network can be represented in a supermatrix. This new concept consists of a two-dimensional element-by-element matrix which adjusts the relative importance weights in individual pairwise comparison matrices to build a new overall supermatrix with the eigenvectors of the adjusted relative importance weights. According to Saaty [2], the ANP model comprises the following steps:

(i) Identifying the components and elements of the network and their relationships.

(ii) Conducting pairwise comparisons on the elements.

(iii) Placing the resulting relative importance weights (eigenvectors) in pairwise comparison matrices within the supermatrix (unweighted supermatrix).

(iv) Conducting pairwise comparisons on the clusters.

(v) Weighting the blocks of the unweighted supermatrix,

by the corresponding priorities of the clusters, so that it can be column stochastic (weighted supermatrix).

(vi) Raising the weighted supermatrix to limiting powers until the weights converge and remain stable (limit supermatrix).

More details on the Analytic Network Process (ANP) can be found in [1], however, the main steps are summarized here for completeness.

Some of the most recent applications of ANP to decision making problems have been: R&D project selection [3], [4], construction project selection [5]; resource allocation in transportation [6]; enterprise information system project selection with regard to BOCR [7]; supplier selection [8], selection of logistics service provider [9], contractor selection [10], purchasing decisions [11]; solid waste disposal options [12], locating undesirable facilities [13]; concept evaluation in a new product development [14]; evaluation of alternative fuels for residential heating [15], strategic e-business decision analysis [16], asset valuation [17], [18], choice of best management alternative of the supply chain in a company [19], determination of the appropriate energy policy [20], product mix planning [21], selection of best actuation for end-of-life computers [22].

The reasons for using an ANP-based decision analysis approach in the present work are: (i) Risk-based project selection is a multicriteria decision problem, (ii) there are dependences among groups of risks and between these and the projects under evaluation that have to be analyzed, (iii) the detailed analysis of interdependences between clusters forces the decision maker to carefully reflect on his/her project priority approach and on the decision-making problem itself, which results in a better knowledge of the problem and a more reliable final decision.

III. THE DECISION MAKING PROCESS AND THE ANP MODELING APPROACH

A. Description of the Decision Making Process

The decision-making process followed in the study was divided into three phases: problem analysis, synthesis and evaluation. The study was developed jointly by the research team of the Department of Engineering Projects of the Polytechnic University of Valencia, who are experts in MCDA and played the role of Analysis Team (EA), and a top manager of the investment company who is an expert in the management and execution of photovoltaic solar power plant projects and who played the role of Decision Maker (DM). Fig. 1 shows the decision-making process followed in the study.
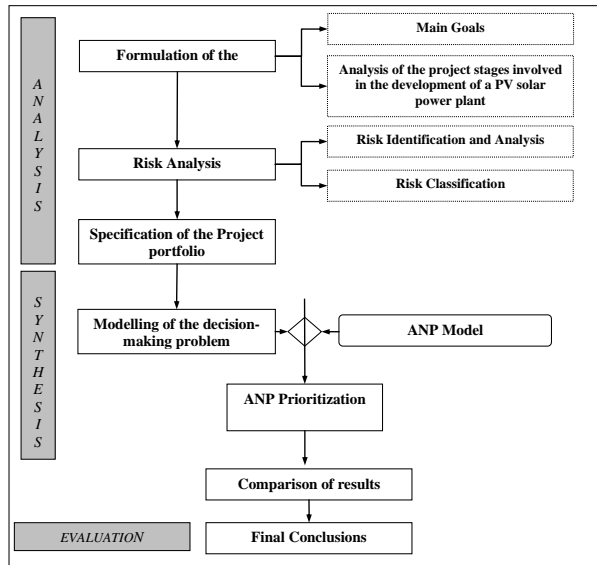
Fig. 1 Decision making process

B. Phase of Problem Analysis

In this phase the problem was defined. At the first two meetings between the Analysis Team and the Decision Maker the decision problem was formulated and the main goal of the analysis process was identified as mentioned in the Introduction of the paper. Next, the stages involved in the development of a photovoltaic solar power plant were analyzed and the possible risks associated with each stage of the project were identified. From the project portfolio of the company, the decision maker selected four alternatives. Following is a description of the different stages of the process.

C. Analysis of the Stages of a Photovoltaic Solar Power Plant Project

At this stage the process of developing a photovoltaic solar power plant was analyzed from the selection of the best plant site to the execution, exploitation and maintenance of the plant. Annex 1 shows a list of the different steps of the process. This analysis allowed the DM to identify project delay or stoppage risks for each stage of the process.

D. Risk Identification

For the identification of risks, in addition to the project analysis mentioned above, social, legal, political, as well as technical and economic factors were taken into consideration. These factors are mutually related. Since this step is essential in the decision-making process, risk identification was done in an iterative way. In the first iteration the DM elaborated a list of risks grouped by concepts associated with the different steps of the project. The risks in turn were grouped into six specific categories: political risks (P), technical risks (T), economic risks (E), time delay risks (T), legal risks (L) and social risks (S). In the second iteration, the risks were put into these categories, and some risks which could fall into two

categories were re-defined so as to obtain a final well-defined classification of risks. Finally 50 bottom-level risks were identified grouped into 16 second-level sub-groups. The 16 sub-groups in turn were grouped into 6 high-level groups or categories. Table II shows the different risk categories grouped as mentioned above.

TABLE II
RISK IDENTIFICATION AND CLASSIFICATION

GOAL: Risk Maximization	
Political Risks	
Macroeconomic	
C1	Changes in the Energy Policy
Urban planning	
C2	Obtaining of the Local Body approval
C3	Obtaining of Construction License
Technical Risks	
Associated with the plant location	
C4	Technological adequacy to climate change
C5	Estimation of flood risks
C6	Estimation of effective solar radiation hours
C7	Earthworks
C8	Geotechnical problems of the terrain
Associated with technology	
C9	Development of new photovoltaic solar power systems
C10	Selection of the PV cell
C11	Selection of inverter
C12	Selection of solar tracker
C13	Connection to the electric grid
C14	Possibility of alternative power generation systems
Economic Risks	
Associated with plant exploitation	
C15	Plant operation costs
C16	Corrective maintenance costs
C17	Prevention maintenance costs
C18	Performance losses
Associated with plant location	
C19	Revenue estimation based on effective solar radiation time
C20	Revenue estimation due to the climate change
C21	Earthworks Resources
C22	Flood prevention works
C23	Solution of geotechnical problems
Associated with plant start-up permits	
C24	Costs of connection to electric grid
C25	Costs of agreement with land owner
C26	Possibility of constructing the power connection line
C27	Economic risks related to the obtaining of the construction license
Associated with technology	
C28	Costs due to wrong selection of PV cell
C29	Costs due to wrong selection of inverter
C30	Costs due to lack of consistency in the selection of the solar tracker
Macroeconomic	
C31	Obtaining of bank financing
C32	Changes in power demand
C33	Changes in the price of money

C34	Changes in energy prices
Time Delay Risks	
	Connection to Electric grid
C35	Delays in the construction of the power connection line
C36	Delays in the obtaining of the administration approval for the construction of the line
C37	Delays in the obtaining of plant Start-up Act
C38	Delays in the signature of the agreement with the Electricity supply company
	Urban planning
C39	Delays in the obtaining of the Local Body Approval
C40	Delays in the obtaining of the EIS
C41	Delays in the obtaining of the construction license
Legal Risks	
	Associated with legal issues
C42	Changes in specific legislation
C43	Changes in general legislation
	Connection to Electric grid
C44	Legislative changes in the Administrative Authorization of the power distribution line
C45	Legislative changes in the obtaining of the plant Start-up Act
C46	Obtaining of the Registration in the Register of Production Facilities in special Regime
	Urban planning
C47	Legislative changes in the EIS
Social Risks	
	Related to Plant Exploitation
C48	Thefts
C49	Vandalism
	Urban planning
C50	Social consequences resulting from land acquisition

E. Specification of the Company´s Project Portfolio

At this stage, the DM identified the projects that were used as alternatives in the decision process. Project selection was based on criteria of economic profitability, and technical and environmental feasibility. Four projects with different characteristics and plant location were finally selected. Annex 2 shows the main features of the four selected projects.

F. Phase of Data Synthesis

In this phase, the ANP procedure was used: the risks were weighted; then each alternative was valuated for each risk so as to obtain the desired final priority order of the projects under study.

- *The ANP Model*

This model consists of elements grouped into clusters. 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.

- *Determination of the Network*

The first step of the ANP method is the representation of the decision problem using a network model. This requires a deep knowledge of the problem by the DM and the advice given by the AT based on the data collected in previous stages. The steps needed for the construction of the network are: i) determination of the elements, ii) determination of the clusters, and iii) determination of the influence network. The first step has been described above in the section Problem Analysis. In order to establish the clusters, six risk categories were identified (political, technical, economic, time delays, legal and social); however, the economic and technical clusters contained more than 9 elements, which is not

recommended by the ANP method. This was solved by defining additional economic and technical clusters with less than 9 elements each. In this way, the resulting network contains 12 clusters (Fig. 2).
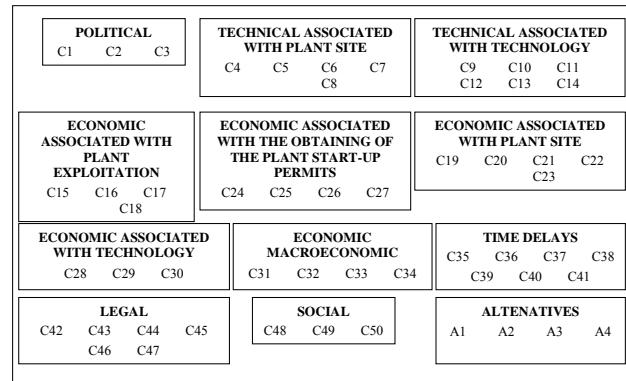
Fig. 2 ANP network model

For the determination of the influences a zero-one interfactorial dominance matrix was used [2] whose elements a_{ij} take the value 1 or 0 depending on whether there is or there is not some influence of element i on element j. The rows and columns of the matrix are formed by all the elements of the network.

In ANP, this 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, the DM has to accurately identify the influences of some elements upon others based on his knowledge and experience. If the DM fails to identify one influence, the model will not take it into account and some valuable information will be lost. For this reason the DM was asked about the influences that each risk exerted on the other risks and on the alternatives and vice versa. As there are 50 risks in the model, this means 2500 questions of the type "Do you think that risk Ri has any influence on Rj?". To facilitate the DM's task, the AT designed a questionnaire, organized into clusters and divided into two steps. In the first step the DM was asked to analyze the criteria groups, e.g. the "political criteria", and to reflect on "whether any element of the group influences or is influenced by any of the risks belonging to another group, e.g. the "technical risks". The actual wording of the question is "In your opinion, does any political risk have influence on any technical risk?" The DM then only had to tick the Yes or No box in the questionnaire.

In the second step another questionnaire was designed in which the DM was asked about element-to-element relationships, but only for those clusters in which the DM had marked the existence of some relationship in the previous questionnaire. In this way many detail questions were eliminated from the questionnaire, which facilitated the DM's task. Thus the 2500 possible questions were simplified to 969 (the group of alternatives was supposed to influence and be

influenced by all the risks). The questionnaire was organized into groups in such a way that the questions about external influences, i.e. possible influences among risks belonging to different clusters, were asked first, and then the questions about internal influences, i.e., feedback or influences among risks within the same cluster. Annex 3 shows the resulting interfactorial dominance matrix.

With the data obtained from the questionnaire the decision model was built with the help of the Super Decisions v1.6.0. software (www.superdecisions.com). Fig. 3 shows the relationships among the clusters.
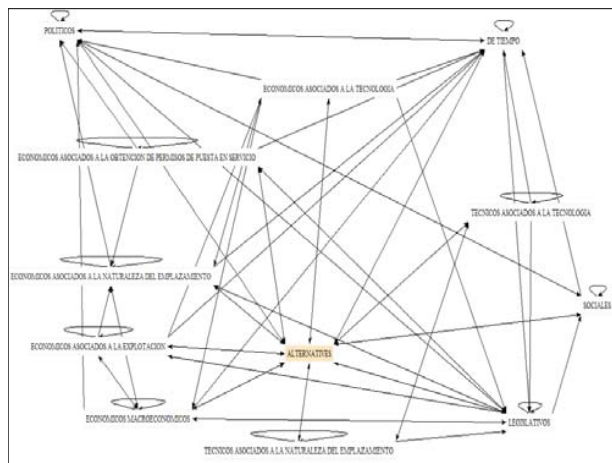

Fig. 3 Structure of the relationship among the clusters of the ANP network

- *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 risk is analyzed in terms of which other risks have influence upon it; then the corresponding pairwise comparison matrices of each risk group are generated in order to obtain the corresponding eigenvectors.

The procedure is the following: let's suppose that some or all the elements (risks) e_{ik} of cluster C_k influence one element e_{ij} of cluster C_j (e.g. the three risks of the cluster "economic risks associated with technology" have influence on the risk "prevention maintenance costs" of the cluster "economic risks associated with exploitation"). To determine which elements (among those that have some kind of influence) of C_k have more influence on element e_{ij} of C_j, a reciprocal pairwise comparison matrix is built with the elements of C_k. In order to fill in each component of the matrix $n(n-1)/2$ questions (n being the number of risks of C_k that influence e_{ij}) have to be answered. This procedure is repeated for each cluster whose elements exert some influence on element e_{ij} of C_j. In this way, for each column of the e_{ij} elements of the unweighted supermatrix we can identify blocks corresponding to each of the clusters that exert some kind of influence on that element and whose values form the eigenvector that represents the

relative influence of the elements of each cluster on element e_{ij}.

As in the case study different risks from different clusters have influences on one risk cluster the unweighted matrix is non-stochastic by columns. Thus, according to [2], all clusters that exert any kind of influence upon each group have to be prioritized using the corresponding cluster pairwise comparison matrices. 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. Annex 3 shows the unweighted and weighted matrices

For this end, a new questionnaire about priorities was designed to be answered by the DM. This questionnaire analyzed each risk in terms of which of the other risks that have influence on it and belong to a certain cluster exerts a greater influence on it and to what extent. This is done by means of the pairwise comparison. The DM had to answer 332 questions in this model. Additionally the questionnaire had questions specifically designed to determine the priorities among clusters. This meant 200 additional questions. The questionnaire was designed as a multiple-choice test into tables that grouped the questions relative to the pairwise comparison matrices. Tables III and IV show an example of the questionnaire.

With respect to the criterion "achievement in the obtaining of the construction license", which criterion from the following criteria belonging to the group "time delays" exerts the greatest influence and to what extent?

TABLE III
EXAMPLE OF THE QUESTIONNAIRE ABOUT PRIORITIZATION OF ELEMENTS

Criterion with the greatest influence				To what extent?
Delays in the Local Body Approval	▣	Delays in the obtaining of the EIS	☐	"In this box the DM writes a value of the 1-9 scale "
Delays in the Local Body Approval	▣	Delays in the obtaining of the construction license	☐	
Delays in the obtaining of the EIS	▣	Delays in the obtaining of the construction license	☐	

With respect to the cluster of "Technical" risks associated with "features of the plant site", which cluster exerts the strongest influence and to what extent?

TABLE IV
EXAMPLE OF THE QUESTIONNAIRE ABOUT PRIORITIZATION OF CLUSTERS

Cluster with the greatest influence				To what extent?
Alternatives	☐	Legal criteria	☐	"In this box the DM writes a value of the 1-9 scale "
Alternatives	☐	Technical criteria associated with features of the plant site	☐	
Alternatives	☐	Technical criteria associated with technology	☐	
Legal criteria	☐	Technical criteria associated with features of the plant site	☐	
Legal criteria	☐	Technical criteria associated with technology	☐	
Technical criteria associated with features of the plant site	☐	Technical criteria associated with technology	☐	

- *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 Tables V and VI and in Annex 4.

G. Phase of Evaluation of Results

Table V shows the results obtained in the study. The "best" alternative is the alternative with the overall "lower risk" and therefore the alternative with the "lowest" value. The alternative selected as the best option is alternative A3, which is the alternative with the lowest risks throughout the execution process, from project formulation to plant start-up. The priority order shown is A3 P A4 P A1 P A2, alternative A2 being by far the alternative with the highest risks.

TABLE V
PRIORITIES OF SOLAR PLANT PROJECTS IN % ACCORDING TO THE ANP MODEL

A1	28.32
A2	40.95
A3	**14.64**
A4	16.07

Table VI shows the comparison of the 15 risks with the highest importance or influence in each model. The cluster to which the risk belongs is shown in brackets: P = political risk, E = economic risk, T = time delay risk, S = social risk, L = legal risk, I = technical risk. Annex 4 shows the weights of all risks calculated with each model.

TABLE VI
PRIORITIES OF THE 15 RISKS WITH THE HIGHEST IMPORTANCE/INFLUENCE (IN %)

risks	Weight (%)
C1 (P)	12.04
C50 (S)	10.74
C40 (T)	6.53
C48 (S)	6.48
C47 (L)	6.44
C2 (P)	6.07
C19 (E)	4.59
C39 (T)	4.19
C30 (E)	2.87
C22 (E)	2.69
C43 (L)	2.55
C38 (T)	2.36
C49 (S)	2.14
C18 (E)	2.05
C42 (L)	1.56

The two most relevant risks are "changes in the energy policy" (C1) and "social consequences resulting from land acquisition" (it evaluates the risk that some social sector stands against the project) (C50).

With these results the question issued by the DM was: if only the alternative projects are analyzed, it is clear that projects A3 and A4 are the best alternatives provided there is enough money to develop two projects. The ANP model supports this decision.

The DM agreed to use the results obtained with the Network ANP model, despite the fact that then risk analysis depends on the particular alternative under analysis. As stated by Saaty (2001, op.cit. 96) "the entries of the weighted supermatrix itself give the direct influence of any element on any other. But an element can influence a second element indirectly through its influence on some third element and then by the influence of that element on the second". There can be many hidden influences through indirect relationships. Therefore, because we wish to capture the transmission of influence along all possible paths of the supermatrix, we need to raise the supermatrix to powers. The ANP model takes into consideration all the influences perceived by the DM. However, the authors want to reflect upon the complexity of the model. This is the main weakness and also the main strength of the method: weakness in the sense of the complexity of the model, and strength in the sense of the reflections, experience and deep knowledge gained by the DM on the case study.

Further analysis will allow discussion on whether certain risks can be neglected or should be included in the analysis of

the alternatives. Thus, in further similar decision making problems with other alternative projects under study, the information about risk influences provided by the DM can be used in the new decision process and only the mutual influences between risks and alternatives will have to be studied.

It is worth mentioning that, since the DM possessed a deep knowledge on this kind of projects, the results coincided with his initial intuition. Despite the great efforts spent in answering the questionnaires, his conclusion was that he answered the questions fast and that the questions helped him reflect on the problem. This greatly helped him to select the best projects and to identify the risks with the greatest influences.
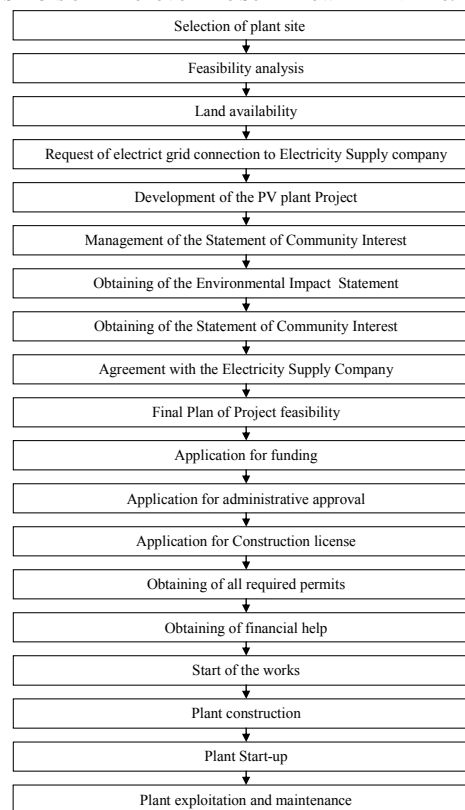
IV. CONCLUSION

This paper presents a practical application of the ANP method to the field of project selection. In the case study the investment company is particularly sensitive to these decisions since in addition to investing in the exploitation of photovoltaic solar power it also designs and builds the plants. Therefore delays in the execution of the project are considered very relevant as the company's resources cannot be inactive.

The novelty of the present approach is to consider the decision making process from the point of view of project risks and to take into consideration risk influences using ANP. ANP provides the relative importance of each criterion in terms of its influence on the other selection criteria and between criteria and alternatives. Results show that ANP generates evaluation results very close to the expert's intuition.

However, the use of ANP involves a number of considerations:

- The questionnaires to be answered by the DM have to be carefully designed (to allow for the correct analysis of influences among criteria and criteria prioritization.

- Cluster structure and components have to be well-defined to simplify the network as much as possible.

- Large models should be simplified either through subnets, semi-complete pairwise comparison matrices or less detailed models.

APPENDIX 1
STAGES OF A PHOTOVOLTAIC SOLAR POWER PLANT PROJECT

Selection of plant site
Feasibility analysis
Land availability
Request of electrict grid connection to Electricity Supply company
Development of the PV plant Project
Management of the Statement of Community Interest
Obtaining of the Environmental Impact Statement
Obtaining of the Statement of Community Interest
Agreement with the Electricity Supply Company
Final Plan of Project feasibility
Application for funding
Application for administrative approval
Application for Construction license
Obtaining of all required permits
Obtaining of financial help
Start of the works
Plant construction
Plant Start-up
Plant exploitation and maintenance

APPENDIX 2
CHARACTERISTICS OF THE SOLAR POWER PLANT PROJECTS (ALTERNATIVES)

Alternative 1	
Name	Hoya de los Vicentes
Location	Jumilla (Murcia)
Voltage	20 MW
Power system	Single axle tracker
Land classification	Non urbanizable
Electrical connection system	132 kV Line
Land owner	Local Council of Jumilla
Environmental impact	No problems
Current situation of the Project	At an advanced stage

Alternative 2	
Name	Campo de Santa Teresa
Location	Lorca (Murcia)
Voltage	30 MW
Power system	Single axle tracker
Land classification	Non urbanizable
Electrical connection system	132kV line
Land owner	Private land owner with lease agreement with the builder
Environmental impact	No problems
Current situation of the Project	Preliminary stages pending

Alternative 3	
Name	Universidad Politécnica de Valencia
Location	Valencia (Valencia)
Voltage	4 MW
Power system	Fix
Land classification	Urban
Electrical connection system	20 kV line
Land owner	Universidad Politécnica de Valencia
Environmental impact	No problems
Current situation of the Project	Under feasibility study

APPENDIX 3
INTERFACTORIAL DOMINANCE MATRIX

UNWEIGHTED SUPERMATRIX

WEIGHTED SUPERMATRIX

The table below shows the weighted supermatrix with column groups: Alternativas, De tiempo, Económicos Explotación, Económicos Emplazamiento, Económicos Permisos, Económicos Tecnológico, Económicos Macroeconómicos, Legislativos, Políticos, Sociales, Técnicos Emplazamiento, Técnico tecnológico.

REFERENCES

[1] Saaty TL. The analytic hierarchy process: planning, priority setting, resource allocation. RWS Publications: Pittsburgh; 1996.

[2] Saaty TL. Decision making with independence and feedback: The Analytic Network Process. RWS Publications: Pittsburgh; 2001.

[3] Meade LM, Presley A. R&D project selection using the analytic network process. IEEE Transactions on Engineering Management 2002; 49; 59-66.

[4] Mohanty RP, Agarwal R, Choudhury AK, Tiwari MK. A fuzzy ANP-based approach to R&D project selection: a case study. International Journal of Production Research 2005; 43(24); 5199-5216.

[5] Cheng EWL, Li H. Analytic network process applied to project selection. Journal of Construction Engineering and Management 2005; 131; 459-466.

[6] Wey WM, Wu KY. Using ANP priorities with goal programming in resource allocation in transportation. Mathematical and Computer Modelling 2007; 46; 985-1000.G. O. Young, "Synthetic structure of industrial plastics (Book style with paper title and editor)," in Plastics, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 15–64.

[7] Liang C, Li Q. Enterprise information system project selection with regard to BOCR. International Journal of Project Management, doi:10.1016/j.ijproman.2007.11.001

[8] Gencer C, Gürpinar D. Analytic network process in supplier selection: A case study in an electronic firm. Applied Mathematical Modelling 2007; 31; 2475-2486.

[9] Jharkharia S, Shankar R. Selection of logistics service provider: An analytic network process (ANP) approach. Omega-The International Journal of Management Science 2007; 35; 274-289.

[10] Cheng EWL, Li H. Contractor selection using the analytic network process. Construction Management and Economics 2004; 22; 1021-1032

[11] Demirtas EA, Üstün Ö. Analytic network process and multi-period goal programming integration in purchasing decisions. Computers and Industrial Engineering (in press), doi:10.1016/j.cie.2006.12.006

[12] Khan S, Faisal MN. An analytic network process model for municipal solid waste disposal options. Waste Management, doi:10.1016/j.wasman.2007.06.015

[13] Tuzkaya G, Önüt S, Tuzkaya UR, Gülsün B. An analytic network process approach for locating undesirable facilities: An example from Istanbul, Turkey. Journal of Environmental Management, doi:10.1016/j.jenvman.2007.05.004

[14] Ayağ Z, Özdemir RG. An analytic network process-based approach to concept evaluation in a new product development environment. Journal of Engineering Design 2007; 18(3); 209-226.

[15] Erdoğmuş Ş, Aras H, Koç E. Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making. Renewable and Sustainable Energy Reviews 2006; 10; 269-279.

[16] Raisinghani, H.S., Meade, L., Schkade, L. Strategic e-business decision analysis using Analytic Network Process. IEEE transactions on Engineering Management 2007, 54 (4); 673-686.

[17] Aragonés-Beltrán P., Aznar J., Ferrís-Oñate J., García-Melón M. Valuation of urban industrial land: an Analytic Network Process approach. European Journal of Operational Research 2008; 185–1; 322-339.

[18] García-Melón M., Ferrís-Oñate J., Aznar J., Aragonés-Beltrán P., Poveda-Bautista R. Farmland appraisal: an Analytic Network Process (ANP) approach. Journal of Global Optimization (in press), DOI 10.1007/s10898-007-9235-0, 2007

[19] Agarwal A, Shankar R, Tiwari MK. Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach. European Journal of Operational Research 2006; 173; 211–225.

[20] Haktanılar B. Determination of the appropriate energy policy for Turkey. Energy 2005; 30; 1146-1161.

[21] Chung S, Lee AHI, Pearn WL. Analytic network process (ANP) approach for product mix planning in semiconductor fabricator. International Journal of Production Economics 2005; 96; 15-36.

[22] Ravi V, Shankar R, Tiwari MK. Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach. Computers & Industrial Engineering 2005; 48; 327-356.

[23] Niemira MP, Saaty TL. An Analytic Network Process model for financial-crisis forecasting. International Journal of Forecasting 2004; 20; 573-587.