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CONTENTS

Contents	i
Chemical Engineering and Mining	
Torrado-Agrasar, Ana; Pérez-Rodríguez, Noelia; Pérez-Bibbins, Belinda; Moldes, Ana Belén; Cruz, José Manuel; Domínguez González, José Manuel (Spain): "Strategies to Enhance the Enzymatic Generation of Xylose from Corn Cob for Xylitol Production"	1
Vecino, Xanel; Pérez-Ameneiro, María; Barbosa-Pereira, Letricia; Devesa-Rey, Rosa; Domínguez, José Manuel; Moldes, Ana Belén; Cruz, José Manuel (Spain): "Simultaneous Production of Biosurfactants and Coagulants-Floculants from Trimming Vineyards"	7
Vecino, Xanel; Devesa-Rey, Rosa; Domínguez, José Manuel; Cruz, José Manuel; Moldes, Ana Belén (Spain): "Effect of Soil Loading and pH During Batch Solvent Extraction of Fluorene from Soil Using a Lipopeptide Biosurfactant Aqueous Solution"	11
Disciplinary Research and Development	
Abdelaal, Magdy *; Fakhry, Tayaz **; Mohammadi, Farah ** (* Saudi Arabia, ** Canada): "Optimization of a Compact Thermal Model for a Ball Grid Array (BGA) Package Using Experimental Data"	14
Khan, Abid A.; Khan, Nadeem S. (Pakistan): "MASS Distribution Effects on Flutter Characteristics as Result of Sawtooth"	18
Polatidis, Heracles; Ivanell, Stefan (Sweden): "Micro-Siting/Positioning of Wind Turbines: Introducing a Multi-Criteria Decision Analysis Framework"	23
Zhang, Nian; Rochac, Juan F. R.; Ososanya, Esther; Mahmoud, Wagdy; Lakeou, Samuel (USA): "VLSI Design and Verification of a CMOS Inverter Using the Tanner EDA: A Case Study"	28
Engineering Concepts, Relations and Methodologies	
Li, Weiqing; Wang, Jianchong (China): "Analysis of Thermo-Mechanical Coupling Characteristics and Structural Design of Rotary Liner Hanger Bearing in Ultra-Deep Well Drilling"	33
Posada C., Julio Enrique (El Salvador): "New FACTS Equipment in an Enhanced Version of Smart Grids. The Magnetic Gate"	40
Posada C., Julio Enrique (El Salvador): "Attenuator of Seismic Movements in High-Rise Buildings"	46

Micro-siting/positioning of wind turbines: introducing a multi-criteria decision analysis framework

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ABSTRACT

In the context of wind energy planning the wind turbine micro-siting/positing issue refers to the optimal placement and arrangement of individual turbines in a wind farm. Different approaches have been proposed for tackling this problem in the literature including several types of optimization techniques, generic & meta-heuristic algorithms and applications of realistic models of integrated economic performance of wind farms, among others. In this article we propose Multi-Criteria Decision Analysis (MCDA) techniques as a complement to current practices for identifying an initial compromise solution to the problem of wind turbine micro-siting. After a short literature review on contemporary methods for micro-sitting/positioning of wind turbines in a specific site, and an introduction to the MCDA methods, we highlight the potential usefulness of MCDA methods in siting wind turbines in a certain terrain as a complement to current practices. We finally argue that MCDA methods could account for the inclusion of a number of socio-environmental parameters in the relevant process that was not apparent so far.

Keywords: Wind Turbines, Micro-sitting, Multi-Criteria Analysis, Wind project development.

1. INTRODUCTION

In the context of wind energy planning the wind turbine micro siting/positing problem refers to the optimal placement and arrangement of individual turbines in a wind farm. Different approaches have been proposed for tackling this problem in the literature with linear & non-linear optimization techniques and the use of Generic Algorithms (GAs) prevail together with the more recent implementation of meta-heuristic algorithms and applications of realistic models of integrated economic behavior of wind farms. The whole process is actually a challenging subject involving fluid dynamics and decision making and could play a crucial role in local wind energy planning.

Nevertheless, the methods used so far focus in optimizing a number of rather restricted parameters related to maximizing total electricity production and minimizing initial investment and overall life-cycle cost. In order to achieve this, specific criteria used for positioning individual wind turbines in a predefined site are the minimization of the wake effect, minimization of distance to access roads and electrical

infrastructure, minimization of total land requirements and land cost, maximization of operational safety and the minimization of the topographic effect among others. Nonetheless, these criteria afford limited consideration to other environmental and social issues that may also be present as elements which can be included in the optimal micro-design for wind farms. In particular, factors such as visual impact, noise production, bird disturbance, biodiversity loss, impact on wild-life & habitats and the shadow effect, inter alia, can be studied during the micro-siting of turbines in a wind farm. In this way, it would be possible to assess and mitigate even further the particular local impact of the wind project on the environment.

It may therefore be an imperative, that new complementary to the already existent planning tools would be developed to identify the preferred micro-siting and design option for a wind project, balancing different, sometime intangible, environmental and social/cultural issues as well as functional, technical and economic requirements.

In this article we propose Multi-Criteria Decision Analysis (MCDA) techniques as appropriate for finding an initial compromise solution to the problem of wind turbine micro-siting. MCDA deals with the process of making decisions in the presence of multiple objectives. The goal is to choose among several alternatives using a number of decision criteria. In most cases, there is no alternative that performs better than all of the others according to all selected criteria; therefore, the solution must be a compromise. MCDA methods aid the process of identifying this compromise solution. The use of MCDA techniques has a long history in renewable energy and environmental planning and decision analysis and provides a comprehensive methodological framework for integrated evaluation and appraisal MCDA applications include areas such as (renewable) energy, manufacturing, services, medical, public policy, transport, environmental management, etc. In the context of this paper, MCDA methods may aim to help identifying a distribution of wind turbines in a given terrain in such a way that wind is captured more effectively while satisfying several criteria/constraints on economic, social, environmental and resource-based issues.

The paper unfolds as follows. First we provide a literature review that deals with issues such as methods and techniques for micro-sitting/positioning of wind turbines in a specific site, appropriate criteria, related constraints and objectives of the process. Then we continue with a short introduction to MCDA

methods and their applications in energy and environmental planning and wind farm design and decision analysis in particular. Subsequently, we highlight the potential usefulness of MCDA methods in siting wind turbines in a certain terrain as a complement to current practices. We finally argue that MCDA methods could account for an integrated framework for the inclusion of socio-environmental parameters in the relevant process of micro siting of wind turbines that was not apparent so far. The purpose of this paper is not to provide for such a MCDA framework for wind turbines micro-sitting, but rather to highlight its necessity and potential usefulness.

2. LITERATURE REVIEW

Current practices in micro-sitting of wind turbines

The micro-siting of wind turbines in a given site has recently attracted a lot of consideration due to the growing progress of wind energy [1]. This trend has led to the development of wind farms in areas of greater orographic complexity, raising doubts on the use of simple, linear, mathematical models of fluid dynamics, and basic micro-economic models for optimal positioning of wind turbines [2]. Nevertheless, micro-sitting of wind turbines is one of the several issues that a developer/planner has to tackle in identifying the appropriate overall design of a wind farm. Other design attributes include the identification of the optimal site in a given area, the number of wind turbines to be installed, the type of wind turbines, the technical specifications, grid connection, accessibility, the need to avoid excessive turbulence, environmental issues, operational safety, etc. Each of these attributes could be further decomposed into a number of sub-attributes. For example appropriateness of a site could incorporate issues such as average wind speed, direction of wind, legislative restrictions, suitability of soil and terrain, local topography, and so forth while the assessment of the wake effect could incorporate issues such as wind direction, turbulence level, atmospheric stability conditions etc. The production, maintenance and turbine lifetime also highly depend on the farm layout and farm control systems. To optimize a farm considering layout, cable costs and foundation costs in relation with maintenance and lifetime estimation is very complex. Still, it is apparent that the wind turbine micro-sitting problem is in fact only a part of the wider issue of local wind farm planning and the level and complexity of analysis can be extremely high [3]. Thus, even in the case of the most simplified objective function (maximization of the annual energy production), the optimization problem cannot be solved by classical optimization techniques [4]. To cope with this problem, most authors have used type of meta-heuristics techniques which have proved to be efficient when searching for the optimal solution to this problem [1, 4]. These type of techniques could include GAs [5, 6, 7, 8], several optimization methods [9] and other integrated economic models of wind farm performance [10, 11], among others.

Mosseti et al, 1994 were actually the first to develop, apply and propose a methodology for identifying the optimal wind turbine distribution at a given site by means of a GAs. The purpose of their paper was to investigate the feasibility of GAs by analyzing the results obtained in some simple applications. The rather basic parameters they optimized included the maximization of energy production and the minimization of installation costs [5].

Grady et al, 2005 employed a GA in order to obtain optimal placement of wind turbines for maximum production capacity while limiting the number of turbines installed and the land occupied by each wind farm. They tested their approach in three distinct cases, namely unidirectional uniform wind, uniform wind with variable direction and non-uniform wind with variable direction. Results also included, total power output, efficiency of power output and optimal number of turbines for each configuration out of the many they included in the analysis, among others [6].

Marmidis et al, 2008 proposed an approach based on a more general statistical and mathematical method to appropriately arrange wind turbines in a given farm. As a test case, a square site is subdivided into 100 square cells that can be possible turbine locations and as a result, the program concluded the optimal arrangement of the wind turbines in the wind park, based on Monte Carlo simulation [10].

Very recently Gonzales et al, 2014 provided an excellent review on recent developments in the optimal wind turbine micro-sitting problem. In their paper they list 148 articles and they highlight the main aspects which need to be taken into consideration when facing the overall issue of local wind farm design. In addition they propose potential areas of further research that include the need to provide for in-depth analysis of the computational costs required by each optimization method used, the necessity to explicitly account for different types of uncertainties in project development, the consideration of different conflicts of interest that may emerge and the requisite to take into account environmental issues such as visual impact and noise disturbance [4].

Since a considerable number of these latest factors can be analyzed by means of MCDA methodologies, we subsequently shortly introduce the main families of MCDA techniques and their applications in energy and environmental planning and management.

An introduction to Multi-Criteria Decision Analysis

In decision-aiding for energy-environmental planning, in particular, several alternatives are analyzed in terms of multiple non-commensurate criteria, and many different stakeholders, with conflicting preferences, are involved [12]. For energy planning, there exists a need to select and rank the most favorable projects because energy resources are scarce and there are limited financial means available. It is necessary, therefore, to select a reliable methodology and to rank energy development projects according to a variety of objectives and criteria. MCDA methods are considered a realistic approach to such a complex choice problem.

Several different multi-criteria methods have been applied to energy and environmental issues. The key approaches can be classified based on the type of decision model they apply. The main categories of methodologies include [13]:

- (A) Outranking methods, such as the ELECTRE and the PROMETHEE families [14, 15, 16, 17, 18]
- (B) Value/Utility-based methods, such as the Multi-Attribute Utility Theory (MAUT) [19], the Simple Multi-Attribute Rated Technique (SMART) [20], the Analytic Hierarchy

Process (AHP), that can be also found in Other methods according to different categorizations [21] and the most elementary multi-criteria technique the Simple Additive Weighting (SAW)

(C) Interactive - programming methods [22, 23, 24]

(D) Other methods like NAIADA [25], FLAG [26] and SMAA [27] among others.

The first category (A) is the so-called Outranking methods. These methods use pair-wise comparisons between potential alternative actions aiming to build an outranking relation between them. These methods are not bounded into a rigorous mathematical model but, providing further exploitation and processes, deduce to support the Decision-Maker (DM) in finding a what could be called “good” decision, depending on the available information.

The second category (B) is the Value System approach (American School). Its purpose is to build a value-utility function that aggregates the DM’s preferences on the evaluation criteria. This formula provides a quantitative mode that guides the DM in reaching his decision. These methods have the advantage to be based in a fully-defined mathematical problem that can eventually formulate a complete preorder of the possible actions. Nonetheless, in many cases, they lack of a realistic representation of reality since the overall preferences on a standpoint are only modeled with severe difficulty by a unique function.

The third category (C) includes the interactive-programming methods. They are based on a kind of procedure that consists of an alteration of stages of computation and discourse. In the beginning the analyst establishes an initial solution. The DM acts in response by providing additional data regarding his preferences. This supplementary information is then introduced into the model in the next calculation stage. The procedure is repeated until the DM feels that he/she has reached an acceptable solution.

Finally the rest of the methods (category D) are just different types of techniques that actually cannot be easily sorted in one of the above mentioned categories.

The use of MCDA techniques has a long history in energy planning and provides a sound methodological framework for (renewable) energy evaluation and appraisal [28, 29, 30]. For example, when developing a renewable energy source, one of the important issues is the degree of exploitation of the source. Is the maximum possible number of wind turbines going to be installed? Should a decision be made to proceed with caution, installing a limited number each time and examining the consequences? A number of conflicting factors, technological, economic, environmental, social, risk, etc., must be taken into account, especially in places where limited exposure to similar projects, may lead to local opposition that might jeopardize future developments [31].

3. MCDA AS A COMPLEMENT TO CURRENT PRACTICE FOR WIND TURBINE MICRO-SITTING

It is quite evident that, so far, a number of rather restricted parameters are taken into consideration when positioning wind

turbines in a certain site. Factors such as visual impact, impact on birds, other wild life and habitats, noise disturbance, impacts to particular sites of interest like archeological sites & traditional villages/settlements, change of rural life-style, local societal habits and old-style landscape character etc. are sometimes hard to quantify and are often neglected from the analysis. Nevertheless, the expected further augmented need for wind resources exploitation would somehow mandate that care continues to be taken to ensure that wind turbines are sited and designed so that adverse effects are minimized, and that areas which are highly valued for their landscapes and scenery are given due protection [32].

These additional parameters/criteria could be taken into account in the micro-sitting process of wind turbines via the inclusion of MCDA methodologies in the planning process as a complement to currently used techniques. By those means the inherent uncertainties associated with any type of project development, the sensitive environmental parameters like for example the visual impact to specific nearby sites of interest and the different local societal preferences, among others could be considered (Fig. 1).

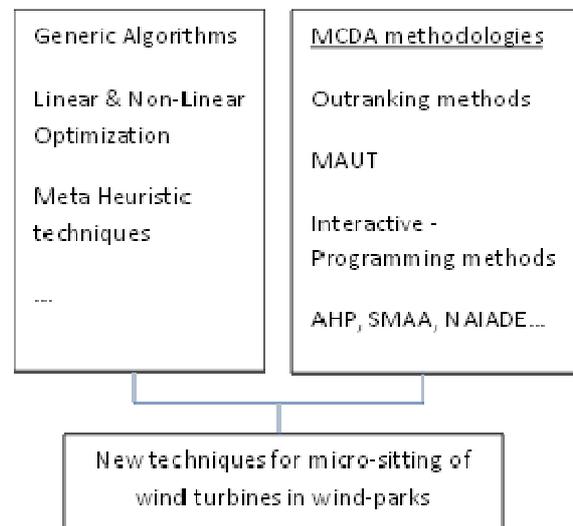


Fig. 1: MCDA methods as complement to current techniques for wind turbine micro-sitting

In particular, MCDA methods could aid in (Fig. 2):

- the treatment of uncertainty via threshold values, probability distributions, fuzzy sets and belief functions [13].
- the addressing of the visual impact to a particular nearby site of interest as it could be assessed for example via the method found in [33].
- the inclusion of different local societal values and viewpoints via the preference elicitation exercise when assessing pertinent criteria weights [13].
- the identification of a final proposal that could manage the conflicts raised between all the above parameters via the iteration process in the searching for a group compromise solution [31].

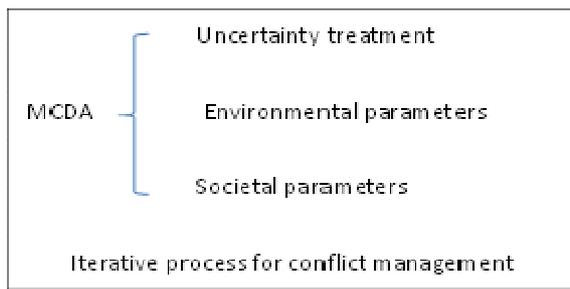


Fig. 2: Potential particular contribution of MCDA techniques in the process of wind turbine micro-siting

Particularly during this process of iteration, different societal perceptions of landscape and visual impact could also be taken into consideration and a visually balanced, simple and consistent image could be better identified.

4. CONCLUSIONS

Micro-siting/positioning of wind turbines in a given site refers to the process of optimizing total energy production of an entire wind park and at the same time take into account a number of environmental, economic, societal, technological etc. constraints by suitable placement of individual wind turbines. Several assessment tools and various techniques have been used to date to tackle this issue. In most cases, however, current approaches concentrate on optimizing particular criteria that are usually related to technical and economic issues, for example the analysis of the interactions between wind turbines, and often give little attention to environmental and other wider societal parameters that are also pertinent. Furthermore, it is usually the case that the attributes taken into account are studied in isolation and it seems that a wider framework to provide for an integrated type of optimization is missing. In this paper we introduce MCDA methodologies as a complement to current approaches of wind turbine micro-siting. Several specific features of MCDA methods like their ability to explicitly account for project uncertainty, environmental parameters, societal values and conflict management may render these techniques quite applicable to the problem of micro-positioning of wind turbines. Nonetheless, the development and application of such a planning framework still remains a future research priority.

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