Towards a Dynamic Multi-criteria Approach based on GIS and MCDM for Wind Farm Site-selection in Morocco

Asmae Azzioui[1][a], Rafika Hajji[2][b], Mohammed Ettarid[3] and Moulay Hafid Bouhamidi[1]
[1]*Exploration Department, Masen (The Moroccan Agency for Sustainable Energy), Rabat, Morocco*
[2]*Department of Geodesy and Topography, Hassan 2nd Institute of Agronomy and Veterinary Medicine, Rabat, Morocco*
[3]*Department of Photogrammetry and Cartography, Hassan 2nd Institute of Agronomy and Veterinary Medicine, Rabat, Morocco*

Keywords: Wind Energy, Site-selection, GIS, MCDM, Criteria.

Abstract: Wind energy is one of the most available energies in Morocco that could contribute appreciably to the improvement of national energy mix. Thus, identifying optimal locations for wind farm energy is a key issue in the wind energy development process. However, site selection is a complex study that involves not only technical considerations, but also economic, social and environmental requirements. Our research aims to develop a dynamic, comprehensive, multiscale and multi-criteria approach for the assessment of quality wind power sites resulting from an in-depth bibliographic study and extensive consultation of a set of professionals in the field. Our approach is based on Geographic Information System (GIS) and Multi-Criteria Decision Making analysis (MCDM) to assess suitable locations for wind farm energy in Morocco. The approach is aimed to be dynamic by consideration of relevant criteria for site selection and by using data of high quality and resolution. This paper aims to present the framework of our research. We start by exposing and analysing basic concepts and methods of wind farm site selection from the literature, then we present and discuss the first methodological guidelines of the research.

1 INTRODUCTION

During the current century, energy has become one of the most critical issues in human life, due to global warming, air pollution and other issues caused by fossil fuels. Energy is one of the important inputs for economic development and power generation (El Khchine et al., 2019).

Wind is one of the renewable sources of energy which have an important role in the mitigation of climate change. In the world, the global wind installed capacity was around 651 GW at the end of 2019. It accounted for around 5.3% of global electricity production in 2019 (www.connaissancedesenergies.org). Wind energy is a clean energy (a wind turbine does not consume water and is not pollutant) which is characterized by a very low surface footprint and a negligible impact on biodiversity (IEA, 2013). In particular, offshore wind energy is becoming more attractive due to the restrictions of land availability for onshore installations. The cumulative annual capacity of offshore wind energy has tripled over the past five years, reaching around 28.3 GW (Sönnichsen, 2020). Offshore resources are by far the most interesting in terms of potential thanks to the regularity of their wind (no turbulence created by landforms or buildings and locally characterized by low roughness) and their limited impact on the terrestrial landscape.

Morocco benefits from an exceptional wind potential due to its good climatic and geographic conditions. Its potential is estimated at 25 GW (1215 MW installed until the end of 2018) in identified on-shore regions and at 250 GW along 3,500 km of off-shore regions (the equivalent of 10 times the national wind potential in on-shore (MEM, 2015)). Several actions have been undertaken to increase the access to electricity produced from renewable energies as part of the objectives of reducing Green House Gas (GHG) emissions and ensuring 52% of the country's

[a] https://orcid.org/0000-0003-3367-336X
[b] https://orcid.org/0000-0002-1291-397X

energy mix from renewable sources by 2030. Masen (Moroccan Agency for Sustainable Energy), is the national agency responsible for managing renewable energy in Morocco by developing integrated projects to reach an objective of an additional 3,000 MW of clean electricity capacity by 2020 and a further 6,000 MW in 2030 (www.masen.ma).

Wind project development begins with a prospecting phase which consists of identifying potential wind power sites with maximum energy production and minimum of CAPEX (CAPital EXpenditure) (EWEA, 2009). Site selection occurs at a stage in the development process before significant resources have been allocated to a particular site (Shaheen et al., 2016). Furthermore, building a wind power plant is a costly process. Although the average service life of a typical wind turbine is about 20 years, site selection has to consider the return of investment on them.

Site selection of wind farms is a complex study. This is due to the multiplicity of constraints and parameters to be considered (environmental, topographical and geographical, public opposition, regulatory barriers, etc). In other words, planners are facing a double challenge as they have to design projects that will contribute to economic growth while minimizing environmental risks and reducing opposition from local stakeholders. Consequently, it is required to identify (assess) suitable locations for the development of wind farms.

"*Multi-Criteria Decision Making analysis (MCDM) aims to provide a decision-maker with the tools to progress in solving the decision problem where several points of view, often contradictory, must be taken into account*"(Chakhar, 2006). MCDM is one of the best-known branches of decision analysis in research which contribute to solve problems involving variety of factors. The MCDM deals with the decision-making process in the presence of multiple objectives. The goal is to choose among several alternatives using a number of decision criteria (Ben Mena, 2000). In the literature, the process of choosing wind farm sites is generally treated under a MCDM approach combined to GIS to analyze the potential locations of a wind farm. The particular characteristics of GIS and MCDM complement each other. GIS has great capabilities for manipulating, storing, managing, analyzing and visualizing geospatial data, while MCDM provides a collection of procedures, techniques and algorithms to solve complexities in decision making, for structuring, designing, evaluating and prioritizing alternative decisions (Gigović et al., 2017).

This paper aims to provide a bibliographical review of the methods of wind farm site selection and to highlight and discuss the first methodological guidelines for our ongoing research. The first part (section 2) is devoted to a state of the art of the used approaches for wind site-selection both in the global and local context of Morocco. The second section analyses and discusses the existing methodologies and then defines the objective and research methodology. While the third section presents and discusses the proposed approach. Finally, the paper ends with a conclusion.

2 BACKGROUND

2.1 Wind Farms Site-selection Criteria

There are two types of variables in an MCDM approach for site selection (Eastman et al. 1993):

- Constraints or exclusion criteria: based on Boolean criteria (true/false), are in the form of a limit threshold, a buffer zone, a setback distance, allowing the exclusion of some zones upstream of the site selection procedure (Sánchez-Lozano et al., 2016).
- Selection or ranking criteria (also called factors) allows assessing the degree of opportunity of a site. They are associated with preference parameters (e.g. weight, discrimination thresholds, etc.) according to their importance (Chakhar, 2006). They define areas or alternatives based on a continuous measure of suitability, reinforcing or diminishing the importance of an alternative resulting from the exclusion of areas defined by restrictions (Gigović et al., 2017).

Selecting a site for a wind farm requires taking into account several criteria and adopting assessment methods to determine the best possible location and to minimize or eliminate obstacles to the development of wind power. Fig. 1 shows an example of the hierarchical structure of the decision process. It contains four levels: goal, constraints, objectives or criteria and factors.

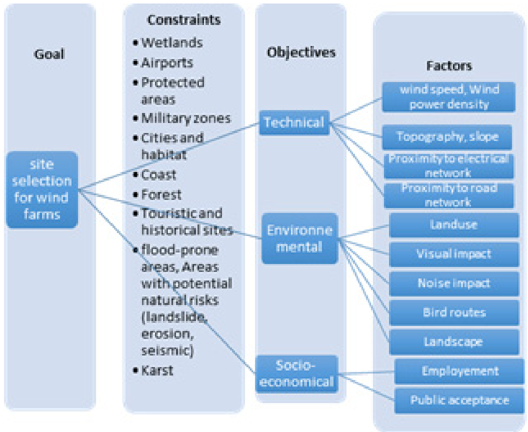

Figure 1: Decision Process hierarchy (Adapted from Cathcart, 2011).

The success of a wind project depends on the correct choice of a site which takes into consideration a variety of criteria: technical aspects (regular wind potential without excessive turbulence, topography, proximity to the electricity and road network, size of the project / land, etc.), technical easement constraints (aviation easements, housing and forest), socio-economic constraints and aspects of land use planning, local acceptance, environmental constraints (visual and sound impact, land use, protected areas and issues related to birds and bats) and the landscape (emblematic sites, remarkable landscapes, registered or classified sites, etc.). Table 1 represents the results of a bibliographical review about site selection criteria, covering a large number of studies carried out in various countries around the world.

Site selection is also the cornerstone to the success of offshore wind farm projects, both economically and technically. An offshore site must be selected in terms of wind speed, depth of the sea, territorial waters, military zones, civil aviation, maritime traffic (shipping roads), pipelines and submarine cables, aquaculture, sand and gravel extraction areas, marine archaeology sites, seascapes as public heritage, offshore renewable energy projects already installed in the region of interest and their corresponding characteristics (water depth, distance to shore, distance from the operation and maintenance base, seabed geology, social and regulatory issues, safety). In addition, relatively minor environmental and social concerns, such as noise and visual impact from wind farms, movement of birds and mammals, may place restrictions on offshore wind farm sites. Many other limitations, such as the location of oil and gas platforms and mining areas, are typically taken into account in other countries when identifying the site of a wind farm. Bathymetry and properties of the seabed should be carefully considered as soil structure influences the cost of turbine installations (Argin et al., 2018).

2.2 Wind Site-selection Approaches

Many studies have associated GIS with topics related to wind energy (Gigović et al., 2017) (Sánchez-Lozano et al., 2016) (Hansen, 2005). GIS capabilities facilitate the work of decision-makers to identify potential sites for wind turbines, and can so save time and reduce the financial costs of a project (Mari et al., 2011). The input database is made up of dozens of parameters to be evaluated (map of wind speeds, distance to roads, etc.), and the resulting output is a suitability map of the optimal sites for the installation of wind turbines. GIS are efficient tools for spatial and multi-criteria analysis. However, they lack a set of mechanisms allowing the integration and the evaluation of conflicting objectives and criteria (Laaribi, 2000). While MCDM methods are considered as an efficient approach to such a complex decision problem.

(Malczewski, 2006) lists 319 works which integrated GIS and MCDM during the period 1990-2004, in the field of science, urban planning, environment, transport, agriculture, ecology, remote sensing, biology and engineering. In particular, the number of studies using GIS-based MCDM for planning of wind farms is low and some of them are to be reviewed here. The GIS-based MCDM approach gained significant interest in early 2000's and has been utilized in several countries like Turkey, Greece, Denmark, USA, UK, Germany, Poland, Vietnam and Sweden. Several researchers have grouped site selection problems under various topics such as network layout, mixed integer programming, capacity-limited, hierarchical, single/multiple product, fixed/flexible demand, static/dynamic period, deterministic/ stochastic, single/multiple objective models, etc (Malczewski, 2006).

The main categories of methodologies include: a) Outranking methods; b) Value / Utility based methods; c) Interactive methods – programming and d) Other methods, which we expose in the next paragraphs.

a) Outranking methods, such as the ELECTRE (Elimination and Choice Translating Reality) families, the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution): These methods use pairwise comparisons between potential alternatives and establish an outranking relationship between them.

b) Value / Utility based methods (American School), such as Multi-Attribute Utility Theory (MAUT), Simple Multi-Attribute Rated Technique (SMART), Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW): their purpose is to create a utility function of values that groups together the decision-maker preferences about evaluation criteria. This formula provides a quantitative mode which guides the decision maker.

c) Interactive methods – programming: like Artificial Neural Network (ANN). They are based on an iterative process. At the start, the analyst establishes an initial solution. The decision-maker responds by providing additional data about the preferences. This additional information is then introduced into the model during the next calculation step. The procedure is repeated until an acceptable solution is reached (Aydogan et al., 2017).

d) Other methods such as NAIADE (Novel Approach to Imprecise Assessment and Decision Environment), Flag model and SMAA (Stochastic Multi-Criteria Acceptability analysis), among others: there are just different types of techniques that are difficult to put into any of the categories mentioned above.

Regarding the application of MCDM methods, restricted or exclusion zones where it is strictly forbidden to install wind turbines are excluded from the beginning of the studies (Gigović et al., 2017) (Atici et al., 2015) (Noorollahi et al., 2016), either by the Fuzzy method (Aydin et al., 2009), or by the Boolean method (Latinopoulos et al., 2015). Subsequently, the most important factor in the MCDM is how to affect "weights" to a set of criteria according to their importance. According to (de Lourdes Vazquez et al., 2011), the weight of factors is calculated from interviews with different actors and professionals. They estimate their scores based on political, environmental and economic standards. (Hansen, 2005) used direct assignments of criteria weights based on common sense or subjective opinion of authors. (Latinopoulos et al., 2015); (Sánchez-Lozano et al., 2016) ; (Bennui et al., 2007) evaluated the weights of the criteria by the AHP method, which is the most widely used method to quantify the weight according to the expert opinion. It consists in ranking the criteria through a comparison matrix. To overcome the drawback of inconsistently when assigning weight, a Fuzzy Analytic Hierarchy Process (FAHP) which combines fuzzy theory with AHP can be used on each factor to determine the fuzziness weight of its attributes. It is an improvement addressing "the vagueness, imprecision and uncertainty associated with the process" of traditional hierarchy process (Asakereh et al., 2017). (Baban et al., 2000) tested two methods. First, the authors standardized the factors into the same number of classes. Then, the first method consists in superimposing the factors with equal weights (Aydin et al., 2009), and the second, in combining them with weights derived from AHP. Their results favor the second method. (Sánchez-Lozano et al., 2016) combined the AHP method for analyzing and weighting the factors and the TOPSIS method (Villacreses et al., 2017) for assessment of alternatives. TOPSIS is a method based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest from the negative one (Sánchez-Lozano et al., 2013). The final ranking is obtained using a closeness index. In terms of the combination of the criteria, the three most frequent methods are Weighted Linear Combination (WLC) (Latinopoulos et al., 2015) (Hansen, 2005), Weighted Index Overlay (WIO) (Noorollahi et al., 2016), Ordered Weighted Averaging (OWA) (Aydin et al., 2009); (Villacreses et al., 2017). Thematic maps must first be standardized into the same number of classes for the three methods. The difference between the methods is that the OWA studies two variables, the order of importance of the factor and its weight. This method is used in conjunction with the Fuzzy approach. While the WLC and WIO methods build the decision map using just the weight of the factors.

In the category c) of methods, MCDM hybrid model combining fuzzy multi-criteria analysis with analytical capabilities that SOLAP systems (Spatial OnLine Analytical Processing) can provide is used to evaluate, rank and select the strategic industrial location for implanting new business corporation in the region of Casablanca (Hanine et al., 2013). In this kind of models, data is well organized multi-dimensionally so that the decision makers could analyze them interactively and iteratively at a detailed and/or aggregated level. The main difference between these techniques, and others consist at the ability to control the temporal evolution (time dimension's role) of a given problem.

ANN method was applied to identify suitable areas for the installation of Photo-Voltaic (PV) systems. The final index is determined by combining the quantitative criteria using an ANN, trained with values corresponding to the sites of existing PV plants in the given region (Mondino et al., 2015). (Ari et al., 2020) proposes within the scope of linear programming perspective, two models using mixed integer linear programming based on power maximization. In (Ari et al., 2020), three approaches were examined based on MCDM methods: SMAA (a simulation-based approach with different kinds of uncertain information), AHP (a conventional deterministic approach), and AHP-SMAA (a hybrid approach) were applied separately in Turkey. (Shaheen et al., 2016) proposed an efficient method for utilization of data mining techniques in wind site selection.

Dynamic multi-criteria decision making (DMCDM) is an emerging subject in the decision-making field until the challenge to consider time as an interesting variable has become important. (Campanella et al., 2011) proposed a flexible framework as a general DMCDM model that combines feedback information (historical data) with current information, for each alternative, in a spatial-temporal decision process. Further, the dynamic decision model was adapted for a business-to-business general supplier selection process. (Jassbi et al., 2014) investigates an MCDM model for group decision making, by taking into consideration its dynamic perspective. A case-study about hotel ranking, involving multi-groups in the decision-making process is sketched to illustrate the approach. (Jassbi et al., 2014) introduces a DMCDM with future knowledge for supplier selection. In this work, the authors extend a dynamic spatial-temporal framework, designed to deal with historical data (feedback), to address the problem of considering future information/knowledge (feed-forward). Recently, (Thong et al., 2020) proposed an extension of dynamic internal-valued neutrosophic sets. Based on this extension, the authors develop some operators and a TOPSIS method to deal with the change of both criteria, alternatives, and decision-makers by time. (Dissanayake et al., 2020) explicitly incorporated linkages between inter-temporal price changes and location of selected and future reserve sites in a dynamic optimization framework. This study presents a two-period linear integer programming model for conservation reserve design that incorporates amenity driven price feedback effects inherent in the reserve development problem. (González-Prida et al., 2014) presented the proposed methodology called DAHP (Dynamic AHP). In short, the DAHP applies the same AHP methodology but considers the influence of the decisions in the boundary conditions. In other words, while the AHP provides a fixed picture of a system in a specific moment with its best local decision, the DAHP provides a motion picture of the system where the best decision can be different to the ones calculated in determined moments.

2.3 Analysis and Discussion

Several studies relative to the development of wind energy aimed at assessing the suitability for sites selection based on various MCDM methods. The adopted techniques have both advantages and disadvantages, which are summarized in (Choudhary et al., 2012). The most widely used MCDM method is the AHP method proposed by (Saaty, 1980) and WLC for energy planning. AHP is universally recognized for its robustness, flexibility, ease of application and its suitability for complex decision-making processes. Furthermore, it allows the integration of qualitative and quantitative criteria and permits testing the consistency of the weight allocation process by reducing the bias in the decision-making progression. However, some authors who use AHP do not provide a consistency ratio and do not include pairwise comparison matrices. The authors also pointed out that because of the specificity of the decision-making process in energy planning, hybrid methods of MCDM are increasingly used. Some of the drawbacks of the AHP method are the large number of pairwise comparisons needed as the number of alternatives increases (Choudhary et al., 2012) and the critic regarding the measurement scale of the pairwise comparisons. In addition, in many cases, AHP cannot give a good representation of reality, as general preferences from a point of view are very difficult to model by a single function.

Moreover, in the literature, no consensus on the ranking order nor the relative importance of the criteria could be found. In some cases, authors assign weights based on their previous experiences or by using questionnaires and interviews (involving experts, planners and students). According to (Uyan, 2017), collecting expert opinion is the best option for assigning relative weights. However, it is important that the experts should be familiar with the study area. According to (Uyan, 2017), using the same criteria and restrictions for different areas is a mistake. Some relevant criteria may be applied in the same way around the world (e.g. wind speed), but others vary widely due to market differences in national regulations and laws (e.g. distance from urban areas). While the constraints are similar in the works mentioned (Table 1), some differences exist in the nuances of the thresholds between countries, which are linked to land and landscape development and planning. They are more or less rigorous from one

Table 1: Bibliographical review of site selection criteria.

Paper / Criteria	Ljumobir et al., 2017	Gass et al., 2013	Millet et al., 2014	Haaren and Fthenakis, 2011	Harrison et al., 2012	Aydin et al., 2010	Baris et al., 2015	Baban et Parry, 2001	Mentis, 2013	Latinopoulos et al., 2015	Nourollahi et al., 2016	Abed et al., 2017	Bennui et al., 2007	(Siyal et al., 2015)	(Nguyen)	(Vogt, 2011)	(Krewitt et al.)	Hansen et al.
Country	Serbie	Autriche	USA	USA	USA	Southwest Turkey	Turkey	Lancashire, UK	Afrique	Greece	Iran	Afghanistan	Thailand	Sweden	Vietnam	Poland	Germany	Northern Jutland, Denmark
Dist / roads	>200m	>150m	<10km	<5km >500m	500m-8km		>500m	<10km		>150m (500-200m)	>500m	<10km	>500m highways	>200 m	>100m	>100m	>500m	150-450m
Dist / cities		>1km		>2km	1600m-16km	>2km	>2km	2km		>1km	>2km	>2km	>2500m urban	>1km				
Dist / habitat	>500m			1km		>500m		>500m		>500m	>500m	>500m	>1km rural	>500 m	>2000m	>500m	>500m	500-1500m
Dist /electrical network	>200m		<20km	Cost analysis	<8km		>250m	<10km	<100km		>250m			>200 m		>200m		
Dist to wetlands, rivers and coastline	Restricted		Restricted	>3km	>800m	>400m	>3km	>400m from water bodies	Restricted	1km Restricted	>500m	>400m	>200m water bodies and rivers	>100 m	>400m	>200m		1000-4000m coast 150-650m (rivers)
Lakes							>3km				>1km							150-650m
Dist to historic tourist areas	>1km							>1km		>1km	>700m		>2km					
Forest / National parks / reserve / protected areas	>2km	>200m			>1600m	>1km	>2km	>1km (parc) 500m from forest	Restricted	>1km	>2km	Restricted			>500m	200-1000m	>500m	300-800m
Military installation	>5km				>1600m													
Telecom networks	>250 m						>600m											1000-2500m radio masts
Airports	>3km		Restricted		>1600m	>6km	>5km			>3km	>2.5km	>3.5km	>3km	2.5km		3km		5-7.5km
Railway			Restricted				>500m				>300m			>200 m				
Wind speed / Energy	>3.5m/s		>7.5 m/s à 50m		>7m/s à 50m	400 W/m²		>5m/s	>7.5m/s à 80m	>4.5m/s (5-7.5m/s)	>5.6m/s à 80m	>6m/s à 50m	>100 W/m²	Turbine output			>4 m/s (at 10m AGL)	250-650W/m²
Wind Direction								Ouest										
Slope	<7%	<15%	<7%	<10%	<20%		<10%	<10%	<10deg	<25%	<15%	<10%	<15%			<25%		
Soil type / geology				Exclusion Karst >100m	Exclusion of karst		Dist / faults >200m				Dist / faults >500m							
Landuse			Agrarian and bare soil		Pature, zone agraire herbacé, sol nu			Agricultural land excluded	Exclude agrarian areas (Africa) artificial industrial, commercial, mining, agrarian and wet (Greece)			Exclude snow covered area and sand dunes	Roughness: 400mm -0.1mm					
Elevation		<2000m					<1500m		<2000m			Exclude high mountains	>40m					

region to another depending on local issues. For example, in Turkey and Iran which are located in areas with high seismic risk, the proximity factor to faults is studied for security reasons but with low weight compared to other factors (Atici et al., 2015) (Noorollahi et al., 2016). In addition, the karstic geomorphological structure was excluded from the study on the area between Washington State and Oregon, since the risks associated with the development of this formation are varied. (Bennui et al., 2007) is the most demanding on the distance between a wind farm and rural (> 2,500 m) and urban (> 1,000 m) area. Their choice may be related to the vast rural and populated areas of Thailand. Another example is about Turkish legislation which imposes thresholds concerning noise pollution, safety, nature reserves and the size of surfaces occupied by wind turbines (Atici et al., 2015). On the other hand, it considers forests as potential sites (Aydin et al., 2009). The distance to the electrical grid is one of the 10 most important criteria defined by the American Wind Energy Association for the construction of wind farms (AWEA, 2007). However, the importance of this criterion in the literature is ambiguous. It seems to depend strongly on the location of the study area. The majority of studies use wind speed as the first rank criterion. However, wind speed is a parameter which varies significantly both spatially and temporally. We therefore propose to opt for the Wind Power Density (WPD) (Liu et al., 2020) which is calculated on the basis of the frequency distribution and allows to clearly understand the turbulence of the resource.

2.4 The Moroccan Context

In Morocco, MCDM combined with GIS has been used in recent years in the process of site selection for the development of renewable energies. Particularly, in solar site prospecting, the most quoted regional studies are (Tahri et al., 2015); (Tazi et al., 2018); (Azmi et al., 2017); (Sedrati et al., 2019) and (Kamli et al., 2016) which are largely based on Boolean and AHP methods. In the case of wind energy, we can quote only three studies. The first one is conducted by the CDER (Centre de Developpement des Energies Renouvelables) and has resulted in a wind potential map. However, the adopted method does not allow a refined assessment of the suitability of a site. It is mainly based on wind potential criterion for choosing sites without considering exclusion criteria. Moreover, the wind used data isn't based on the Moroccan Wind Atlas set up by Masen in the form of a GIS database with high spatial resolution (2km) covering the whole country with a buffer zone of 30 km offshore along the Moroccan coast.

The second study of (Elmahmoudi et al., 2020) investigated the selection of the location of wind farms in the Tarfaya region of Morocco. In order to calculate the weight to be assigned to each criterion, AHP, Fuzzy-AHP algorithm from Buckley and the geometric mean Fuzzy-AHP method, were combined to GIS. The third study of (Achbab et al., 2020) presented a model based on GIS coupled with a MCDM using the Fuzzy AHP method to locate a hybrid solar-wind energy system with high potential in the Dakhla region located in the south of Morocco. Looking at the two studies, it turns out that they only concern a small, particular region of Morocco, with a limited number of criteria and no exclusion criteria has been considered for the first one. In addition, impacts on avifauna are not considered. Furthermore, the used data have a limited spatial resolution (wind data and electrical network).

In general, we can state that most current wind farm site selection procedures lack systematic methods and models, and are mainly based on ad hoc decisions and individual experiences of the decision makers or planners in charge. Therefore, this motivates us to conduct this research in order to propose an innovative approach based on a spatial decision support system and advanced modelling techniques which allow precise and dynamic simulations of wind farm sites in Morocco.

3 OUR APPROACH

Our research aims to develop a dynamic approach for wind sites selection, based on precise data and a detailed analysis of relevant criteria for wind site selection by including those related to environment and social impact. Our approach will allow simulation and assessment of various resulting scenarios through a dynamic platform. Therefore, we can arise the following questions: 1) What criteria are relevant for site selection of wind turbines? 2) How these criteria can be weighted? 3) Which approach to be adopted for modelling the process and assessing the potential location of wind turbines?

Some researches already exist in DMCDM area but when compared with static decision-making models, DMCDM needs more work to be applicable in real industrial problems. The purpose of our study is to deal with the change of criteria, alternatives, and decision-makers during time. In a recent systematic literature review (Shao et al., 2020) of MCDM applications for renewable energy site selection performed, covering a total of 85 papers published from 2001 to 2018 in high-level journals, no article has dealt with a dynamic simulation for wind site selection.

Our research will also lead to two main outputs: 1) a proposal of a national standard for site selection of wind turbines and 2) a national map for wind potential which can serve as a support for the establishment of the electricity grid in some unconnected areas.

3.1 Methodological Workflow

Firstly, the aim of the process is to mask and eliminate all the constrained areas. Then, the DAHP method will be used to determine the weight of the factors. The final map will be drawn by a weighted overlay of thematic layers (WLC). Thus, an overall relevance or suitability index (SI) will be calculated for each cell. This method can be modified to meet the requirements of experts and in the field. Sensitivity analysis (SA) is a beneficial measure to include in MCDM approaches because it allows a better understanding of the sensitivity of outputs (i.e. areas suitable for development) to errors, erroneous assumptions, or disturbances in input values (ie, criterion values and / or criterion weights). SA helps to assess the accuracy and limitations of the model (Chen et al., 2010). AS can therefore help to identify areas of greatest uncertainty, and criteria that need to be assessed. more carefully (Chang et al., 2008).

Wind farm sites will be identified after a comprehensive approach is carried out upstream, over a large area to locate potential areas for hosting wind turbines. The identified areas are delimited and prioritized and analysed in a more detailed way in order to reach a suitable portfolio of sites. Accordingly, the model will be applied first to the national territory then by downscaling to each area of interest. Finer resolution data will be used for refining the site choice.

Figure 2 shows the basic steps of the methodological workflow.

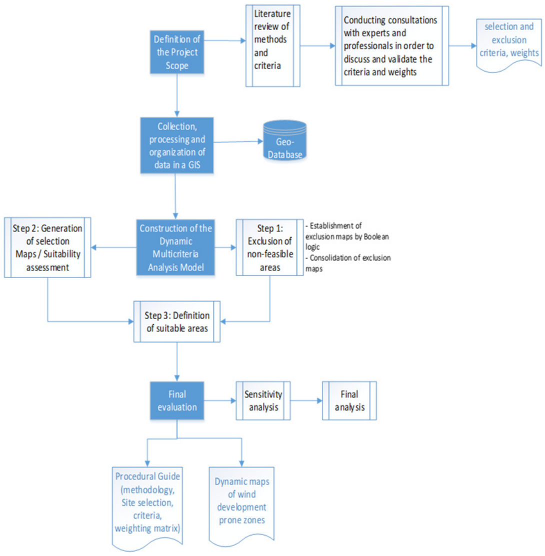

Figure 2: Methodological Workflow.

3.2 Material

Table 2 below summarizes the data to be used in the process of wind site selection.

Since wind speed and WPD are the main criterion for the wind sites assessment, the use of high quality wind atlas is crucial. In the literature, most of the authors use low quality and resolution (or interpolated) wind maps (Liu et al., 2020).

Table 2: Data characteristics.

Data	Format	Source
Wind speed / energy	Raster layer of wind speeds, Wind power density at 2 km resolution at 60m, 80m and 120m above ground	Masen (based on mesoscale simulation of reanalysis data)
Cities and towns	Vector layer	Digitized on Google Maps background
Road Network Map	Vector layer	http://www.diva-gis.org/
Electric grid map	Vector layer	ONEE
Map of the hydrographic network	Vector layer of watercourses and bodies of water (dams and lakes)	http://www.diva-gis.org/
Airports	Vector layer	ICAO database (International Civil Aviation Organization)
Elevation	Digital elevation model SRTM at 30m resolution	SRTM (Shuttle Radar Topography Mission) http://srtm.csi.cgiar.org
Slope	Map of slopes in (%) at 30m resolution	Calculated on the basis of the DEM
Landuse	Raster layer of 24 soil classes at 1km resolution	USGS
Coasts	Vector layer (nearly 3500 km)	Digitized on border of Morocco
Bodies of water	Vector layer	http://www.diva-gis.org/
Military installation & Dense forest with significant height	Vector layer	Extracted from the land use map
National parks / reserve / protected areas / Ramsar / SIBE	Vector layer from the World Database on Protected Areas	WDPA (Version 3.1)
Bird and bats flight corridor	Vector layer of IBA (Important Bird Area)	International Database (Birdlife International)

Furthermore, the database is to be completed by physical or environmental data like the layer of existing wind projects, summary map of technical easements, map of regulatory protection of heritage and landscapes, flood areas, landslide and karst risk areas, map of landscape entities and other non-spatial data (planning standards, environmental standard, safety requirements, and location of sensitive buildings).

3.3 Expected Results

This research aims to draw up a dynamic map of areas suitable for wind power development and to elaborate a procedural guide / standards for the choice of sites for wind power projects. In the absence of legislation and regulations related to wind energy in Morocco, we used the bibliography and knowledge of the field to choose the threshold of constraints and local factors for wind prospecting. The most recurrent and relevant factors and constraints in the literature and adapted to Morocco were selected. Pairwise comparison values were assigned based on the literature analysis and our knowledge of the study area to establish a criteria weighting matrix specific to Masen.

4 CONCLUSIONS

Morocco has many natural resources and many assets in terms of space which can allow reconciling the development of sustainable energies, land use planning and the preservation of the environment. Our research focuses on wind energy which is one of the most important sources of clean energy with high potential in Morocco. We aim at developing a new method for potential site selection. As the process is multidimensional, the adopted approach should deal with all the variables and the aspects of the decisional process.

This research aims to set up a dynamic, innovative and multiscale site choice approach using as input very high quality data based on the combination of GIS and MCDM in order to simulate location of potential sites for large -scale wind power projects. The input data and the weight of the criteria are fundamental in defining the final result. Therefore, the factors and criteria must correspond as much as possible to the characteristics of the studied territory. We are aware that the final decision is also the result of other processes, such as political strategies. However, the "scientific" identification of the best solution is undoubtedly an important decision-making support.

REFERENCES

Younes El Khchine, Mohammed Sriti, Nacer Eddine El Kadri Elyamani, Evaluation of wind energy potential and trends in Morocco, Heliyon, Volume 5, Issue 6, 2019, e01830, ISSN 2405-8440.

www.connaissancedesenergies.org

International Energy Agency. Wind Eng (2013) https://www.iea.org/

Sönnichsen. N., 2020. Carbon Dioxide emissions in Sweden 2000-2018

http://www.mem.gov.ma/SiteAssets/Dicsours/Discours2015/Disc22-23juin15.pdf

www.masen.ma

European Wind Energy Association. (2009). The Economics of Wind Energy. Brussles.

Shaheen, Muhammad & Khan, Muhammad Zeb, 2016. "A method of data mining for selection of site for wind turbines," Renewable and Sustainable Energy Reviews, Elsevier, vol. 55(C), pages 1225-1233.

Salem Chakhar. Cartographie Décisionnelle Multicritère: Formalisation Et Implémentation Informatique. Université Paris Dauphine - Paris IX, 2006. Français.

Sami Ben Mena. Biotechnol. Agron. Soc. Environ. 2000 4 (2), 83–93 Introduction aux méthodes multicritères d'aide à la décision

Gigović, Ljubomir & Pamucar, Dragan & Božanić, Darko & Ljubojević, Srđan. (2017). Application of the GIS-DANP-MABAC multi-criteria model for selecting the location of wind farms: A case study of Vojvodina, Serbia. Renewable Energy. 103. 501-521.

Sánchez-Lozano, J. M., García-Cascales, M. S., & Lamata, M. T. (2016). GIS-based onshore wind farm site selection using Fuzzy Multi-Criteria Decision Making methods. Evaluating the case of Southeastern Spain. Applied Energy, 171, 86-102.

Cathcart, S. C. (2011). A Group-based Spatial Decision Support System for Wind Farm Site Selection in Northwest Ohio (Doctoral dissertation, Bowling Green State University).

Argin, Mehmet & Yerci, Volkan & Erdogan, Nuh & Kucuksari, Sadik & Cali, Umit. (2018). Exploring the offshore wind energy potential of Turkey based on multi-criteria site selection. Energy Strategy Reviews. 23. 33-46. 10.1016/j.esr.2018.12.005.

Hansen, Henning. (2005). GIS-based multi-criteria analysis of wind farm development. ScanGIS 2005 - Proceedings of the 10th Scandinavian Research Conference on Geographical Information Sciences.

Mari, R., Bottai, L., Busillo, C., Calastrini, F., Gozzini, B., & Gualtieri, G. (2011). A GIS-based interactive web decision support system for planning wind farms in Tuscany (Italy). Renewable Energy 36, 754-763.

A. Laaribi, SIG et analyse multicritère, 2000.

Malczewski, Jacek. "GIS-based Multicriteria Decision Analysis: A Survey of the Literature." International Journal of Geographical Information Science 20, no. 7 (2006): 703-26.

Aydogan, E. K., & Ozmen, M. (2017). The stochastıc vikor method and its use in reverse logistic option selection problem. RAIRO-Operations Research, 51(2), 375-389.

Atici, K. B., Simsek, A. B., Ulucan, A., & Tosun, M. U. (2015). A GIS-based Multiple Criteria Decision Analysis approach for wind power plant site selection. Utilities Policy, 37, 86-96.

Noorollahi, Y., Yousefi, H., & Mohammadi, M. (2016). Multi-criteria decision support system for wind farm site selection using GIS. Sustainable Energy Technologies and Assessments, 13, 38-50.

Latinopoulos D, Kechagia K (2015) A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece. Renew Energy 78:550–560

Aydin, N. Y., Kentel, E., and Duzgun, S., 2009, GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey: Renewable and Sustainable Energy Reviews, v. 14, p. 364-373.

de Lourdes Vazquez, M., Waaub, J. P., Ilinca, A., & Chaumel, J. L. (2011, October). Analyse spatiale et approche d'aide multi-critères et multi-acteurs à la négociation pour évaluer des scénarios d'implantation des parcs éoliens.

Bennui, Adul & Rattanamanee, P. & Puetpaiboon, U. & Phukpattaranont, P. & Chetpattananondh, K.. (2007). Site selection for large wind turbine using GIS. PSU-UNS International Conference on Engineering and Environment. 561-566.

Villacreses, G., Gaona, G., Martínez-Gómez, J., & Jijón, D. J. (2017). Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: The case of continental Ecuador. Renewable energy, 109, 275-286.

Asakereh, A., Soleymani, M., & Sheikhdavoodi, M. J. (2017). A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran. Solar Energy, 155, 342-353.

Baban, M. J. S., and Parry, T., 2000, Developing and applying a GIS-assisted approach to locating wind farms in the UK: Renewable Energy, v. 24, p. 5971.

Sánchez-Lozano, J.M.; Teruel-Solano, J.; Soto-Elvira, P.L.; García-Cascales, M.S. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. Renew. Sustain. Energy Rev. 2013, 24, 544–556.

Hanine, Mohamed & Boutkhoum, Omar & Tikniouine, Abdessadek & Agouti, Tarik. (2013). Approach to integration SOLAP tools and multicriteria analysis for spatial decision support. 1-6.

Mondino, E.B.; Fabrizio, E.; Chiabrando, R. Site Selection of Large Ground-Mounted Photovoltaic Plants: A GIS Decision Support System and an Application to Italy. Int. J. Green Energy 2015, 12, 515–525.

Ari, E. S., & Gencer, C. (2020). Proposal of a novel mixed integer linear programming model for site selection of a wind power plant based on power maximization with use of mixed type wind turbines. Energy & Environment, 31(5), 825–841.

Arı, E. S., & Gencer, C. (2020). The use and comparison of a deterministic, a stochastic, and a hybrid multiple-criteria decision-making method for site selection of wind power plants: An application in Turkey. Wind Engineering, 44(1), 60-74.

G. Campanella, R.A. Ribeiro, A framework for dynamic multiple-criteria decision making, Decis. Support Syst. (2011)

Jassbi, J. J., Ribeiro, R. A., & Dargam, F. (2014, June). Dynamic MCDM for multi group decision making. In Joint International Conference on Group Decision and Negotiation (pp. 90-99). Springer, Cham.

Jassbi, J. J., Ribeiro, R. A., & Varela, L. R. (2014). Dynamic MCDM with future knowledge for supplier selection. Journal of Decision Systems, 23(3), 232-248.

Thong, N. T., Smarandache, F., Hoa, N. D., Son, L. H., Lan, L. T. H., Giap, C. N., & Long, H. V. (2020). A Novel Dynamic Multi-Criteria Decision Making Method Based on Generalized Dynamic Interval-Valued Neutrosophic Set. Symmetry, 12(4), 618.

Dissanayake, S. T., & Önal, H. (2011). Amenity driven price effects and conservation reserve site selection: A dynamic linear integer programming approach. Ecological Economics, 70(12), 2225-2235.

González-Prida, V., Viveros, P., Barberá, L., & Márquez, A. C. (2014). Dynamic analytic hierarchy process: AHP method adapted to a changing environment. Journal of Manufacturing Technology Management.

Choudhary, D., & Shankar, R. (2012). An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India. Energy, 42(1), 510-521.

Saaty, T.L. (1980). The analytic hierarchy process: Planning, priority setting, resource allocation, McGraw-Hill International Book Co., New York/London.

Uyan, M. (2017). Optimal site selection for solar power plants using multi-criteria evaluation: a case study from the Ayranci region in Karaman, Turkey. Clean Technologies and Environmental Policy, 19(9), 2231-2244.

Liu, L. R., Huang, G. H., Baetz, B., & Turchenek, K. (2020). A GIS-based Decision-Making Support System for Wind Power Plant Site Selection, Case Study for Saskatchewan. Journal of Environmental Informatics Letters, 2(2), 102-110.

Tahri, M.; Hakdaoui, M.; Maanan, M. The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco. Renew. Sustain. Energy Rev. 2015, 51, 1354–1362.

Tazi, G., Jbaihi, O., Ghennioui, A., Merrouni, A. A., & Bakkali, M. (2018, June). Estimating the Renewable Energy Potential in Morocco: solar energy as a case study. In IOP Conference Series: Earth and Environmental Science.

Azmi, R., Amar, H., & Kacimi, I. (2017, December). Photovoltaic site suitability analysis using analytical hierarchy process and sensitivity analysis methods with GIS and remote sensing in Southern Morocco: case of Draa-Tafilatet Region. In 2017 International Renewable and Sustainable Energy Conference (IRSEC) (pp. 1-5). IEEE.

Sedrati, M., Maanan, M., & Rhinane, H. (2019). PV Power Plants Sites Selection Using GIS-FAHP Based Approach in North-Western Morocco. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences.

Soufiane Kamli, Ettarid Mohammed, Bouhamidi Moulay Hafid. Automatisation du processus d'identification des sites potentiels pour les projets solaires, par les outils SIG et l'analyse multicritère. Rapport de Projet de Fin d'Etudes. 2016

F. Elmahmoudi, O. E. k. Abra, A. Raihani, O. Serrar and L. Bahatti, "GIS based Fuzzy Analytic Hierarchy Process for Wind Energy Sites Selection in Tarfaya Morocco," 2020 IEEE International conference of Moroccan

Geomatics (Morgeo), Casablanca, Morocco, 2020, pp. 1-5.

E. Achbab, H. Rhinane, M. Maanan and D. Saifaoui, "Developing and applying a GIS-Fuzzy AHP assisted approach to locating a hybrid renewable energy system with high potential: Case of Dakhla region–Morocco-," 2020 IEEE International conference of Moroccan Geomatics (Morgeo), Casablanca, Morocco, 2020, pp. 1-6.

Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S., & Zhao, Y. (2020). A review of multi-criteria decision making applications for renewable energy site selection. Renewable Energy.

Chen, Y., Yu, J., & Khan, S. (2010). Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environmental modelling & software, 25(12), 1582-1591.

Chang, Ni-Bin, G. Parvathinathan, and Jeff B. Breeden. “Combining GIS with Fuzzy Multicriteria Decision-Making for Landfill Siting in a Fast-Growing Urban Region.” Journal of Environmental Management 87, no. 1 (2008): 139-53.