Collaborative decision-making on wind power projects based on AHP method

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Abstract. The complexity of projects implementation in Renewable Energy Sources (RES) requires finding collaborative alliances between suppliers and project developers in RES. Links activities in supply chain in RES, respectively, transportation of heavy components, processing orders to purchase quality raw materials, storage and materials handling, packaging, and other complex activities requiring a logistics system collaboratively to be permanently dimensioned properly selected and monitored. Requirements imposed by stringency of wind power energy projects implementation inevitably involves constraints in infrastructure, implementation and logistics. Thus, following an extensive research in RES project, to eliminate these constraints were identified alternative collaboration to provide feasible solutions on different levels of performance.

The paper presents a critical analysis of different collaboration alternatives in supply chain for RES projects, selecting the ones most suitable for particular situations by using decision-making method Analytic Hierarchy Process (AHP).

The role of AHP method was to formulate a decision model by which can be establish the collaboration alternative choice through mathematical calculation to reduce the impact created by constraints encountered.

The solution provided through AHP provides a framework for detecting optimal alternative collaboration between suppliers and project developers in RES and avoids some breaks in the chain by resizing safety buffers for leveling orders in RES projects.

1. Introduction

Given that presently discussions about dramatic decline in fossil fuel prices are still debated, the benefits provided by renewable energy development has already proven to be a very good solution to the actual problem of global energy. The development of renewable energy sector has the tendency to maximize the benefits that nature has to offer, more than that, wind project developers being aware of the long-term benefits propose major investments in developing countries even more than investments in already industrialized countries [1]. Development projects that support renewable energy production have a significant potential which contributes to a sustainable development in green energy and aims to improve and implement new methods which streamline the implementation process of RES projects [2]. Accomplishing all EU directives through Directive 2001/77/EC, RES projects implementation in Romania has rose by 2.9 percent last year, or 124 MW, to 4.400 MW, according to Transelectrica [3].
The increase of installed capacity in renewable energy is due to the fact that Romania has complex areas of landforms, which allows it to exploit wind, solar and biomass energy. A particular situation respectively real areas isolation of many human communities, are deprived of RES benefits due to the landform conditions. Such locations are relatively numerous in Romania, with wide range of applications: dwellings, isolated agriculture farms, sheepfolds, touristic chalets, stations broadcast relay etc. In these situations, economic efficiency is the determining factor that lead to the assessment of the opportunity for this kind of projects.

This research presents a RES exploitation project in isolated regime made by a team composed by key representative from a company, direct interested in research theme, and the authors. In this project the research team identifies through long debates and multi-criteria decision an efficient and economical way to choose a wind turbine power and an optimal assembly method in isolated regime. These decisions were based on project activities which involved research, development and implementation correlated with some disciplines that include a wide range of specialties such as: Mechanical structures and wind turbines (MSWT); Electrical machines (EM); Power electronics (PE); Automatic controlling strategies (ACS); Project management and administrative problems (PM).

1.1. Wind power projects implementation
RES exploitation project in isolated regime covers a wide range of activities, this requiring a dispersed set of skills. A major challenge for these kind of project empowered wind power project developers to identify and surpass the obstacles that they encounter in their way, when implementing project specifications. These obstacles were present for the entire project life cycle, namely research, development and implementation.

Activities within the project:
Research: the tower, the nacelle, and the rotor blades.
Development: communication sessions between the parties that made the project: communication with funders, communication with local authorities (to obtain approvals and permits), communication with suppliers
Implementation of a windmill: preparation of the site (roads cut, land graded and leveled), a concrete foundation is made with the underground cables, the tower is assembled on site and erect with a special crane, the fiberglass nacelle is assembled with inner workings off site (main drive shaft, gearbox, and blade pitch and yaw controls), the utility box for each wind turbine and the electrical communication system are installed simultaneously with the placement of the nacelle and blades.

2. Specific collaboration in sharing risks in such projects
The research team identify constraints in RES project in isolated regime and established a complex and suitable decision model which underpin the decision selection of wind power turbine and the way of assembly.

2.1. Bottlenecks in wind power supply chain
Most common situations encountered by developers in wind power project were:
- Developing a project plan, which includes defining project goals, how task and objectives will be achieved.
-What resources are need, associating budgets and timelines for completion, implementing the project plan, and ensure that the plan is being managed according to the project.
-The process of obtaining necessary permits and approvals is laborious and time-consuming and construction works sometimes can be atypical, hampered by placement location without power supply and water. Weather conditions also can influence the development work in the field.
- The analysis and research of the cost reduction possibilities, through diversification and simplification of the equipping, multiple usages of the components.
- The necessary financial funds, various reorganizations and restructurings are necessary to complete the project in time and achieve the desired goals.
- It can be difficult finding companies that have the ability to achieve some different materials elements of high precision.
- Transportation of heavy components, processing orders to purchase quality raw materials, storage and materials handling, packaging.
- Bottlenecks in infrastructure, implementation and logistics (Figure 1).

2.2. Problem statement

The first part of the project was very complex because of the region isolation special conditions so finding suitable sites and transportation routes for turbine installation it was a challenge for project developers.

Another aspect was the deficiency quality of rural roads that are designed for low traffic or light vehicles. New roads construction on slopes to access grows, lead to erosion causing degradation of the landscape location. Higher components transportation that need to be assembly at the farm site implies a higher cost.

A possible solution to obtain minimal costs transportation implies that the assembly process of the wind turbine should integrate more possible operations at the component manufacturing [4].

Figure 1. Bottlenecks in wind power supply chain
2.3. Optimal collaboration alternatives

In this paper there are presented several pre-assembly methods with different characteristics that are technically adequate to achieve the economic objective for such projects identified above. The methods are classified according to the number of lifts required for each turbine [5].

**Method 1** - low-power wind turbines: less than 12m blades diameter rated power of less than 1.0 MW and turbine pillar 7 m height. Hub and all three blades are assembled at the farm site. Remaining sub-assemblies (lower tower and transition piece, lower and upper tower sections, upper tower and nacelle) are done at the farm site. Two tower sections and the nacelle are transported separately. 4 lifts (operation) are required for each turbine during loading and during installation.

**Method 2** - medium power wind turbines: less than 45m blades diameter rated power between 1.0 MW and 2.0 MW turbine pillar 9 m height. Two tower sections are assembled at the farm site, also the nacelle and hub are assembled together all the remaining components are transported separately to farm site. For each turbine, 5 lifts (operation) are required during loading and during installation. During installation, first the tower is assembled to the transition piece, then the nacelle and hub sub-assembly is attached to the tower, finally three blades are lifted and assembled to the hub.

**Method 3** - high power wind turbines: 46m blades diameter exceeding rated power over 2.0 MW-2.5 MW turbine pillar 12 m height. The nacelle and hub are assembled together at the farm site all the other components are transported to the farm site separately. 6 lifts are needed for each turbine for loading and for installation. During installation, first the lower tower is assembled to the transition piece, then two tower sections, after that the nacelle and hub sub-assembly is attached to the upper tower; finally, three blades are bolted to the hub one by one.

3. Methodology

Finding suitable sites and transportation routes for wind farms is a complex decision-making problem, involving several, sometimes conflicting, criteria and multiple objectives. Apart from the manufacturing turbines cost, energy cost is significantly affected by transportation and installation costs operations of wind turbines and turbine components maintenance operations.

Through optimum selection of decision variables, such as turbine installation method and rated power output of each turbine, cost of transportation and installation operations can be minimized. Pre-assembly at the farm site area is another controlling variable of transportation and installation cost. More pre-assembly done results in lower number of lifts and assembly.

3.1. Decision making methods

In order to have a clear classification of the presented pre-assembling methods we identify base on our RES project very important criteria that need to be assess when pre-assembly components must be achieved at the component manufacturing.
The criteria presented are: region isolation degree, wind velocity, distance from electrical grid, accessibility settlement degree and distance from manufacturing to assembly place. To rank this classifications, the research team used a software online application (Priority Estimation Tool-AHP) [6] (Figure 2).

To achieve optimal selection a MULTI-CRITERIA DECISION MAKING (MCDM) methods provide a logical framework to investigate, analyze, and solve such problems:

- provide an effective structure in decision-making process;
- shows objectives which decision maker has identified;
- measurable evaluation criteria of objectives are established;
- provides several ways of aggregating data concerning criteria for obtaining indicators (scores) of alternatives performance;
- helps to maintain decision makers thinking models by deriving the relative weight of each component;
- it is assigned a numerical value to each alternative of the problem;
- through mathematical calculation is chosen the optimal alternative.

### 3.2. Analytic Hierarchy Process Method

The algorithm AHP is done in six stages:

1. Hierarchical scheme composition of the problem that need to be analyzed (Figure 3). In this phase it is presented fundamental purpose of the problem to be analyzed. Decision criteria are identified and, if necessary, separating them into sub-criteria. Depending on the preferences of the analyst alternatives are presented and ranked by the decision;

2. Establish relative weights by comparing them in combinations of two. The relative weights are based on a numerical scale from 1 to 9 through Saaty scale followed by subjective evaluation of the decision-maker comparisons are made in pairs. By comparison is obtained the degrees of importance of a criterion to each other (Table 1) [7];

3. The relative prioritization of the sub criteria is obtained by comparing sub-criteria two by two depending on the decision criterion, in order to rank them;

| Numerical value | Verbal meaning for risk factor evaluation | Verbal meaning for alternative evaluation |
|-----------------|------------------------------------------|------------------------------------------|
| 1               | Equally important                        | Equally preferred                        |
| 2               | Equally to moderately more important     | Equally to moderately preferred          |
| 3               | Moderately more important                | Moderately preferred                     |
| 4               | Moderately to strongly more important    | Moderately to strongly preferred         |
| 5               | Strongly more important                  | Strongly preferred                       |
| 6               | Strongly to very strongly more important | Strongly to very strongly preferred      |
| 7               | Very strongly more important             | Very strongly preferred                  |
| 8               | Very strongly to extremely more important| Very strongly to extremely preferred     |
| 9               | Extremely more important                 | Extremely preferred                      |

4. Pairwise comparison is made of decision criteria (criteria and sub-criteria) gives them a global priority. Global priority for each decision criterion is determined by the result of multiplying each priority vector for each criterion on the second level of the decisional tree with relative prioritization of sub-criteria from the third level of decisional tree;

5. Performance matrix is achieved by calculating the relative prioritization of the alternative for each sub-criterion. In this step is necessary to assess alternatives relative weights from fourth level of the hierarchy, the process is similar to that has been used in criteria and sub-criteria group for the purpose decision-making. This process is executed as the previous step, but the
difference does that this step is performed assessment of each alternative beside each sub-criterion;
6. The final decision is obtained by choosing alternative priority with maximum points and argumentation of the obtained solution.

![Figure 3. Decision tree through AHP method](image)

Utilization of AHP method involves the decision tree decomposition into criteria and alternatives (Figure 4). AHP method designated as region isolation degree, wind velocity and the distance from electrical grid that they were the main important criteria with higher rank to emerge from the analysis decision. For wind turbine pre-assembling methods, they were chosen turbines with different powers, namely, less than 1.0 MW, 1.0-2.0 MW and 2.0-2.5 MW.

![Figure 4. Decision tree decomposition into criteria and alternatives](image)

Applying the method AHP, has required to use Method 1, namely the importance given to each criterion and by comparison matrices, revealed a very high value on region isolation degree (0.5271). In this scenario the isolated region characteristics they had relative disadvantages because of the extremely weather conditions and landform, which made it the wind turbine difficult to implement. The number of panels where smaller, and the size of wind generators were also reduced, namely a
Theft implies a critical impact. In this case it is knowing that Method 2 and Method 3 involve a greater risk for pre-assembling of wind power turbine in such conditions. Inspection of the local areas around the target site and many visits to select the site was made by the research team to estimate wind power potential, namely wind velocity measurements. Analysis of daily and annual wind velocity \((0,2641)\) measuring system was delivered and in-house tested together with data processing system and wireless communication. Also the distance from electrical grid \((0,1122)\) has implied a system which is not vulnerable to surges from lightning, solar flares, earthquakes, ice storms, wind. This technique provides delivering renewable energy over long distances (Figure 4).

![Figure 4](image-url)

**Criteria importance**

1. Region isolation degree \((0,5271)\)
2. Wind velocity \((0,2641)\)
3. The distance from electrical grid \((0,1122)\)
4. Distance from manufacturing to assembly place \((0,0574)\)
5. Accessibility settlement degree \((0,0393)\)

**Alternatives rankings with structure**

1. METHOD 1 less than 1.0 MW \((0,6835)\)
2. METHOD 2 1.0-2.0 MW \((0,2064)\)
3. METHOD 3 2.0-2.5 MW \((0,1102)\)

**Wind turbine pre-assembling methods**

1. METHOD 1 less than 1.0 MW \((0,6835)\)
2. METHOD 2 1.0-2.0 MW \((0,2064)\)
3. METHOD 3 2.0-2.5 MW \((0,1102)\)

![Figure 5](image-url)

**Figure 5.** Final results presentation

4. Conclusions and future work

The solution provided through AHP, Method 1 provides a framework for detecting the optimal alternative and avoid less costs in the wind supply chain by choosing the right method of pre-assembling components and obtain minimal transportation cost to install the wind turbine in special conditions. Using AHP algorithm offers both advantages and disadvantages as its defining by the elements it can be decide which combination is suitable to elaborate a wind turbines economical installation plan in isolated regions.
AHP method also highlights the ability to obtain correct weights of each criterion in the case of the present study, these being developed on the economic point of view. This method allows alternatives and criteria analysis to be upgraded during the RES project development so that all beneficial factors to be considered and lead to the fulfillment of the ultimate goal.

RES projects in isolated regime are a compromise solution, but implementation on such projects provides local energy needs in isolated locations. Even in this case these represent an important way for generating green energy which in a visible manner sustain the strategy to achieve Romania’s mandatory targets within the EU strategy 20/20.

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