Global opportunities for airborne wind

A combination of the conjunctive screening method with multi-criteria decision making to assess the most suitable nations for airborne wind energy

Master of Science Thesis

Ir. J. Wijnja

December 9, 2014

Faculty of Technology, Policy and Management

TU Delft Delft University of Technology

Challenge the future

Global opportunities for airborne wind

A combination of the conjunctive screening method with multi-criteria decision making to assess the most suitable nations for airborne wind energy

Master of Science Thesis

For obtaining the degree of Master of Science in Management of Technology at Delft University of Technology

Ir. J. Wijnja

December 9, 2014

Faculty of Technology, Policy and Management · Delft University of Technology

Delft University Of Technology
Department Of
Economics of Technology and Innovation

The undersigned hereby certify that they have read and recommend to the Faculty of Technology, Policy and Management for acceptance a thesis entitled **"Global opportunities for airborne wind"** by **Ir. J. Wijnja** in partial fulfillment of the requirements for the degree of **Master of Science**.

Dated: December 9, 2014

Head of department: ______________________
Prof.dr. R.W. Kunneke

First supervisor: ______________________
Dr. D.J. Scholten

Second supervisor: ______________________
Dr.ir. E.J.L Chappin

External supervisor: ______________________
Dr. J.R. Ortt

Daily supervisor: ______________________
Dr.ir. M. Dignum

Supervisor Google[x] Makani Power: ______________________
A. Woodrow

Abstract

It is the objective of this graduation research to determine the nations with the highest deployment opportunity for airborne wind energy (AWE) generation systems. Compared to conventional, ground based, wind energy systems, the flying structure of the airborne wind turbine substitutes the rotor blades and a tether substitutes the tower. These systems have the potential to harvest electricity against much lower cost, will soon become commercially available, and could take a significant share of the growing wind energy market.

A unique top down approach is applied by analyzing all 193 United Nations member states with a combination of the conjunctive screening method with PROMETHEE-AHP multi criteria decision making. First, a set of conjunctive screening rules will determine if the basic conditions for wind energy are present. Nations which satisfy these rules are subject to a detailed multi criteria analysis. The unique set of relevant criteria in this analysis are determined from a combination of the renewable energy planning, and international business literature in combination with the view of airborne wind energy experts. The relative importance of these criteria is determined with an expert survey, based on the Analytical Hierarchy Process (AHP), at which 26 experts participated from various background. A novel extension to the classical AHP weight factor calculation methodology is proposed, verified and applied to verify the breakdown of criteria into sub criteria.

The results of this study are compared with the current activity in airborne and conventional wind energy. This study was able to select the nations with (airborne) wind energy activity. However this study also showed that many nations with high opportunities in airborne wind have no current activity in this field. Additionally it was found that nations, which are characterized by the highest installed capacity do not necessarily have a highest opportunity for airborne wind and vice versa. Hence many airborne wind resources in nations with high opportunity for airborne wind are still untapped and offer a great potential for future energy harvesting. Due to many similarities of the technologies, the conventional wind energy industry can also benefit from the results of this study.

Acknowledgements

This master thesis emerged as a first collaboration project between the faculty technology, policy and management of Delft University of Technology and Google[x] Makani Power. From both parties many people inspired, advised and helped to advance the research challenges I faced.

From the faculty of technology, policy and management I would like to gratefully thank my supervisors Dr. Daniel J. Scholten, Dr.ir. Émile J.L Chappin and Dr. Roland Ortt for their guidance and valuable discussions, which greatly improved the quality of this research. I want to especially thank my daily supervisor Dr.ir. Marloes Dignum for her continuous guidance, help and patience during the entire project. My appreciation goes to Prof.dr. Rolf W. Kunneke for this involvement throughout the project and for being the head of the graduation committee.

From Google[x] Makani Power my gratitude goes to the business team lead Alden Woodrow for many inspirational discussions and the set up of a very interesting and challenging research project.

My last words go to my parents, friends, family and especially my girlfriend who supported me throughout the project and who had to continuously compete for quality time during the Master thesis. When finished, I'll make up for the lack of quality time. I promise!

Delft, The Netherlands Ir. J. Wijnja
December 9, 2014

Contents

Chapter 1

Introduction

It is the goal of this first chapter to introduce the topic of airborne wind energy nation selection and provide information to comprehend the significance of this thesis. In section 1.1, the thesis relevance and its goal are defined. In section 1.2 the challenges of reaching this goal are outlined, which results in the main research question and its subquestions. In section 1.3, the research approach to answer these research questions is introduced. In section 1.4, the contribution of this thesis to the current body of knowledge is given. Finally, in section 1.5, the outline of the remaining of this report is given.

1.1 Research relevance and goal

In 2013, the global energy demand has increased with about 50% with respect to 1990, and is expected to rise with another 40-50% in the next two decades [1–4]. Currently fossil fuels account for the largest share of the global final energy consumption, about 75-80% [5]. However, in the last decades resistant rose agains the use of large scale conventional fossil fuels for energy generation.

These fossil fuels are a major contributor to the increase of atmospheric carbon dioxide, which in turn is a major driver to atmospheric temperature rise. The heating of the Earth already resulted in melting glaciers and the Greenland and Arctic ice sheets. This melting of ice sheets in combination with the ocean thermal expansion resulted in a 19cm sea level rise from 1900-2010 [6]. An increase of sea level rise will increase the risks to large scale flooding. This is one example of climate change. However, climate change already has and will continue to have a more significant effect on ecosystems, human health, fresh water resources and agriculture [6]. To mitigate the risks involved with climate change, many nations have committed to internationally binding emission reduction targets [7]. Sustainable energy sources are necessary to reach these targets.

Various renewable energy (generating) systems (RESs) have been developed, such as photovoltaic cells (PV) to capture the energy from the sun, wind turbines to capture the energy from the wind, and underwater turbines to capture the tidal energy. An innovative wind energy concept is airborne wind energy (AWE). Compared to conventional, ground based, wind energy systems, a flying structure substitutes the rotor blades and a tether substitutes the tower as shown in Figure 1.1. With respect to conventional wind energy, airborne wind works on the same principles to harvest energy from the wind. However AWE systems only use a fraction of the materials and the tether allows to reach higher altitudes, inaccessible to conventional wind turbines, at which the winds are more consistent and stronger [8]. These systems have the potential to harvest electricity against much lower cost.

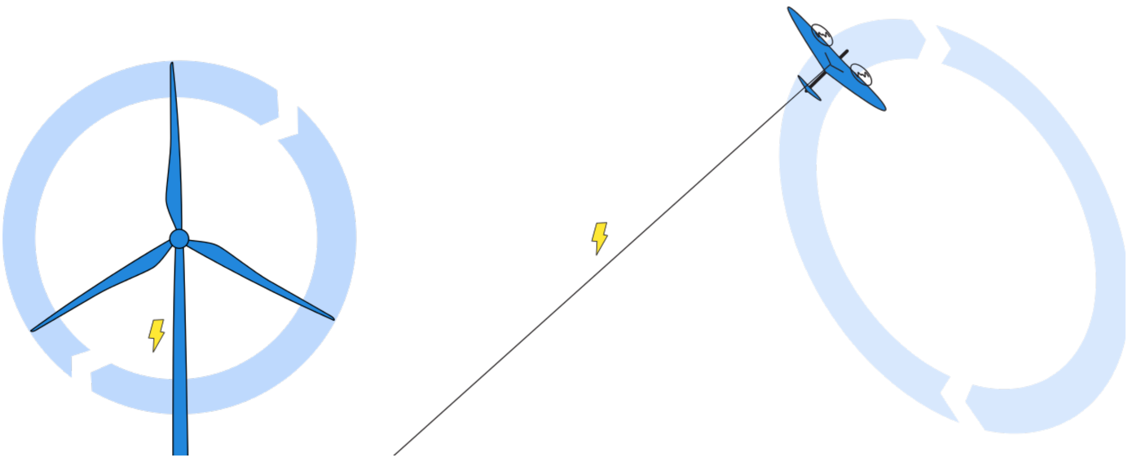


Figure 1.1: Conventional ground based wind turbine versus the airborne wind turbine concept. In this particular airborne wind concept, the electricity is produced by on-board generators and fed into the grid by an electricity conducting tether.

Another difference between the technologies is found in the degree of maturity. Conventional wind energy technology has been commercialized for many years and the technology has converted to a single concept, whereas the airborne wind industry is still in its infancy with many concepts explored [8].

Actually, airborne wind energy systems have not yet been commercialized but the first commercial systems will soon become available [8, 9]. The commercialization phase of this new technology is a highly unexplored research field, especially from an academic level [8, 10]. For a successful market entry of any renewable energy system, the selection of the most appropriate locations is a crucial factor [11], but due to the novelty of airborne wind, this research field has not yet been explored for this technology. Many technical, economic, political and social factors influence the degree of opportunity for all renewable energy systems [11]. These factors differ considerably across nations. Therefore a first attempt is made to select nations based on their opportunity for airborne wind energy deployment by analyzing all 193 United Nations (UN) member states on a national level.

This leads to the research goal of this study:

Research goal: Determine the most appropriate nations for the deployment of airborne wind energy systems.

1.2 Research problem

Before the 1973-1974 oil crises, energy was generally viewed as plentiful, and energy was supplied according to a single criteria: minimizing costs [12, 13]. The energy crises created a greater public awareness of depleting fossil fuels, and at the same time the environmental impact of energy production was stressed by environmentalist. Different (groups of) actors with various interests entered the decision making process.

From this moment, the view upon energy planning changed from a single objective and single criteria problem towards a problem characterized by multiple actors, such as environmental groups, investors, authorities, and utility companies, in combination with conflicting objectives, such as cost minimization and reduced environmental impact [12]. In this 'new' decision making process, each actor's view/opinion should be taken into account to create a widely-supported decision [14]. Therefore new methodologies are explored and developed for efficient and deliberate decision making in (renewable) energy planning.

Some methods for (sustainable) energy planning have been applied on the national and local level, such as the siting of a wind farm in Catalonia (Spain) [15], the selection of optimum RESs (wind, solar, small hydro, geothermal or biomass) for the island Thassos (Greece) [16], and Turkey [17]. Because of the similarities of airborne wind turbines and conventional wind turbines the research into wind farm siting could be applied for airborne wind as well. In these studies the problem is generally approached from the perspective of the energy policy makers of a specific region[11]. Hence only a specific region is part of the analysis. In this study the view of the fictive policy maker of the world is taken to determine the best locations in case the entire word is taken into account. This view will also help (airborne) wind farm developers to determine in which nations the locations are present with the highest opportunity. A global analysis is necessary to determine in which nations the most appropriate locations are present and can be seen as a first step in location selection for (airborne) wind systems. This first step is crucial, because it limits the options op locations. However this step is generally skipped, because the problem is seen from a regional policy maker's perspective [11].

Because wind farm siting studies are currently focused on the local level, the criteria which are irrelevant on the local scale, but relevant on the global scale are not taken into account in these models. One such a criterion is the national policy landscape regarding renewable energy support policies and targets. This policy landscape is not taken into account in the current models [11], whereas a financial support policy is one of the main factors influencing the development and deployment of RESs [5].

The research goal together the experience from the (sustainable) energy planning results in the main research question and its subquestions:

Main research question: In which nations are the most appropriate locations for the deployment of airborne wind energy systems?

Sub questions

1. Which criteria are relevant for analyzing the nation selection for airborne wind energy systems.
2. Which research framework is capable of analyzing airborne wind nation selection based on the criteria listed in subquestion 1.
3. Based on this research framework, what nations are most suitable for the deployment of airborne wind energy systems?
4. How sensitive are these results to (1) changes in the external environment and (2) model inaccuracies?

1.3 Research approach

Generally a bottom up, single case study approach is taken in wind farm site selection. A single case study allows a lot of detail to be collected for a specific case. The main disadvantage of a single case study for wind farm siting is that the results are not compared to other wind farm sites. Hence results always tend to be satisficing; the wind farm site is chosen because it is 'good enough', rather than 'the best' [18].

To analyze all globally possible (airborne) wind farm sites with case studies, thousands of different case studies should be conducted, which would be very time consuming and inefficient. Many sites are analyzed with very low opportunities for wind energy deployment, e.g. because the wind climate is very unfavorable, the region is politically unstable or the regional decision makers are not interested in renewable energy sources. In case a few wind farm sites are analyzed with few case studies, the changes are low that the regions are selected with the highest deployment opportunities. Currently no literature is available about the selection of these regions and locations and this study attempts to fill this literature gap. In this top down approach all 193 United Nations (UN) member states are analyzed for their deployment opportunities for airborne wind.

The approach of this study is given with a flowchart in Figure 1.2. This approach is characterized by two distinct analyses. Before a nations can enter the detailed analysis phase II, some basic conditions for wind energy should be met, e.g. there should at least be some wind to extract the energy from. In this first phase of this study, the nations are withdrawn from further analysis if the basic conditions for wind energy are not satisfied. Next, the other factors influencing the nation selection for airborne wind and their level of importance is determined. Based on these factors, the nations are analyzed according to their suitability for the deployment of airborne wind energy systems.

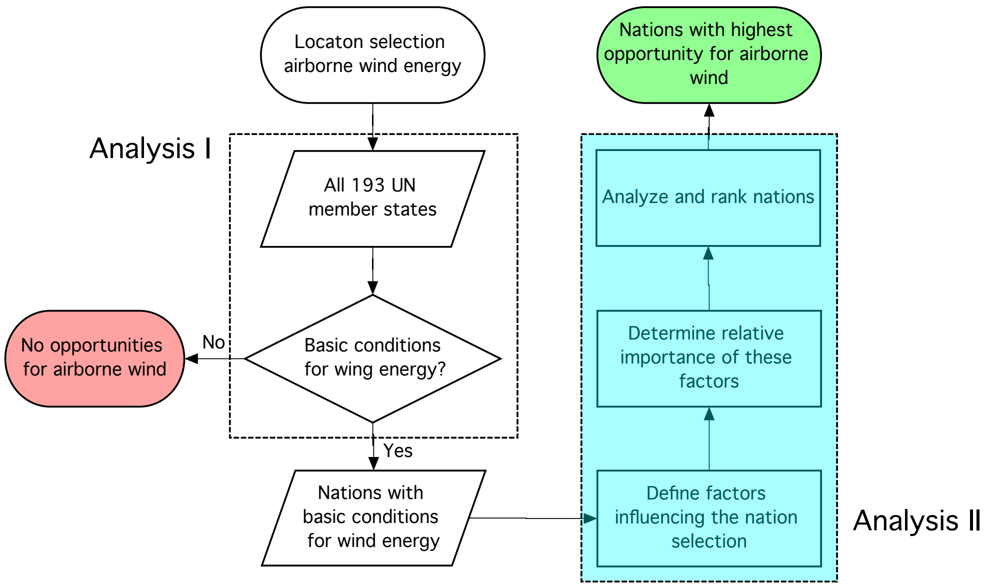


Figure 1.2: Flowchart of the approach

1.4 Scientific contribution

With this study five contributions to the current body of knowledge are made. First a comprehensive list of criteria, which influence the degree of opportunity for airborne wind, is determined. This list is based on the international business and local wind energy planning literature, and additionally the expert view of Makani Power's business lead, Alden Woodrow[1]. Makani Power is a leading airborne wind turbine developer and soon its first products will become commercially available [8]. Makani Power is exploring the market opportunities of these systems.

Second this list is verified and the relative importance of these factors is determined with an expert survey at which 26 experts from various backgrounds participated; 12 experts from the airborne wind industry, 3 from academic institutions working on airborne wind, 2 from academic institutions working on energy and infrastructure, 6 from the conventional wind energy industry, 2 from NGOs and 1 with a governmental background.

Third a novel extension to the Analytical Hierarchy Process (AHP) weight factor calculation is proposed. With this extension the breakdown of a criteria into sub criteria can be verified.

Fourth a funnel methodology is developed by introducing a combination of the conjunctive screening method with PROMETHEE-AHP multi criteria decision

[1]Alden Woodrow leads the business team for the Makani project at Google[x]. Alden directs Makani's strategy, business development, communications, policy, and partnership efforts. He previously worked for a power project developer financing utility-scale wind farms, and as an economic and environmental consultant on topics ranging from climate policy to dog house manufacturing.

making. The conjunctive screening method will eliminate nations in case the basic conditions for wind energy are not met, AHP will determine the relative weight factors and PROMETHEE will rank the nations.

Finally, all 193 UN member statesn are included in this analysis, which would give insight in the worldwide opportunity for airborne wind. Because of the many similarities, it is likely that nations which have a high opportunity for airborne wind will also have high opportunities for conventional wind turbines. Literature of conventional wind energy site selection is focussed on the local analysis, whereas this study could give insights in the worldwide opportunities.

1.5 Thesis outline

In chapter 2, the technical and commercial potential of airborne wind is described. Chapter 3 establishes a methodological framework to determine the nations with the greatest potential. In chapter 4, this methodology is applied to the nations selection of airborne wind energy systems. In chapter 5, the input data for this model is described and the complete model is build. In chapter 6 the ranking results, which follow from this model, are presented and analyzed. In chapter 7 the conclusions and recommendations for future research are given.

Chapter 2

Airborne wind development

It is the goal of this chapter to show the technical and commercial potential of airborne wind energy, and additionally to show the current state of development. In section 2.1 the trends in wind energy technology is described followed by its market trends. In section 2.2 a brief introduction into airborne wind is given and this section describes the different concepts which are currently explored. Special attention is given to two characteristic concepts; the TU Delft pumping cycle and the Google[x] Makani Power crosswind on board power generation system. In section 2.3 the conclusions of this chapter are given.

2.1 Trends in wind energy

Two types of trends in wind energy can be distinguished; technology and market trends. The most relevant technology trends, which are relevant for airborne wind energy are given, and subsequently the current market trends and future prospects.

2.1.1 Technology trend

In order to decrease the cost of electricity production from wind energy systems, wind turbines have dramatically increased in size; both the hub height and the rotor size. Between 1980 and 1990 the average rotor diameter and hub height were respectively about 17m and 30m. These turbines had an average nameplate capacity equal to 75kW. In the five subsequent years, the average rotor size almost doubled, quadrupling the capacity. This trend continued as shown in Figure 2.1 and average rotor size and hub height of currently installed wind turbines is about 100m and 80m, with a rated power output of 2,000kW. In the next years this trend is expected to continue [19]. Increased hub heights and larger rotors allow turbines to generate more renewable electricity, in part by taking advantage of the stronger, more consistent winds that are often found at higher altitudes [20].

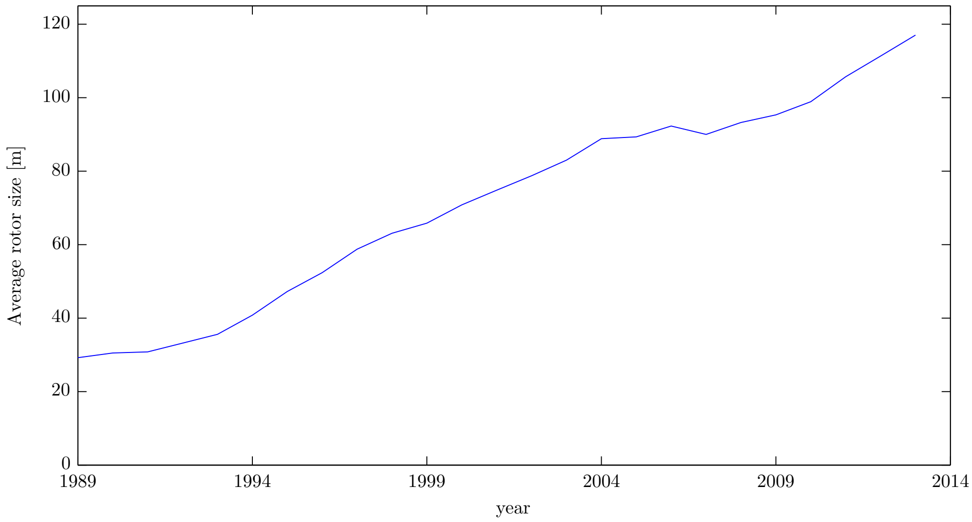


Figure 2.1: Technology trend wind turbines; average rotor size

2.1.2 Market trends

Wind energy is developing towards a competitive and reliable power technology. The improvements in technology have reduced the costs of onshore wind energy to competitive prices, and the technology has become more mature since the world's first wind farm installation in 1980 [19, 21].

The installed wind energy capacity has increased from 6.1GW in 1996 to 318.1GW in 2014. Currently wind energy generates about 2.5% of global electricity. In the last five years, from 2008-2013, the installed capacity has increased with 163%. This growth trend is expected to continue, however to a less degree. In the next five years, the total forecasted growth in installed capacity is 87% [22]. In these years, the upcoming economies in Asia and Latin America, are expected to growth faster than Europe and North America as shown in Figure 2.2. The European share of installed capacity has declined in the last 5 years from 55% to 38% and is expected to decline further towards 32% in the next five years.

The global offshore installed capacity is about 5.5GW, which is about 1.7% of the global installed capacity of wind energy installed. The offshore industry is highly concentrated in Europe (90% share), and also China (9% share) and Japan (1% share) got some offshore installed capacity. Although the small market share of offshore wind, the European Union has recognized the potential and the expected installed capacity is expected to increase with 500% in 2018 with respect to 2013.

To summarize the market trends related to wind energy; the onshore and offshore wind energy is expected to continue to grow, for at least, the next 5 years.

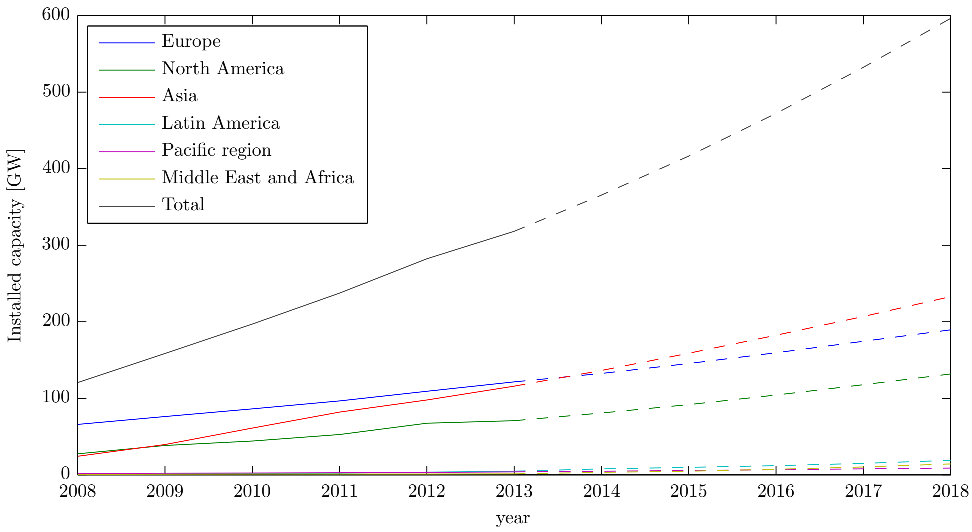


Figure 2.2: Installed capacity of the last 5 year the prospect for the next 5 years [22]

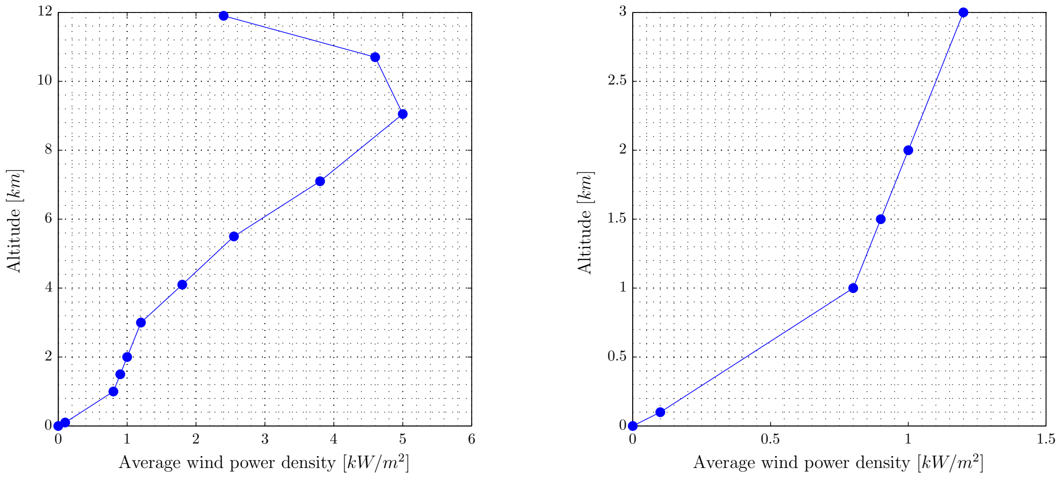
2.2 Airborne wind energy

The trend of a growing market gives trust for all wind energy generating systems, including airborne wind (AWE). Following the technology trends of increasing rotor size and hub height, airborne wind energy systems harvest winds at higher altitudes, which generally contain higher energy density winds as shown in Figures 2.3a and 2.3b [23]. These Figures show the 20 year average wind profile for De Bild, the Netherlands. This wind profile differs from location to location, but generally, wind velocity increases with altitude, up to about 9-10km.

In comparison with conventional horizontal axis wind turbines, the tower is substituted by a tether, which allows for higher altitudes compared to conventional wind turbines. Generally the wing flies crosswind and mimics the highly efficient outer part of the turbine blades, see Figure 1.1.

However the AWE concept is not new; already in 1820s, the transportation with kite systems was explored and a kite coach was developed. This is a small vehicle powered by a kite [25]. Next to land transport, kite systems were applied to transport ships overseas. In the early 1900s kite research was booming and the first man lifting kites were developed. In these decades at the dawn of air transportation technology, kites were a serious competitor for airplanes. Since powered aircraft are more versatile and independent of wind, the kite systems lost this competition and the research stagnated [8, 26].

Serious interest in airborne wind energy arose again in 1980 with the publication of Loyd's study [27], which describes the concept of kites for large scale wind energy production. A C-5A aircraft is simulated as a kite to demonstrate a theoretical



(a) Wind velocity versus altitude up to 12km

(b) Wind velocity versus altitude up to 3km

Figure 2.3: 20 year average wind velocity versus altitude, retrieved from KNMI station De Bild, the Netherlands [24]

power output of 6.7MW. Loyd's theory was further developed by several academics, and currently the principles of crosswind power generation are well understood [26, 28, 29].

2.2.1 AWE concepts

In 2000 about 3 institutions were actively involved in AWE [8]. Over the following years significant interest in AWE arose and as of 2013 about 50 institutions are actively involved in AWE. Most of the research and development activities are concentrated in Europe and Northern America as illustrated in Figure 2.4. From the 50 AWE institutions, a classification in on-board power generation and ground-based power generation is made. These concepts will be explained next.

On-board power generation

Most on-board power generating systems apply an energy generating system, which is tethered to the ground. One way to generate power is by attaching wind turbines to a crosswind flying kite to extract wind energy from the high relative air velocity. The energy is transmitted to the ground station by a high voltage power line. Google[x] Makani Power uses this concept, which is explained in more detail in section 2.2.3. Another technique that uses on-board power generation relies on lighter than air material to lift a rotor or another device to generate power in the medium to high altitude winds [30].

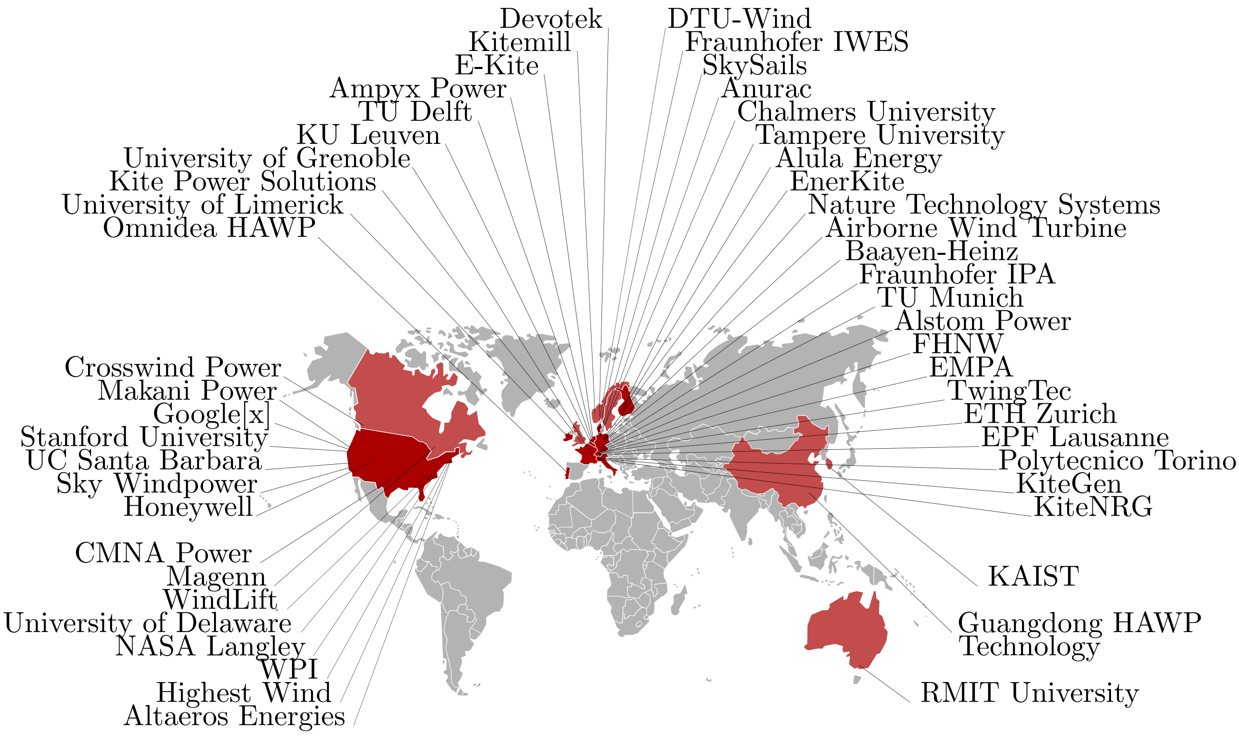


Figure 2.4: Airborne wind energy institutions worldwide [8]

Ground-based power generation

Most ground-based power generation systems are based on a cross-wind flying kite that creates tether tension to unroll the tether from a drum to drive the generator at the ground. For continuous operation a so-called '*pumping cycle*' is used. In the reel-out phase the kite is flying at its optimum lift and drag coefficient to create maximum tether force. This high tether force drives the drum and creates a significant amount of power. In the reel-in phase the kite is de-powered to create a low tether force. Therefore, the motor reels in using a fraction of the energy that was extracted in the reel-out phase. A battery network is used to buffer the energy over the cycles.

Ground-based power generation concepts have been devised with rigid or flexible wings, such as the TU Delft concept explained in section 2.2.2. Many flexible kite systems exist. However, few rigid wing ground-based power generation concepts are currently in development [8]. AmpyxPower, a TU Delft spin-off company, is probably in the furthest state of development. AmpyxPower deploys a 5.5m span prototype plane which complies all air safety requirements as set by the civil airworthiness requirements. However, at the moment there is no publicly available commercialization plan.The working principle of AmpyxPower is similar to the TU Delft pumping cycle power system, which is explained next.

2.2.2 TU Delft pumping cycle power system

The TU Delft laddermill concept with rigid wings is first described in 1999 [31]. In a subsequent paper, this concept is explored for kites and Ockels states: *'A laddermill is a self-supporting system that consists of an endless cable connected to a series of high-lifting wings or kites moving up in a linear fashion, combined with a series of low-lifting wings or kites going down. The cable drives an energy generator placed on the ground.' [32]* The concept is elaborated further and it is proposed, on the basis of theoretical analysis, that a single standalone laddermill could generate 50MW [24]. This would be equal to 10 currently available large offshore wind turbines with 120m rotor diameter. This potential in energy production leads to the installation of the kite lab at the faculty aerospace engineering and the set-up of a dedicated research group for kite power. In 2012, the team consists of 20-25 staff members and students.

However, the laddermill concept relies on many kites and faces many technical challenges. Hence, research is currently focused on single kite systems to establish a body of knowledge about controlled and reliable operation of kites for energy generation. Since January 2010, TU Delft AWE uses a 25m^2, 20kW tech-demonstrator, which is fully instrumented and with cameras mounted at several positions. This kite is used for experimental purposes and validating theoretical results with measurement data. In June 2010, the automatic generation of the power generating kite was demonstrated over extended periods of time [33].

2.2.3 Makani Power airborne wind turbine

Google[x] Makani Power is a leading company in the airborne wind energy field and these systems could become the first to become commercially available. This section describes a brief history of the company followed by an introduction into the working principle and development plan.

Company history

Makani Power was founded in 2006 by Saul Griffith, Corwin Harham and Don Montague. The first 6 years of development were supported by Google and the U.S. Department of Energy. From 2006 to 2009 the concept of a soft textile kite powering a generator on the ground was used. In 2009 a revolutionary change of concept took place. Makani recognized that research into flexible kites was highly unexplored, whereas for rigid wings the aerodynamic and other physical phenomena are better developed. Therefore Makani switched from a soft kite to a rigid wing with on-board power generation. In 2010 the first wing with on-board power generation was built in combination with autonomous control. In 2011 Makani designed a new airframe, which was the first wing to launch and land from a perch. In 2012 a full autonomous flight was performed including launching and landing. The kite took off from a perch, hovered while the tether reeled out, transitioned to a crosswind flight mode, an finally transitioned back to a hovering flight mode and landed. In 2013 Google[x] acquired Makani Power [34].

Working principle and development plan

The working principle of Makani's current airborne wind turbine is similar to the TU Delft AWE concept in that both systems harvest high energy dense winds from high altitudes with the absence of a tower. However, the TU Delft pumping cycle system, is based on ground-based power generation and a flexible kite, whereas the Makani principle is based on on-board power generation and a rigid wing. Makani's current AWT prototype consists of a tethered wing outfitted with wind turbines as shown in Figure 2.5.

Figure 2.5: Makani AWT [35]

The traction force at the tether is not used to generate power, but allows fast crosswind flight. Energy is extracted from the wind using small on-board turbines driving high-speed, direct drive generators. The electricity is transmitted to the ground via a conducting tether, where it is fed into the grid [36].

The on-board avionics computer guides the wing along a circular path. Due to its speed, the tip of conventional wind turbine blades is the most effective part. The Makani wing mimics the path and speed of these blade tips, capturing all of the benefits using only a fraction of the materials. At scale, the entire span of the Makani wing operates at the speed of the aerodynamically effective tip of the wind turbine [37, 38].

Next to the generation of wind energy the on-board turbines at the blade serve a second purpose in the launch stage. They act as propellers to launch the AWT using energy from the grid. When reaching the target altitude, the wing is operated crosswind in a circular pattern. The turbines now act as a wind turbine and energy is created by driving a generator. To land the system, the wing is transitioned into hover mode, by using the turbines as propellers, and slowly descended to the perch [37, 38].

Currently, Makani has developed a prototype with 30kW rated power. Makani aims to scale this system to a 600kW system within the next year. This carbon fibre M600 will operate at altitudes between 140-310m and has a wing span of about 28m [38]. This 600kW system will be the first to become commercially available of the Makani series.

2.3 Conclusion

Airborne wind energy systems follow the technology trends of increasing wind turbine size in order to access the stronger and more consistent winds. These systems are able to reach higher altitudes by substituting the tower with a tether. The market for wind energy has been growing and will continue to grow for the next years. Airborne wind turbines have great potential to capture part of this market share in the (near) future, because these systems have the potential to generate electricity at lower costs. In the last decade, interest in airborne wind has increase and various concepts are currently explored. Soon the first commercial products will become available.

Chapter 3

Theory and methodology

In the previous chapter is was shown that airborne wind energy has a great technical and commercial potential. It is the goal of this chapter to establish a methodological framework, and to understand its underlying theory, needed to determine the nations with the greatest potential. This nation selection problem can be seen as a decision making problem and hence in section 3.1 the decision making theory is introduced. In section 3.2, the most relevant methodologies applied in renewable energy problems are described. These are the social cost benefit analysis, Delphi techniques, the SWOT analysis, multi criteria decision making, and the conjunctive screening method. At the end of this section the methodologies are linked to the decision making theory and a deliberate choice for a combination of the conjunctive screening method and the multi criteria decision method is made. In section 3.3, the most relevant multi criteria decision making methodologies are outlined and an informed choice is made for a specific multi criteria decision making method. Finally in section 3.4 the conclusions of this chapter are given.

3.1 Decision making theory

The problem of this study - selecting the most appropriate nations for the deployment of airborne wind energy systems - can be formulated as a problem for decision makers like airborne wind turbine manufacturers or wind farm developers; which nations are my targets market? But also also for energy policy makers; can airborne wind become a proper part of the national electricity mix? Therefore this problem can be seen as a decision making problem. The nation selection problem is characterized by a finite set of alternatives, the 193 UN member states, and many different factors influencing the opportunities for airborne wind energy. In the next sections, the decision making theories and accompanying models are explored with the goal to select the most suitable methodology for this problem, and to understand the underlying theory.

The way humans make decisions is widely studied by psychologist, philosophers and economics, and different decisions can be understood with a different theory. The intuitive decision theory and rational decision theory are the most contrary views. The intuitive-decision states that decisions are generally made intuitively, and also the best decisions are, at least partly, made by intuition[39, 40]. On the other hand, the rational decision theory states that decisions are made completely rational [41, 42].

The intuitive decision theory states that decision making is mostly an intuitive process and when faced with a difficult problem intuition usually plays a major role in the decision making process [40, 43]. The human brain is incapable of the deliberate, quantitative trading off of risks and benefits and therefore humans rely on the their intuition in decision making. In these situations an individual makes decisions based on intrinsic and unconscious knowing without deduction or reasoning [39, 44]. This theory finds most application in decisions at which subjective judgements are involved, such as selecting your life partner.

Rational choice theory has found a wide application in the economic and social science [45]. In this theory it is assumed that individuals make perfectly rational decisions, because they have perfect information and the cognitive ability and time to evaluate all the options. Also the preferences for individuals are completely in accordance with the principles of logic or reason [45]. For example in economics: this theory states that individuals make decisions by calculating the expected return of an investment. Assume an investor has two options with a $10,000.- investment: option 1; $10,000 profit with a 10% likelihood of success, and option 2; $750.- profit with a 100% likelihood of success. According to the rational choice theory the investor would always choose option 1, because of the higher expected return ($1,000 vs $750.-) [46].

The bounded rationality theory builds on the rational choice theory, but states that the rationality of individuals is limited by the availability of the information, the cognitive limitations and a time constraint [47].

Each decision is best understood with a specific decision making theory. In example, in describing the human behavior of every day decisions, the intuitive decision theory could be best applicable, whereas the rationality has found a wide application in economics [41]. It can be argued that in most cases, decisions are neither completely rational nor completely intuitive, but rather a combination of the two [39], and therefore theories have been developed, which describe decision making as a combination of intuition and rationality.

3.2 Methodologies

Each theory, or set of theories, describes a specific decision making problem best. To apply the theories in practice, many tools and methodologies have been developed. Each typical set of tools, with their specific characteristics, is applicable to typical problems. Therefore the review of methodologies is limited to methods applied to similar problem.

3.2.1 Analysis phase I

In this fist phase, the nations which do not meet the basic conditions for wind energy are eliminated from further research. The remaining nations are subject to the more comprehensive analysis phase II.

The conjunctive screening method applies a set of conjunctive screening rules to determine if a certain alternative meets the minimum of the set of requirements. This is a completely non-compensatory methodology; for each factor influencing the decision making process, at least a minimum performance level is required. If this minimum cutoff value is not met, the alternative is subsequently eliminated [153].

This conjunctive screening method is applied to restrict a set of alternatives prior to using another, more complex, decision making method [151–153]. This methodology is frequently applied in the marketing costumer choice models, but has also found other applications, such as the supplier selection in the airline retail industry [151].

The conjunctive screening method is especially designed for screening if the minimum requirements are met and has found applications in studies at which the set of alternatives are limited with the conjunctive screening method and subsequently a more comprehensive analysis was performed. Therefore this method will be applied in the first stage at which nations are eliminated in case the basis conditions for wind energy are not present.

The conductive screening method finds most support from the rational decision making theory. The decision maker's preferences clear and set by the conjunctive screening rules. All necessary data is available in order to make a well informed decision based on these screening rules.

3.2.2 Analysis phase II

For the second analysis phase, a more comprehensive analysis will determine the nations with the highest opportunity for airborne wind, a type of renewable energy. Therefore in this section, the typical tools applied in renewable energy location planning are analyzed. These are, the (social) cost-benefit analysis (CBA), Delphi techniques, SWOT (strengths, weaknesses, opportunities and treats), and multi-criteria decision making (MCDM).

The main functionalities of each methodology is explained together with its main advantages and drawbacks. Also its origin is described to gain an understanding of the original intentions of the methodology developer, and the type of questions this models are originally designed to answer. Next the current applications of these models in renewable energy problems is described and the methodology is linked to the nation selection problem.

Social cost-benefit analysis

Cost-Benefit Analysis (CBA) estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile.

The social cost benefit analysis has been derived from the traditional cost-benefit analysis, at which the project market costs and market benefits over the entire lifetime are determined to calculate the net present value (NPV) of the project. The NPV calculates all future incoming and outgoing cash flows in terms of current monetary terms. A project characterized by a NPV > 0 is profitable and may be accepted. The higher the NPV, the higher profit in absolute terms. However this NPV lacks information about the relative profitability with respect to the initial investment. The profitability index aims to resolve this problem by dividing NPV with the initial investment. This profitability index can be used to rank projects [48]. This traditional cost-benefit analysis lacks information about externalities; benefits and costs not directly incurred by the decision making party [49]. In example, the damage on public health due to air pollution of fossil fuel energy generation. In the social CBA , the benefits and costs of these externalities are quantified and monetized.

Social CBA offers a consistent analytical framework for decision-making and is typically designed to help decision-makers allocate scarce resources by determining which option among a competing set should be selected in order to maximize social welfare. This welfare objective encompasses measurable monetary benefits as well as more intangible non-market benefits or public good externalities [50].

The main assumption of social CBA is that all attributes relevant to a problem can be quantified and monetized. Therefore, the social CBA is more generally best applicable to projects with relative low uncertainty and with the availability of quantitative data. The main criticism towards social CBA is targeting that some aspects are possibly hard to monetize. In example, 'safety' is an often applied criterion in renewable energy planning, which implies that the human life should be monetized. This involves ethical and moral principles if human life can be given a monetary value [51–54].

The origin of the cost benefit analysis is found by Dupuit's publication in 1844 related to the measurement of utility (measured in monetary terms) of public works; the costs of the project are split into the costs of building the bridge (costs for the owner) and the costs for bridge crossing (costs for the users). Additionally Dupuit gives the benefits in monetary terms for crossing the bridge; both for the bridge owner and the consumers. Dupuit has used this social cost benefit analysis to show that the utility produced is divided between the bridge owner and his consumers, and the distribution of utility is highly dependent on the toll rate. In this study he calculates the toll rate in case the bridge is private or public property. The project market costs and market benefits over the entire lifetime are determined to calculate the net present value of the project. In his analysis he assumes that the only aim, of the owner of a private bridge, is to maximize profits and subsequently shows that the total utility would be higher in case the bridge would be public property and therefore social ownership is a better solution. Dupuit view of maximization of overall utility is known as utilitarianism.

There are various examples of social CBA in the energy planning; in [50], social CBA is applied to analyze the economic feasibility of a Scottish wind farm project, including the positive and negative externalities. This study calculates the carbon dioxide avoided, as a result of replacing fossil fuels with wind energy and also the carbon dioxide released during manufacture, construction and deforestation. Also the visual and noise disamenity for residents and visitors are quantified in monetary terms. In [55], several future energy scenarios are analyzed ranging with the degree of penetration of renewable energy. The European Commission's external costs of energy (ExternE) methodology framework [56] is applied to determine the energy related externalities, including the carbon dioxide, sulfur dioxide and mono-nitrogen oxides emissions. In [57], the solar, wind, hydropower, nuclear and fossil fuel energy generation are evaluated based on cost-to-benefit ratios. Including all externalities, the RES were determined to be the best systems for electricity power generation.

The nations selection of airborne wind energy projects is a project at which many actors are involved; the owners of the wind farm, the manufacturers of airborne wind turbines, the households connected to the electricity grid at which the wind farm is connected to, persons living nearby the wind farm, etcetera. Therefore the total welfare calculation of the social cost benefit analysis could give an insight into the nations at which an airborne wind farm would give the highest welfare. The nation with the highest added welfare could be chosen as the nation with the highest opportunity for airborne wind.

Delphi techniques

This subjective-intuitive research technique is characterized by dealing with complex problems by structured communication among a group of experts. Generally the process consists of several anonymous survey rounds with the aim to gain consensus on a particular topic [58, 59]. In example, a two-round Delphi research study: in the first round a large group of participants is given the same questionnaire. The questionnaire results are analyzed, and in the second round, the same questionnaire is given to the same group of participants. In this second round, the participants also receive feedback about the previous questionnaire results. The respondents, which were not confident with their answers, could adjust their answers based on the overall trend of views, on the majority view. In case the second round lacks general consensus, subsequent questionnaire rounds could be added to reach consensus.

The Delphi technique assumes that communication and group judgement give most valuable results. Some critics argue that the Delphi technique has a low scientific level, because the results are based on the judgement of experts, and the possible ambiguity in the questionnaires [60–63]. However, they also admit that in the case that data availability is very limited the Delphi technique can be the best option.

This technique is first introduced in the 1950s and 1960s by the RAND Corporation to study scientific breakthroughs, population control, automation, space progress, war prevention and weapon systems. All of these topics were characterized by a high degree of uncertainty and it was the goal to gain consensus on the long term trends.

In renewable energy planning, the Delphi techniques have e.g. been applied to construct an expected scenario for the planning of a sustainable transportation system [64], and to *"gain information on general conditions concerning national* [Israel] *politics and economy, environmental protection, social aspects as well as general trends in energy sector development and issues related to energy supply and demand in the light of national energy safety in the time perspective of the next few dozen years."* [65], and as a help to redesign the regional energy system in Jaén (Spain) by expert opinions about the most appropriate RES and the amount of renewables in the region [66], and in [67], a two-round Delphi research study measured the expectations of renewable energies in Turkey.

The Delphi technique could be applied to determine the nations with the highest opportunity for airborne wind. In several questionnaire rounds, consensus could be build on the experts' views on the most suitable nations for airborne wind. To increase the objectivity, experts from various backgrounds should be involved in this process.

SWOT analysis

This method was originally developed in the 1960s and 1970s as a business management tool, and nowadays also found its application in (renewable) energy planning. The Strengths and Weaknesses are indicators for an internal situation, whereas the Opportunities and Threats are indicators of the external environment [68]. The SWOT analysis allows for continuously identifying changes by incorporating the dynamic external effects by establishing the risks and opportunities.

The SWOT analysis assumes that a certain internal environment is relatively stable, whereas the external environment is inherently dynamic. Various product are designed for several years (constant internal environment). However it is seldom that the external environment factors (e.g. competitors and political factors) are constant for several years. Hence SWOT is able to capture these dynamics. The main drawback of SWOT is that is unable to compute the impact of each individual factor [69].

The SWOT analysis was originally developed by Albert Humphrey. He was leading a research project at the Stanford University using data from many top companies. His study focussed on the identification of key areas. Originally this SWOT analysis was termed SOFT analysis defining the categories. Satisfactory, what is good in the present. Opportunity; good in the future. Fault; bad in the present.

SWOT found various applications in the renewable energy industry. In example, in [70] a SWOT analysis was a used to diagnose current problems in the regional renewable energy planning in Jaén (Spain) and to establish suitable strategies to overcome these problems. In [71], the Macedonian energy sector is analyzed and concluded that the national energy mix should change progressively towards more renewable sources. The Brazilian wind energy sector is analyzed in [72] and concluded that there is a great potential for wind energy, but the high initial costs and lack of specialized construction companies slow down the implementation.

The SWOT analysis could be applied to the nation selection problem. The strengths, weaknesses, opportunities and threats of each nation could be defined and next the nations with the greatest strengths and opportunities and lowest opportunity and threats could be selected as the nation with the highest potential for airborne wind deployment. This technique would give insight in each nations current attractiveness for the deployment of airborne wind and additionally in the future prospects.

Multi-criteria decision making

The study on multi-criteria decision making (MCDM) as applied nowadays, started in the 1960s and a tremendous amount of approaches has been explored, designed, and applied in various industries [73]. Despite the unique characteristics of each individual research framework, there exist an overarching concept that comprises the idea that a decision maker faced with a problem with at least two alternative solutions and at least two conflicting criteria, can use a MCDM framework to make a choice of alternative taking all criteria into account. These criteria can be of quantitative or qualitative nature.

Currently MCDM is characterized by two distinct classes. The class according to multi attribute utility theory (MAUT) and according to outranking methods. MAUT assumes that all qualitative and quantitative values assigned to certain criteria can be transformed and quantified to a single criterion value: utility. Ranking method ranks an alternative with respect to the other alternative, data can be qualitative and/or quantitative.

The main disadvantage of MCDM methods are its relative complexity with respect to the other models described. Various actors bring different criteria on the table and its relative importance needs to be determined.

The first formally stated form of multi-criteria decision making is found by Benjamin Franklin in 1772 [74, 75]. For complex decisions he took a paper, on one side he wrote arguments in favor of the decision, on the other side, he wrote the arguments again. Next he stroke out arguments on each side that were of relatively equal importance. When all arguments on one side were struck out, the side with the remaining arguments was supported.

Although current MCDM methodologies are more advanced, the problems they solve have the same characteristics. At least two alternative solutions (in favor or agains a certain decision) and at least two conflicting criteria (at least one argument in favor and agains the decision). Franklin's method allows to evaluate the importance of each argument by pair-wise comparison, and hence this is a first weighting method. This is a unique characteristic of MCDM, it gives insight in the level of importance

Table 3.1: Multi-criteria decision making in renewable energy planning

	Energy system selection	Country selection (European/global level)	Location selection (national level)	Site selection (local level)
Wind	[77–83] **[84–91]**		**[84, 92–96]**	[79, 97] **[98–108]**
Solar	[77–83, 109–112] **[84, 89–91]**		**[84]**	[79] **[108, 113]**
Hydro	[78, 114, 115] **[86, 89, 90]**			[116]
Biomass	[77, 80, 83, 111, 115]			
Others	[77, 78, 82, 111, 117, 118] **[84, 89, 90]**	[119–123]		[14, 124]
All	[125–139] **[94, 140–150]**			**[16]**

The bolt references are retrieved from papers published in the years 2009-2014. The others are retrieved from MCDM review studies performed in Pohekar & Ramachandran (2005) [76] and Wang et al. (2009) [11]

of the factors influencing the decision and also also the degree to which a certain decision is supported in favor or again. At the point all arguments on one side are stroke out and still a long list of arguments remain on the other side, the decision is supported in a high degree. On the other side, if only one or two argument remain on the other side, the decision is supported to only a minor degree.

Renewable energy planning problems tend to have a multi-criteria character: several actors such as the local and global governmental, environmental organizations, consumers and energy producers, bring different criteria on the table such as economic, environmental, technical and social criteria. Hence MCDM has found a wide application in the renewable energy industry. The review studies of Pohekar & Ramachandran in 2005 [76] and Wang et al. in 2009 [11] review more than hundred papers related to MCDM and renewable energy. The selection of a particular renewable energy system for a given location got most emphasis as shown in Table 3.1.

In these review studies, two studies are related to the siting of a wind energy project. The use of MCDM models for wind energy and in particular wind energy siting projects is a relatively new research field. About 75% of all scientific papers related to wind energy and MCDM are published after 2009 according to Scopus search engin [1]. As shown in Figure 3.1, the research into this field has expanded rapidly after.

The research of siting of wind turbines is even more recently developed; more than 75% of scientific papers found by Scopus were published in 2011 or later[2]. This one

[1] search terms 'wind energy' AND 'multi-criteria', 150/199 publications in 2009 or later.

[2] search terms 'wind energy' AND 'multi-criteria' AND 'siting', 20/26 publications in 2011 or later.

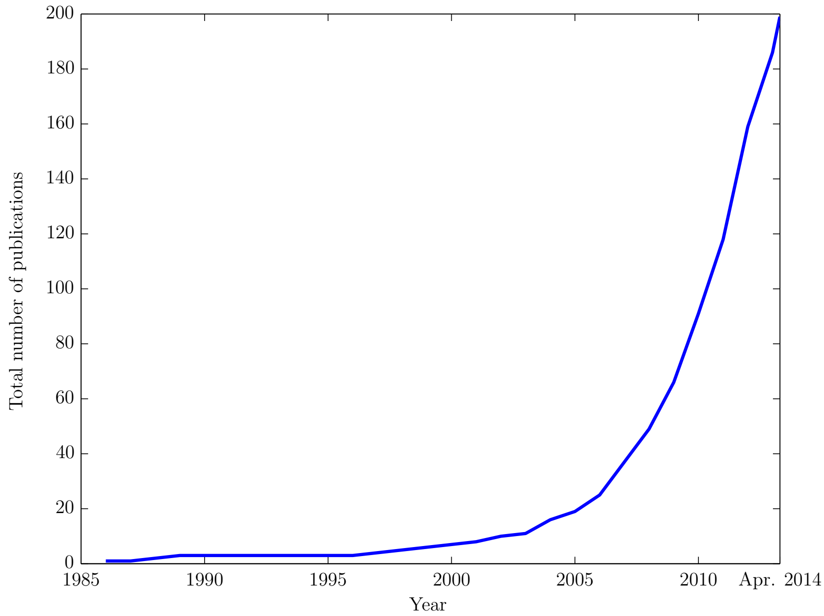


Figure 3.1: Scientific publications related to wind energy and multi-criteria decision making

shot approach is not intended to give an overview of all research performed in this field, but to show that research of MCDM and the siting of wind energy project is getting recent attention and still under development. The most relevant studies are listed in Table 3.1. Wind energy project siting on the national level is studied in [84, 92–96] and on a local level in [79, 97–108]. Some interesting and relevant examples:

In [84] the optimum RES for powering a water desalination system in Mauritania is determined. Several locations are analyzed based on energy potential, economic costs, operational and maintenance cost, environmental impact and adequacy[3]. In [92] geographic information system (GIS)[4] is linked to a MCDM model to determine the optimum wind farm site in Egypt based on the average wind speed, environmental planning, hydrology, protected an cultural heritage, elevation, bird migration, location of airports and the costs. The combination of GIS and MCDM is also applied in [99] at which the optimum wind farm site is determined for New York State based on economic, technical and ecological criteria.

It should be clear from the examples, Table 3.1 and Figure 3.1 that MCDM has a wide application in renewable energy and also in wind energy (siting) projects.

In case the MCDM methodology would be applied to the nation selection problem, the views from multiple actors would be taken into account in order to determine the influencing factors, and their relative importance. An overall index can be calculated in order to determine the preference of a specific nations with respect to another

[3]adequacy relates to the adaptation of energy sources and the desalination technology.
[4]GIS is a computer system that presents all geographical data and allows for analysis as well.

nation.

Theory related to methodologies

The (social) cost benefit method is closely related to the rational decision making theory: the necessary data is available and can be quantified, the decision makers preferences is to maximize utility and this tool will help to evaluate all options to make a rational decision.

The Delphi technique is mostly related to the intuition decision making theory; data availability is limited and consensus is build based on the experts feelings and intuition.

The SWOT analysis and the multi criteria decision making methods are mostly related to the bounded rationality theory. SWOT focusses on the four key areas, because of limited availability of information and time constraints. In MCDM it is assumed that the most important criteria influencing the decision making process can be set by the decision maker and the data is available in quantitative of qualitative form.

Discussion of models

The subjective-intuitive Delphi techniques are especially designed to gain consensus on the long term trends in case data is limited. Due to the low scientific level, it is argued that this methodology is only the best option in case data is unavailable. It was found in this study that data was generally available for many factors influencing the deployment opportunities of airborne wind (see section 4.2.3). Therefore a methodology with a higher scientific level is preferred.

The SWOT analysis is intended to evaluate the current and future strengths and weaknesses of a specific company. When applied to the nation selection problem, it will give an insight in these key areas of each nation. However this methodology is not developed to compare different options, whereas this is the main goal of this study. Therefore SWOT is not used this analysis.

The social cost benefit analysis and the multi criteria decision making method are both designed to evaluate many alternative options. Also, these methods are designed to take the views from multiple actors into account. Both methods give insight in the overall opportunity for airborne wind of a nation with respect to the other nations. The cost benefit analysis, however, assumes that all attributes relevant to a problem can be quantified and monetized. The airborne wind energy is a highly innovate technology and hence it is likely that a some data is uncertain or unavailable. The MCDM methodologies are especially designed to deal with these data uncertainties. Additionally MCDM has found a wide application in renewable energy problems, indicating that these problems are solved particularly well with these methods. Therefore MCDM is chosen for analysis phase II.

To conclude, a combination of conjunctive screening method with multi criteria decision making will be applied in this study to first eliminate the nation if the basic conditions for wind energy are not met and subsequently the remaining nations will be subject to a more comprehensive analysis.

3.3 Multi-criteria decision making methods

In this section the available MCDM methods are outlined first after a choice is made for a specific model.

3.3.1 Available methods

Many types of MCDM methodologies can be found in various literature fields. However the MCDM methodologies applied in renewable energy is mainly limited to two distinct classes. The multiple attribute utility theory and (out)ranking methods [11, 76]. In the remainder of this section the specifications of the mostly applied methods within these classes are explained.

Multiple attribute utility theory

MAUT assumes that all qualitative and quantitative values assigned to certain criteria can be transformed and quantified to a single criterion value: utility. In this section the two most widely applied MAUT methods in (renewable) energy planning are introduced: the weighted sum method and the analytical hierarchy process (AHP).

Weighted sum method
The weighted sum method can be argued to be most simplistic MAUT method. The total utility of an alternative is simply the sum of the weighted utility per attribute. The weights are a measure of importance. In an equation:

$$u_i = \sum a_{i,j} w_j \tag{3.1}$$

In this equation, u_i is the total utility of alternative i, $a_{i,j}$ is the utility score for alternative i at criterion j, and w_j is the weight associated with criterion j.

The 'best' alternative according to the weighted sum method is the alternative with the highest total utility. This simple method assumes that the scores of all attributes can be transferred to a single criteria: utility. However, the methodology of assigning utility values to, i.e. qualitative data is lacking. A more sophisticated approach, the analytical hierarchy process (AHP), attempts to overcome this drawback.

Analytical hierarchy process
AHP is developed in the 1970s by Saaty [157–159] and is able to deal with verbal,

Table 3.2: AHP scaling system

$a_{i,j}$ value	Interpretation weight scaling	Interpretation activity comparison
1	objectives i and j are of equal importance	activity i and j contribute equally to the objective
3	objective i is weakly more important than objective j	experience and judgement slightly favors activity i over j
5	objective i is strongly more important than objective j	experience and judgement strongly favor activity i over j
7	objective i is very strongly or demonstrably more important than objective j	an activity is favored very strongly over another; its dominance is demonstrated in practice
9	objective i is absolutely more important than objective j	the evidence favoring i over j is of the highest possible order of affirmation

qualitative and quantitative data by introducing the pair-wise comparison according to Table 3.2.

AHP's scaling system, Table 3.2, is applied to determine the weights of each criteria. Next each alternative's criteria is pairwise compared to the other alternatives, which creates a pairwise comparison matrix. The summation of the weights with the pairwise comparison matrix results in an overall score of each alternative.

Outranking methods

The first publication about outranking methods belongs to Roy in 1968 [160]. His ELECTRE (elimination et choix traduisant la realité) method ranks an alternative with respect to the other alternative. Another widely applied ranking method is PROMETHEE (preference ranking organization method of enrichment), which is developed by Brans et al. [161]. These two methods account for almost all outranking methods applied to renewable energy MCDM problems evaluated by the review studies of [11] and [76].

ELECTRE
This outranking method is developed by Roy and characterized by the pair-wise comparison of actions. The preference for an action a with respect to action b is labeled 'strong' in case the criteria scores for action a are higher than the criteria scores for action b plus a certain preference threshold. The label 'weak preference' is applied in case the criteria score for action a are smaller than the criteria scores for action b plus the preference threshold, but higher than the criteria score for action b plus the indifference threshold. The label 'indifference' is applied in case the difference in criteria scores for action a and $b$are smaller than the indifference threshold.

$$g(a) > g(b) + p(g(b)) \Leftrightarrow aPb \tag{3.2}$$
$$g(b) + q(g(b)) < g(a) \leq g(b) + p(g(b)) \Leftrightarrow aQb \tag{3.3}$$
$$g(b) \leq g(a) \leq g(b) + q(g(b)) \Leftrightarrow aIb \tag{3.4}$$

In these equations $g(a)$ and $g(b)$ are the criteria values for alternative a and b, p and q are the preference and indifference thresholds, P represents a strong preference, Q are weak preference and I indifference.

ELECTRE III is especially developed to deal with uncertainties in data and to rank all alternatives from best to worst. First an accordance and discordance index is calculated and finally the credibility index, which is a measure of strength that alternative a is at least as good as alternative b. First determine the outranking degrees alternative a and b for criterion j:

$$c_j(a,b) = \begin{cases} 1 & \text{if } g_j(a) + q_j \geq g_j(b) \\ 0 & \text{if } g_j(a) + p_j \leq g_j(b) \\ \frac{p_j + g_j(a) - g_j(b)}{p_j - q_j} & \text{otherwise} \end{cases} \tag{3.5}$$

The concordance index is then calculated by summing the outranking degrees with the criteria weights:

$$C(a,b) = \frac{1}{k} \sum k_j c_j(a,b) \tag{3.6}$$

Next the discordance index is calculated by introducing the veto threshold. The veto threshold with regard to a certain criterion is the maximum difference between the score of b and a on this criteria over which it is reasonable to reject the hypothesis of outranking a over b. Hence one single criterion can reject the hypothesis. The discordance matrix for each criterion is defined as:

$$d_j(a,b) = \begin{cases} 0 & \text{if } g_j(a) + p_j \geq g_j(b) \\ 1 & \text{if } g_j(a) + v_j \leq g_j(b) \\ \frac{g_j(b) - g_j(a) - p_j}{v_j - p_j} & \text{otherwise} \end{cases} \tag{3.7}$$

The combination of the concordance and the discordance index is applied to determine the credibility degree:

$$\rho(a,b) = \begin{cases} C(a,b) & \text{if } d_j(a,b) \leq C(a,b) \forall j \\ C(a,b) \prod\limits_{j \in J(a,b)} \frac{1 - d_j(a,b)}{1 - c_j(a,b)} & \text{otherwise} \end{cases} \tag{3.8}$$

In this equation $J(a,b)$ is the set of criteria for which $d_j(a,b) > C(a,b)$.. This credibility degree is a measure of strength of outranking, the measure that alternative a is as least as good as alternative b.

PROMETHEE
PROMETHEE is an outranking method based on pair-wise comparison similar to ELECTRE and AHP. Its distinctive character is found by its use of various preference functions. The preference criterion with linear preference and indifference area, as shown in Figure 3.2, is similar to ELECTRE's outranking degrees.

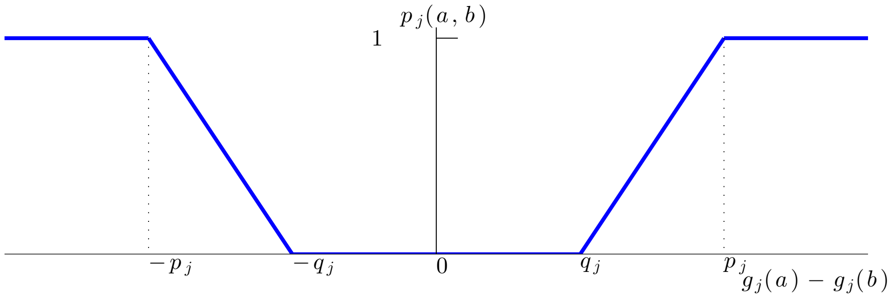


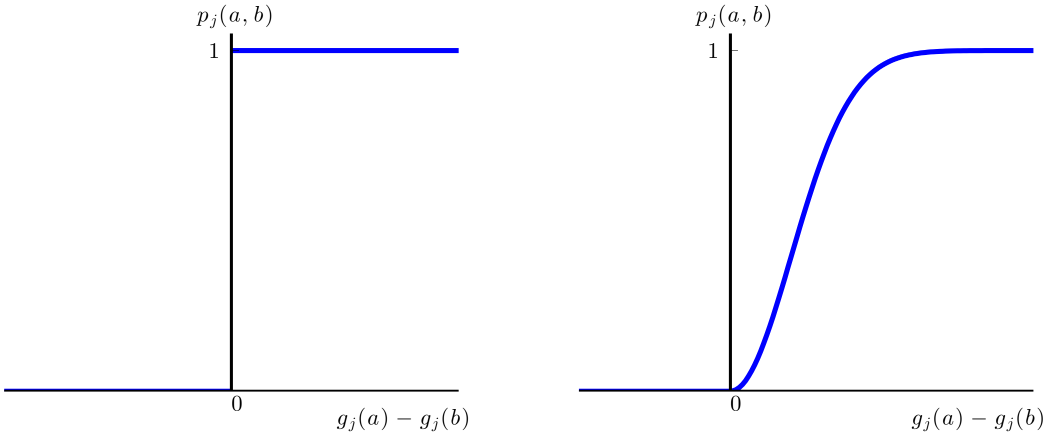
Figure 3.2: PROMETHEE preference criterion with linear preference and indifference area

The preference for an alternative a with respect to alternative b is equal to 1 in case difference in criteria scores is larger than a certain preference threshold, p_j. In case the difference in scores is smaller than the indifference threshold, q_j, there is zero preference for alternative a with respect to alternative b. In case the difference in criteria scores is in between the indifference and the preference threshold, the preference for alternative a with respect to alternative b is following a linear regression. In an equation:

$$p_j(a,b) = \begin{cases} 1 & \text{for } g_j(a) - g_j(b) \geq p_j \\ 0 & \text{for } g_j(a) - g_j(b) \leq q_j \\ \frac{g_j(a)-g_j(b)-q_j}{p_j-q_j} & \text{otherwise} \end{cases} \tag{3.9}$$

However, for a decision maker not all preferences follow the function of the preference criterion with linear preference and indifference area. Therefor several other preference functions are defined in the PROMETHEE outranking methods. Two other preference function are treated next, for a complete overview of PROMETHEE preference functions, see [13, 161]. In case there is a strict preference for an action a with respect to an action b in case the action a outperforms action b (even with the smallest amount), the preference criterion is termed the usual criterion. A preference function according to the usual criterion is shown in Figure 5.9a. In that case:

$$p_j(a,b) = \begin{cases} 1 & \text{for } \forall (g_j(a) - g_j(b)) > 0 \\ 0 & \text{for } \forall (g_j(a) - g_j(b)) \leq 0 \end{cases} \tag{3.10}$$



(a) Usual criterion (b) Gausian criterion

Figure 3.3: PROMETHEE preference criteria

Alternatively the preference of a decision maker can follow an 'S' curve, defined by the Gaussian criterion, which is shown in Figure 3.3b and is given in an equation as:

$$p_j(a,b) = \begin{cases} 1 - e^{-\frac{[g_j(a)-g_j(b)]^2}{2\sigma^2}} & \text{for } g_j(a) - g_j(b) \leq 0 \\ 0 & \text{for } g_j(a) - g_j(b) > 0 \end{cases} \tag{3.11}$$

When the preference function for each criteria is defined, the preference index is calculated as:

$$\pi(a,b) = \frac{1}{k} \sum k_j p_j(a,b) \tag{3.12}$$

Next the valued outranking graph is constructed from the outgoing and the incoming flow. The out coming flow is defined as the dominance of an action a with respect to its alternative, the incoming flow is the degree to which a is dominated by its alternatives.

$$\phi^+(a) = \sum \pi(a,b) \tag{3.13}$$

$$\phi^-(a) = \sum \pi(b,a) \tag{3.14}$$

In these equation, $\phi^+(a)$ is the outgoing flow of a and $\phi^-(a)$ the incoming flow. With these parameters the out raking of alternatives is equal to:

$$\begin{cases} a \text{ outranks } b & aPb \quad \text{if} \begin{cases} aP^+b \ \& \ aP^-b \\ aP^+b \ \& \ aI^-b \\ aI^+b \ \& \ aP^-b \end{cases} \\ a \text{ is indifferent to } b & aIb \quad \text{if } aI^+b \ \& \ aI^-b \\ a \text{ and } b \text{ are incomparable} & aRb \quad \text{otherwise} \end{cases} \tag{3.15}$$

In these equations P^+, P^- I^+ and I^- are defined as:

$$\begin{array}{llll} aP^+b & \text{if } \phi^+(a) > \phi^+(b) & aI^+b & \text{if } \phi^+(a) = \phi^+(b) \\ aP^-b & \text{if } \phi^-(a) < \phi^-(b) & aI^-b & \text{if } \phi^-(a) = \phi^-(b) \end{array} \tag{3.16}$$

3.3.2 Discussion of models

Four different MCDM methods were discussed in the previous sections. The weighted sum method and the AHP belonging to the multiple attribute utility theory, and the ELECTRE and PROMETHEE outranking methods. Each of the methods is characterized with advantages and disadvantages, and the selection of the most suitable MCDM method is in itself a multi criteria problem.

In this multi criteria analysis phase of this study, it is the goal to determine the top nations based on multiple, possibly conflicting, criteria, which influence the decision making process. The nation selection of airborne wind systems is an unexplored research field and hence the relative importance of these criteria is currently unknown. Also for this technology, which is in its infancy, a significant amount of data is uncertain or unavailable. This data can be quantitative or qualitative. In the MCDM the relative preference for an alternative with respect to the others should be determined.

Already in section 3.2.2, four criteria were determined to analyze a model's appropriateness for this study. Each of the analyzed multi criteria decision making models are able to deal with large datasets and have to ability to calculate a final score. However, they differ greatly of some some other aspects relevant for this study.

- *Cope with input data uncertainty*, some of the data can be uncertain or unreliable and hence the model should be able to deal with this uncertainty in data.
- *Cope with different types of input data*, the model should be able to deal with qualitative and quantitative data.
- *Judgement scale*, the scores on each criteria should be judged according to the decision makers' opinion.
- *Weight factor calculation*, the model should be able to determine the relative importance of each criteria.

- *Model complexity*, the underlying theory of the model should be relatively easy to understand and apply in order to be able to understand the ranking.

The scores of each evaluated MCMD method on these criteria are given in Table 3.3.

Table 3.3: Pros and cons of MCDM models applied in the renewable energy industry. WS is weighted sum, AHP is analytical hierarchy process, ELEC. is ELECTRE, and PROM. is PROMETHEE

	WS	**AHP**	**ELEC.**	**PROM.**
Data uncertainty	-	-	+	+
Different data types	-	+	+	+
Judgement scale	-	+/-	+/-	+
Weight factor calculation	-	+	-	-
Model complexity	+	-	+/-	+/-

The weighted sum method is easy to use and is able to cardinally rank the alternatives. However this model is unable to cope with data uncertainty or different data types. Also this methods lacks the underlying theory for the weight factor calculation. The model assumes that all criteria can be judged according to their utility, and hence all data should be transferred to one single criterion, e.g. utility, which is not always possible.

The AHP method is relatively hard to understand because of its use of Eigenvalues and Eigenvectors, and the method lacks the ability to cope with uncertainty in data. However, quantitative and qualitative data can be used, the method is able to rank all criteria cardinally and it is the only method equipped with a method for weight factor calculation to determine the relative importance of each weight. The artificial 1-9 judgement scale has been criticized because it inherently can cause inconsistencies [162–164]. In example:

> *Assume three different alternatives (A, B and C) are judged according to a specific criteria. Assume alternative B is very strongly favored over A, and therefore, according to the AHP score table (Table 3.2), the preference for B with respect to A is equal to 7 ($P(B, A) = 7$). Next assume that alternative C is strongly favored over B, and hence the preference for C over B scores a 5 ($P(C, B) = 5$). For a consistent set of pair-wise comparisons, the preference for C with respect to A should be equal to 35, $P(C, A) = 35$. However this is impossible with the AHP 9 point scale.*

According to AHP developer Saaty, *"the human brain is unable to deal with stimuli which differ too much in size. In such cases hierarchically arranged clusters should be created with elements that are comparable when using the 9 point scale"* [165].

The PROMETHEE and the ELECTRE method lack an integrated methodology to determine the importance of each criteria. However, these methods are moderately easy to understand and apply, are designed to deal with different data types with high uncertainty, and are able to cardinally rank the alternatives. The difference between both models can be found in the judgement scales. ELECTRE is characterized by one specific judgement scale for all criteria, whereas PROMETHEE is equipped with a set of 6 preference function. These preference functions are relatively easy to understand and add flexibility to the model.

To conclude, PROMETHEE is the preferred MCDM method. However this method lacks the ability calculate weight factors, and therefore a combination of PROMETHEE and AHP could be applied to synergize the strengths of both models. Next the theory related to weight factor calculation is explored to determine the most appropriate method for this study.

Weight factors

In Wang et al.'s review study [11], it was found that equal weights are most often applied in renewable energy decision making processes. Most likely, because of its ease of use (no additional information is required about the decision makers' preferences), and it can be argued that this simple method produces results which are nearly as good as the more complex and time consuming rank-order weighting methods [166].

The rank-order weighting method are classified into the subjective weighting method, the objective weighting method and combination weighting methods. In the subjective weighting method the weights are determined with methods based on the subjective judgement of decision makers, whereas the objective weighting is based on the quantitative measured data [11]. In Wang et al.'s evaluated literature, the objective weighting methods found applications in the sustainable energy decision making only *seldomly*. The subjective weighting measure found a wide application. The most popular methods are, ranked on complexity from low to high: (1) priority given to one indicator with others being the same, (2) pair-wise comparison, and (3) analytical hierarchy process (AHP). In the pair-wise comparison method each criterion is compared to the other criteria to determine its relative importance with respect to the others. AHP builds on this model, and additionally introduces a matrix for pair-wise comparison (equation 3.17) and a scale for pair-wise comparison, Table 3.4.

$$D = \begin{bmatrix} C_1/C_1 & C_1/C_2 & \cdots & C_1/C_3 \\ C_2/C_1 & C_2/C_2 & \cdots & C_2/C_3 \\ \vdots & \vdots & \ddots & \vdots \\ C_n/C_1 & C_n/C_2 & \cdots & C_n/C_n \end{bmatrix} \tag{3.17}$$

From the above mentioned weighting methods, AHP is capable of giving the most accurate results, but it is also the most complex weighting methods. However, literature reports that this method is experienced as relatively simple and easy to use [94, 97, 98, 107, 111, 145, 165, 167, 168]. Therefore AHP is chosen as the optimum weighting method for this study.

Table 3.4: AHP scaling system

$a_{i,j}$ value	Interpretation weight scaling	Interpretation activity comparison
1	objectives i and j are of equal importance	activity i and j contribute equally to the objective
3	objective i is weakly more important than objective j	experience and judgement slightly favors activity i over j
5	objective i is strongly more important than objective j	experience and judgement strongly favor activity i over j
7	objective i is very strongly or demonstrably more important than objective j	an activity is favored very strongly over another; its dominance is demonstrated in practice
9	objective i is absolutely more important than objective j	the evidence favoring i over j is of the highest possible order of affirmation

A combination of PROMETHEE and AHP has been successfully applied in several studies. For example in an information system outsourcing decision [169]. The AHP is applied to determine the importance of the criteria and PROMETHEE for the ranking of the alternatives and a sensitivity analysis. In [170], this combination is used for selecting the best equipment among many alternatives. Again, the AHP calculates the relative weights of each criteria and PROMETHEE ranks the alternatives. Scopus does not find any combination of AHP and PROMETHEE methods applied in the wind energy industry[5]. These examples show that the combination of PROMETHEE-AHP has been successfully applied in different research fields and hence gives trust that it can successfully be applied in this study as well.

3.4 Conclusion

A combination of the conjunctive screening method with the PROMETHEE-AHP multi criteria decision making method will be applied to determine the most appropriate nations for airborne wind. The conjunctive screening method will eliminate the nations which lack the basic conditions for wind energy, and subsequently the PROMETHEE-AHP methodology calculates the overall nation scores for the opportunity for airborne wind. These multi criteria models give insight in the factors which influence the nation selection problem, can handle large datasets with significant uncertainty and additionally can rank nations based on a final pair-wise comparison score. AHP will determine the weight factors and PROMETHEE's ranking functionalities will be applied. Both methodologies are based on the pair-wise comparison of actions, and PROMETHEE's methodology includes six preferen

These methods find their base in respectively the rational and bounded rationality decision making theory. Hence the decisions from this model are made rationally, but is is recognized that this rationality is limited by the availability of the information

[5]Scopus search for "AHP" AND "PROMETHEE" AND "wind"

and time constraints. It is the aim of the model to account for the limited cognitive functionalities of the human brain.

Chapter 4

Applied methodology

In the previous chapter the methodology and its underlying theory were determined. It is the goal of this chapter to apply this methodology - the conjunctive screening method in combination with the PROMETHEE-AHP - to the nation selection of airborne wind energy. Section 4.1 describes funnel approach with two distinct analysis phases. In section 4.2 the factors which influence the decision making process are determined from the international business and renewable energy planning literature in combination with an expert's view. In section 4.3 the weight factor methodology is described. A novel adjustment to the classical AHP weight factor calculation methodology is proposed to overcome the classical AHP drawbacks and expert survey is proposed for data collection. In section 4.4 this chapter's conclusions are given.

4.1 Research approach

In the introduction the approach was already briefly introduced. This section will elaborate on this approach with the goal to set-up a research framework for the remaining of this study. This framework consists of two distinct analysis phases:

Phase I conjunctive screening method: select nations at which the basic conditions for wind energy are present,

Phase II PROMETHEE-AHP: analyze these nations on a national level, rank these nations based on their opportunities for airborne wind energy deployment, and subsequently select the nations with the highest potential for airborne wind energy,

A graphical representation of these analysis phases is given in Figure 4.1.

From Figure 4.1 follows that, in the first phase, nations are withdrawn from further analysis in case the basic conditions for wind energy are not present in this nation.

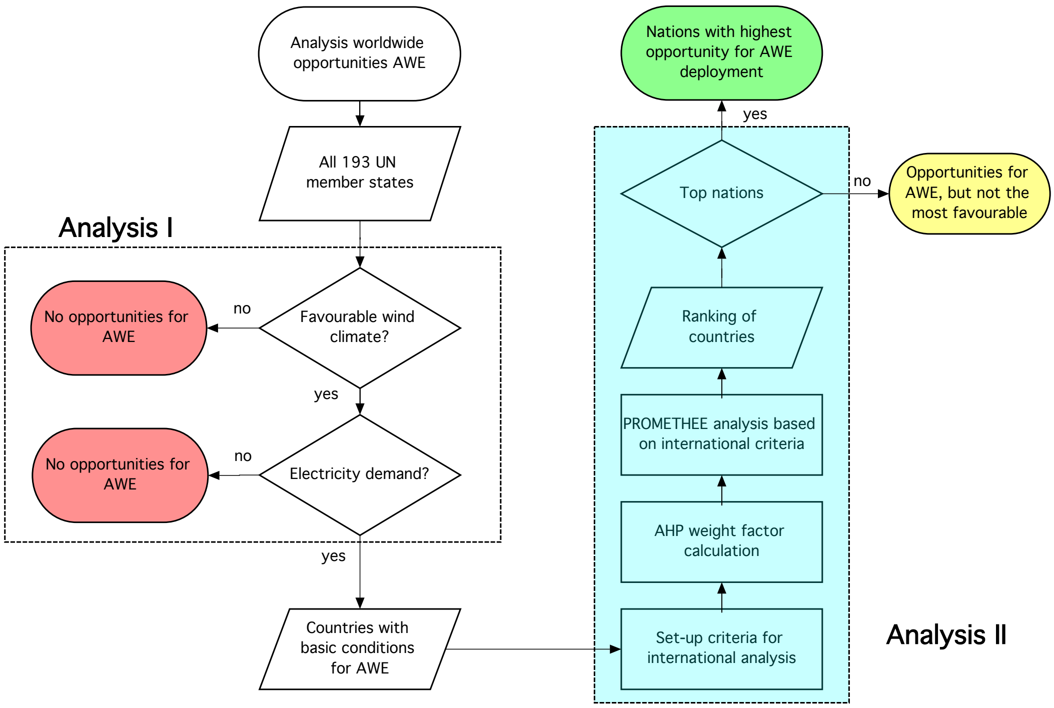


Figure 4.1: Detailed flowchart of the research approach

Airborne wind energy systems generate electricity from the wind. Hence, a nation should at least have a certain demand for electricity and some wind resources which can be harvested by the wind turbine. In case a nation lacks one of these two pillars (electricity demand or wind resource), a nation is eliminated for further analysis.

Next, in the second phase, the remaining countries, which meet the basis requirements for wind energy deployment, will be ranked with the PROMETHEE method. First the relevant criteria, which influence the decision making process of airborne wind energy location selection, are determined from the literature and an AWE business expert as explained in section 4.2. Next the relative importance of these criteria are determined with an expert survey according to an adjusted AHP method as explained in section 4.3. With these inputs, and the country data for the relevant fields, a complete PROMETHEE ranking is performed based on a nation's opportunity for future airborne wind deployment.

4.2 Criteria

Renewable energy, and especially (airborne) wind energy, location planning has not been applied on a global scale. However, literature is available for local/national renewable energy site selection and also for general global business opportunities.

The criteria of these two research fields are merged, as shown in Figure 4.2, to create a set of criteria relevant for the international analysis for airborne wind energy site selection. Additionally the expert view of Makani Power's business lead, Alden Woodrow[1], is included in creating this list of criteria.

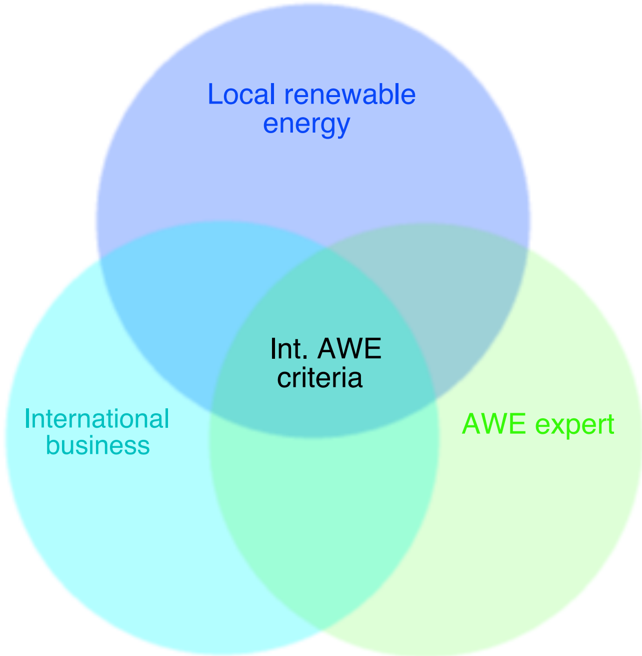


Figure 4.2: International business and local renewable energy criteria from the literature and an expert's view are merged into international airborne wind energy criteria

4.2.1 Renewable energy

The criteria of MCDM problems in sustainable energy decision making are generally divided into technical, economic, environmental and social criteria [11]. Wang et al.'s review study in 2009 [11] lists the most commonly used criteria, see Table 4.1.

These criteria are a summary of all criteria applied in the MCDM process for renewable energy projects. However, as described in section 3.2.2, MCDM models are only since recently applied to the siting of wind turbines (75% is published in 2011 or later) and hence the criteria given by Wang et al.'s study might lack relevancy for the siting of wind energy projects. From the most recent studies, some of the investigated studies mainly focus on technical and/or economic criteria [92, 95, 96, 98, 102, 103, 105, 106, 108]. From the remaining investigated studies [83, 91, 93, 94, 100, 101, 104, 107] the study performed by Lee et al. in 2009 [107] is

[1] Alden Woodrow leads the business team for the Makani project at Google[x]. Alden directs Makani's strategy, business development, communications, policy, and partnership efforts. He previously worked for a power project developer financing utility-scale wind farms, and as an economic and environmental consultant on topics ranging from climate policy to dog house manufacturing.

Table 4.1: Criteria in renewable energy decision making [11]

Main criteria	Sub-criteria	#papers
Technical	Efficiency	15
	Safety	9
	Reliability	9
	Primary energy ratio	4
	Exergy efficiency	3
	Maturity	3
Economic	Investment cost	24
	Operation and maintenance cost	13
	Fuel cost	9
	Electric costs	7
	Net present value	5
	Payback period	4
	Service life	4
	Equivalent annual cost	4
Environmental	CO_2 emission	21
	NO_x emission	12
	Land use	10
	SO_2 emission	8
	Noise	6
	Particle emission	5
	CO emission	3
	Non-methane volatile organic compounds	3
Social	Job creation	9
	Social benefits	5
	Social acceptability	4

the most comprehensive and most comparable study with respect to the study of the suggested research proposal. Lee et al. focusses on the siting of a wind farm project in an anonymous province in China. The evaluation criteria applied in this study are given in Table 4.2. In this particular study, the criteria are classified as either a benefit, opportunity, cost or risk, and is different from the usual classification of criteria as technical, economic, environmental and social. However the end results, the criteria subject to the MCDM framework, is similar.

4.2.2 International business

Multi-criteria decision making has found its application in the international business research field. A significant scientific contribution was made in 2003 by Beim and Lévesque in [171]. This study ranks countries based on their international business opportunities and reviews the available literature. Some of the most often applied, for this study relevant economic, political/legal, and social criteria as listed by [171] are given in Table 4.3. This literature review especially focussed on publications related to Foreign Direct Investment (FDI) and county investment risk. FDI is an investment in an economy other than that of the investor. In case an investment

[2] WEG, Wind Electric Generator, synonym for wind turbine.

Table 4.2: Criteria for wind farm project as specified by [107]

Merits	Criteria	Sub-criteria
Benefits	Wind availability	Geographical distribution of wind speed frequency Mean wind speed density Annual mean wind speed
	Site advantage	Influence of selected height of installation Effect of wind gusting Micro-siting of WEG[2]
	WEG[2] functions	Real and technical availability Affordable, reliable, and maintenance free Power factor, capacity factor
Opportunities	Financial schemes	Switchable tariff Discount of tax rate and duty rate Other investment and production incentives
	Policy support	Wind power concession program Clean development mechanism program Other policy supports
	Advanced technologies	Computerized supervisory Variable wind speed power generation Swept area of a turbine rotor Static reactie power compensator, etc
Costs	Wind turbine	Design and development Manufacturing Installation, maintenance
	Connection	Electric connection Grid connection
	Foundation	Main construction Peripheral construction
Risks	Concept conflict Technical risks Uncertainty of land	Entrepreneurs, policy makers, residents Technical complexity and difficulties Loyalty or lease agreement, geology suitability, etc

into an other company is made, the investing company must own at least 10% of the shares of the invested company[172].

After the publication of this study in 2003, globalization has increased further and more publications related to the country selection on which to open a foreign branch became available. The criteria applied in some of the most relevant (the most similar) studies are also given in Table 4.3.

4.2.3 International (airborne) wind energy

The the criteria used in MCDM framework of this study are a combination of the renewable energy and the international business criteria and given in Table 4.4.

Table 4.3: Criteria for international business opportunities. The references given in **bold** are found in the literature study of [171].

	Criteria	Literature
Economic	Market size	[**173–175**] [176, 177])
	Market growth	[**178**] [176, 177]
	Economy strength (GDP/GNP)	[**173, 179–182**]
	Economy growth	[**173, 175, 179, 182**]
	Tax conditions	[**179, 180, 183**][176, 184–187]
	FDI	[**173–175, 179**]
	Export growth	[**179, 181**]
Political/Legal	Ease of doing business	[**173, 175, 178**] [184, 185, 187]
	Political stability	[**173, 175, 178–181**] [177, 185, 188–190]
	Infrastructure quality	[**179, 183**]
	Incentives for FDI	[**175, 179**]
	IP protection	[**171**] [190]
Social	Cultural factors	[**173, 179, 183**]

The criteria ‘electricity portfolio’, ‘political risk’ , ‘ease of doing business’, and ‘level of IP protection’ have not been found in the renewable energy evaluated literature, but can influence the decision making process in case the focus shifts from local to global and also the criteria from the international business analysis play a role.

Description of the criteria

The ‘wind climate’ is split into two sub criteria, (1) local wind power density and (2) the national wind energy potential. The local wind power density is a measure of the wind resources at one specific location, whereas the national wind energy potential is a measure of the entire country’s technically possible wind resources, which can be harvested.

The ‘grid system’ criterion is split into the, (1) the electrification rate, and (2) the grid quality. The electrification rate is the degree of households and businesses connected to the grid. The grid quality is a measure of the number of annual outages. A high degree of households and businesses connected to a high quality grid is most beneficial for the deployment of airborne wind.

The ‘levelized cost of electricity’ criterion is split into (1) the wind turbine investment cost, (2) the cost of land, (3) the operations and maintenance cost, and (4) the grid connection cost. These costs are given as cost per kWh produced and represents the main cost components of conventional and airborne wind energy systems [218].

[3] In this case the policy support is not included in the levelized cost of energy.
[4] [203] lists the European wind energy targets.
[5] Support policies, permitting and grid integration of 12 wind energy markets
[6] [215] lists the public acceptance of wind energy in 12 European countries
[7] [216] lists the public acceptance of wind energy in the US; ’east’, ’midwest’, ’south’ and ’west’
[8] [217] shows the public acceptance of wind energy in South Africa

Table 4.4: Criteria for this study, [· · ·] are data collection references. Some criteria are intended for local analysis only and this data will be retrieved at a later research stage.

	Criteria	Sub-criteria
Technical	Wind climate	Local wind power density [191–193] National wind energy potential [191, 193, 194]
	Grid system	Electrification rate [5] Grid quality [195, 196]
Economic	Levelized cost of electricity[3]	Wind turbine investment costs Cost of land (only local) Operations and maintenance costs Grid connection costs (only local)
	Cost of electricity	Electricity costs [197] Competitive RES costs (only local)
	Tax benefits	Corporate tax rate [198]
	Market size	Current electricity demand [199] Electricity demand growth prospect [200]
Political	Governmental support for RES	Specific wind energy support programs [5, 201, 202] [203][4] General RES support [5, 201, 202, 204] [205][5]
	Electricity portfolio	Current electricity portfolio [202, 206–208] Renewables target [5, 202] Wind energy target [5, 202] Import/export of electricity [206–208]
	Political stability	Political risk [209]
	Ease of doing business	Level of standardized aviation regulations [210] Construction permit complexity [211] Level of investor protection [212]
	Intellectual property	Level of IP protection [213]
Social	Visual impact	Visual quality of the landscape (only local) [15]
	Social acceptance	Market acceptance by current installed capacity per capita [214] Public acceptance [215][6], [216][7], [217][8]

The 'cost of electricity' production is split into (1) electricity cost and (2) competitive RES cost. The electricity costs is the estimated average national electricity production cost. The competitive RES cost is the cost of electricity production from other renewables like conventional wind power, solar power, etcetera. A high current cost of electricity production, either from conventional fuels or renewables, is beneficial for airborne wind, because airborne wind can be more cost competitive.

The 'corporate tax rate' is the income tax for companies. A low degree of income tax allows companies, like wind farm developers and airborne wind turbine manufacturers to keep more of its revenues as profits and hence these companies are willing to invest in nations with a low corporate tax.

The 'market size' is split into the current electricity demand and the electricity demand growth prospect. The current demand represent the current national electricity consumption. A high current consumption indicates an high opportunity for airborne wind to take a share. The energy demand growth prospect is the expected energy demand growth in 2020. In case the energy demand is increasing, additional energy generating systems are required to supply the energy, and hence indicates a market opportunity for all energy generating systems.

The electricity portfolio is a measure of the current and future degree of renewables in the electricity mix, and in particular wind energy. The criterion 'electricity portfolio' is divided into sub-criteria, (1) current electricity portfolio, (2) renewables target, (3) wind energy target, and (4) import/export of electricity. The electricity portfolio is a measure of the current state of renewable energy, and in particular wind energy. A high degree of renewables indicates that the current political landscape and the infrastructure is supporting these energy generating systems. The renewables and wind energy target are measures of the degree of intended renewables and in particular wind energy in the future. An increase in the intended degree of renewables and wind energy indicates a market potential and additional a political willingness to include more renewables and wind energy into the existing electricity mix. The electricity import/export characteristics indicate the degree of (economic) dependency on specific energy resources.

The 'ease of doing business' criterion is divided into sub-criteria (1) aviation regulations (2) permitting complexity, and (3) level of investor protection. The aviation regulations relate to the the degree at which standardized aviation regulations are applied in the country. With respect to conventional, ground based, wind turbines this is a unique criteria for airborne wind energy systems, which also falls into the aviation regulations. For an AWE supplier and for the country policy makers it is more beneficial to use a standardized aviation regulation. Once the AWE system is approved according to this standardized regulations, the AWE supplier can use its license in all countries which follow these regulations. The policy makers, on the other hand, know they can trust the technology based on the standardized regulations. The construction permitting complexity relates to the degree of complexity concerning the legislation of construction permits. A high degree of complexity is time consuming and costly and therefore unfavorable.

The political stability is *"the degree to which political institutions are sufficiently stable to support the needs of businesses and investors"* [219]. A country characterized with a high political stability reflects a low risk of investment, which is beneficial for the AWT supplier.

The 'level op IP protection' is the criterion which encompasses patent protection and copyright piracy. The highly innovative airborne wind turbines industry is characterized by high degree of research and development costs, and an AWT supplier aims to protect their efforts. Therefore countries with a high degree of IP protection is beneficial.

The visual impact of airborne wind turbines is measured by the visual quality of the landscape. It has been found that the visual impact of wind turbines are dependent of the visual quality of the landscape. A low visual impact of the landscape is beneficial to protect tourism, to keep rural identity, to avoid mountain industrialization and to avoid land and houses' value to decrease [15].

The 'social acceptance' criterion is divided into (1) market acceptance and (2) public acceptance. The market acceptance is a measure of how well market parties adopt and support the energy. This is not only the customers, but also investors and intra-firm acceptance. The public acceptance is a measure of how well the public is in favor or against a particular technology.

Breakdown of criteria

The breakdown of a criteria into sub criteria is, at least to some extend, a subjective process. In example, consider the criterion 'policies for renewables', which is seen as a political criteria in this study. However, policies, like feed in tariffs, can have an economic character. A feed in tariff policy offers stable long-term contract at which access to the grid is guaranteed together with a fixed price for electricity production.

To increase trust in the breakdown of criteria, a novel extension to the classical AHP methodology is proposed next.

4.3 Weight factor

The Analytical Hierarchy Process (AHP) methodology is applied to determine the weight factors associated with the criteria. The classical AHP methodology got certain drawbacks and hence an adjusted approach is proposed.

4.3.1 Classical AHP

In the classical AHP methodology, the problem is split into several factors (criteria) which influence the decision making process. Next, the relative importance of these criteria are calculated by pair-wise comparison. In case many different decision criteria are included, individuals can become confused resulting in large inconsistencies in their pair-wise comparison. Therefore a maximum number of 7 criteria is recommended [158, 220]. In case more criteria need to be assessed, some criteria should be grouped together. Next the groups of criteria are pair-wise compared and also the relative importance of the (sub)criteria belonging to a grouped (or overarching) criteria are pair-wise compared.

This classical AHP weight factor methodology is applied to determine the weight factors at three levels, as illustrated in Figure 4.3.

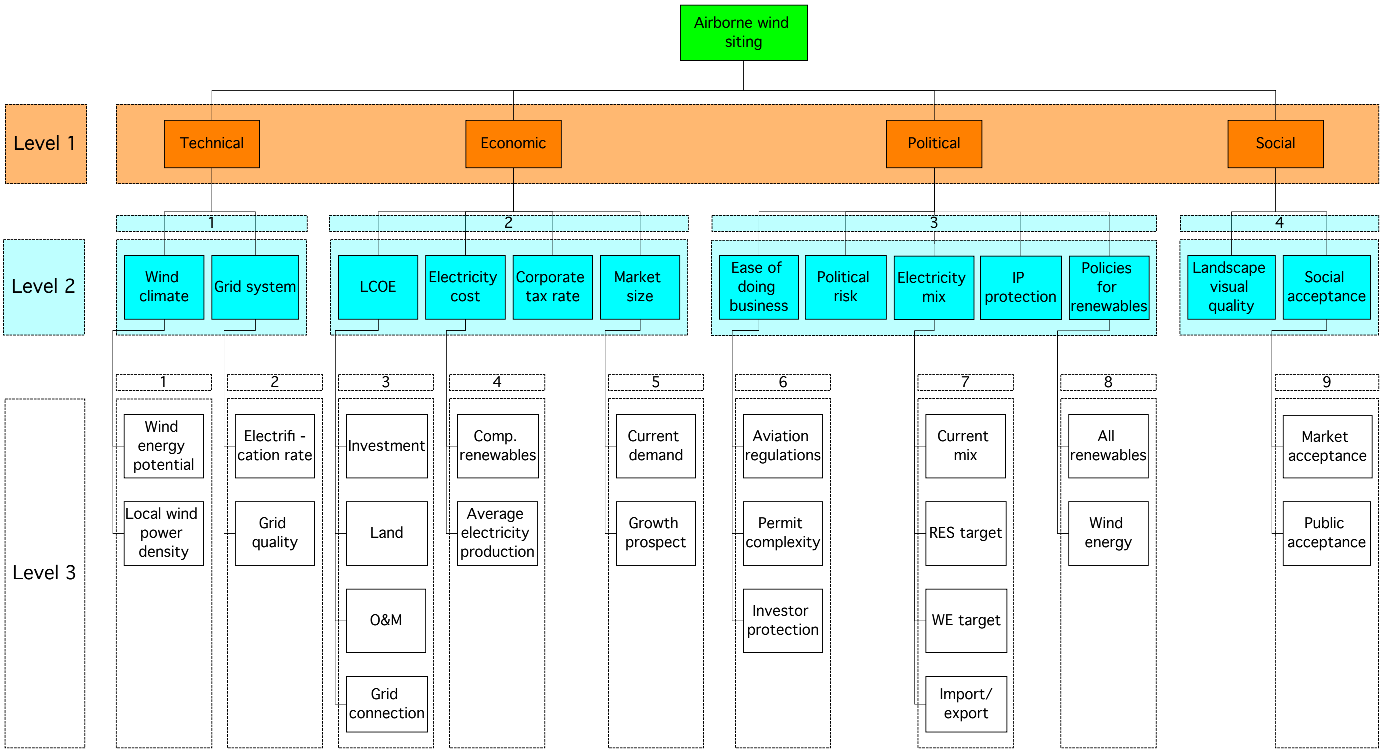


Figure 4.3: Classical AHP weight factor calculation methodology

The relative importance of the criteria is now determined at each of the three levels:

1. The four overarching criteria; technical, economic, political and social, are pair-wise compared to determine the relative importance of each main criteria.

2. Next, the family of subcriteria belong to a certain overarching criteria are pairwise compared. In example the technical criteria. The importance of the wind climate with respect to the grid system is determined. And for the economic criteria. The levelized cost of electricity of airborne wind energy, the cost of electricity generation, the corporate tax rate, the current and future prospect of the market size and the ease of doing business are pair-wise compared. The same method is applied for the political and social criteria.

3. Finally, the family of sub-sub-criteria belonging to a certain criteria are pair-wise compared to calculate their relative importance. In example the subcriteria wind climate. The relative importance of the national wind energy potential is determined with respect to the local wind power density. As shown in Figure 4.3, 9 sets of level 3 pair-wise comparisons are executed in the survey.

The pair-wise comparison results in pair-wise comparison matrices. In example the subcriteria belong to the political criteria, which are given by equation 4.1. In this matrix, p stands for political, subscript 12 denotes the relative importance of subcriteria 1 with respect to 2. The relative importance of a criteria with respect to itself is always equal to 1; equally important.

$$\begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix} \tag{4.1}$$

However this classical methodology got certain disadvantages. In cases at which no general consensus exists for the grouping of subcriteria to an overarching criteria, the subcriteria might not be appropriate to represent the overarching criteria. In this study, a unique combination of international business criteria and criteria from the local renewable energy literature are combined to set the criteria for the international analysis for airborne wind energy systems, see section 4.2. This set has not been applied in other studies, and hence no consensus exist regarding the grouping of certain subcriteria.

A different method is applied to overcome this disadvantage; it allows to verify the trustworthiness of the split of a criteria into the subcriteria. E.g. in case a respondent believes that, for level 1, the technical criteria are most important. In that case also, the level 2, criteria of the technical criteria (wind climate and grid system) should be seen as very important with respect to all other level 2 criteria.

4.3.2 Adjusted AHP

In this adjusted AHP method, level 1 and level 3 remain unchanged. However, the pair-wise comparison of level 2 is modified. What remains unchanged is that the subcriteria, which fall under a certain overarching criteria, are still pair-wise compared to each other. But, additionally, the subcriteria *across* overarching criteria are also pair-wise compared, e.g. the relative importance of the wind climate is not only determined with respect to the grid system, but also with respect to the levelized cost of electricity of the airborne wind energy system (LCOE), the current electricity cost, etcetera. Hence in this survey, the level of importance of all 13 level 2 criteria are pair-wise compared. This is illustrated in Figure 4.4.

Compare Figures 4.3 and 4.4. The adjusted AHP weight factor calculation methodology allows to directly determine the relative importance of all 13 level 2 criteria with respect to each other regardless their overarching criteria. This methods results in a 13x13 pair-wise comparison matrix at which also the relative importance of the criteria belonging to a certain overarching criteria can be determined, as shown in the comparisons matrix of equation 4.2. In this matrix t represents a technical e an economic, p a political and s a social subcriteria. This allows to compare the results

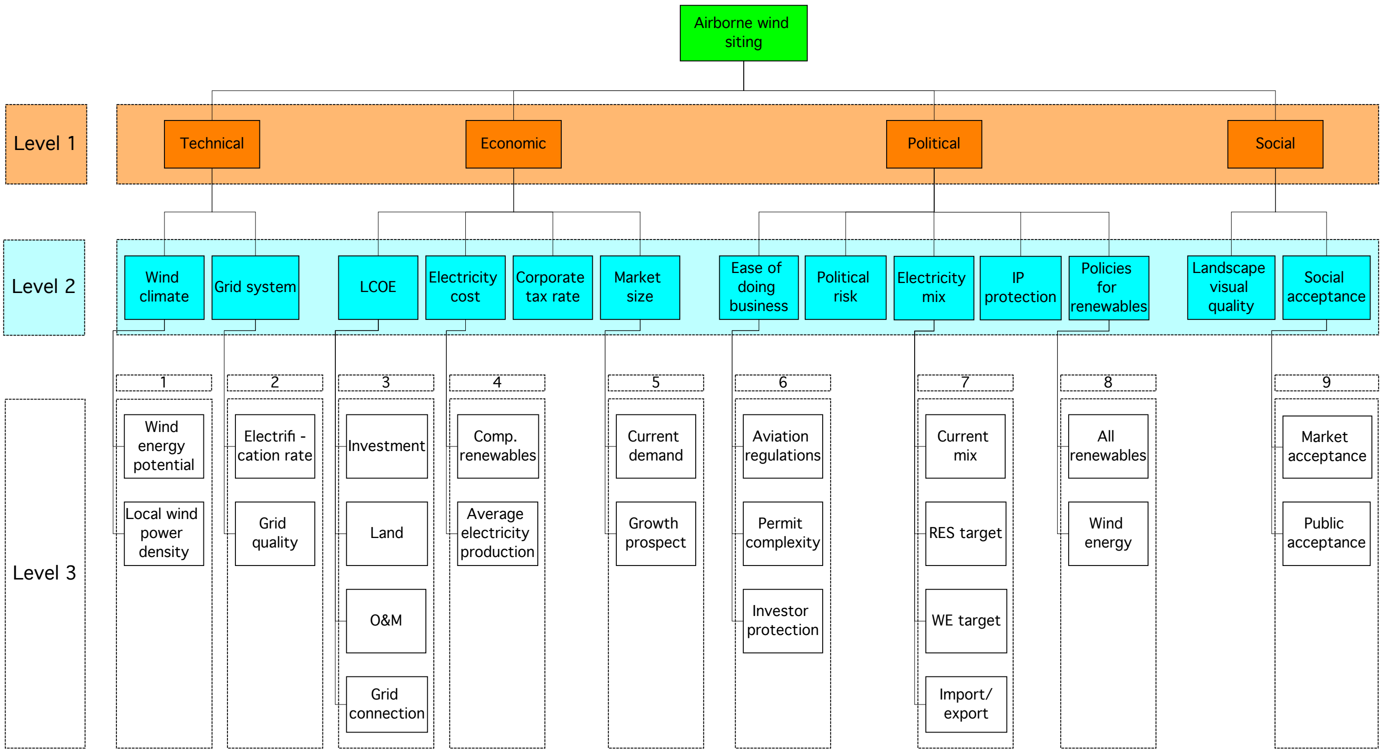


Figure 4.4: Adjusted (level 2) AHP weight factor calculation methodology.

of the adjusted AHP with the classical AHP.

$$\begin{bmatrix} \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} & & & \\ & \begin{bmatrix} e_{11} & e_{12} & e_{13} & e_{14} \\ e_{21} & e_{22} & e_{23} & e_{24} \\ e_{31} & e_{32} & e_{33} & e_{34} \\ e_{41} & e_{42} & e_{43} & e_{44} \end{bmatrix} & & \\ & & \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix} & \\ & & & \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \end{bmatrix} \tag{4.2}$$

The adjusted AHP methodology got a certain disadvantage with respect to classical AHP. With the AHP methodology a maximum of 9 criteria, of which none are equally important, can be pair-wise compared consistently. This is embedded in the application of Saaty's 9-point scale as explained in section 3.3.1. The application of

Saaty's 9-point scale for the pair-wise comparison of 13 criteria will inevitably lead to inconsistencies. However, this 9-point scale can also be inadequate for the pairwise comparison of less than 9 criteria. Even for three criteria, inconsistencies might be inevitable with Saay's 9-point scale, and is therefore often criticized [162–164]. A simplified example, similar to the example from [162], to illustrate:

> *Assume three different criteria are relevant in the decision making process for a new car; (1) price, (2) color, and (3) fuel consumption. For this illustrative example, assume that the price is 3 times as important as the fuel consumption. The fuel consumption in turn, is 4 times as important as the color. For a consistent set, the price should be 12 (3 · 4) times as important as the color. However Saaty's 9-point scale does not allow to compare a criteria which is more than 9 times as important with respect to another.*

To conclude; in classical AHP inconsistencies are likely to occur, and care must be taken with the interpretation of the results. With the adjusted method, inconsistencies are not only more likely to occur, but actually inevitable, and hence extra care should be taken with the interpretation. As an extra measure to verify the respondents' answer consistency, the experts rank all 13 level 2 criteria at the end of the survey. The full list of level 2 criteria is given, and the experts drag and rank these criteria. The most important criteria on top and the least important at the bottom. This allows to qualitatively verify the AHP calculated weight factors. This adjusted AHP method could also be applied to the level 3 criteria, but with 25 different criteria, it is likely that the disadvantages do not outweigh the advantages anymore.

4.3.3 Consistency check

After the survey is filled by several experts, it is likely that the expert judgements about the importance of each weight differs considerably. According Saaty[9], the geometric mean has been proven to be representative for the group decision, based on the individual inputs [221]. The geometrical mean is a type of mean, which uses the product of the values.

$$\left(\prod_{i=1}^{n} w_i\right)^{1/n} = \sqrt[n]{w_1 w_2 \cdots w_n} \tag{4.3}$$

In this equation, w_i is the mean weight for criterion i and $w_1 w_2 \cdots w_n$ are the weights given by the individual experts.

It is common that inconsistencies are present in a pair-wise comparison matrix. According to Saaty only slight inconsistencies are allowed [157–159]. The consistency

[9] Prof. Thomas L. Saaty is the internationally recognized founder of the AHP framework [94, 97, 98, 107, 111, 145, 165, 167, 168].

of the weight matrix is evaluated with the consistency ratio (CR), which is the fraction of the consistency index (CI) and the random index (RI). For a completely consistent $n \times n$ matrix, the eigenvalue $\lambda_{\max}$ is equal to n. Therefore the deviation of $\lambda_{\max}$ with respect to n is a measure of inconsistency. This measure is termed the consistency index:

$$\mathrm{CI} = \frac{\lambda_{\max} - 1}{n - 1} \tag{4.4}$$

The random index is an average value to account for increase potential for inconsistencies in case the matrix size is increased. Saaty's RI values are given in Table 4.5.

Table 4.5: Saaty's constancy index values for various matrix sizes

n	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Finally the constancy ratio is calculated as:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{4.5}$$

In case CR is smaller than 0.1, the matrix is consistent according to Saaty [157–159].

4.3.4 Data collection

Section 4.2 defines the initial criteria based on the literature and an AWE expert's view. To increase the trustworthiness, these criteria and their relative importance, indicated by the weight factors, are evaluated by experts. The airborne wind energy (AWE) industry is in its infancy; at the moment AWE systems have not yet been commercialized. Therefore, the industry lacks experience and expertise in the field of project development. However the conventional wind energy projects are to some extend similar to AWE projects, and hence experts in project planning of onshore and offshore wind farms have valuable expertise. These project developers can be representatives of the local or national government, or project developers from the industry like utility companies, wind turbine developers, or other project developing companies. Despite the lack of commercialization of AWE systems, research institutes and universities got experience in this field, e.g. the TU Delft kite power group is established in 2005 and has about 9 years of experience with the technology, and in these years also the commercialization potential has been analyzed. The experience from this group could be valuable in evaluation the criteria for airborne wind farm siting and the relative importance of each criteria. Therefore, the proposed criteria from Table 4.4 are evaluated by a group of experts with different backgrounds and interest.

This method was also applied in [167], at which a group of experts evaluated the criteria by filling a survey. An example question:

Compare the following Risk criteria according to their relative importance. Which risk is more important for Accepting or Rejecting a project?

- ☐ L1C11 Political instability of the country
- ☐ L1C12 Changes in energy policy
- ☐ They are of equal importance

If one risk is more important than the other, to what extent?

- ☐
- ☐ Moderate importance over the other set
- ☐
- ☐ Strong importance over the other set
- ☐
- ☐ Very strong importance over the other set
- ☐
- ☐ Extremely more important

In this study two separate expert surveys are set-up to determine the weight factors according to (1) the classical AHP and (2) the adjusted AHP. In both surveys, the respondents are introduced to the survey first followed by a few questions related to the expert's background and experience. Next the respondents are made familiar with the AHP scaling method and an example question is used to introduce the pair-wise comparison method. After the respondent is familiar with the type of questions asked, the respondents apply the pair wise comparison method to determine the relative importance of the overarching criteria; technical, economic, political and social. Subsequently the respondents answer questions related to the relative importance of all criteria and sub-criteria defined in Table 4.4. The survey questions related to the level 1 and level 3 criteria are equal for both survey types. For the level 2 criteria, the classical AHP only compares the sub criteria within a certain group of criteria, whereas the adjusted AHP also compares the sub criteria *across* the groups of criteria.

An example question from the adjusted AHP to determine the relative importance of the criterion 'size of the market' with respect to all other level 2 criteria is given in Figure 4.5

The set-up of this pair-wise comparison matrix is intuitive. If an expert feels that two criteria are of equal importance, the radio button exactly in between the two criteria (at 0) is checked. If an expert feels one of the criteria is more important than another, a radio button closer to the more important criteria is checked. The entire survey and the list of experts invited to fill the survey can be found in Appendix A.

4.4 Conclusion

It was found from the literature and an AWE business expert's view that several technical, economic, political and social criteria influence the nation selection decision of airborne wind. These criteria are split into several sub-criteria and subsequently

Compare the following criteria according to their relative importance with respect to the **size of the market**.

The size of the market is a combination of the current electricity consumption and the prospected future growth.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
LCOE	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Corporate tax rate	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Electricity cost	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Electricity portfolio	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Grid system	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
IP protection	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Social acceptance	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Political risk	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
RE support schemes	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Ease of doing business	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Visual quality landscape	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size
Wind climate	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	Market size

Figure 4.5: Example question of the survey to determine the relative importance of each criteria and sub-criteria. Checking the radio button at 0 means that, according to the expert's opinion, both criteria are of equal importance. Checking the radio button at 8 or -8 means that, according to the expert's opinion, the criterion on respectively the left and the right hand side, is extremely more important the the criterion on the left hand side.

into measurable sub-sub-criteria. This unique criteria set has not been applied in other studies, and hence no consensus exist regarding the grouping of certain subcriteria. A novel adjustment to AHP is proposed to verify the trustworthiness of the split of a criteria into the subcriteria. Experts with backgrounds in (airborne) wind energy industry and academia, NGO's and the government a will complete a survey to determine the weight factors based on (1) the classical AHP methodology and (2) the adjusted AHP methodology. These results can be compared to verify the adjusted AHP methodology.

Chapter 5

Model building

In the previous chapter the conjunctive screening method in combination with the PROMETHEE-AHP methodology was applied to the nation selection problem for airborne wind energy. It is the goal of this chapter to build on this methodology and include all data needed for ranking the nations. In section 5.1, the conjunctive screening method will eliminate nations with insufficient wind resources or electricity demand. In section 5.2 the PROMETHEE-AHP model is build. First the weight factors are calculated with the classical and adjusted AHP methodology. These weight factors are compared for verification of the adjusted AHP methdodoloy and additionally the validity of grouping sub criteria into overarching criteria is checked. Next the PROMETHEE preference functions are described. In section 5.3 the data processing technique is outlined with a flowchart. Finally in section 5.4 the conclusions of this chapter are given.

5.1 Phase I: Conjunctive screening

Airborne wind energy systems generate electricity from the wind. Hence, a nation should at least have a certain demand for electricity and some wind resources which can be harvested by the wind turbine. In case a nation lacks one of these two pillars (electricity demand or wind resource), a nation is eliminated for further analysis.

5.1.1 Wind climate

The wind climate is divided into onshore wind and offshore wind. A nation is eliminated from further research in case it lacks both resources.

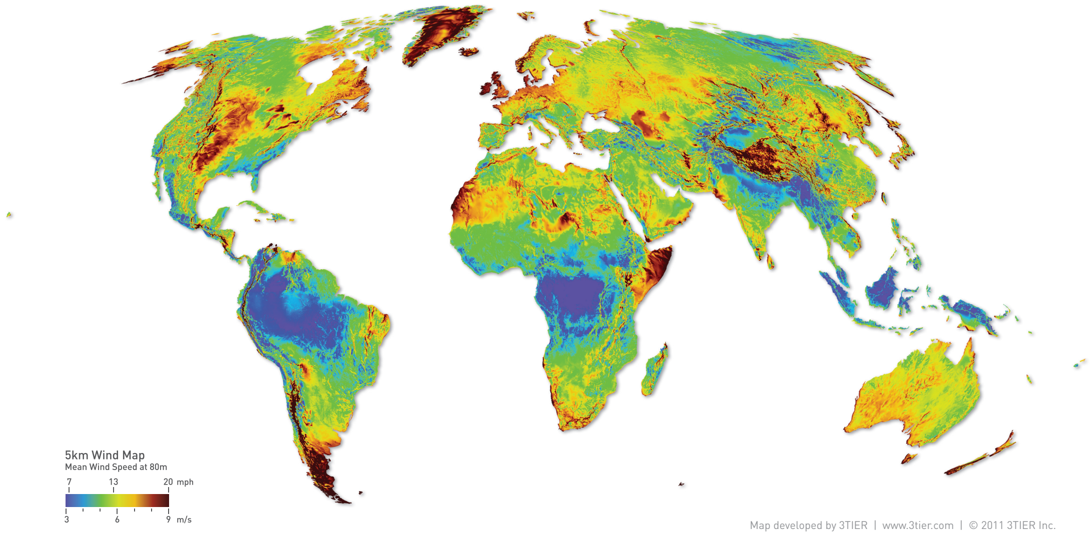


Figure 5.1: On land global mean wind speed map at 80m altitude [222]

Onshore wind

The national and regional wind speeds are visualized for various countries by the National Renewable Energy Laboratory (NREL). The data set is extensive, but mostly focusses on the United States. From the 427 available wind maps, 89% targets part of the United States [193].

The international renewable energy agency (IRENA) has developed an interactive map, by combining several regional, national and global wind speeds studies. Globally the wind speeds are analyzed with two different methodologies; NASA's 'modern-era retrospective analysis for research and applications' (MERRA) and 3Tiers' combination of integrated statistical methods with a numerical weather production (NWP) model. Both wind speed models give similar results and 3Tiers' wind map is given in Figure 5.1.

One of the most comprehensive studies on the onshore (and offshore) wind energy potential is performed by Lu et al. in 2009 [191]. Most studies focussing on the global potential of wind energy only include the wind climate, whereas the geographical constraints are not taken into account. In [191], the onshore and offshore wind energy potential is calculated based on wind energy harvesting at locations suitable for the installation of wind turbines. Hence densely populated regions, areas occupied by forest and environments permanently covered by snow and ice are excluded from the analysis. In this study the efficiency for wind energy harvesting is given by its capacity factor[1]. The onshore capacity factor are given in Figure 5.2.

[1]The capacity factor of a specific wind turbine is equal to the fraction of the harvested wind energy with respect to potential in wind energy if the wind turbine would operate at its maximum capacity at all times.

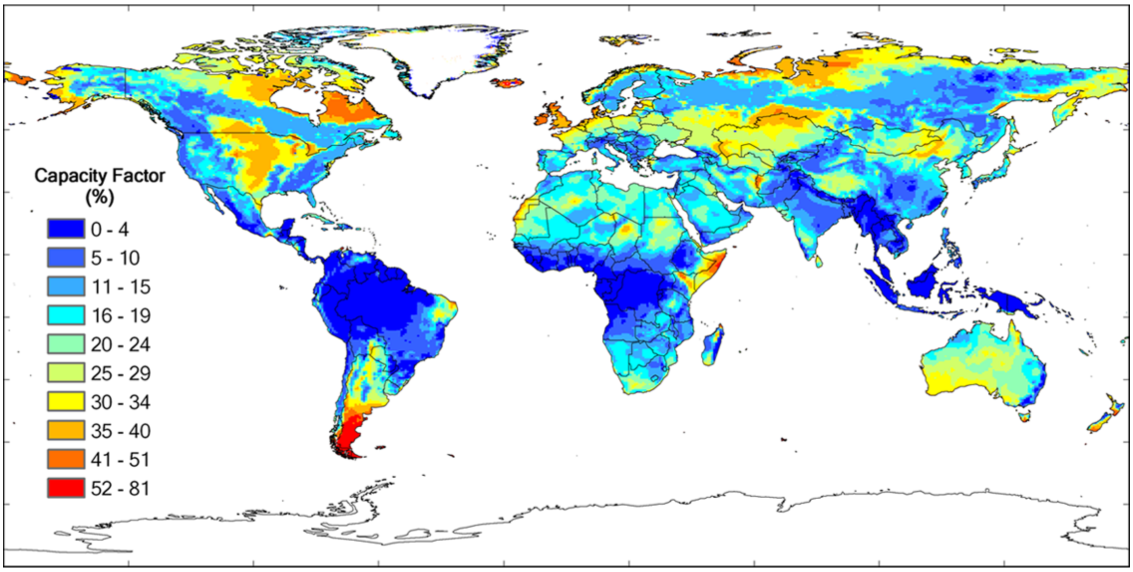


Figure 5.2: Onshore capacity factor for winds at 100m [191]

Note that the onshore wind climate figures from 3Tiers [222] and Lu et al. [191], respectively Figures 5.1 and 5.2, are similar. In [191] the global wind energy potential is calculated for regions with capacity factor higher than 20%. Regions characterized by lower capacity factors are thereby classified as unfavorable. Following this approach, countries with capacity factors lower than 20% are excluded from further analysis in case this country has no offshore wind energy potential.

Offshore wind

Currently offshore wind energy takes account for only a small fraction of all installed capacity. Therefore the research into offshore wind maps is more limited with respect to onshore wind. However NREL has created the offshore wind map given in Figure 5.3.

In [223], NREL calculates the global wind energy potential for for sites characterized with wind speeds higher than 8m/s. This indicates that sites characterized by wind speeds lower than 8m/s are unfavorable. Following this approach, countries which have no onshore wind energy potential and lack offshore wind speeds higher than 8m/s are eliminated from further research.

The nations withdrawn for further research due to a lack of onshore and offshore wind resources are listed in Table 5.1.

5.1.2 Electricity demand

The installed capacity of the airborne wind farm subject to this study is equal to at least 100MW. With a 50% capacity factor, this wind farm will generate about

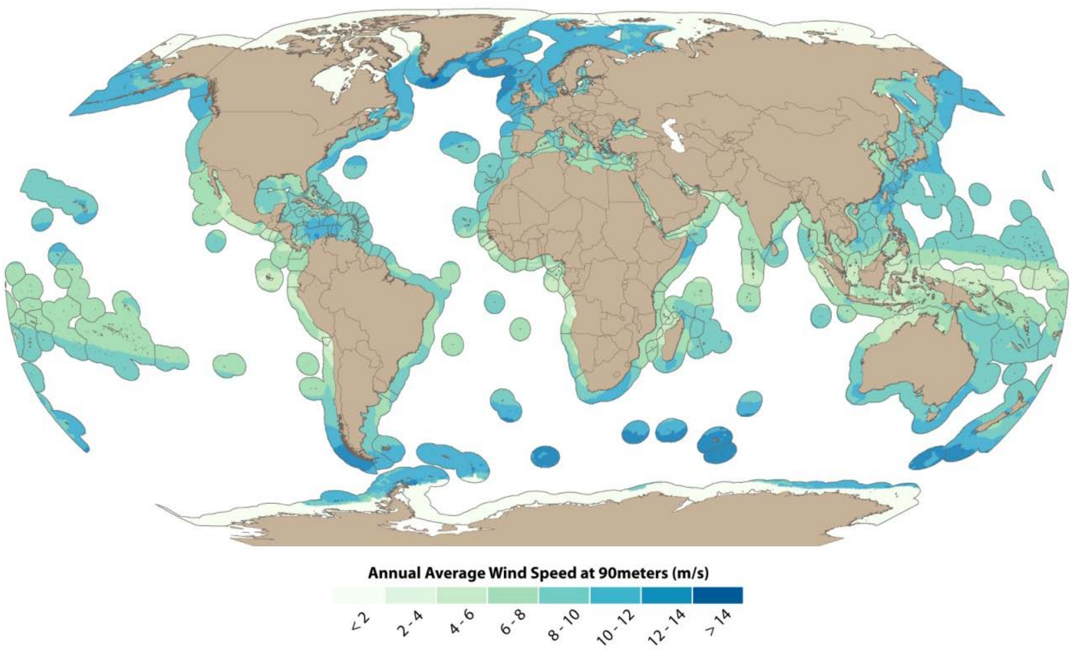


Figure 5.3: Offshore global mean wind speed map at 90m altitude [223]

Table 5.1: Nations withdrawn for further research due to a lack of onshore and offshore wind resources

1.	Andorra	18.	Gabon	35.	Myanmar
2.	Armenia	19.	Gambia	36.	Nepal
3.	Bangladesh	20.	Georgia	37.	Qatar
4.	Benin	21.	Ghana	38.	Rwanda
5.	Bhutan	22.	Guinea	39.	Serbia
6.	Botswana	23.	Guinea Bissau	40.	Sierra Leone
7.	Brunei	24.	Israel	41.	Singapore
8.	Burkina Faso	25.	Jordan	42.	Slovakia
9.	Burundi	26.	Kyrgyzstan	43.	Slovenia
10.	Cambodia	27.	Laos	44.	Swaziland
11.	Central African Republic	28.	Lebanon	45.	Switzerland
12.	Congo	29.	Lesotho	46.	Tajikistan
13.	Cote d'Ivoire	30.	Liberia	47.	Thailand
14.	Dem. Rep. of the Congo	31.	Macedonia	48.	Togo
15.	East Timor	32.	Malawi	49.	Zambia
16.	El Salvador	33.	Malaysia	50.	Zimbabwe
17.	Equatorial Guinea	34.	Montenegro		

438GWh. As a reference, this airborne wind farms would be able to electrify about 125,000 Dutch households.

In case the current national electricity demand of a country is smaller than the expected electricity production of this AWT farm, and is not expected to increase considerable in the next 5 years, this country is withdrawn for further research. The list of withdrawn countries is given in Table 5.2. Most of these countries can be classified as small islands, and low electricity demand is a result of the small the population size. Liechtenstein and San Marino are small European nations with a population of about 35,000. Chad, Djibouti, Eritrea and Somalia are African nations with a low electricity demand, mostly because these countries are underdeveloped.

Table 5.2: Nations withdrawn for further research due to a lack of electricity demand

1	Antigua and Barbuda	12	Liechtenstein	22	Saint Vincent and the Grenadines
2	Cape Verde	13	Maldives		
3	Chad	14	Marshall Islands	23	Samoa
4	Comoros	15	Mauritania	24	San Marino
5	Djibouti	16	Micronesia	25	Sao Tome and Principe
6	Dominica	17	Monaco	26	Seychelles
7	Eritrea	18	Nauru	27	Solomon Islands
8	Grenada	19	Palau	28	Somalia
9	Guyana	20	Saint Kitts and Nevis	29	Tonga
10	Haiti	21	Saint Lucia	30	Tuvalu
11	Kiribati			31	Vanuatu

5.1.3 Data unavailability

In the first stage, 81 nations were withdrawn from further analysis, either because the national wind climate was too unfavorable or the electricity demand is too low. Unfortunately not all data is available for all remaining nations and some nations need to be withdrawn from the complete analysis due to a lack of available data. Most of these nations lack three or less data inputs, which is always a combination of the data related to grid quality, corporate tax rate, intellectual property right protection, the current electricity mix or permit complexity. To calculate these nations' opportunity for airborne wind energy deployment, the multi criteria analysis is performed while excluding these critical criteria. The next sections will discuss this multi criteria PROMETHEE analysis in detail.

The ranking of the score for the nations, which lack three or less datapoints is given in Table 5.3. From these analyzed nations Iran is ranked highest at the 52nd position and only lacking data related to the corporate tax rate. This study is interested in the top nations for the deployment of airborne wind energy system, and it is not expected that any of the nations from Table 5.3 will be near a top ranking in case the missing data would be included.

Nations which lack more than three datapoints are not subject to any PROMETHEE analysis. These nations are Cuba, French Guyana, North Korea, South Sudan, Syria and Turkmenistan.

In the next stage the remaining 82 nations are subject to the complete AHP-PROMETHEE analysis.

Table 5.3: Nations withdrawn from the complete analysis, due to a lack of available data. In this table GQ is grid quality, CT is corporate tax rate, IP is the level of intellectual property right protection, EM is the current electricity mix and PC is the construction permit complexity.

	Nation	GQ	CT	IP	EM	PC	Ranking
1.	Afghanistan	x		x			87/90
2.	Albania					x	73/83
3.	Angola			x			85/85
4.	Azerbaijan		x				74/87
5.	Bahamas	x		x			88/90
6.	Barbados			x	x		86/94
7.	Belarus	x		x			74/90
8.	Belize	x	x	x			90/105
9.	Cameroon		x				85/87
10.	Fiji	x	x	x			96/105
11.	**Iran**		**x**				**52/87**
12.	Iraq	x		x			62/90
13.	Libya					x	71/85
14.	Mongolia		x	x			72/92
15.	Namibia			x			78/87
16.	Nicaragua		x				72/87
17.	Niger	x	x	x			103/105
18.	Papua New Guinea	x	x	x			85/105
19.	Senegal		x				86/87
20.	Sudan		x	x			82/87
21.	Suriname			x	x		93/94
22.	Tunisia		x	x			59/92
23.	Uzbekistan	x	x	x			69/105
24.	Yemen			x			82/85

5.2 Phase II: PROMETHEE-AHP

In this phase the weight factors for each criteria are calculated first with the classical and the adjusted AHP method. The resulting weight factors are compared for verification of the adjusted AHP method and next the grouping of sub criteria is verified. Fnally the preference functions for the PROMETHEE analysis are defined.

5.2.1 AHP weight factors

The weight factors are calculated with two different expert surveys by applying the AHP pair wise comparison methodology. The quality of the responses is first checked with the consistency index and next the weight factors for all criteria and sub criteria are calculated and the results from the adjusted AHP method are compared with the results from the classical AHP method. Finally, the grouping of certain criteria in an overarching criteria is verified with the results from the adjusted AHP-method.

Overarching, level 1, criteria

The weight factors for the level 1 criteria are determined for the consistent datasets and also for all datasets (consistent and inconsistent), see Figure 5.4. Including all datasets has a leveling effect; it decreases the relative differences between the weight factors. However the difference between the weight factors calculated with only consistent or with all datasets is small. It is determined that the economic criteria are most important followed by the technical and the political criteria. The social criteria are generally seen as the least important of the four.

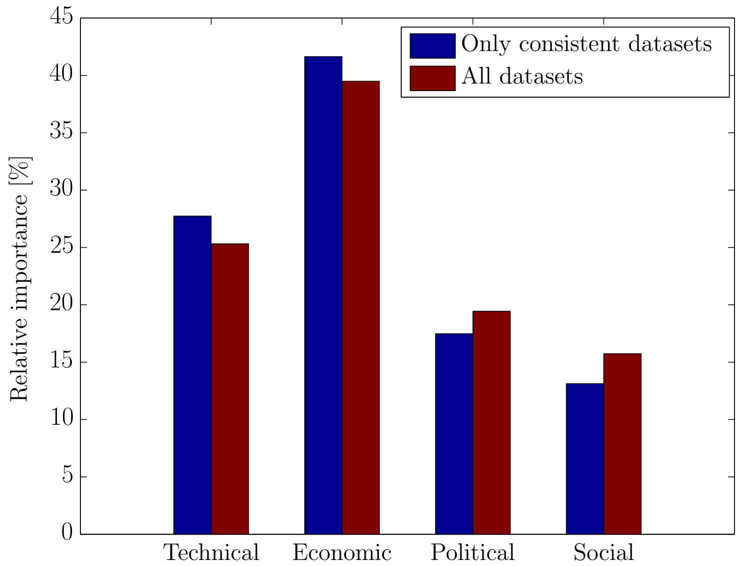


Figure 5.4: Weight factors for the overarching criteria; technical, economic, political and social. The 'all datasets' consists of 26 entries, and the consistent set of 11 entries.

Level 2 criteria

Economic and political criteria The weight factor calculation for the level 1 criteria suggests that the weight factors calculated with the consistent datasets are similar to the weight factors calculated in case all datasets are included; the consistent and the inconsistent datasets. In the previous sections was explained that two different methods were applied to calculate the weight factors for the level 2 criteria; one according to the classical AHP methodology and an adjusted AHP. To analyze the economic and political criteria again the consistent datasets and non-consistent datasets are analyzed for both the classical and adjusted AHP. Therefore four different weight factor calculation methods are applied:

- Classical AHP only consistent datasets

- Adjusted AHP only consistent datasets
- Classical AHP, all datasets
- Adjusted AHP, all datasets

The weight factors for the economic and the political criteria are given in Figures 5.5 and 5.6.

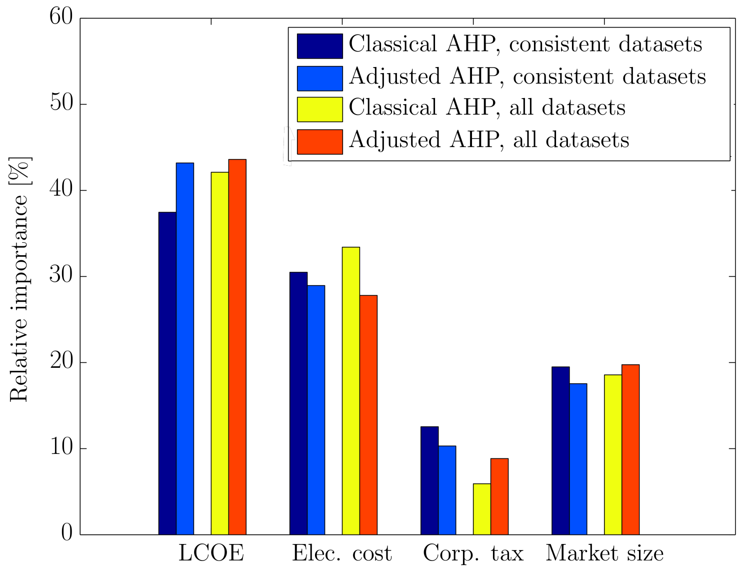


Figure 5.5: Weight factors for the economic criteria; levelized cost of electricity (LCOE), the electricity production cost (Elec. cost), corporate tax rate (Corp. tax) and the current future size of the market (Market size). The 'classical AHP consistent dataset' consists of 5 datasets, the 'adjusted AHP, consistent datasets' consist of 10 datasets, the 'classical AHP, all datasets' consist of 16 datasets, the 'adjusted AHP, all datasets' consists of 18 datasets.

Regarding the economic criteria, for all four methods, the levelized cost of electricity is calculated to be the most important criteria followed by the production cost of electricity and the current and future size of the market. The corporate tax rate is generally seen as the least important criteria in all four cases. The different methods result in slight differences in calculated weight factors, but in general the calculated weight factors are similar.

For the political criteria, the renewable energy (financial) support policies is generally seen as the most important criteria followed by the ease of doing business and the political risk. The current and future electricity mix and the level of intellectual property right protection are generally seen as the least important factors. This ranking is independent of the methodology used; classical or the adjusted AHP.

Technical and social criteria The technical and social criteria are both split in only two sub criteria. By definition, the pair-wise comparison of a set of two criteria

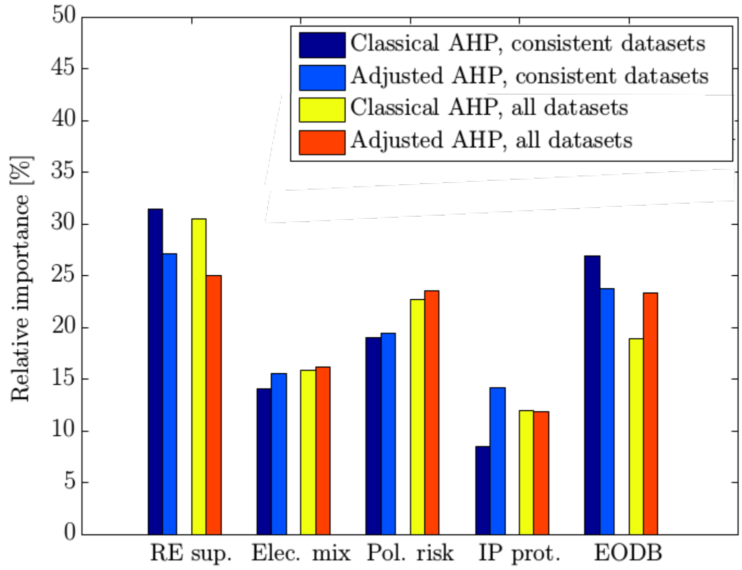


Figure 5.6: Weight factors for the political criteria; renewable energy (financial) support policies (RE sup.), the current and future electricity mix (Elec. mix), the political risk (Pol. risk), the level of intellectual property right protection (IP prot.), and the ease of doing business (EODB). The 'classical AHP consistent dataset' consists of 8 datasets, the 'adjusted AHP, consistent datasets' consist of 8 datasets, the 'classical AHP, all datasets' consist of 16 datasets, the 'adjusted AHP, all datasets' consists of 18 datasets.

is always consistent. A distinction between consistent and non-consistent datasets cannot be made. The consistency checks allow for a sanity check of the data. This check is lacking for these sets of criteria, but the previous results, comparing the consistent datasets to all datasets have shown that similar results are obtained. The technical criteria is split into the wind climate and grid system. The social criteria is split into the social acceptance and the visual quality of the landscape. The relative weight factors are given in Figure 5.7.

The data from Figure 5.7 shows that, for the technical criteria, the wind climate is generally seen as more important than the availability of a suitable grid system. In the adjusted AHP methodology this preference is smaller. Regarding the social criteria; the social acceptance is generally seen as more important than the visual quality of the landscape. It is noticed by some experts that these two factors are closely interrelated. In case of a very high landscape visual quality, is is more likely that the social acceptance is less. However, in this analysis the social acceptance is analyzed on a national level, whereas the landscape visual quality is analyzed on a local level.

These datasets suggest that the adjusted AHP methodology got a leveling effect; reducing the preference differences of two criteria. In the other analyses, with a pair-wise comparison consisting of more than two criteria, this effects was not present.

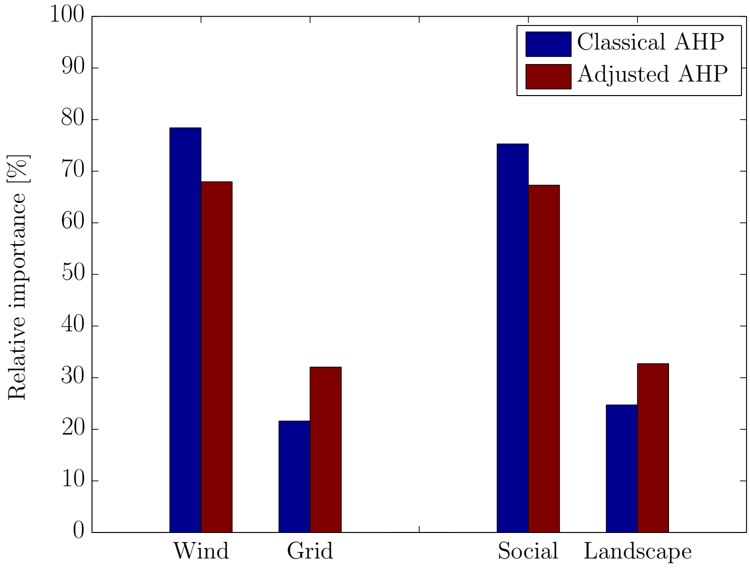


Figure 5.7: Weight factors for the technical and social criteria. The technical criteria is split into the wind climate (Wind) and the availability of a suitable grid system (Grid). The social criteria is split into social acceptance (Social) and the visual quality of the landscape (Landscape). The 'classical AHP' consists of 16 entries, and the 'adjusted AHP' consistent set of 18 entries.

Conclusions With the adjusted and the classical AHP methodologies, similar weight factors are calculated. In the adjusted AHP, the consistency of the pair-wise comparisons has not been decreased significantly with respect to the classical AHP. The average duration to complete the adjusted AHP survey was about 30 minutes, with respect to 10 minutes of the classical AHP survey. Before starting the survey, the respondents were informed about the expected completion time. A possible explanation in the similar consistency indices can be found in the degree of commitment. The 10 minutes survey could be filled in 'in between', whereas the respondents might have reserved some time to adequately fill in the 30 minutes survey.

Because of the similar results of the two methodologies and similar consistencies, the adjusted AHP results are useful to check the sanity of the chosen criteria belonging to a certain overarching criteria. The ranking by importance based on the adjusted AHP method is given in Table 5.4. For each overarching criteria the importance of the belonging sub criteria are ranked equally as with the classical AHP, e.g the political criteria; the governmental renewable energy (financial) support schemes are generally seen as most important, followed by the ease of doing business, the political risk, the current and future electricity mix and the level of intellectual property right protection. This ranking is in accordance with the results from the classical AHP methodology, Figures 5.6 and 5.8 (explained in the next section).

Table 5.4: Criteria ranked by importance according the the adjusted AHP methodology. The most important criteria on top. All criteria are pair-wise compared, regardless their overarching criteria.

	Criteria	Overarching criteria
1.	LCOE	Economic
2.	Electricity cost	Economic
3.	Wind climate	Technical
4.	RE support schemes	Political
5.	Market size	Economic
6.	Grid system	Technical
7.	Ease of doing business	Political
8.	Political risk	Political
9.	Electricity mix	Political
10.	Social acceptance	Social
11.	IP protection	Political
12.	Corporate tax rate	Economic
13.	Landscape visual quality	Social

Also most important, the criteria belonging to the economic overarching criteria are generally seen as most important, followed by the technical, the political and social criteria. This is in accordance with the results from the overarching criteria. However, at first glance there might be one difference; the corporate tax rate, an economic criteria is seen as the second least important factor, whereas economic criteria are generally seen as the most important. However, also within the economic criteria, the corporate tax rate is seen as the least important, with only a 6% weight factor, indicating that this particular economic parameter is significantly less important with respect to the other economic criteria.

Concluding, the adjusted AHP allowed to check the relevancy of the particular criteria to a certain overarching criteria, and the results suggest that the sub-criteria choice give a proper representation of the overarching criteria in terms of their relative level of importance.

Subcriteria, level 3

The subcriteria, level 3 criteria, are only analyzed according to the classical AHP methodology. It was acknowledged that the pair-wise comparison of 23 different criteria was not only too time consuming for the respondents, but it is likely that it would result in intolerable large inconsistencies. In case the set of subcriteria is larger than two, only the consistent data-sets are used. The calculated weight factors are given in Figure 5.8.

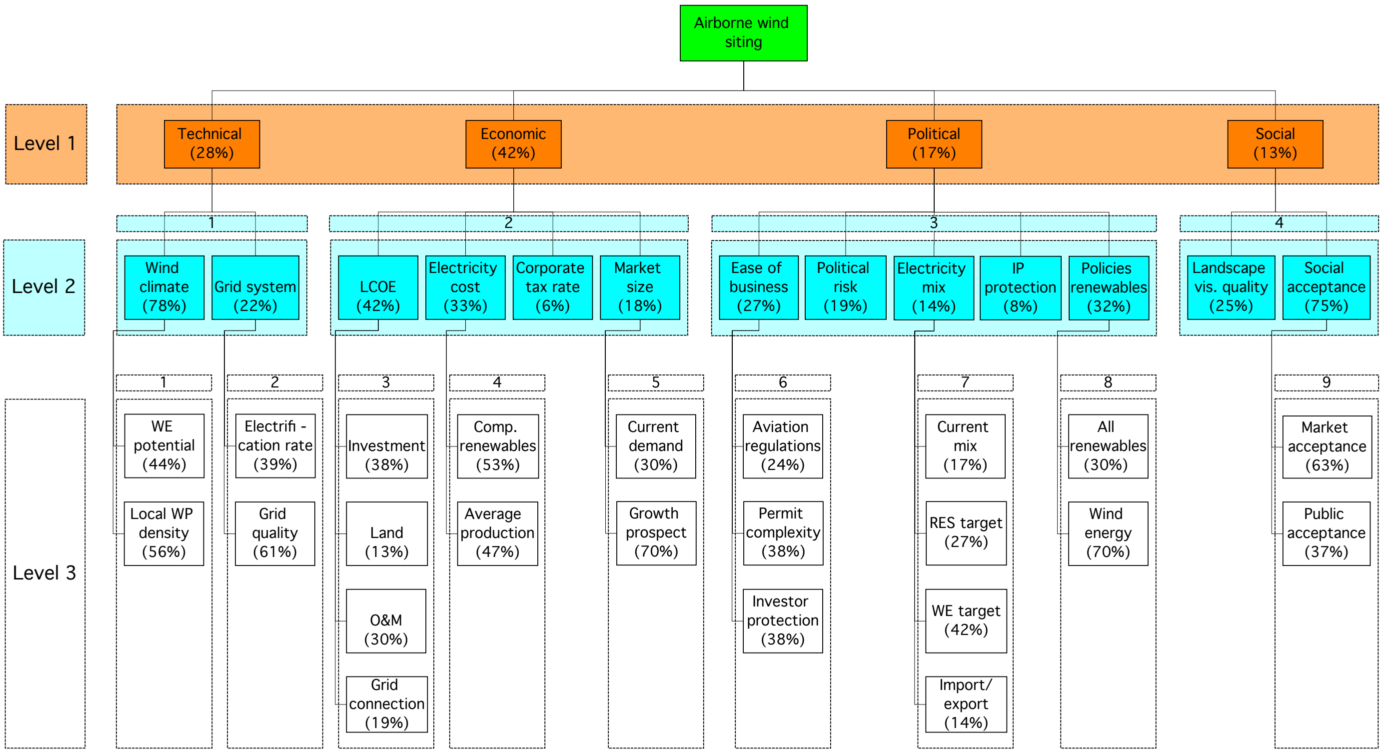


Figure 5.8: Flowchart weight factors including the calculated weight factors.

5.2.2 PROMETHEE preference functions

The complete PROMETHEE ranking of countries is based on the list of criteria given in Table 5.5, which follow from the set of criteria defined in the research methodology, see Table 4.4. In this analysis locations are analyzed on a national level. Hence the local level criteria are withdrawn from this analysis. Also the levelized cost of airborne wind energy criterion, the import/export of electricity, the level of standardized aviation regulations and the public acceptance are withdrawn from this analysis for various reasons:

- For the levelized cost of airborne wind energy, the investment and operations and maintenance cost per nation are highly unknown and no data is publicly available at this moment.
- No consensus exists about the relation between import/export of electricity and the opportunity for airborne wind deployment.
  - On the one hand, it can be argued that a nation prefers domestic generation of electricity in order to become electricity independent and prevent premium payments to its international electricity supplier. In that case a high degree of import of electricity creates an opportunity for airborne wind.

- On the other hand, it can be argued that a nation prefers to import some of its electricity. A nations could prefer to supply its own base loads and import electricity to account for peak loads. In this way a nation could have the highest capacity factors for its domestic electricity production plants. Following this reasoning, a high degree of import does not necessarily create an opportunity for airborne wind.

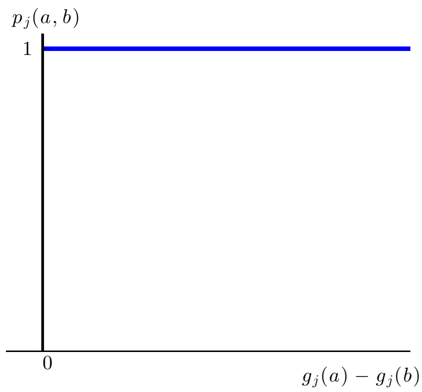
- Regarding the level of standardized aviation regulations; each nation is a member of the International Civil Aviation Organization (ICAO), which is responsible for the global aviation safety plan [210]. Therefore at this moment not distinction is made between the nations related to the level of standardized aviation regulations.

- The data for national public acceptance is only available for some European nations and lacking for many other nations. Therefore this criterion is not taken into account at this moment.

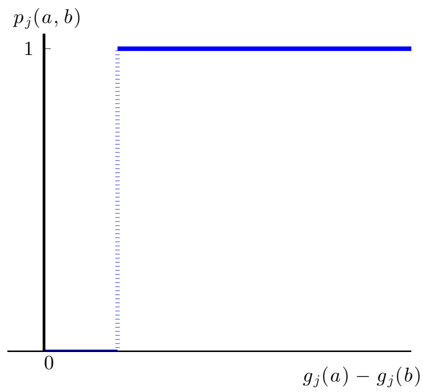
Table 5.5: Criteria applied in the MCDM, global level

	Criteria	**Sub-criteria**
Technical	Wind climate	Onshore wind energy potential
		Onshore maximum capacity factor
		Offshore wind energy potential
		Offshore wind speed
	Grid system	National electrification rate
		Grid downtime
Economic	Electricity price	
	Corporate tax rate	
	Market size	Current electricity demand
		Electricity consumption growth 2020
	Ease of doing business	Construction permits
		Strength of investor protection
Political	Policies for renewables	General renewables policies
		Specific wind energy policies
	Electricity portfolio	Renewables ex. hydro in portfolio
		General target renewables
		Specific wind energy target
	Political risk	
	IP protection	
Social	Social acceptance	Market acceptance

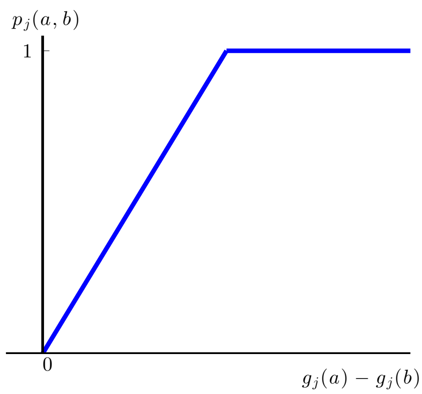
Each criterion is associated with one of PROMETHEE's preference function given in Figure 5.9.



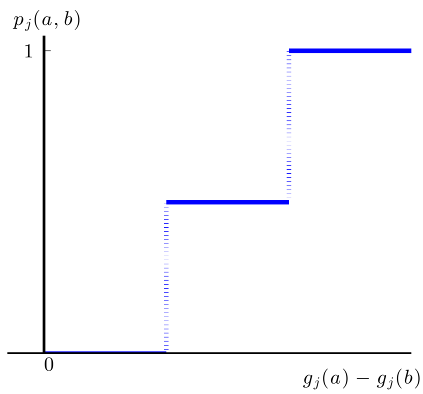
(a) Type I; usual criterion



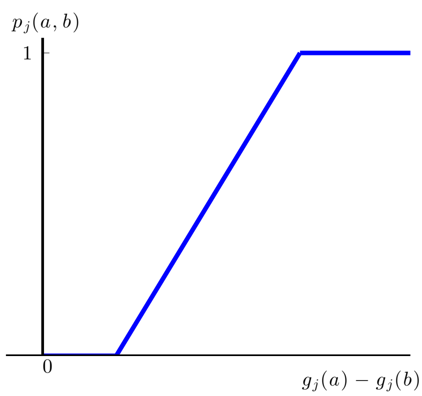
(b) Type II; u-shape criterion



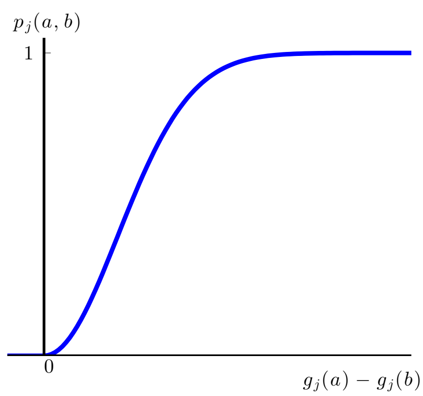
(c) Type III, v-shape criterion



(d) Type IV, level criterion



(e) Type V, linear criterion



(f) Type VI, Gaussian criterion

Figure 5.9: PROMETHEE preference functions

To choose the right preference function, the indifference (q) and preference (p) thresholds are introduced [224]:

- The indifference threshold represent the largest deviation that is considered as negligible in the comparison of two scores. The indifference threshold should at least be equal to the uncertainty of the data.
- The preference threshold is the smallest difference between two criteria scores that can be considered as definitely important. The preference threshold should as least be smaller than the difference between the maximum and the minimum values, the range of the criterion.

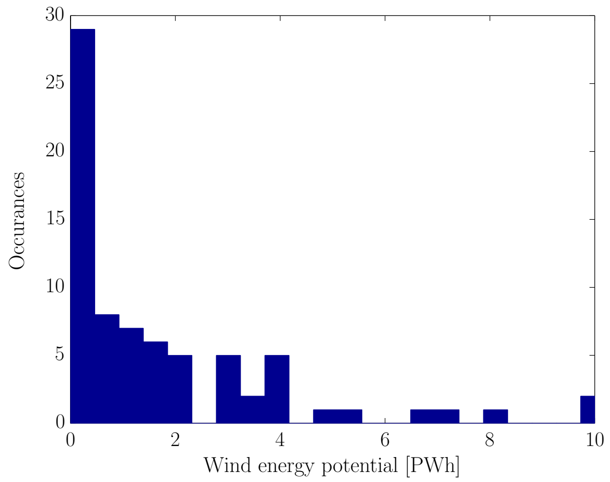
With these definitions for the indifference and preference threshold some guidelines for choosing the right preference functions are given by [225] as:

- For quantitative data, the v-shape (type III), the linear (type V), and the Gaussian preference functions are best suited. The linear preference functions includes an indifference threshold, whereas the v-shape preference function does not. The v-shape is best applicable to a dataset with low uncertainty, and in case any deviation has an impact on the preference for one of the alternatives. The Gaussian preference function is less often used, because it is more difficult to parameter.
- For qualitative data, the usual (type I), type u-shape (type II), and level (type IV) preference functions are best suited. The usual preference function is best applicable to a yes/no criteria. The level criterion is best applicable to differentiate smaller deviations from larger ones. The u-shape preference function is a special case of the level one.

Wind climate

To represent the wind climate, data is available for the onshore wind energy potential and capacity factor, and the offshore wind energy potential and wind speed category.

The onshore and offshore global wind energy potential in PWh/year is given by [191]. In this analysis only nations with a wind energy potential higher than 0.5PWh/year are given a non-zero value. The data histogram is given in Figure 5.10.



		[PWh/year]
1.	Russia	139
2.	Canada	99
3.	United States	88
4.	Australia	79
5.	Argentina	47
6.	China	44
7.	Kazakhstan	41
8.	Mongolia	17
9.	Sudan	15
10.	Mauritania	11
	Brazil	11
12.	United Kingdom	10
	Algeria	10
14.	Ukraine	8
15.	Chili	7

Figure 5.10: National wind energy potential

With this histogram a choice for preference function and, if necessary indifference and preference threshold is made. The data is quantitative and hence the v-shape, linear or Gaussian preference functions do best suit this data. In this early stage of the research, the increased complexity related to the parameterization of the Gaussian preference function is outside the scope of this research. The linear preference function is best applicable for datasets with a indifference and a preference threshold. The dataset contains only the wind energy potential in case values are the wind energy potential is higher than 0.5PWh/year. Hence this step-in value (0.5PWh/year) is equal to the uncertainty of the dataset and an indifference threshold is necessary. Recall that the maximum preference threshold is equal to the range of the dataset. Russia got the largest wind energy potential with 139PWh/year. The minimum is 0PWh/year for many nations. If a preference threshold equal to 139PWh/year would be applied, the preference of an arbitrary nation a with an wind energy potential equal to 10PWh/year with respect to nation b with 0PWh/year is calculated with equation 3.9 as:

$$p(a,b) = \frac{E_{\text{pot}}(a) - E_{\text{pot}}(b) - q}{p - q} = 0.07 \text{ (out of 1.00)} \tag{5.1}$$

A preference $p(a,b) = 0.07$ is only a slight preference in favor for nation a. However, this nation got a great potential for wind energy (top 12 in the world) and this slight preference is not representative for the preference of nation a with respect to nation b. To decrease the flattening effect of the few outliers, a preference threshold equal to $p = 10$PWh/year is chosen. Hence, if nation a got a wind energy potential larger or equal than $p + q = 10.5$PWh/year with respect to nation b, this nation got a preference $p(a,b) = 1.0$.

To summarize; for the wind energy potential, a linear preference function is applied with an indifference threshold, $q = 0.5$PWh and a preference threshold, $p = 10.0$PWh.

The histogram of the onshore capacity factor is given in Figure 5.11. The onshore capacity factor is based on Figure 5.2. The preferred preference function for the capacity factor is the linear (type V) preference function, because the data is quantitative and the data is grouped in mostly a 5% capacity factor range. Therefore the indifference threshold, $q = 5\%$. As shown in the histogram, and the accompanying table, two nations (Argentina and Iceland) got a maximum capacity factor equal to 81%. The capacity factor of the remaining nations is quite well distributed over the capacity factor range from $5\% - 51\%$, therefore the preference threshold is equal to this range, $p = 46\%$.

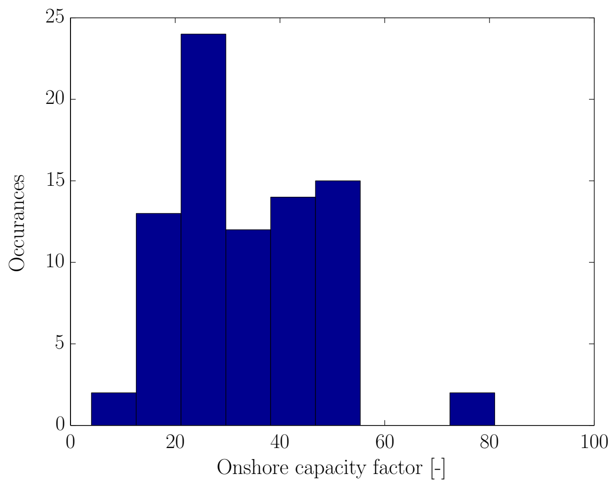


Figure 5.11: Onshore maximum capacity factor

		[%]
1.	Argentina	81
	Iceland	81
3.	Afghanistan	51
	Australia	51
	Brazil	51
	Canada	51
	Chili	51
	Colombia	51
	Denmark	51
	Germany	51
	Ireland	51
	Kazakhstan	51
	Kenya	51
	Madagascar	51
	New Zealand	51
	Russia	51
	United Kingdom	51
	United States	51

The offshore wind speed category is based on Figure 5.3, and categorized in the five categories given in Table 5.6. The limited number of groups make this dataset especially suitable for a level (type IV) preference function. Five different levels are chosen so represent the five categories. The histogram of the dataset is given in Figure 5.12.

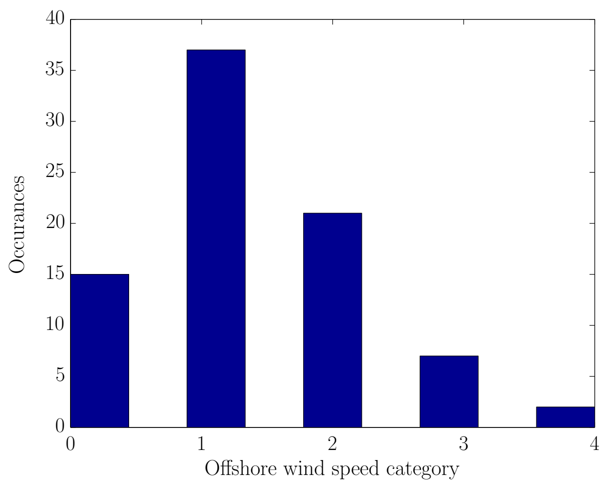


Figure 5.12: Onshore wind

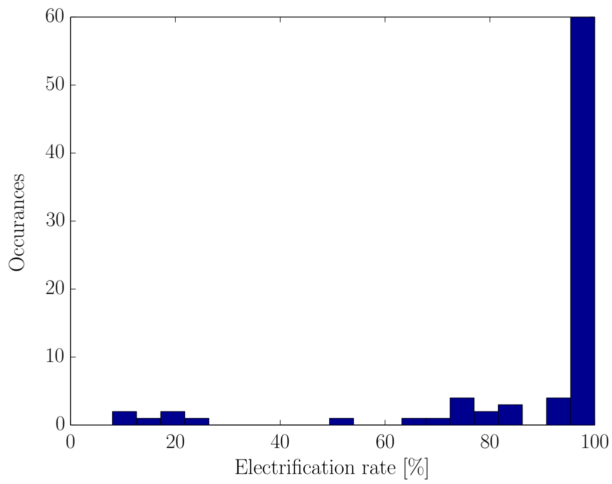
		[Cat.]
1.	Argentina	4
	Chili	4
2.	Australia	3
	Canada	3
	China	3
	Iceland	3
	New Zealand	3
	Russia	3
	South Africa	3
9.	Many nations	2
	...	

Table 5.6: Offshore wind speed categories

wind speed [m/s]	Category
< 8	0
$8 - 10$	1
$10 - 12$	2
$12 - 14$	3
> 14	4

Grid system

A histogram of the dataset for the electrification rate is given in Figure 5.13. Most nations got an electrification rate higher than 95%. However also some nations, especially African nations only got an electrification rate smaller than 50%. For this quantitative dataset, the linear preference function is most applicable. The data set is obtained from several sources, [5, 226, 227], and hence it is likely that some inconsistencies exist. Hence an indifference threshold equal to $q = 5\%$ is chosen. The preference threshold is chosen as $p = 50\%$ to include the differences in almost the entire dataset.

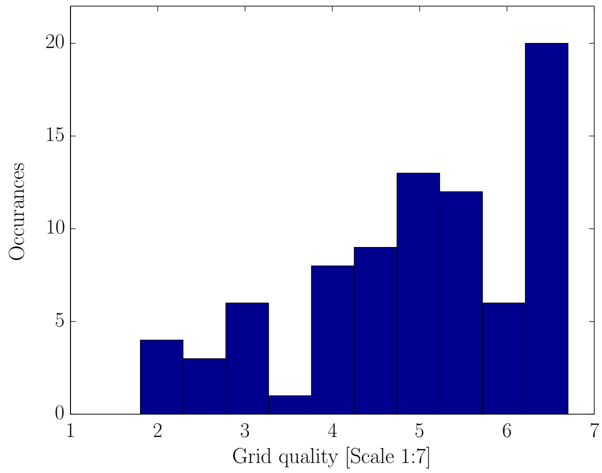


		[%]
70.	Sri Lanka	77
71.	India	75
	South Africa	75
73.	Indonesia	73
74.	Bolivia	71
75.	Pakistan	67
76.	Nigeria	50
77.	Ethiopia	23
78.	Madagascar	19
79	Kenya	18
80.	Tanzania	15
81.	Mozambique	12
82.	Uganda	8

Figure 5.13: Electrification rate

The grid quality is given by he World Economic Forum [228] as the quality of the electricity supply in terms of lack of interruptions and lack of voltage fluctuations. In this study experts rate the quality of the domestic quality of electricity supply with respect to the other countries, 1 = worse than in most other countries; 7 = meets the highest standards in the world. The fluctuations of the dataset is shown in Figure 5.14; the data ranges between 6.7 and 1.8, a difference of 4.9 points.

For this quantitative dataset with low uncertainty, the v-shape preference function is most applicable; a preference threshold equal to $p = 4.9$ is chosen to cover the entire range of data differences.



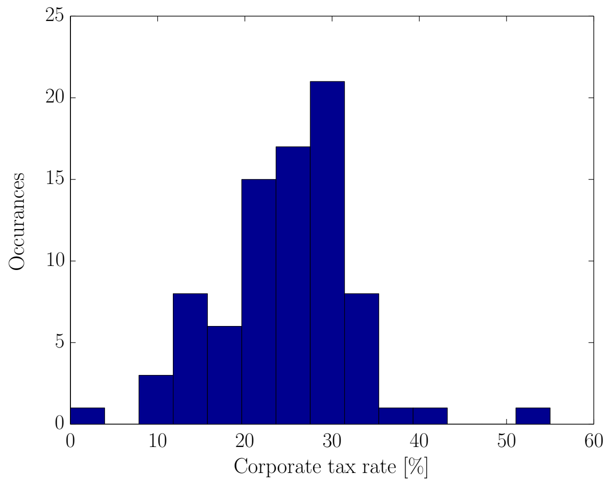
		[hours]
1.	Austria	6.7
	Denmark	6.7
	Finland	6.7
	Iceland	6.7
	United Kingdom	6.7
.	.	.
.	.	.
78.	Tanzania	2.3
79.	Dominican Republic	2.1
80.	Pakistan	2.0
81.	Venezuela	1.8
	Nigeria	1.8

Figure 5.14: Grid quality

Corporate tax rate

The corporate tax rate ranges from 0% in Bahrain up to 55% in the United Arab Emirates [229, 230]. As shown in the histogram, Figure 5.15, 95% of all analyzed nations got a corporate tax rate between 10% and 36%, a relative difference of 25%.

For this dataset with relatively low uncertainty, the v-shape preference function is most applicable with a preference threshold of 25%.



		[%]
1.	Bahrain	0
2.	Bosnia and Herzegovina	10
	Bulgaria	10
	Paraguay	10
5.	Moldova	12
	Oman	12
.	.	.
.	.	.
79.	Argentina	35
	Malta	35
80.	Japan	36
81.	United States	40
82.	United Arab Emirates	55

Figure 5.15: Data distribution corporate tax rate [229, 230]

Electricity portfolio

Three data entries are required to estimate the current and future electricity portfolio; the current share of renewables (excluding hydro), the target for renewables and a target of wind energy. The share of renewables excluding hydroelectric power generation is measure of the current willingness to incorporate innovative renewables into the electricity mix, and the targets are a measure of the future goals.

As shown in Figure 5.16, most nations got a limited share of renewables in their current electricity mix, and only 13 nations have a renewables share > 10%. Denmark got the maximum share of renewables, of these 42.4%, wind is responsible for 27.9% of the complete electricity mix [199].

For the share of renewables in the electricity portfolio quantitative dataset, the v-shape preference function is most applicable with a preference threshold equal to $p = 10\%$. The yes/no type of criteria for the renewables and wind energy target is best represented with the usual preference function.

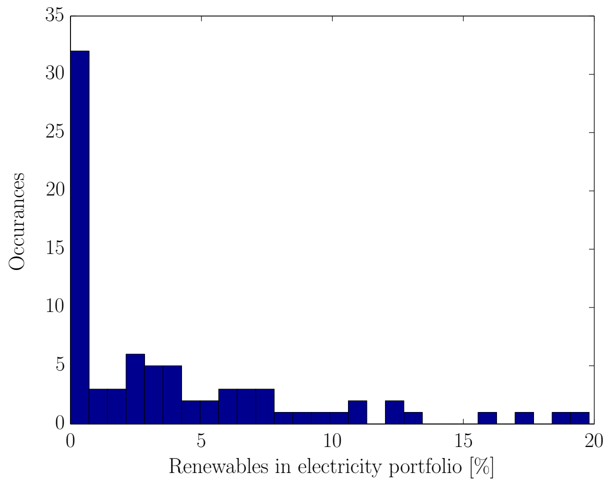


Figure 5.16: Renewables in electricity portfolio [199]

		[%]
1.	Denmark	42.4
2.	Guatemala	25.3
3.	Portugal	24.2
4.	Spain	19.3
5.	Germany	18.4
6.	Ireland	17.0
7.	Finland	16.2
8.	Lithuania	13.1
9.	Sweden	12.7
10.	the Netherlands	12.4
11.	Italy	11.2
12.	Austria	11.0
13.	Belgium	10.4
14.	Uruguay	9.3
15.	Estonia	8.9

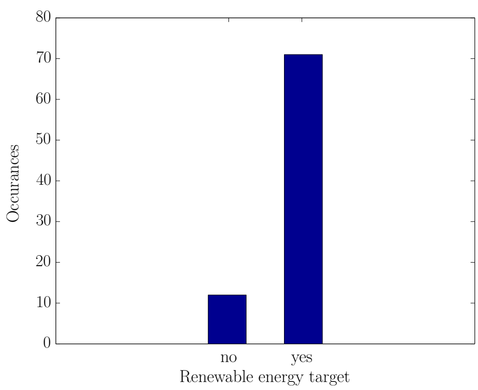


Figure 5.17: Renewables target [5, 202]

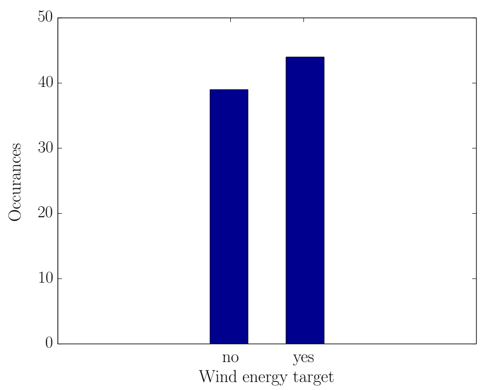


Figure 5.18: Wind energy target [5, 202]

Renewable energy support schemes

There exist a diverse set of renewable energy (financial) support schemes, e.g. Feed-In Tariffs (a guaranteed rate that provides stable prices through long-term contracts for energy generated), tradable renewable energy certificates (RECs), capital subsidies, tax incentives, public investment loans etcetera. The renewable energy policy network for the 21st century (REN21) has organized these different support schemes into three categories: (1) regulatory policies, (2) fiscal incentives and (3) public financing [5, 202]. To use this data for the analysis, a nation can get a score between 0 and 3, depending on number of support scheme categories in force. A histogram on this data for general renewable energy policies and specific wind energy policies in given in Figures 5.19 and 5.20.

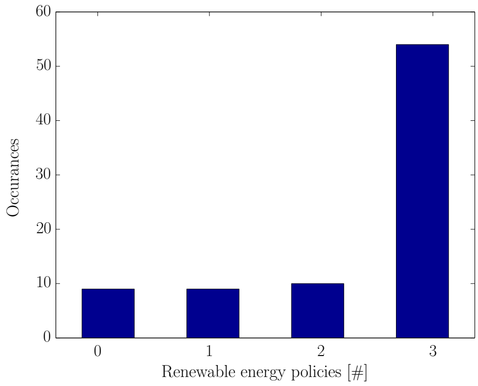


Figure 5.19: Renewables support schemes [5, 202]

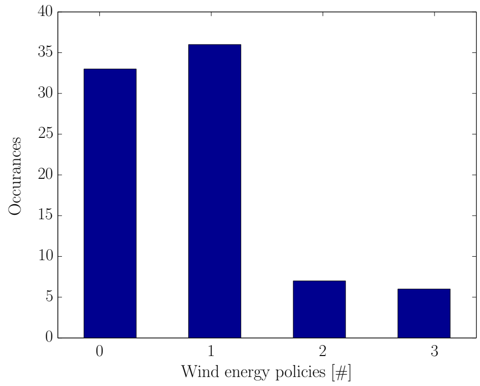


Figure 5.20: Wind energy support schemes [5, 202]

As shown in these histograms, more than 50 out of the 82 analyzed nations have all three types of renewable energy policies into place. However only 5 nations for all three specific wind energy policies into place. These nations are China, Estonia, Finland, France, India and the United Kingdom.

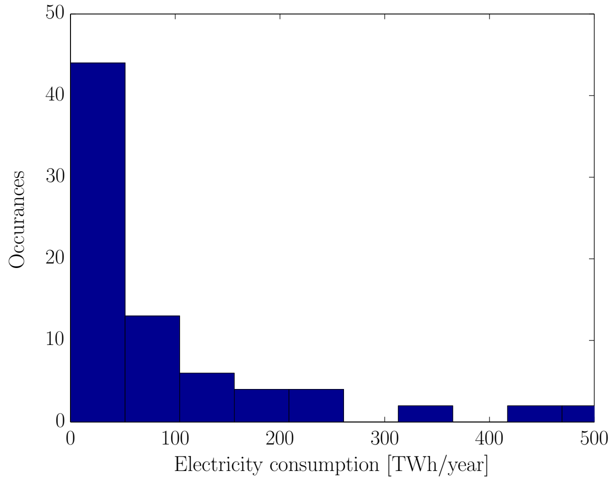
For this quantitative, step-wise data, the level criteria is best applicable. Four different levels are applied to allow a score ranging between 0 and 3.

Market size

Airborne wind turbines' sole function is to generate electricity and hence the size of the market is measured with the current electricity consumption and the electricity demand growth prospect.

China and the United States consume most electricity. However, the electricity consumption per nation varies considerably as shown in Figure 5.21. The national annual electricity consumption is less than 200TWh for about 90% of all analyzed nations and less than 50TWh for more than 50% of the nations represented in the dataset.

For this quantitative dataset, the v-shape preference function is best applicable. To be able to distinguish also the preference differences for the smaller markets a preference threshold equal to $p = 200$TWh is chosen.

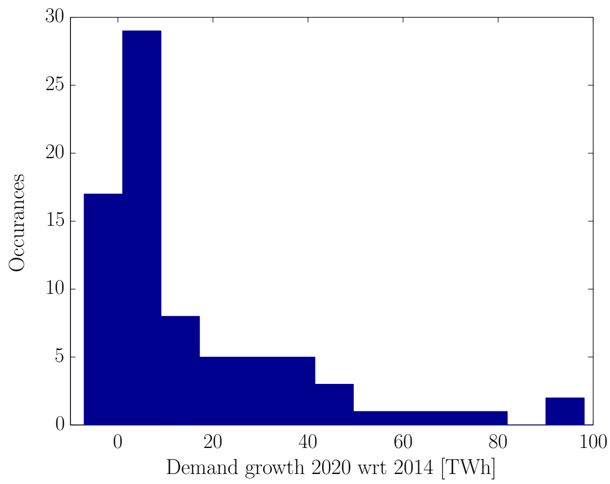


		[TWh]
1.	China	4,693
2.	United States	3,886
3.	Russia	1,038
4.	Japan	859
5.	India	699
.	.	.
.	.	.
78.	Jamaica	3
79.	Mauritius	2
80.	Uganda	2
81.	Malta	2
82.	Madagascar	1

Figure 5.21: Electricity consumption [231]

The four economic upcoming BRIC countries (Brazil, China, India and Russia) are ranked in the top 5 based on the electricity demand growth prospect. The United States completes this top 5. Some nations, especially European nations are characterized with a (small) negative electricity demand growth prospect. The demand growth for about 90% of the nations is less than 50TWh in 2020 with respect to 2014 as shown in Figure 5.22.

For this quantitative dataset, the v-shape preference function is best applicable with a preference threshold equal to $p = 50$TWh.



		[TWh]
1.	China	2,421
2.	United States	525
3.	India	507
4.	Russia	170
5.	Brazil	140
.	.	.
.	.	.
78.	Jamaica	-1
79.	Norway	-1
80.	Belgium	-2
81.	France	-3
82.	Germany	-7

Figure 5.22: Electricity demand growth prospect [200]

Ease of doing business

The ease to do doing business in a particular nation simplified to two factors; permit complexity and strength of investor protection.

The permit complexity is split into the number of procedures to obtain a building permit and time required to obtain a building permit. Specific wind energy farm permit complexity data is unavailable. Therefore the general world bank data is used, at which the number of procedures and time required are determined to obtain approvals to build a commercial warehouse and connect it to water, sewerage and a fixed telephone line. This includes all the inspects and certificates [211]. The histograms of the data sets for the number of procedures and time required are respectively given in Figures 5.23 and 5.24. On average 15 procedures are required to obtain a building permit and 90% the data is between 7 and 24 procedures, a difference of 17 procedures. The average time required to obtain a building permit is about half a year, 167 days. About 90% of the data is covered between 67 and 267 days, a difference of 200 days.

For both quantitative dataset, the v-shape preference function is best applicable; for the number of procedures a preference threshold equal to $p = 17$ procedures is applied, for the time required $p = 200$ days is applied.

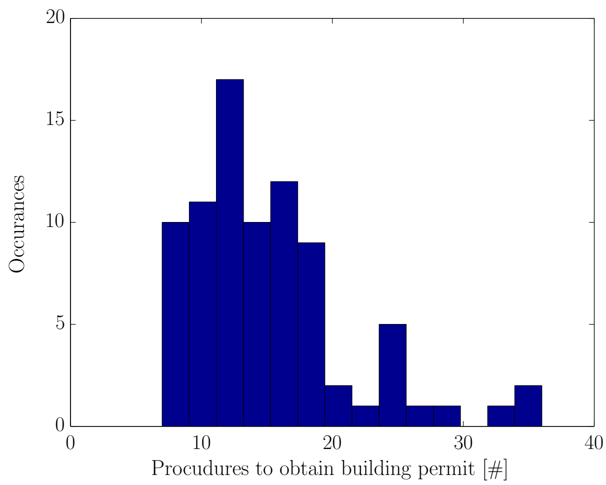


Figure 5.23: Number of procedures to obtain building permit [211]

		[#]
1.	Sweden	7
2.	Colombia	8
	Denmark	8
	Jamaica	8
6.	Cyprus	9
	Ethiopia	9
	France	9
	Germany	9
	Kenya	9
	Spain	9
.	.	.
.	.	.
76.	China	25
	Philippines	25
78.	Moldova	26
79.	Kazakhstan	29
80.	Czech Republic	33
81.	India	35
82.	Russia	36

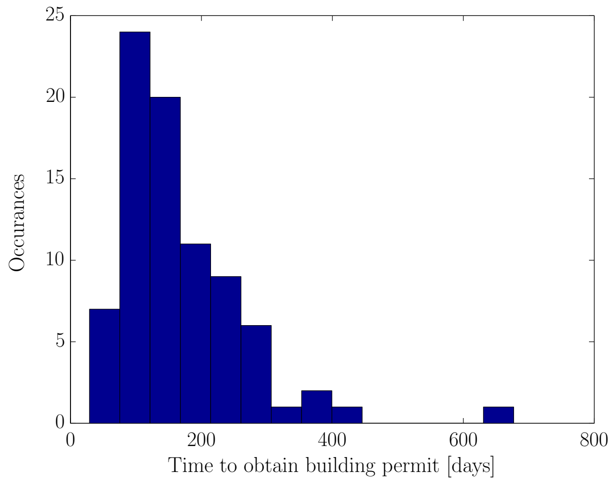


Figure 5.24: Time to obtain building permit [211]

		[days]
1.	South Korea	29
2.	United Arab Emirates	44
3.	Colombia	54
4.	Bahrain	60
5.	Finland	66
6.	Denmark	67
7.	Ukraine	73
.	.	.
.	.	.
76.	Moldova	291
77.	Russia	297
78.	Croatia	317
79.	Argentina	365
80.	Venezuela	381
81.	Brazil	400
82.	Cyprus	677

The strength of investor protection is a measure of the strength of shareholder protection agains directors' misuse of corporate assets for personal gain. This investor protection is measured by (1) transparency of related-party transaction, (2) liability for self-dealing, and (3) the shareholders' ability to sue officers and directors for misconduct [212]. Each of these three factors account for one third to the strength of investor protection. Again no specific wind energy project data is available and hence the general investor protection from the world bank is used as a first approximation. The strength of investor protection is measured as a scale from 1:10, about 90% of the data is ranged between 4.0 and 8.0 as shown in Figure 5.25.

For this quantitative dataset the v-shape preference function is applicable, a preference threshold equal to $p = 4.0$ is chosen.

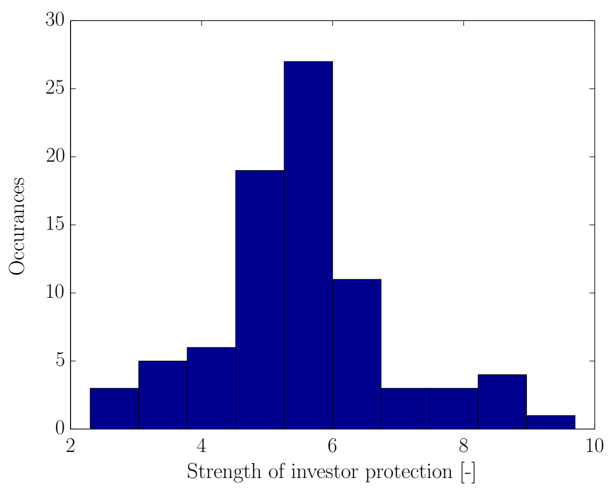


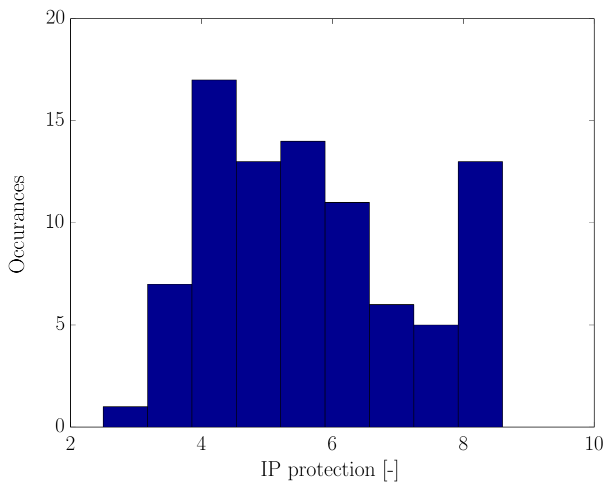
Figure 5.25: Strength of investor protection [212]

		[-]
1.	New Zealand	9.7
2.	Canada	8.7
3.	Colombia	8.3
	Ireland	8.3
	United States	8.3
6.	South Africa	8.0
	United Kingdom	8.0
.	.	.
.	.	.
75.	Egypt	3.7
76.	Croatia	3.3
	Ethiopia	3.3
	Guatemala	3.3
	Vietnam	3.3
80.	Costa Rica	3.0
	Honduras	3.0
82.	Venezuela	2.3

Intellectual property protection

The level of intellectual property right protection is measured at a scale 1:10 and is a combination of the protection of intellectual property rights, patent protection and copyright piracy [213]. In general the well developed nations are characterized by a higher level of intellectual property right protection. From the histogram of the level of intellectual property right protection dataset, Figure 5.26, follows that the average score is 5.8, the minimum score is 2.5 and the maximum score is 8.6; a range of 6.1, without major outliers.

For this quantitative dataset the v-shape preference function is best applicable and a preference function equal to the range is chosen, $p = 6.1$.



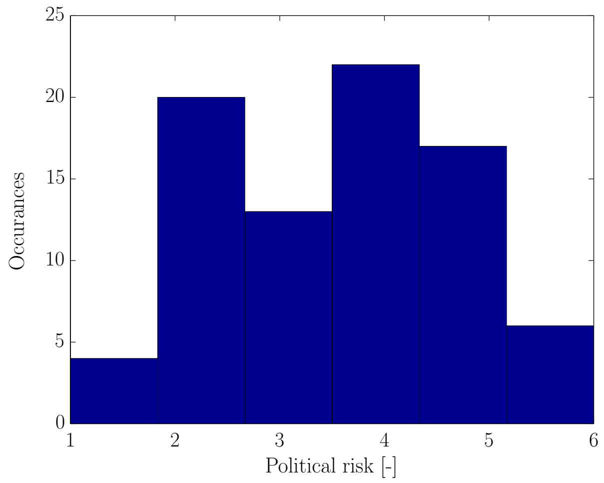
		[-]
1.	Finland	8.6
2.	Japan	8.3
	the Netherlands	8.3
	United Kingdom	8.3
	United States	8.3
	Japan	8.3
.	.	.
.	.	.
78.	Kazakhstan	3.5
	Bosnia and Herzegovina	3.5
80.	Venezuela	3.4
81.	Algeria	3.4
82.	Moldova	2.5

Figure 5.26: IP protection [213]

Political risk

The national political risk index includes data regarding the risk on conflict, terrorism, macroeconomic stability, the rule of law, and regulatory and business environments. In general Northern American and European nations are characterized by low political risk, whereas African, South American and Asian nations generally are characterized by a higher political risk index. Also the upcoming BRIC nations got a risk index of medium to high risks. The risk indices range between 1-8, 8 meaning an extreme risk; an extreme political risk index is given for nations like Somalia and Syria, but these nations are not subject in the current analysis; these nations lack other data. The range of risk indices in the complete dataset is between 1-6 as shown in Figure 5.27.

For this dataset the level preference function is applied with scores between 1 and 6.



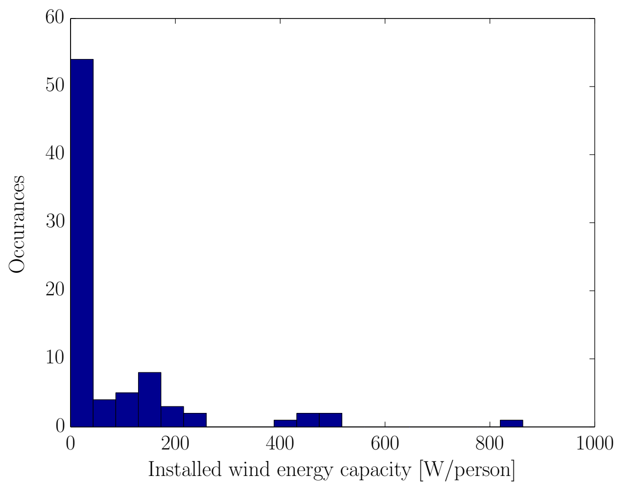
		[-]
1.	Estonia	1
	Finland	1
	New Zealand	1
	Norway	1
5.	Many nations	2
.	.	.
.	.	.
77.	Algeria	6
	Egypt	6
	Nigeria	6
	Pakistan	6
	Russia	6
	Venezuela	6

Figure 5.27: Political risk data distribution [209]

Social acceptance

The social acceptance in this stage is only measured with the market acceptance. As an approximation to the market acceptance of wind energy, the installed capacity per capita is applied. This list is dominated by western European nations; the entire top 6 consist of western European nations. However also Canada and the United States can be found in the top 10, with an installed capacity equal to respectively 226.2 W/capita and 195.1 W/capita, by the end of 2013. However more than half of the nations got an installed capacity less than 20 W/capita as shown in Figure 5.28 and about 90% of the nations has an installed capacity less than 200 W/capita.

For this quantitative dataset with major outliers, the v-shape preference function is chosen with a preference threshold equal to $p = 200$W/capita.



		[W/capita]
1.	Denmark	862.9
2.	Sweden	491.8
3.	Spain	491.1
4.	Portugal	439.0
5.	Ireland	436.1
6.	Germany	425.4
7.	Canada	226.2
8.	Estonia	218.2
9.	Austria	204.9
10.	United States	195.1
11.	Greece	173.3
12.	United Kingdom	168.0
13.	Norway	163.7
14.	the Netherlands	159.9
15.	Belgium	158.3
16.	New Zealand	145.2

Figure 5.28: Installed wind energy capacity per capita

5.3 Data processing

Data processing with spreadsheets such as Microsoft Excel, Libre Office Calc or Google Docs Spreadsheet is an intuitive approach, because the input and output data is always presented. However, the pair-wise comparison of 82 nations results in an 82x82 matrix. For 19 criteria, this would results in 19 of these matrices, which all need to be analyzed in a later stage again. For such large data sets and matrix multiplications the technical computing program Matlab is especially useful and therefore a Matlab script ranks the nations based on the input data and the PROMETHEE ranking methodology. The layout of this script is given in Figure 5.29.

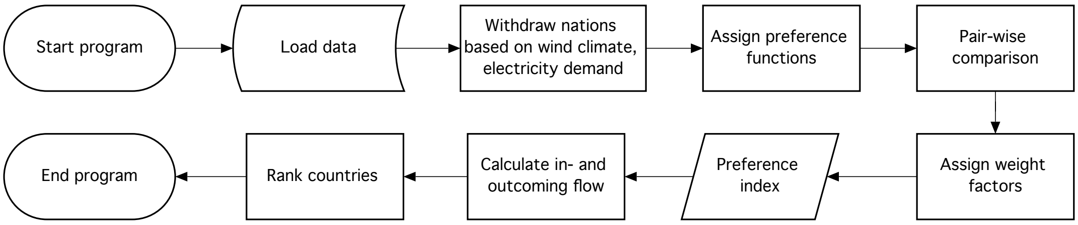


Figure 5.29: Flowchart PROMETHEE data processing

First the data is loaded in the program. These are the scores of each nation on each individual criterion. Next the nations which lack the minimum required wind climate or the minimum required electricity demand are withdrawn from further analysis. For the remaining criteria the preference functions including the indifference threshold and the preference threshold are assigned and the criteria scores are pair-wise compared according to the assigned preference functions. Next the weight factors are assigned to the criteria and the preference index for each nation with respect to the other nations is calculated, see section 3.3.1 for more details and recall equation 3.12.

$$\pi(a,b) = \frac{1}{k}\sum k_j p_j(a,b)$$

From the preference index, the out-coming and in-coming flow is calculated. Recall from section 3.3.1 that the out coming flow is defined as the dominance of an action a with respect to its alternative and the incoming flow is the degree to which a is dominated by its alternatives, recall equations 3.13 and 3.14:

$$\phi^+(a) = \sum \pi(a,b)$$
$$\phi^-(a) = \sum \pi(b,a)$$

With the incoming and out coming flow the countries are ranked according to the PROMETHEE II ranking. The net flow is calculated as the difference between the out-coming and in-coming flow. A high degree of net-flow is results in a high ranking.

$$\phi^{\text{net}}(a) = \phi^{+}(a) + \phi^{-}(a) \tag{5.2}$$

5.4 Conclusions

In the conjunctive screening phase the number of nations is limited from 193 to 82. A total of 50 nations lack sufficient wind resources, 31 nations lack electricity demand for the deployment of a 100MW airborne wind farm. Another 24 nations were withdrawn from further analysis, because of data unavailability. A PROMETHEE analysis, at which these data fields were excluded, showed that none of these nations are expected to have a high opportunity for airborne wind.

In the PROMETHEE-AHP analysis the weight factors calculated with the adjusted AHP method were similar to the classical AHP method, which gives trust in the application of adjusted AHP. This method showed that level 1 criteria - technical, economic, political and social - are well represented by the level 2 criteria. This verification step was unavailable with the classical AHP method. The economic criteria are seen as most important followed by the technical, the political and social criteria. Next, the PROMETHEE preference functions for each data field is determined which finished the model building and a complete PROMETHEE ranking of nations based on their opportunities for airborne wind can be made.

Chapter 6

Results and analysis

In the previous chapter, the conjunctive screening phase has limited the amount of nations and set the model for the PROMETHEE-AHP multi criteria analysis. It is the goal of this chapter to present the ranking results and also to analyze these. In section 6.1 the complete ranking of nations is given including the corresponding PROMETHEE scores. In section 6.2 the consistency indices of the respondents' answers to the weight factor survey are given. In section 6.3 the sensitivity of the results are determined for data inaccuracies, the preference function's threshold values, time dependency and weight factor inaccuracies. In section 6.4 the ranking is made with equal weight factors for all criteria to show the (ir)relevance of the extensive weight factor expert survey. In section 6.5 the generalizability of the results is discussed. In section 6.6, the results are compared to the historical and recent activity in (airborne) wind to determine the results of this study for airborne wind with respect to the real world trends. Finally in section 6.7 the conclusions of this chapter are given.

6.1 PROMETHEE scores

The PROMETHEE scores and the ranking is first given while excluding the national average electricity production cost. Gathering this data for all nations was too costly. Next for the top nations the average power generation cost are included.

6.1.1 Excluding electricity production cost

The ranking of nations for airborne wind farm deployment opportunity is given in Table 6.1. India's rank at the 26th position catches the eye. This nation got a significant amount of current installed wind energy capacity; the fifth largest in the world, and the fourth largest added installed capacity in the last three years. To

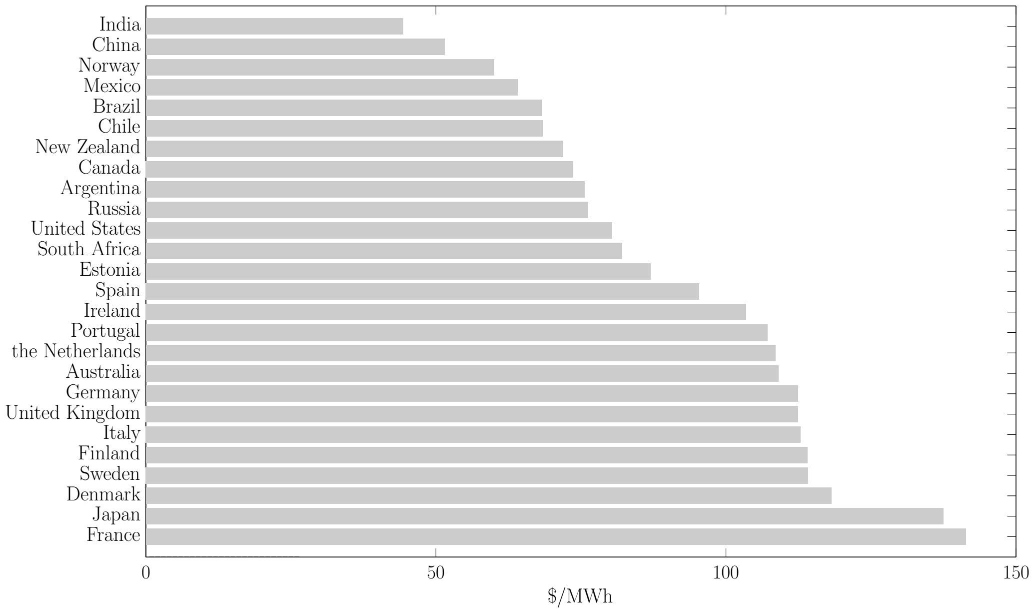


Figure 6.1: Electricity production cost for the top 26 nations [199, 232]

determine the possible effect of the electricity cost criterion, assume India's electricity production cost are infinity high. Even then India would not be ranked in the top 5 nations; India would be ranked seventh. Therefore it is assumed that including the levelized cost of electricity for the top 26 nations is sufficient to calculate the high potential nations.

6.1.2 Results including electricity production cost

For many nations data is lacking considering the average price of electricity generation and gathering this data is costly and time consuming. Therefore, only for the most promising nations an average electricity production price is calculated. Bloomberg's estimates for the technology specific levelized cost of electricity [232] is used in combination with the electricity mix to determine the average cost of electricity production [199]. In case data was available for a specific nation, this nation specific data was used. In case this data was lacking, the regional average was applied. Three regions were specified in the dataset: the Americas, Europa, and Asia and Pacific. The calculated electricity production costs are given in Figure 6.1.

From Figure 6.1 follows that, from the nations analyzed, the electricity production cost of France and Japan are highest. These hight costs in France are caused by a combination of welfare (with respect to nations like China, Brazil and Russia) and a 75% use of nuclear energy, which is an expensive technology. In Japan the costs for hydro power (accounting for 8% of total electricity generation), nuclear power (25%) and gas (25%) are relatively high. The average electricity production costs in India and China are cheapest, because of the use of relatively cheap coal fired plants.

Table 6.1: Ranked nations for the opportunities for the deployment of AWTs, excluding electricity production cost

	Nation	ϕ^{net}		Nation	ϕ^{net}
1.	Canada	100.00	42.	Philippines	29.69
2.	United States	96.84	43.	Cyprus	29.03
3.	Australia	84.15	44.	Luxembourg	29.01
4.	United Kingdom	83.03	45.	Egypt	28.82
5.	China	74.25	46.	Latvia	27.58
6.	Russia	69.42	47.	United Arab Emirates	27.15
7.	Germany	68.30	48.	Algeria	27.13
8.	Denmark	67.52	49.	Bulgaria	26.48
9.	Argentina	66.38	50.	Czech Republic	25.74
10.	Ireland	65.50	51.	Mauritius	24.64
11.	Spain	63.37	52.	Morocco	24.09
12.	New Zealand	57.82	53.	Indonesia	23.65
13.	Brazil	57.51	54.	Kenya	23.03
14.	Sweden	56.83	55.	Jamaica	22.55
15.	France	55.36	56.	Bosnia and Herzegovina	21.57
16.	Finland	53.52	57.	Croatia	20.48
17.	Portugal	52.98	58.	Guatemala	20.44
18.	Chile	52.19	59.	Hungary	19.96
19.	the Netherlands	51.73	60.	Kuwait	19.65
20.	Estonia	50.97	61.	Sri Lanka	19.32
21.	Norway	50.92	62.	Oman	18.92
22.	Japan	50.21	63.	Dominican Republic	18.89
23.	South Africa	49.39	64.	Ecuador	18.37
24.	Italy	46.95	65.	Costa Rica	18.33
25.	Mexico	45.53	66.	Peru	18.09
26.	India	43.15	67.	Madagascar	17.38
27.	Poland	42.37	68.	Venezuela	16.65
28.	South Korea	41.64	69.	Pakistan	15.54
29.	Belgium	41.53	70.	Malta	14.76
30.	Turkey	41.23	71.	Bahrain	13.58
31.	Iceland	41.00	72.	Trinidad and Tobago	13.07
32.	Austria	40.96	73.	Panama	11.64
33.	Kazakhstan	39.29	74.	Mozambique	11.19
34.	Colombia	37.77	75.	Paraguay	10.17
35.	Greece	36.40	76.	Moldova	9.55
36.	Lithuania	34.35	77.	Nigeria	9.23
37.	Vietnam	33.49	78.	Ethiopia	9.20
38.	Romania	32.43	79.	Honduras	7.57
39.	Ukraine	31.61	80.	Bolivia	6.16
40.	Saudi Arabia	31.14	81.	Uganda	4.13
41.	Uruguay	30.91	82.	Tanzania	0.00

Table 6.2: Ranked nations for the opportunities for the deployment of AWTs, including and excluding electricity production cost

Including electricity cost			Excluding electricity cost		
	Nation	ϕ^{net}		**Nation**	ϕ^{net}
1.	United States	100.00	1.	Canada	100.00
2.	Canada	99.37	2.	United States	94.44
3.	Australia	84.96	3.	Australia	72.13
4.	United Kingdom	82.68	4.	United Kingdom	70.15
5.	Denmark	78.77	5.	China	54.71
6.	Germany	74.13	6.	Russia	46.22
7.	Ireland	64.79	7.	Germany	44.23
8.	Russia	59.83	8.	Denmark	42.87
9.	France	59.53	9.	Argentina	40.85
10.	Sweden	54.37	10.	Ireland	39.31
11.	Spain	53.83	11.	Spain	35.57
12.	China	53.73	12.	New Zealand	25.79
13.	Argentina	50.36	13.	Brazil	25.25
14.	Japan	49.37	14.	Sweden	24.06
15.	Portugal	46.36	15.	France	21.47
16.	Finland	43.68	16.	Finland	18.23
17.	the Netherlands	36.90	17.	Portugal	17.29
18.	Brazil	29.35	18.	Chile	15.89
19.	New Zealand	28.23	19.	the Netherlands	15.09
20.	Estonia	26.14	20.	Estonia	13.75
21.	Italy	26.02	21.	Norway	13.66
22.	South Africa	21.18	22.	Japan	12.41
23.	Chile	20.91	23.	South Africa	10.98
24.	Norway	14.08	24.	Italy	6.68
25.	Mexico	7.37	25.	Mexico	4.18
26.	India	0.00	26.	India	0.00

The difference between the highest and the lowest electricity generation cost is equal to 97$/MWh. For this dataset at which some assumptions lead to uncertainties, the linear preference function is best applicable. The indifference threshold is equal to 10$/MWh and the preference threshold is equal to 97$/MWh.

The top 26 nations including the electricity consumption are ranked in Table 6.2.

From Table 6.2 follows that the top 4 nations for the deployment of airborne wind energy excluding the electricity production cost are also the top 4 nations in case the electricity production costs are included. However Canada and the United States have switched positions. China's low cost of electricity production, after India the lowest of the analyzed nations, leads to a major shift from the fifth to the twelfth position.

6.2 Weight factor survey consistency check

Recall that the weight factors are calculated with two expert surveys. The consistency of these matrices is checked with the consistency index as explained in section 4.3.3. By definitions, the pair-wise comparison of two criteria is always consistent. Therefore the consistency index is calculated for all sets with more than two criteria; one consistency check for the level 1 criteria, two consistency checks for the level 2 criteria and 4 consistency checks for level 3 criteria. In general a maximum inconsistency of 10% is allowed, and also recommend by the founder of AHP Saaty [158]. In case the level of inconsistency is too high, several studies have introduces methods to decrease the degree of inconsistency [233, 234]. Alternatively, other studies have shown that an inconsistency of 15% can be allowed [235–237].

In this study a significant amount of replies with an inconsistency between 10% and 15% was calculated. Two different methods were applied to calculate the weight factors, allowing the comparison of the results. In case the larger inconsistencies result in intolerable differences in weight factors, the degree of maximum allowable inconsistency degree could be decreased. However, the calculated weight factors were similar in both studies, hence the studies from [235–237] were followed and a maximum inconsistency degree of 15% is applied.

The inconsistency indices of the individual pair-wise comparisons of the level 1 criteria are given in Figure 6.2. Out of 21 completed surveys, 11 were filled out with an inconsistency less than 15%.

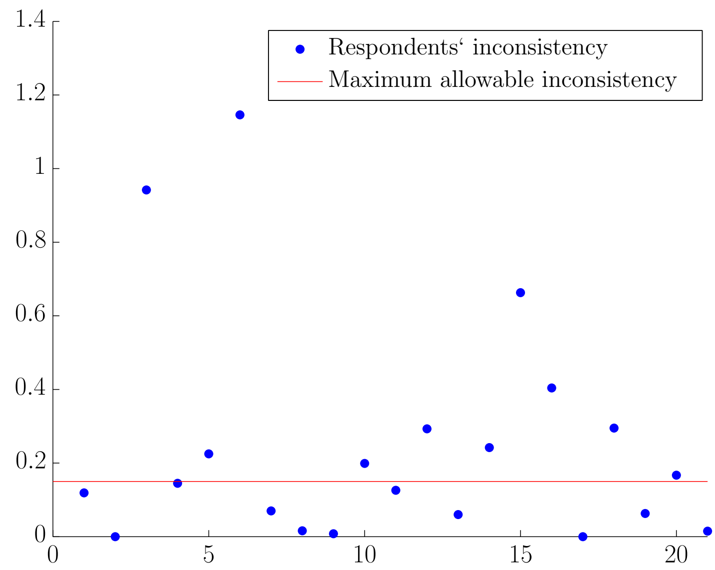


Figure 6.2: Inconsistency check for the level 1 criteria, a 0.15 inconsistency is maximum allowed.

The inconsistency of the two sets of level 2 criteria at which more than two criteria are pair-wise compared is illustrated in Figures 6.3 and 6.4.

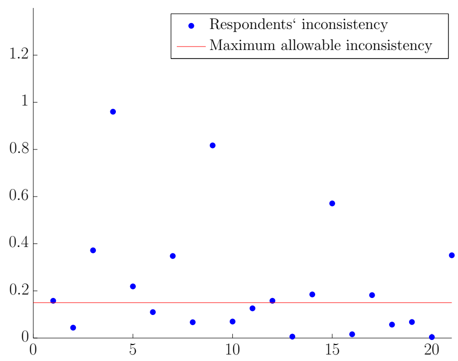


Figure 6.3: Inconsistency check for the level 2 economic subcriteria.

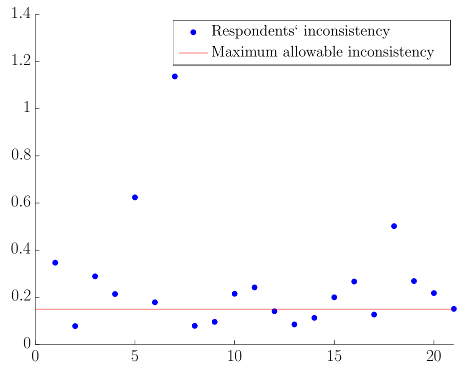


Figure 6.4: Inconsistency check for the level 2 political subcriteria

Figures 6.3 and 6.4 represent the degree of inconsistency of the adjusted AHP methodology. Out of 21 completed surveys, the economic and political set of criteria were respectively 10 and 8 times filled in with an inconsistency less than 15%. These 4x4 and 5x5 matrices were determined from the 13x13 pair-wise comparison matrix. Also the degree of inconsistency is calculated for the classical AHP methodology surveys. These surveys got similar results regarding the degree of inconsistency. Out of 16 completed surveys, the pair-wise comparison of 5 economic and 8 political sets of criteria were within the 15% inconsistency. For the level 3 criteria, the degree of inconsistently is similar to the results from the level 1 and level 2 criteria.

6.3 Sensitivity analysis

In most multi-criteria analyses the stability of the results agains the subjectivity of the experts judgements are tested with a sensitivity analysis by adjusting the weight factors [105, 238, 239]. Additionally the sensitivity for data inaccuracies, time dependency, and the preference function's threshold values can be analyzed [240–244]. All these sensitivity analyses are performed next.

6.3.1 Data inaccuracies

Sensitivity analyses for data inaccuracies are applied for PROMETHEE ranking in various studies. Generally data variances of 10% up to 30% are applied [241–244]. Following these approaches the quantitative data of some nations is varied with ±30%. However, for some qualitative or boxed data this approach is not feasible, and another approach is applied:

- offshore wind speed, wind energy support schemes and renewables support schemes, this data is categorized in respectively 4, 5 and 5 categories. To determine the effect of data inaccuracies the nation is categorized 1 box higher and lower than the original.

- renewables target and wind energy target, this data is categorized as 'yes/no'. The nations subject to this sensitivity analysis have a renewables and wind energy target and the effect is investigated if no target was specified.

To analyze the effect of data inaccuracies on the overall ranking, the data of two nations with a characteristic ranking position are analyzed; Canada and Germany.

Canada

Canada is ranked second according to Table 6.2. The difference with the United States (1) is only 0.63 PROMETHEE points, whereas the gap with Australia (3) is 14.41. It is interesting to determine if data inaccuracies can change the position of Canada either up or down. The relatively large gap between Canada and Australia make Canada an interesting test case; in case data inaccuracies do not results in a ranking shift between Australia and Canada, the top two positions of United States and Canada are insensitive to data inaccuracies. The results of this sensitivity analysis for data inaccuracies is given in Figure 6.5.

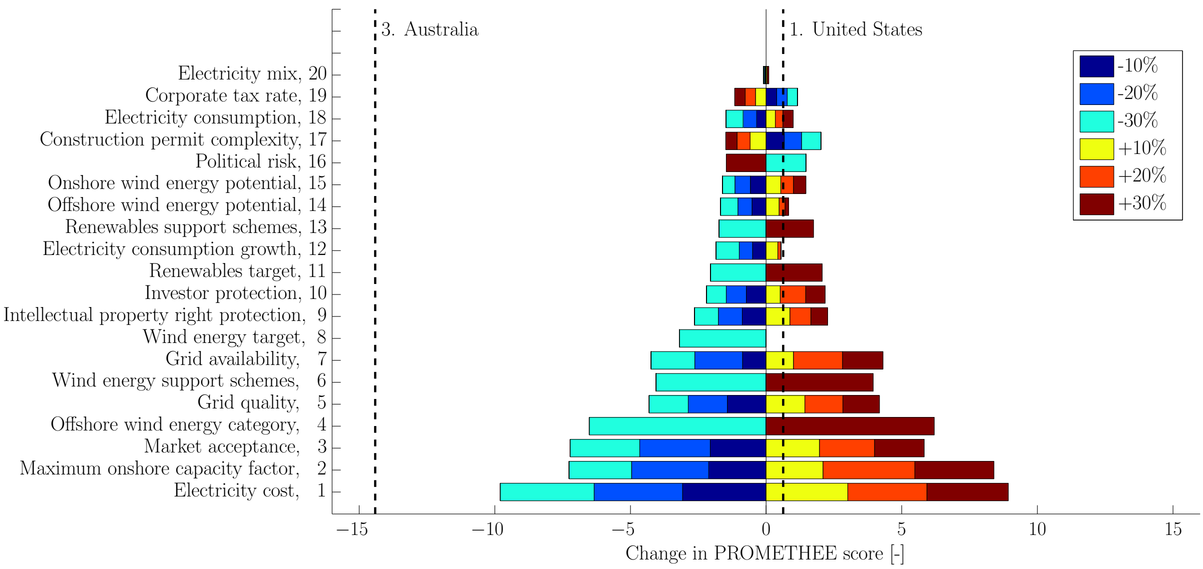


Figure 6.5: Sensitivity analysis for data inaccuracies; the quantitative data fields of Canada are varied with ±30%. For the qualitative and boxed data a different approach is taken as described in section 6.3.1. The dashed lines represent the required difference in score in order to switch ranking position with the specified nation.

From Figure 6.5 follows that:

- Only data inaccuracies of ±30% in the fields electricity cost, maximum onshore capacity factor, market acceptance and offshore wind energy category can result in PROMETHEE score differences of more than 5.00 points.

- The ranking position of Canada with respect to the United States (and vice versa) is very sensitive to data inaccuracies; for most data field inaccuracies of ±10% can already cause this ranking shift.
- The ranking position of Canada with respect to Australia (and the nations ranked below Australia) is insensitive for data inaccuracies. Even inaccuracies of ±30% do not results in a ranking reversal.

Germany

Germany is ranked sixth and the gap with Denmark (5) and Ireland (7) is respectively 4.64 and 9.34. Germany is at a characteristic position, because the gap with Ireland is relatively large, and hence with this sensitivity analysis the robustness of the top 6 positions with respect to the lower ranked nations can be analyzed. Additionally the robustness of the ranking position of the higher nations can be analyzed to determine if data inaccuracies could result in ranking reversal between Germany and Denmark or even the United Kingdom or Australia, ranked respectively fourth and third. The results of this sensitivity analysis for data inaccuracies are given in Figure 6.6.

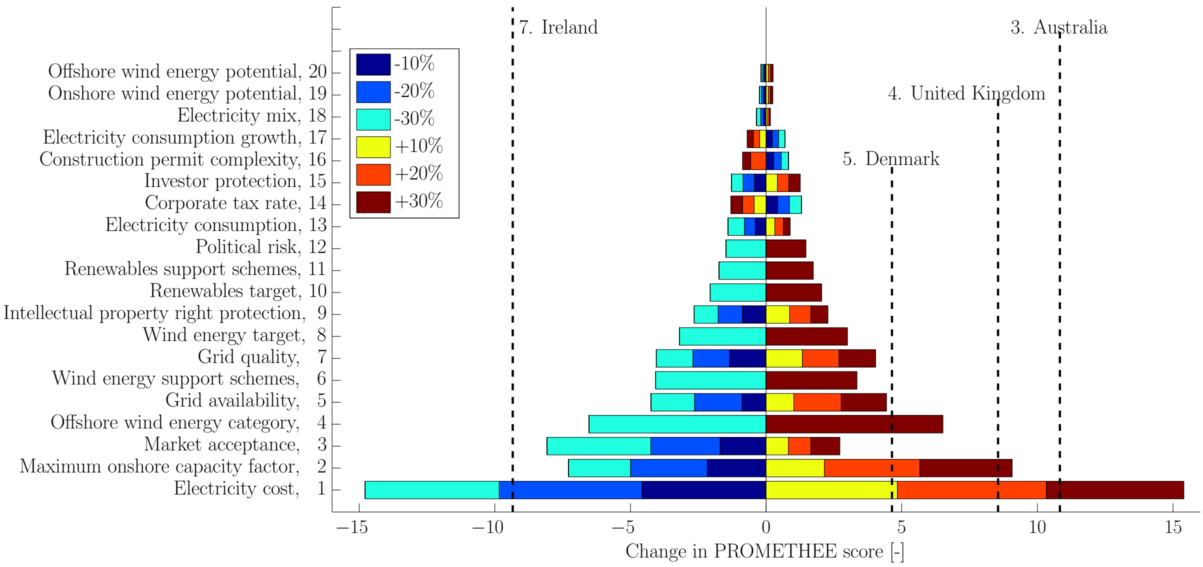


Figure 6.6: Sensitivity analysis for data inaccuracies; the quantitative data fields of Germany are varied with ±30%. For the qualitative and boxed data a different approach is taken as described in section 6.3.1. The dashed lines represent the required difference in score in order to switch ranking position with the specified nation.

From Figure 6.6 follows that:

- Only data inaccuracies of ±30% in the fields electricity cost, maximum onshore capacity factor, market acceptance and offshore wind energy category can result in PROMETHEE score differences of more than 5.00 points. Note that these are the same high impact data fields as in the Canada case.

- The PROMETHEE scores are most sensitive to data inaccuracies in electricity production cost. An increase of electricity production cost with 10% already results in a rank reversal with Denmark. In case the German electricity production cost is about 22% higher, the country would be ranked third.
- The ranking position of Germany with respect to Denmark (and vice versa) is sensitive to data inaccuracies. In case the electricity cost of the maximum capacity factor is increased with respectively 10% and 18% Germany, the ranks would be reversed. Also, in case Germany's offshore wind energy would be categorized in a higher class, rank reversal would occur.
- The ranking position of Germany with respect to Ireland (and the nations below Ireland) is relatively insensitive for data inaccuracies. This hold true for all data inputs, but the electricity costs; a 19% decrease of the German electricity cost would results in rank reversal.

The nations ranked between position 3 and 6 create a *robustness block*; it is unlikely that data inaccuracies could cause Australia (3) to reverse rank with Canada (2) or the United States (1), and it is also unlikely that data inaccuracies could cause Germany (6) to reverse rank with Ireland (7) or any nations ranked lower than Ireland. However within this robustness block, the nations can reverse rank due to data inaccuracies. An equal *robustness block* is created by the United States (1) and Canada (2).

6.3.2 Time dependency

Airborne wind turbines like the Google[x] Makani system will become commercially available within the next two to five years. However, the technical, economic, political and social landscape is dependent on time; in example the government can set new ambitious goals for renewables and apply new support policies. To investigate the time dependency of the ranking results, 2009 data is used in the same model. However, some data fields are time independent or data is unavailable. In these cases the 2014 data is used. Table 6.3 gives an overview of the availability of historic data. The results of the sensitivity analysis for time are given in Figure 6.7.

From Figure 6.7 follows that:

- In general the ranking of nations in 2014 is similar to the rankings of 2009. The average ranking shift of these top 26 nations is equal to 1.42 positions, including the large ranking shift of Sweden; ranked 18 in 2009 and 10 in 2014.
- Sweden's jump in ranking is caused by several factors:

Table 6.3: Data availability of 2009 data for the various criteria applied in the PROMETHEE model.

	Criteria	Data field
Data unavailable	Policies for renewables	Specific wind energy policies
	Market size	Electricity growth prospect
	Electricity price	Electricity production cost
Independent of time	Wind climate	Onshore wind energy potential
		Onshore maximum capacity factor
		Offshore wind energy potential
		Offshore wind speed category
Data available	Grid system	National electrification rate
		Grid quality
	Corporate tax rate	
	Market size	Current electricity demand
	Ease of doing business	Construction permit complexity
		Strength of investor protection
	Policies for renewables	General renewables policies
	Electricity portfolio	Renewables ex. hydro in portfolio
		General target renewables
		Specific wind energy target
	Political risk	
	IP protection	
	Social acceptance	Market acceptance

  – the market acceptance, measured by the installed wind per capita, has increased from 117.4 W/person to 491.8 W/person; a 318% increase, whereas the average increase of these 26 nations is 86%.
  – the corporate tax rate has been decreased from 28% to 22%; a 21% decrease, whereas the average corporate tax decrease between 2009 and 2014 of these 26 nations is 7.1%.
  – one extra renewables support policy has been enforced
  – the strength of investor protection is increased from 5.7 to 6.3 (on a 1:10 scale); an increase of 10.5%, whereas the average increase between 2009 and 2014 of these 26 nations is 2.7%

- The ranking of the top two nations in 2009 is unchanged with respect to 2014. Additionally the gap between the top two nations and the other nations is significant and hence the top two nations are relatively insensitive for time
- The nations ranked in the top 6 positions in 2014 are also ranked in the top 6 positions in 2009.

The nations ranked high in 2014 also ranked high in 2009 and hence it is expected that the results of this analysis are useful for at least the next five years.

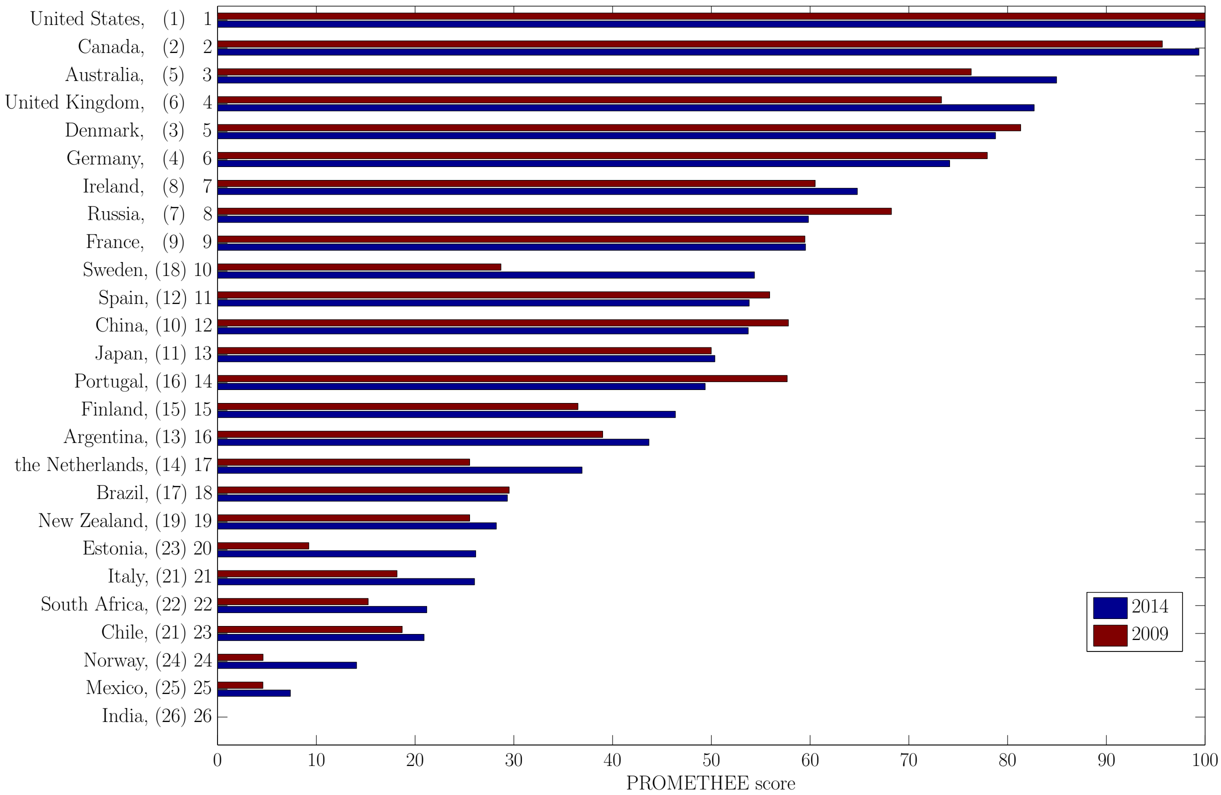


Figure 6.7: Sensitivity analysis for time dependency. On the y-axis, the number in between brackets (..) represents the ranking in case 2009 data is used.

6.3.3 Threshold values

The threshold values for the preference functions, as discussed in section 5.2.2, influence the PROMETHEE scores, and the sensitivity of the results is generally investigated by changing these threshold values with ±20% [241, 243, 244]. The results of this sensitivity analysis are summarized in Figure 6.8

From this sensitivity analysis on threshold values follows that:

- The ranking of the top 2 nations is insensitive to the threshold values
- Nations ranked between 3 and 6 can switch ranks, but will not be ranked higher than the third position or lower than the sixth rank.
- The ranking of nations is not changed dramatically in case the indifference and preference threshold are increase with ±20%

The ranking of the nations is somewhat sensitive for threshold values, but do not result in dramatic ranking shifts.

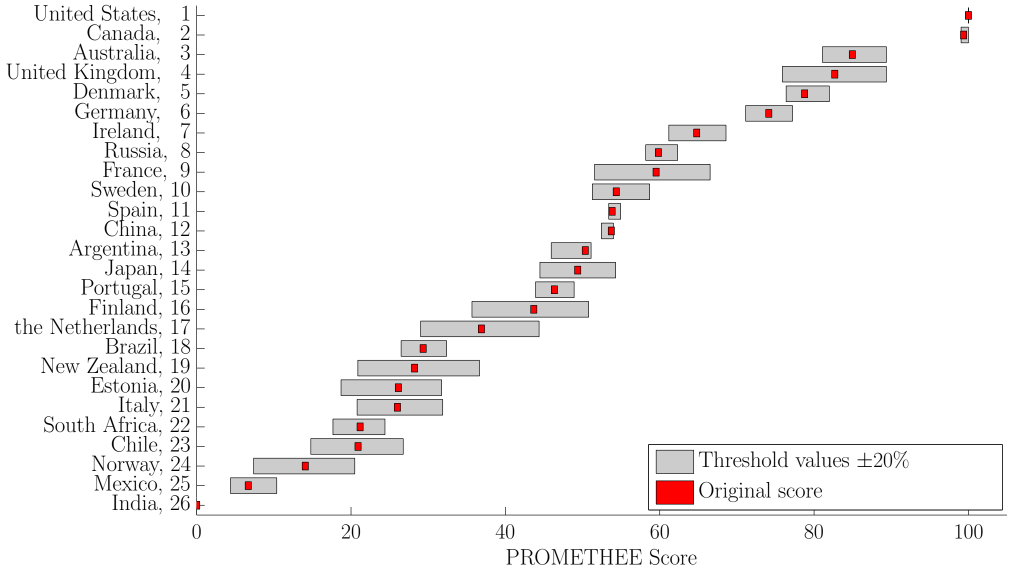


Figure 6.8: Sensitivity analysis threshold values; the threshold values p and q are varied with ± 20%.

6.3.4 Weight factor inaccuracies

In this study, the sensitivity analysis considers the effect of criteria weights changes upon the overall suitability index (PROMETHEE preference points). In section 5.2.1 four different methodologies were applied to calculated the weight factor and the maximum relative weight factor difference between the methods was about 10%. Hence in this sensitivity analysis, the relative importance of the level 1 criteria are increased and decreased with ±10%. Recall that the weight factors for the technical, economic, political and social criteria are respectively 28%, 42%, 17% and 13%. Hence the level of importance of the technical criteria are ranged between 18% and 38%, the economic criteria between 32% and 52%, etceteras. The PROMETHEE scores for the top 26 nations are given in Figure 6.9.

The sensitivity analysis, Figure 6.9, shows a few interesting features:

- The United States and Canada are alternately ranked first and second. The difference is score between these two nations is only 0.63 PROMETHEE points, whereas the gap between second and third nation (Canada and Australia) is 12.17 points. This large difference is not overcome in case the level of importance of the criteria is ranged with ± 10%. In case the level of importance of the technical, political or social criteria is slightly increased Canada is ranked first. A increase of level of importance of the economic criteria keeps the United States ranked first.
- Australia, the United Kingdom, Denmark en Germany are four nations which could be ranked third. In the current ranking, Australia is ranked third.

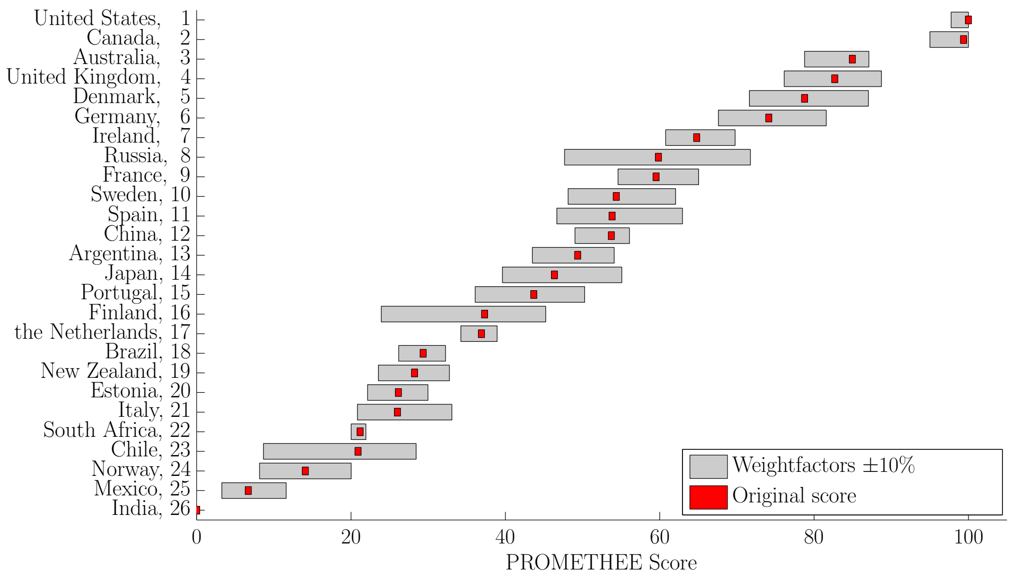


Figure 6.9: Sensitivity analysis PROMETHEE scores; the level of importance of the technical, economic, political and social criteria are increased and decreased with ± 10%.

However, in case 10% importance is added to the social criteria, Denmark will the ranked third followed by Germany, the United Kingdom and Australia. In case 10% importance is added to the political criteria, the United Kingdom is ranked third followed by Denmark, Australia and Germany.

- India is always ranked last (from the top 26 nations analysed). Hence its low position is not caused by high sensitivity of the model.

Finally it can be concluded that the United States and Canada are the top 2 nations, followed by Australia, the United Kingdom, Denmark and Germany. These 6 nations are always in the top 6.

6.4 Comparison with equal weights

Applying equal weights for all criteria is commonly applied in multi criteria decision analysis in sustainable energy decision making, e.g. [55, 80, 117, 125, 132, 245–249]. And, according to [166], weight factors only have a minor effect on the overall decision making process. Applying equal weights would save the time consuming weight factor determination at which many experts were involved. In Figure 6.10, the PROMETHEE scores for equal weights are given with respect to the sensitivity analysis scores.

From Figure 6.10 follows that the United States and Canada are ranked as the top 2 nations, and India last, regardless if equal weights or the weights from the expert survey were applied. In general the countries scoring high at the PROMETHEE

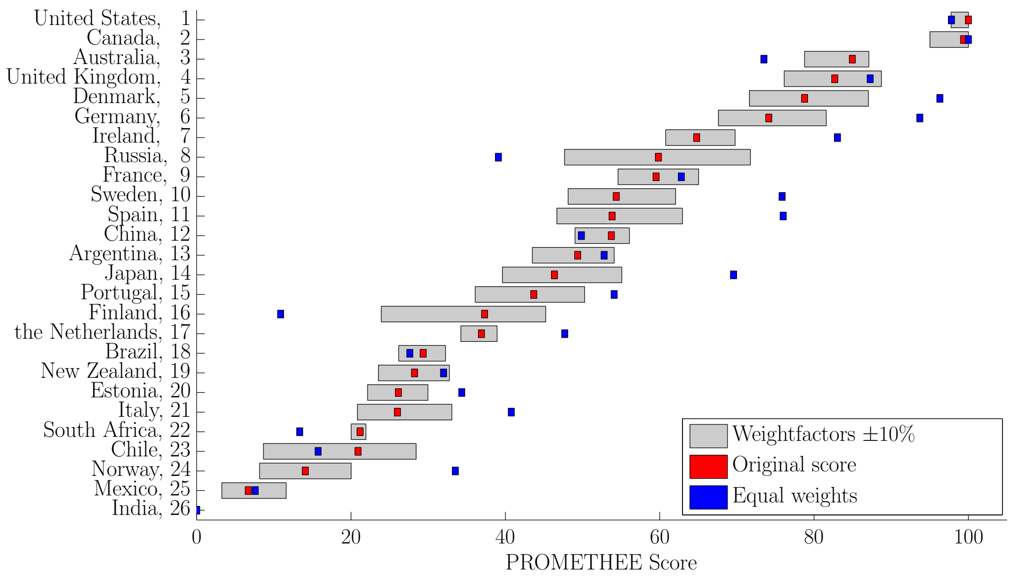


Figure 6.10: PROMETHEE scores in case equal weights are applied versus the sensitivity analysis results

with the weights from the expert surveys also score high in case equal weights are applied. However, for some nations the differences in PROMETHEE scores are relatively large. In the sensitivity analysis the weight factors were varied with ± 10%, because this was the maximum relative weight factor difference between the different survey methods. However in case equal weights are applied the scores of 15 out of the 26 analyzed nations are outside this range.

To conclude, in case equal weights are applied for all criteria, the main trend in scores is similar, but also large differences occur. These large differences fall outside the likely differences due to the subjectivity of the experts judgements, and therefore the use of surveys to calculate the weight factors is of added value.

6.5 Generalizability

The factors influencing a nation's opportunity for airborne wind are similar to the factors for conventional wind energy systems [79, 84, 92–96]. However, the degree of importance of these factors might differ. The sensitivity analysis has shown that the ranking of the block of top 6 nations is insensitive for weight factor fluctuations and hence these nations also got a great future potential for conventional wind turbines.

Many of the factors influencing the nation selection for wind energy systems are similar to the factors for solar energy, tidal energy, biomass and other sustainable energy generating devices [14, 16, 84, 92–96, 108, 113, 124]. Excluding the wind specific factors - wind climate, wind energy target and wind energy policy - the ranking is given in Table 6.4. Out of the top 12 nations including the wind specific

Table 6.4: Ranked nations for the opportunities for the deployment of renewables; the left column represents the ranking for airborne wind energy systems, the right column represents the ranking in case the wind energy specific factors are excluded from the analysis.

	Original ranking			**Excluding wind specific factors**	
	Nation	ϕ^{net}		**Nation**	ϕ^{net}
1.	United States	100.00	1.	Denmark	100.00
2.	Canada	99.37	2.	Sweden	93.33
3.	Australia	84.96	3.	Germany	88.30
4.	United Kingdom	82.68	4.	Spain	87.61
5.	Denmark	78.77	5.	United States	85.94
6.	Germany	74.13	6.	United Kingdom	85.63
7.	Ireland	64.79	7.	Portugal	82.32
8.	Russia	59.83	8.	Ireland	82.29
9.	France	59.53	9.	Canada	75.15
10.	Sweden	54.37	10.	France	70.85
11.	Spain	53.83	11.	Japan	70.68
12.	China	53.73	12.	Australia	70.22
13.	Argentina	50.36	13.	Italy	64.50
14.	Japan	49.37	14.	Finland	51.07
15.	Portugal	46.36	15.	the Netherlands	48.94
16.	Finland	43.68	16.	Estonia	42.87
17.	the Netherlands	36.90	17.	China	34.38
18.	Brazil	29.35	18.	New Zealand	33.84
19.	New Zealand	28.23	19.	Norway	29.36
20.	Estonia	26.14	20.	South Africa	27.63
21.	Italy	26.02	21.	Brazil	26.81
22.	South Africa	21.18	22.	Russia	21.82
23.	Chile	20.91	23.	Mexico	21.23
24.	Norway	14.08	24.	Chile	10.27
25.	Mexico	7.37	25.	India	8.00
26.	India	0.00	26.	Argentina	0.00

factors, only 2 nations (China and Russia) are not ranked top 12 in case the wind specific factors are excluded. However the top 3 is entirely different in both cases. This example illustrates the generalizability of this study's results: the nations characterized as high potentials for airborne wind are likely to be high potentials for other sustainable energy generating devices as well. However, to decrease the uncertainly it is advised to include technology specific details as well.

6.6 MCDM score with respect to current (airborne) wind activity

It iwas the goal of this PROMETHEE multi-criteria analysis to determine the promising nations for the future deployment of airborne wind turbine farms. As explained in section 1.3, a top-down approach was chosen because it could possibly identify nations, which have not yet been recognized as nations with a high (airborne) wind energy potential. Next to the identification of these unexplored nations, the top-down approach should at least be able to identify the nations which would be determined with a bottom-up approach. Different types bottom-up approaches could be chosen; the identification of nations based on:

- the institutions active in the of airborne wind energy industry.
- historical activity of installed capacity of conventional wind energy systems.

6.6.1 Institutional activity in airborne wind

At the moment, November 2014, no commercial systems are available for airborne wind systems generating electricity. However the activity in airborne wind has been growing for the last 15 years and at the moment about 50 institutions are developing airborne wind energy systems. Recall the figure from section 2.2, which shows the worldwide activity in airborne wind.

As shown in Figure 6.11, academic and commercial activity of airborne wind energy development can be found in the United States, Canada, the European Union, China, South-Korea and Australia. This activity is especially concentrated in the United States and Germany; out of 50 AWE institutions, 12 are located in the United States and 9 are located in Germany. The applied method of this research ranked the United States as the second most promising nation for the future deployment of AWE. Germany is ranked sixth. All other nations with AWE activity, 18 in total, are ranked top 25.

The strength of this top-down approach is its ability to identify promising nations for airborne wind, which have not yet been recognized by academia and the industry. Two interesting nations identified by this approach, which have currently no registered institutions active in airborne wind, are Russia, ranked seventh, and Spain, which is ranked as the eleventh most promising nation for the deployment of airborne wind farms.

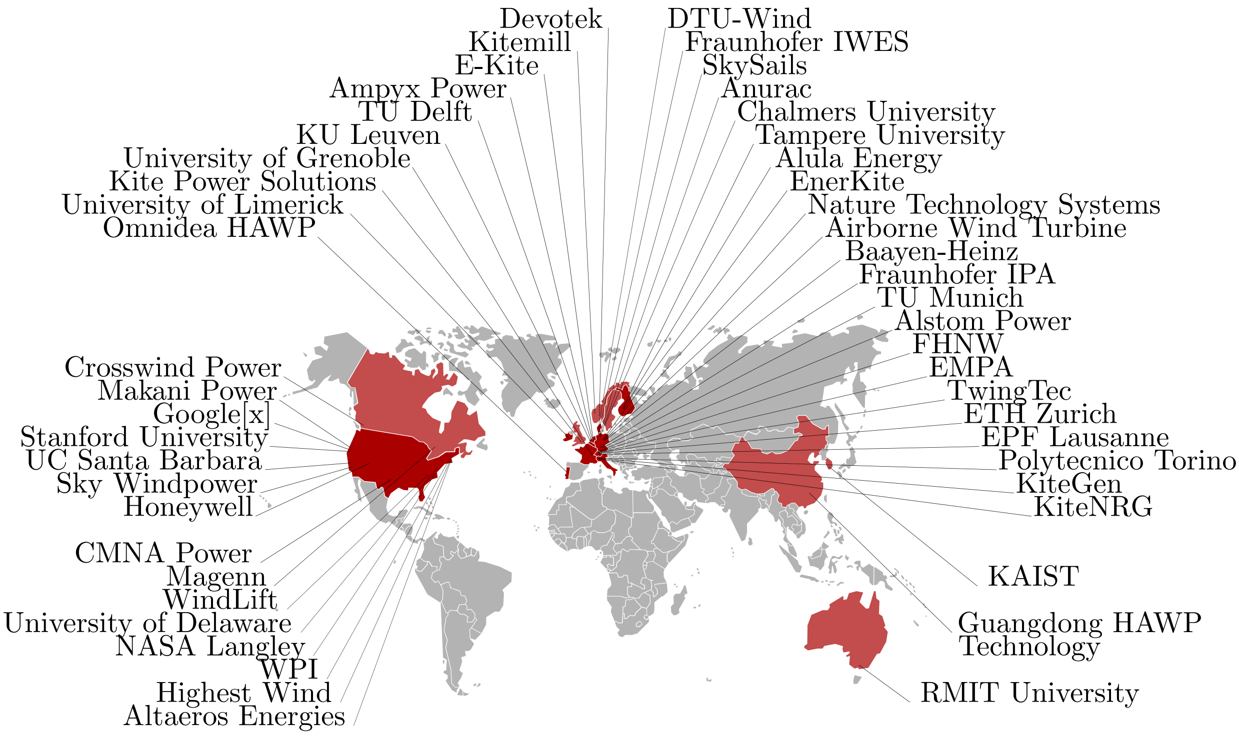


Figure 6.11: Airborne wind energy institutions worldwide [8]

6.6.2 Historical activity in conventional wind energy

In this method, the attractiveness for airborne wind is assumed to be related to the historical attractiveness for conventional wind energy. A measure of historical attractiveness can be found in the installed wind energy capacity. Two different attractiveness measures are used. The attractiveness based on:

- the total installed wind energy capacity.
- the added wind energy capacity of the last three years.

In Figure 6.12 a scatter plot is given at which the PROMETHEE ranking and the ranking based on the installed capacity.

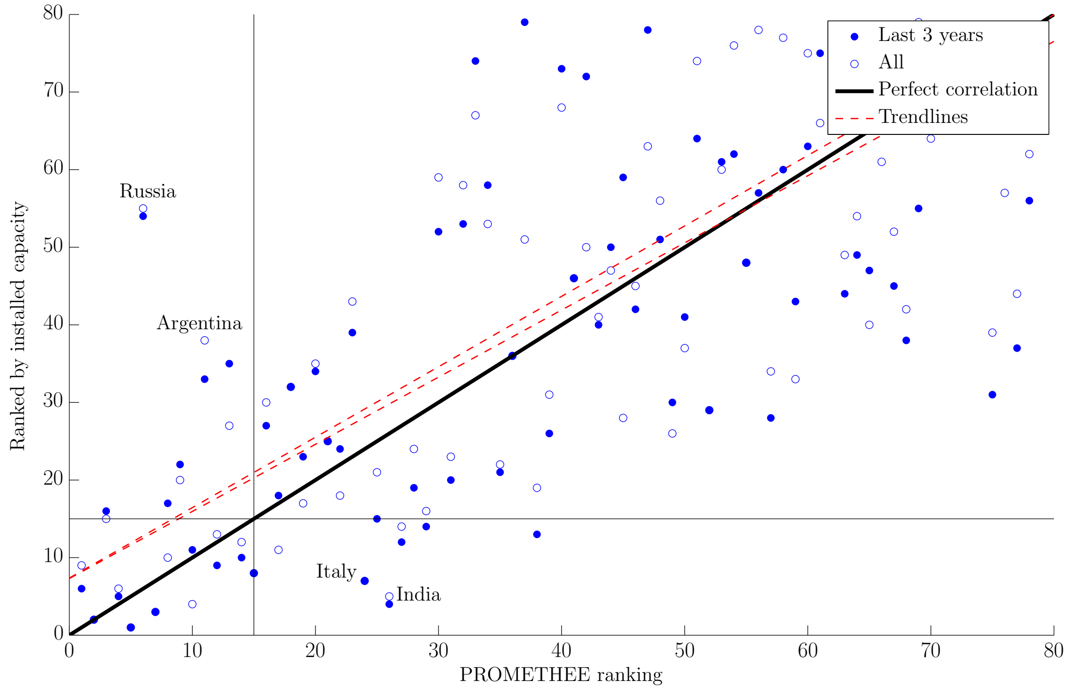


Figure 6.12: PROMETHEE multi-criteria ranking versus ranking by installed capacity. Each nation is represented with two datapoints. The x-axis represents the ranking by the PROMETHEE analysis of this study and the y-axis represents the ranking by (1) the added installed wind energy capacity of the last 3 years and (2) the total installed wind energy capacity.

Although the scatter is significant, the trend lines show a clear correlation between the different methods. More important, from the top 15 nations based on total installed capacity and the added wind energy capacity of the last three years, 11 are also ranked in the top 15 with the top-down method.

The most noticeable ranking differences are listed in Table 6.5:

Table 6.5 shows that the 10 nations based on the total installed capacity and the last three years' added capacity are within the top 27 of this study. However the difference in ranking for India and Italy is relatively large. This study ranked India and Italy respectively as the 26d and 21st most promising nations for AWE deployment, whereas these nations got the 4th and 7th highest installed capacity of the last three years. These nations are analyzed further in the next sections.

The nations with a relative small installed capacity, but which are ranked as highly promising are Russia and Argentina. The current installed capacity of these nations is respectively 17MW and 217MW. As a reference, the total installed capacity of China is equal to 91,434MW. Despite these nations have historically not proven to be very attractive for the deployment of wind energy, the national technical, economic, political and social characteristics, as applied in the MCDM, of these nations are favorable. These nations are analyzed further in the next sections.

Table 6.5: Most noticeable ranking differences top 15 between the top-down and bottom-up approach. The numbers given in this table are the ranks based on the different methods. The total installed wind energy capacity is called *Total*, the added wind energy capacity of the last three years is called *3 Years*, and the PROMETHEE multi-criteria ranking is called *PROM*.

High installed capacity, low rank by MCDM.

	Total	3 Years	PROM.	AWE activity
India	5	4	26	No
Italy	7	7	21	Yes
Poland	14	12	27	No

Low installed capacity, high rank by MCDM.

	Total	3 Years	PROM.	AWE activity
Argentina	44	39	13	No
Russia	55	54	8	No

Most promising nations based on both approaches

	Total	3 Years	PROM.	AWE activity
United States	2	2	1	Yes
Canada	9	6	2	Yes
China	1	1	12	Yes
Australia	15	16	3	Yes
United Kingdom	6	5	4	Yes
Denmark	10	17	5	Yes
Germany	3	3	6	Yes

The nations with a relative high installed wind energy capacity and high scores on the MCMD analysis are analyzed as well. These nations have historically proven to be suitable for the deployment of wind energy and according to this study, these nations are also suitable for the deployment of airborne wind systems. These nations are the United States, Canada, China, Australia, the United Kingdom, Denmark and Germany. Including this analysis, all top 5 nations based on the added installed capacity of the last three years, are analyzed in more detail.

6.6.3 Low AWE potential, high installed capacity

In this section, two nations with high installed capacity but with a relative low AWE potential, according to the research of this study, are further analyzed. These nations are India and Italy. It is the goal of this section to determine the underlying reason for this difference. The relative ranking and score per criteria are given in Table 6.9.

Table 6.6: Rank of grouped and individual criteria.

	India	Italy	China
Technical	**53 (24.0)**	**54 (23.8)**	**6 (74.8)**
Wind climate	33 (23.0)	62 (10.8)	6 (70.8)
Grid system	73 (40.1)	26 (89.0)	45 (80.4)
Economic	**17 (44.3)**	**6 (72.0)**	**8 (62.1)**
Electricity cost	26 (0.0)	6 (69.8)	25 (7.7)
Corporate tax rate	74 (38.2)	71 (42.9)	35 (54.5)
Market size	3 (95.7)	18 (67.1)	1 (100.0)
Political	**25 (65.0)**	**20 (60.2)**	**22 (59.3)**
Electricity portfolio	17 (83.2)	9 (93.2)	24 (78.9)
Governmental support	1 (100.0)	14 (53.3)	1 (100)
Ease of doing business	69 (34.7)	53 (47.3)	77 (18.1)
IP protection	43 (47.2)	24 (66.9)	46 (45.3)
Political risk	60 (20.0)	25 (60.0)	60 (20.0)
Social	**38 (3.7)**	**17 (49.5)**	**27 (22.6)**
Market acceptance	38 (3.7)	17 (49.5)	27 (22.6)

India

As shown in Table 6.9, India scores relatively good on the factors market size, the governmental support, and, too a less extend, its electricity portfolio. Its main low scoring criteria are the grid system, the current cost of electricity production, the corporate tax rate, the ease of doing business and the political risk. Also its wind climate is not classified as the world's best.

Evaluation of the MCDM score The current annual electricity consumption is about 700TWh and ranked fourth largest in the world. The electricity consumption of India's upcoming economy is expected to increase with about 500TWh in the next 15 years, which creates a large market potential for (airborne) wind energy [200, 231]. Although the current electricity mix consists of only 2.27% renewables excluding hydroelectric, the government has set ambitious renewable energy and wind energy targets. In India's 12th five year plan, the government has set a target of adding 18,500MW renewables of which 11,000MW is wind energy. To bring these good intentions into action, the government supports renewables with tax incentives, like the accelerated depreciation. And also wind energy Feed-In Tariffs are into force, ranging from 8.1¢/kWh to 9.0¢/kWh, depending on the region [5, 202, 207, 250].

However, the national quality of the electricity grid in terms of lack of interruptions and lack of voltage fluctuations is worse than in most countries. This low quality of the grid is illustrated by the 2012 black-out at which more than 600million people were affected. Also the Global Wind Energy Council (GWEC) states that the weak transmission and distribution network is one of the key constraints for the future of wind power development [251]. Additionally India is a nation at which the level of investor protection is relatively low in combination with a high building regulation complexity, and a high political risk as a result of a high level of corruption and distrust of the legal system [209, 211, 212, 252–254]. Finally the current production cost of electricity is very low, because of India's use of cheap coal fired plants. The production costs are the lowest out of all 27 explored nations.

Factual (airborne) wind energy situation In India's 8th five year plan(1992-1997), the government set a target of 500MW installed wind and supported this by fiscal incentives and policies to increase the private sector participation. By the end of 1997 940MW of installed wind was achieved. In the years after effective policies were in place and the installed wind energy capacity grew steadily up to 20,150MW in 2013.

Discussion Recall that India has the 4th largest added installed wind energy capacity in the last three years, but is only ranked as the 26d regarding its attractiveness for future AWE systems. The difference is a results of the above mentioned weaknesses regarding the electricity production costs, the grid system, the ease of doing business and political risk. The electricity production cost is classified as the second most important criteria and this greatly influences India's ranking. In case the electricity grid is excluded from the analysis, India would climb 10 positions and would be ranked the 16th most attractive nation for future AWE deployment. Due to its limiting electricity grid and its difficulty of doing business in combination with relatively high political risk, India is still not close with respect to its 4th ranking based on the installed capacity.

However, India is a very large country and the electricity cost, the grid quality, the ease of doing business, corporate tax rate and political risk might differ considerably within the nation. Therefore a regional analysis result in a better informed decision. For this regional analysis, the same AHP in combination with PROMETHEE methodology could be applied.

Italy

Evaluation of the MCDM score The Italian wind climate is ranked relatively low, the annual onshore and offshore wind energy potential is estimated at 0.5PWh, whereas the top 10 wind energy potential nations have an estimated annual wind energy potential of at least 11PWh. Also the local maximum onshore and offshore wind power densities as estimated by [191, 223] are relatively low. Another low score is found in the ease of doing business criteria, due to a high building permit complexity.

Factual (airborne) wind energy situation The Italian government got a long term history in policy setting to enhance renewable energy. Since 1988 a continuous and long-term policy framework has been in place and the tradable green certificate system was an effective mechanism. These certificates require power producers and importers to produce a certain percentage of electricity from renewable sources. Additionally electricity produces from renewables got priority for access to the grid. Currently the national policy for wind energy operates through a set of incentives, which range from indirect regulatory support measures, such as feed-in tariffs and fiscal incentives, to market-based mechanism, such as quota obligations [202, 255]. These policies have proven to be successful, and Italy's cumulative installed capacity has grown rapidly is currently the seventh largest worldwide [256].

Discussion In 2013 Italy got the highest average expenditure for supporting wind power [255]. This is likely caused by the relative low wind speeds; in order to attract investors into these relatively low wind speed zones, the federal and local governmental support needs to be significant. This example shows that highly efficient financial support policies can persuade investors for a region with relatively low wind speeds and also long administrative procedures [255]. However, according to the expert survey, the wind climate is much more important the financial support mechanisms, 21.8% versus 5.4%[1].

6.6.4 High AWE potential, low installed capacity

In this section, two nations are further analyzed with a relatively low currently installed capacity but with a relative high AWE potential, according to the research of this study. These nations are Russia and Argentina; their criteria scores are listed in Table 6.7.

Russia

Evaluation of the MCDM score The Russian wind resources are classified as the best in the world; the onshore and offshore wind energy potential are equal to respectively 116PWh and 23PWH annually. As a reference, the global electricity demand is equal to 23PWh/year. Also the national electricity consumption is qual to about 850PWh, which is the fifth largest market in the world. This electricity consumption is expected to increase with 170TWh in the next 15 years [200, 231]. This is equal to more than 300 wind farms with a rated capacity of about 100MW, assuming a 40% capacity factor. The national electricity mix contains only 0.1% renewables. However the federal Russian government has set goals to increase the amount of renewable electricity and also specific wind energy goal is set: 3,600MW added installed wind energy capacity in 2020 with respect to 2014. Since only recently, October 2013, governmental renewable energy financial support is given and renewable energy auctions are organized

Political violence, corruption and a weak corporate transparency are key drivers for the relatively high political risk in Russia [209, 211, 212, 257]. Also the high permit complexity decreases the ease of doing business. These factors in combination with a weak legal intellectually property right protection system make the Russia a low runner on political criteria.

[1] The weight factor for the overarching technical and political criteria are respectively 28% and 17%. Within the overarching technical criteria the wind climate accounts for 70%, within the political criteria the financial support mechanisms account for 32%. The total weight factors are calculated as the product of the overarching criteria and its subcriteria.

Table 6.7: Rank of grouped and individual criteria for nations with high AWE potential and low installed capacity

	Russia	Argentina
Technical	**3 (95.8)**	**4 (95.2)**
Wind climate	2 (96.3)	1 (100.0)
Grid system	53 (73.2)	66 (55.3)
Economic	**4 (74.3)**	**22 (32.6)**
Electricity cost	17 (32.8)	18 (32.3)
Corporate tax rate	19 (63.7)	79 (36.4)
Market size	4 (95.4)	25 (54.7)
Political	**75 (19.0)**	**35 (48.5)**
Electricity portfolio	33 (75.4)	26 (77.6)
Governmental support	46 (33.3)	7 (76.7)
Ease of doing business	82 (0.0)	78 (9.8)
IP protection	55 (36.4)	59 (34.6)
Political risk	77 (0.0)	38 (40.0)
Social	**56 (0.0)**	**46 (0.0)**
Market acceptance	56 (0.0)	46 (0.9)

Factual (airborne) wind energy situation Despite the governmental renewables and wind energy targets; 3,600MW installed wind energy capacity in 2020, the governmental support programs lack sufficient incentives for large scale wind energy deployment. The auction system has been introduced in October 2013 and and the first auction 1,100MW of wind power was offered, of which only 110MW was secured. In the second auction in June 2014, 1,645MW wind was open for bids, but only 51MW was secured [5, 202, 207, 258, 259].

Discussion Despite Russia's great wind energy potential, and a large and growing electricity market, wind energy did not take off yet due to a lack of political will and a complicated investment landscape. The reason that Russia is ranked that high by the MCDM is that the political factors are given a relative low level of importance with respect to the economic and technical criteria.

Argentina

Evaluation of the MCDM score Argentina's wind climate is ranked as the best in the world; the combination of Argentina's onshore and offshore annual wind energy potential is equal to 47PWh, which is the fifth largest national wind energy potential; only Russia, Canada, the United States and Australia got a higher estimated potential [191, 226]. However not only the national wind energy potential is important, also the local wind power density plays a significant role. In [191, 226], the onshore local wind power density is estimated as the world highest and also the offshore wind speeds exceed 12m/s [223]. This combination of the relatively high wind energy potential and the availability of local sites with outstanding wind resources make the Argentinian wind climate the world's best.

The Argentinian government has recognized this clean energy potential and set specific wind energy targets and financial support policies. The target for wind energy is set at 1,200MW capacity in 2016 with respect to 217MW installed by the end of 2013 and clean power project auctions in combination with Feed-In Tariffs are applied to support. Additionally the Chubut province has set a provincial policy; 100% VAT exemption for wind energy projects in the first 5 years and a 50% exemption in the next 5 years.

Factual (airborne) wind energy situation Despite the governmental intentions only 217MW wind energy is installed, of which 157MW in the last 3 years. In the 2009 auction system 1015MW of clean energy (mostly wind) was offered of which 895 was secures. The average FIT for wind energy was equal to ¢12.7/kWh, which is relatively high compared to the neighboring nations; Uruguay, ¢6.3/kWh and Brazil ¢5.9/kWh. Hence with the greater wind in Argentina the potential returns on investment were extremely attractive. However most of these investments have not yet taken place. One of the reasons is the lack of financing, Argentinian banks are reluctant to lend long term given the unpredictability of the market. Additionally the government has announced intentions to convert dollar-based energy contracts into pesos. And hence in the four years after these tenders, only three out of the 17 approved projects have been build [260, 261].

Discussion Despite the great wind energy potential and the governmental wind energy targets and support policies, the installed capacity is still limited due to the difficulty of doing business and the uncertainty in returns. In the MCDM model, this is also represented by the low score on ease of doing business and political risk. However the calculated weight factor for ease of doing business and political risk are equal to respectively 4.5% and 3.2%[2]. Hence the difference between the PROMETHEE ranking and the actual installed capacity is caused by the relatively low level of importance of the political criteria.

6.6.5 High AWE potential, high installed capacity

In this section, three nations are further analyzed with a high currently installed capacity and with high AWE potential, according to the research of this study. These nations are the United States, Canada and China; their criteria scores are listed in Table 6.8.

[2]The weight factor for the overarching criteria is 17%. Within the overarching political criteria the ease of doing business and political risk account for respectively 27% and 19%. The total weight factors are calculated as the product of the overarching criteria and its subcriteria.

Table 6.8: Rank of grouped and individual criteria for nations with high AWE potential and high installed capacity; United States, Canada and China.

	United States	Canada	China
Technical	**5 (90.6)**	**1 (100.0)**	**6 (74.8)**
Wind climate	5 (85.4)	3 (95.2)	6 (70.8)
Grid system	21 (93.4)	9 (97.6)	44 (80.4)
Economic	**3 (77.9)**	**9 (59.9)**	**8 (62.1)**
Electricity cost	16 (36.7)	19 (30.3)	25 (7.7)
Corporate tax rate	81 (27.3)	49 (51.8)	35 (54.5)
Market size	2 (98.3)	7 (87.9)	1 (100.0)
Political	**6 (79.1)**	**11 (70.1)**	**22 (59.3)**
Electricity portfolio	55 (37.1)	21 (80.4)	24 (78.9)
Governmental support	7 (76.7)	36 (53.3)	1 (100.0)
Ease of doing business	4 (84.3)	22(63.1)	77 (18.1)
IP protection	2 (95.8)	9 (92.8)	47 (45.4)
Political risk	5 (80.0)	5 (80.0)	60 (20.0)
Social	**10 (70.2)**	**7 (76.4)**	**27 (22.3)**
Market acceptance	10 (70.2)	7 (76.4)	27 (22.6)

United States

Evaluation of the MCDM score The United States wind resource is among the best in the world. This wind resource could potentially supply 88PWh annually, which is about 40 times the annual domestic electricity consumption. Also the domestic electricity demand is expected to grow with 525TWh in the next 5 years; the world's second largest growth prospect. These technical and economic criteria in combination with low political risk, high level of intellectual property right protection, low permit complexity, high investor protection and a high degree of governmental support for wind energy, the United States is ranked as the most appropriate nation for the deployment of airborne wind energy systems. Despite the high corporate tax rate, second highest in the world, and a relatively low cost of electricity production.

Factual (airborne) wind energy situation Since 1999 the United Stated wind industry began a period of rapid expansion as a result of a combination of federal and state support in combination with cost reductions of the technology. The effect of the federal production tax credit had a direct effect on the installed capacity; In 1999, 2001 and 2003 the PTC was suspended, causing strong declines in the new installed capacity in the following years. States policies are mostly found in the renewables portfolio standards (RPS); a policy that requires electricity providers to obtain a minimum percentage of their electricity sales from renewables[262]. These support policies have proven to be successful; the last five years average growth rate is about 30% resulting in a current installed capacity is equal to 61,108MW; the second largest in the world [263]. Of this wind energy, about 72% is generated by domestically produced turbines [264].

Discussion In this case the relatively low scores on the corporate tax rate and the electricity cost were, to a certain extend, counteracted by a high score on the (financial) governmental support. This exactly happened in the factual wind energy situation. The governmental incentives were targeted to decrease the level of taxes and to create a more competitive position for wind energy.

Canada

Evaluation of the MCDM score Wind could potentially supply 99PWh annually as a result of excellent onshore and offshore wind resources in combination with world's second largest country area. As a reference, in 2012 Canada's annual electricity consumption was about 0.6PWh. The global electricity consumption was about 23PWh [199]. In combination with an excellent grid system, Canada's technical wind energy potential is the best in the world. Another high score is found in the relatively large electricity market, which is expected to grow in the next 15 years. The national electricity consumption is about 500TWh. As a reference, a 100MW airborne wind farm could potentially supply about 0.5TWh. This electricity consumption is estimated to further increase with an additional 76TWh in the next 15 years [200, 231].

The Canadian government has set an ambitious renewable energy targets to increase the amount of renewables in the national electricity mix; for example 8,000MW added installed wind energy capacity in 2030. To reach this target federal renewable energy financial support is found is terms of fiscal incentives and public financing. Additionally some states apply regulatory policies for renewable energy systems in general and also especially for wind energy projects. For example wind power tenders in Quebec, and feed-in tariffs in Nova Scotia, Ontario and Prince Edward Island [202, 265–267].

The combination of excellent technical resources, a large potential market, a government willing to invest in wind energy, a high intellectual property right protection and low political risk create a great potential for airborne wind energy deployment.

Canada's electricity generation mix consists of 60% hydro, 15% nuclear, 10% coal and 11% gas, and 4% other. This hydroelectric capacity is the second largest in the world and a relative cheap electricity generation [199, 232, 268, 269]. This relatively low cost of electricity generation causes Canada to be ranked second and not first.

Factual (airborne) wind energy situation By the end of 2013, Canada's installed capacity was equal to 7,698MW, which is the 9th largest national worldwide installed capacity; however Canada is ranked 6th in terms of added installed capacity for the last 3 years. Ontario and Quebec collectively account for 70% of the national installed capacity and got ambitious wind energy targets and (financial) support policies in place in order to reach these targets.

Canada lacks a large wind turbine manufacturer and foreign companies have successfully entered this market; most wind turbines are supplied from the United States, Germany and Denmark.

Discussion Canada is ranked 6th regarding the last 3 years installed capacity and hence historical evidence suggest that Canada is a high potential for wind energy. In the MCDM score Canada is ranked 2nd as a result of excellent technical resources in combination with high scores on the economic, political and social criteria. This suggest that great locations for airborne wind deployment are available in Canada.

China

Evaluation of the MCDM score China's national electricity consumption is highest in the word and expected to double in the next 15 years. Additionally the national technical potential for wind energy is ranked as top of the world; the annual wind energy potential is ranked sixth in the world. Also China has set the world highest targets for wind energy; 100,000MW added onshore and 30,0000MW added installed capacity in 2020. To achieve these targets the government support has set lucrative feed-in tariffs, dependent on the region.

However, China's current low cost of electricity due to the use of cheap coal fired plants, in combination with relatively high political risk, low intellectual property right protection and difficulty of doing business, results in a 12th rank. In case the cost of electricity are excluded from the analysis, China would be ranked fifth.

Factual (airborne) wind energy situation In the national tenth five year plan (2001-2005) the concept of a mandatory market share of renewable energy in the national electricity supply was introduced, and additionally the government introduced market based mechanisms such as tendering for wind projects. To support the local economy, a law was introduced requiring wind turbines to be manufactured with 70% domestically produced content. In these years the installed capacity grew from 404MW in 2001 to 1,272MW in 2005 of which 18% was domestically produced. The 2006 first Renewable Energy Law further included a 1% market share of renewables in the country electricity mix in 2010. Additionally feed-in tariffs for wind were introduced and between 2006 and 2009 the total installed capacity doubled each year. By the end of 2009, 25,828MW was installed of which 50% from domestic wind turbine manufacturers. In 2008 the government started the Wind Base Programme and elected seven areas, each to develop more than 10GW and set targets to be reached by 2020. Additionally the feed-in tariffs were revised and the local contact requirement was removed in 2020. This requirement was no longer necessary, as all installed wind turbines were now domestically produced [270]. In 2010 China became the world leading market for wind energy and by the end of 2013, the installed capacity was equal to 91,324MW; about 30% of the world installed capacity. In 2013 China's added installed capacity accounted for 45% of the globally installed capacity.

Discussion China's relatively low electricity cost have not proven to be a barrier for the development of wind energy. The government has greatly supported renewable energy such as wind and hence China has become the wind energy market leader. However, currently domestic wind turbine manufacturers dominate this market and it might be difficult to enter this highly governmentally regulated market. In the

Table 6.9: Rank of grouped and individual criteria for nations with high AWE potential and high installed capacity; Australia, United Kingdom, Denmark and Germany.

	Australia	United Kingdom	Denmark	Germany
Technical	**2 (97.9)**	**9 (65.4)**	**12 (55.4)**	**14 (54.6)**
Wind climate	4 (93.7)	10 (55.3)	15 (43.9)	13 (44.8)
Grid system	21 (93.9)	1 (100.0)	1 (100.0)	23 (92.6)
Economic	**7 (71.0)**	**3 (80.2)**	**15 (46.1)**	**14 (50.1)**
Electricity cost	9 (66.7)	7 (69.4)	3 (74.4)	8 (69.4)
Corporate tax rate	58 (45.5)	28 (61.8)	35 (54.5)	57 (46.2)
Market size	14 (70.6)	11 (75.3)	60 (6.91)	42 (15.6)
Political	**52.1**	**2 (99.3)**	**8 (78.8)**	**4 (84.3)**
Electricity portfolio	58 (35.0)	12 (88.7)	1 (100.0)	4 (97.7)
Governmental support	50 (30.0)	1 (100.0)	14 (53.3)	7 (76.7)
Ease of doing business	17 (66.4)	3 (86.9)	6 (81.7)	19 (65.8)
IP protection	14 (89.5)	2 (95.8)	9 (92.7)	9 (92.7)
Political risk	5 (80.0)	5 (80.0)	5 (80.0)	5 (80.0)
Social	**17 (49.5)**	**12 (59.9)**	**1 (100.0)**	**6 (93.6)**
Market acceptance	17 (49.5)	12 (59.9)	1 (100.0)	6 (93.6)

MCDM model these aspects are represented in the criteria ease of doing business, political risk and intellectual property right protection.

Top 3 battle

The sensitivity analysis showed that four nations could potentially be ranked at the third position; Australia, the United Kingdom, Denmark and Germany. The criteria scores of these nations are given in Table 6.9. These four nations already got a significant installed wind energy capacity and at least one institution exploring the airborne wind concept.

Evaluation of the MCDM score These four nations are all characterized by a high quality grid system, medium high corporate tax rate, low political risk, high intellectual property right protection, relatively low building complexity and high investor protection. What distinguishes these nations from each other are the wind resources, the market size, the governmental targets and policies and the market acceptance.

Australia's top ranking is the result of its world class wind resources available on a large area, which results in a high wind energy potential with respect to the European nations. The European nations have good wind resource, but only available at a limited space. Australia and the United Kingdom are characterized with a prospect of growing electricity demand, whereas Denmark and Germany face an diminishing electricity demand. However Denmark and Germany are characterized by the highest market acceptance of wind energy in the word. The European Union has set specific targets and policies for wind energy, whereas these targets are less ambitious in Australia.

Factual (airborne) wind energy situation The installed wind energy in Australia has been growing, especially in the last years; between the end of 2011 and 2013, the installed wind energy capacity has increased from 2,005MW to 3,049MW [271]. An annual growth rate of 25%. In the United Kingdom, the installed capacity has grown with more than 20% in the last 10 consecutive years and by the end of 2013, 10,531MW wind was installed [271]. Denmark is a pioneering country in wind energy, but his market stagnated between 2003 and 2008, at which only 50MW additional capacity was installed. In the last years the market grew again, from 3,927MW installed in 2011 to 4,772MW in 2013 [271], an average growth rate of 11%. The German wind energy market has grown rapidly between 1997 and 2002 with an average annual growth rate exceeding 40%. In the following years the growth rates decreased to 7%-10% [271]. The annual added installed capacity of the last 3 years was at least 2,000MW and the current installed capacity is equal to 34,660MW.

Hence all these nations face a growing market in terms of installed wind energy capacity. Currently Australia got the least installed wind capacity, but this is market is growing the fastest from these four nations. From these four nations, Germany got the highest installed capacity, but faces the lowest growth rates.

Discussion All four analyzed nations have a high MCDM score and currently face a growing wind energy market. Based on the qualitative evaluation of the MCDM score and the factual wind energy situation, all nations can be equally appropriate for the deployment of airborne wind energy systems.

6.7 Conclusions

The top two nations, United States and Canada, create a *robustness block*. This block is insensitive to model inaccuracies, time dependency of data, inaccuracies in PROMETHEE threshold values, and the subjectivity of the weight factor calculation. However, the positions of the United States and Canada within this robustness block is highly sensitive to these factors. The nations ranked between 3-6 (Australia, the United Kingdom, Denmark and Germany) create an equal robustness block.

The 10 nations in terms of both the total installed capacity, and the last three years' added capacity, are within the top 27 of this study. This indicates that this study is able to identify the nations, which have proven to have high opportunity for airborne wind. However, this study has also identified nations which currently have a very limited installed capacity, such as Russia and Argentina. Also many nations are characterized with opportunities for airborne wind than India and China, which currently have very high installed capacity. This study shows that still many wind energy recourses at nations with high opportunities for airborne wind based on technical, economic, political and social factors are still untapped.

The factors influencing the opportunities for airborne wind are similar to the factors for conventional wind. However it is likely that the level of importance of these factors differ. Therefore the sturdy results can be generalized to conventional wind, but care must be taken. Additionally many factors are generalizable to renewables in general, and hence the study results are - to some extend - generalizable to renewables.

Chapter 7

Conclusions and recommendations

In the introduction, the research goal, the main research question and its subquestions were given. It is the goal of this final chapter to answer these research questions, discuss the implications and limitations of this study, and to give recommendations for future research. In section 7.1, a brief recap of the purpose and the goal of this study is given and the research questions are answered. In section 7.2, a discussion related to the generalizability of the results is given followed by a discussion of the position of this study in the greater process of the implementation of airborne wind energy. In section 7.3, a critical reflection of the theory, the methodology and results is given to assess the limitations of this study. Based on this reflection, section 7.4 gives recommendations for future research.

7.1 Conclusions

Airborne wind turbines will soon become commercially available and wind farm developers of these novel systems are currently exploring their opportunities. Location selection for sustainable energy projects has thoroughly been studied on a local scale, and some studies related to the regional level are performed. However the location selection by including all United Nations member states has not yet been studied. In this study, a first attempt is made to fill this literature gap by introducing a funnel methodology to select nations based on their opportunity for the deployment of airborne wind energy systems.

It was the goal of this study to determine the nations with the highest opportunity for airborne wind energy deployment. To reach this goal, the four research questions need to be answered. These questions are related to (1) the factors influencing the nation selection, (2) the research methodology and theory, (3) results, and (4) the sensitivity of the results.

Factors influencing the nation selection

For this analysis, factors from the international business and local renewable energy planning literature, and the vision from airborne wind energy experts were combined to determine the unique set of economic, technical, political and social criteria. The technical criteria is broken down into (1) wind climate and (2) grid system. The economic criteria is broken down into (1) levelized cost of electricity, (2) current cost of electricity production, (3) corporate tax rate, and (4) size of the current and future market. The political criteria is split into (1) the governmental support for renewable energy systems, (2) the current and future prospected electricity mix, (3) political risk, (4) ease of doing business and (5) the degree of intellectual property right protection. The social criterion is split into (1) social acceptance and (2) the visual quality of the landscape. Each of these criteria is subsequently broken down into sub criteria, which are quantitatively or qualitatively measurable and therefore applicable in the research framework.

However, the validity of this breakdown of criteria is highly uncertain and cannot be checked with the classical Analytical Hierarchy Process (AHP) methodology. With this method only the criteria which fall under a certain criteria group are pair-wise compared. The adjusted AHP method solves this disadvantage by a pair-wise comparison of not only the criteria within a certain group, but also across the groups. This adjustment allows to check the relative importance of any criteria with respect to all other criteria *within and across* the grouped criteria.

To verify the list of criteria, the breakdown of criteria into sub criteria, and to determine the level of importance of each criteria, two distinct expert surveys, at which 26 experts from various backgrounds participated[1], were used. One according to the classical AHP and another according to this adjusted AHP. The results showed that the degree of inconsistency of both models was similar. Also, regardless of the applied models, the calculated weight factors were similar. This combination of equal consistency with similar weight factor calculations increased the trustworthiness in the proposed adjustments to the AHP methodology, and additionally, of the calculated weight factors.

It was found that the economic criteria are generally seen as most important with a 42% weight factor, followed by the technical (28%), the political (17%) and the social criteria (13%).

Research methodology and theory

Already in the research approach, two different analysis phases were proposed. In the first phase, nations are withdrawn from further analysis in case the basic conditions for wind energy are not present. In the second phase the remaining nations are subject to a more detailed analysis.

[1] The participants of this survey: 12 experts from the airborne wind industry, 3 from academic institutions working on airborne wind, 2 from academic institutions working on energy and infrastructure, 6 from the conventional wind energy industry, 2 from NGOs and 1 with a governmental background.

The conjunctive screening method applies a set of conjunctive screening rules to determine if a certain alternative meets the minimum of the set of requirements, and is therefore applied in the first analysis phase. Airborne wind energy systems generate electricity from wind. Hence, the conjunctive screening rules are based on the availability of wind resources and electricity demand.

The nation selection of airborne wind energy systems can be seen as a multiple actor decision making problem with multiple, sometimes conflicting, criteria, and different forms of data and information. Multi criteria decision making (MCDM) methods, such as PROMETHEE and AHP, are especially developed to deal with such problems, and already find a wide application in renewable energy planning problems. PROMETHEE has a cardinal ranking ability, is relatively easy to use, and can deal with quantitative and qualitative data with high uncertainty. Therefore this methodology is applied to rank the nations based on their criteria scores. However this method lacks a methodology to calculate the weight factors. An accurate weight factor calculation method is included in the Analytical Hierarchy Process (AHP) methodology and is used for this purpose. Both methodologies are based on the pair-wise comparison of actions, and PROMETHEE's methodology includes six preference functions, applicable for quantitative and qualitative data, to determine the preference of an action a over b.

The final research framework consists of conjunctive screening methodology in combination with PROMETHEE-AHP. These methods can be understood from the rational and bounded rationality decision making theory. Hence the decisions in this model are made as rationally as possible taking the limited availability of information and time into account. The methods are used to overcome the limited human cognitive capabilities.

Results

The most promising locations for the deployment of airborne wind turbines are within the United States and Canada. Australia together with the European nations, United Kingdom, Denmark and Germany, are ranked after the United States and Canada. These top 6 nations, as calculated in this study, already got a considerable amount of wind energy installed, and additionally at least one institution active in the airborne wind industry. This suggest that these nations, proven to be successful for conventional wind energy, also have a high opportunity for airborne wind farms.

This study's top 27 identified all top 10 nations based on installed wind capacity, which indicates that all major wind energy markets are recognized as such in this study. However, also nations were identified with high opportunities for airborne wind, whereas the conventional wind energy systems only have minor installed base and vice versa. For example, Russia, ranked eight, but only a very limited current installed capacity. Or China, characterized by the highest installed wind energy capacity, but only ranked twelfth in this study. These results are characteristic to the contribution of this study. At first a decision maker might think that the best location for airborne wind is within nations with the largest installed wind energy capacity. However this study showed that this is not necessarily true; 11 nations got greater opportunity for deployment than China, which is characterized by high political risk, low degree of intellectual property right protection and a high degree of permit complexity. Other nations, currently relatively unexplored for wind energy, have been determined to have excellent conditions for airborne wind and these untapped resources are ready to be harvested.

Sensitivity of the results

The sensitivity of the results to changes in the external environment and model inaccuracies is tested with four sensitivity analyses. The effects of changes in the external environment is tested by applying data inaccuracies up to ±30% and time dependency; data of 5 years ago was applied in the model. The sensitivity to model inaccuracies is tested by ±10% additions to the relative importance of the criteria weights, and the adjustment of the PROMETHEE preference thresholds with ±20%.

The ranking of the top 2 nations (Canada and the United States) is relatively robust; they can switch position, but remain top 2. The position of the four nations, Australia, United Kingdom, Denmark and Germany are more sensitive. Each of these nations could possible be ranked third. However none of these nations would be ranked lower than the sixth position, or higher than the third position. Hence the position this block of top 6 nations is robust. Additionally, the sensitivity analysis has shown that the positions of the other nations is relatively robust and no large shifts in positions are expected as a results of changes in the external environment and model inaccuracies.

7.2 Discussion

Generalizability

The factors influencing a nation's opportunity for airborne wind are similar to the factors for conventional wind energy. Although the relative importance of these criteria might differ to some extend, the main results of this study are generalizable to conventional wind energy systems. The largest wind energy market has currently been in China. However, this study has shown that 11 nations are characterized with better opportunities. This gives trust that many wind resources, in nations with excellent conditions, are still untapped and the market can continue to grow.

Additionally it was found that many of the factors influencing the airborne wind location selection problem, are also applicable to other renewables, like solar energy, tidal energy or biomass. Therefore the main results of this study can be generalized to all renewables. This also makes this study is complementary to the literature of the local site selection of renewables - in particular wind energy. This study can be applied to make a more informed decision about the specific location subject to a case study.

Implementation of airborne wind

For the successful implementation of airborne wind the three most important barriers to overcome are defined as the reliability of the systems, the governmental regulations and the control systems [274]. The reliability of the system and the control systems are both technological barriers to be overcome. However this study identified the key national governments to target to set up the laws and regulations. Hence this will help to overcome the second largest barrier to the implementation of airborne wind and will give a boost to the implementation process.

Some companies, like the Dutch AmpyxPower and the American Google[x] Makani Power, have developed a full scale prototype, which is ready for market launch. Both systems apply the rigid wing concept. This study will enhance their change of success to determine the optimal nations for the deployment of these systems. The robustness to time dependency of time shows that the results are still useful in case the first systems become commercially available in the next two to five years.

7.3 Critical reflection

The conjunctive screening method proved to be an effective tool to limit the scope of the more advanced MCDM research. However this completely non compensatory tool also got its limitations, due to imperfect data availability. The wind climate data was coarse and hence specific locations characterized with a beneficial wind climate might have gotten lost in this coarse data. In example, Thailand and Jordan were eliminated from further research. However, Thailand has 193MW wind energy installed and Jordan is planning a 117MW wind farm in the near future. These examples show that wind energy has been developed in nations that this study has categorized as ‘basic conditions for wind energy are not present’.

The AHP weight factor calculation methodology was a valuable tool to determine the weight factors from the expert surveys. However the results were characterized by some degree of inconsistency. In case the experts would handle according to the bounded rationality theory, the surveys would have been filled out consistently. However, the inconsistency shows that the bounded rationality theory is violated. In fact, experts might have filled out the survey based on intuition and a methodology according to the intuitive decision making process could be used in this stage.

The complete PROMETHEE ranking ability in combination with the ability to handle large datasets with some degree of uncertainty, proved to be well suited for this problem. The tool helped to determine the degree of preferences of an action a over an action b in case data was uncertain or only qualitatively was available. However, any multi criteria analysis tool, based on the bounded rationality theory, got its limitations. The results are based on the (subjective) set of criteria defined in this study. The expert survey was used to increase the trustworthiness of this criteria set, but it is acknowledged that relevant criteria might have been overseen and the model is not a prefect representation of the real world.

Looking at the results, the top 6 nations are relatively insensitive to the external environment and model inaccuracies, and these nations already got a significant installed wind energy base. It is likely that these nations would also be determined from a top down approach. However the tool also calculates some nations with a very low installed capacity and hence these nations are the real 'success' results. Also it is shown that many nations have better opportunities for airborne wind, and conventional wind, energy generating systems than the large markets of China and India. These results suggest that many great wind resources located in nations with great potential for airborne, and conventional, wind are highly unexplored. This study has identified these nations and next the best locations within these nations should be analyzed.

7.4 Recommendations for future research

This study is only a first start of location selection for airborne wind, and for analyzing the opportunities of renewables on a global scale. Therefore many improvements and applications of this study are possible. Three types of recommendations for future research are outlined. Recommendations to

- improve the current research framework,
- improve the quality of the location selection,
- apply the research framework in other research field.

Improve the current research framework

Expert surveys were applied to calculate the relative importance of each factor. These expert surveys, at which the AHP pair wise comparison methodology is applied, are generally characterized by a high degree of inconsistency [235, 236], and also in this study the amount of inconsistency filled out surveys was significant. The inconsistent surveys are more unreliable and hence an increase of the number of consistently filled out surveys would improve the reliably of the current research framework. To improve the degree of consistency, experts are asked to revise the inconsistent parts in other studies [107].

However, it can be argued that experts fill out the surveys by intuition and therefore the intuitive-subjective Delphi technique could be applied to determine the relative weight factors. In [154] a MCDM model is applied to evaluate the best main battle tank. The Delphi technique is applied to gain consensus on the criteria and the relative importance of these weights. In [156], the susceptibility of sand encroachment in Kuwait is evaluated. The criteria and their relative importance were determined with Delphi techniques. These examples suggest that the Delphi technique can successfully be applied for weight factor calculations.

Improve the quality of the location selection

In this study the most promising nations were determined. However within nations differences in wind climate, grid quality, political risk, electricity generation cost, public acceptance and market acceptance are likely. Also some nations, like the United States and Canada, have their renewables and wind energy targets as well as their (financial) governmental support policies organized on the federal and state level. For example Canada:

- The wind power potential differs greatly within the nation.
- The electricity generation price differs per state due to the differences in power generation technologies. Some states rely largely on large (and cheap) hydro-electric power generation, whereas other rely on power generation from (expensive) imported fossil fuels and (expensive) nuclear power.
- The electricity demand and growth prospect differ across the states
- The corporate tax rate is organized on a state-level, hence the range of corporate tax is between 25% and 31%.
- The governmental support for renewables is organized on a federal and sate level.
- The national power sector is organized on the state level; some states have renewables and wind energy targets, whereas other lack these. .

This example shows that the opportunities for airborne wind energy deployment differ greatly within a nation. In a follow up study the highly promising nations could be subject to a local PROMETHEE-AHP analyzes as developed in this study. As a criteria to select the location for a local analysis, one could choose the location at which the best local support schemes and/or the set wind sites are present. This approach is visualized in Figure 7.1.

Apply the research framework in other research field

The current research framework is especially designed for the application of airborne wind energy systems. The airborne wind energy industry has many similarities with the conventional, ground based, wind energy industry. Most of the criteria which influence the decision making process for the nation selections for airborne wind, also influence this process for conventional wind. However it is likely that the determined weight factors differ; in example the level of intellectual property right protection might be less relevant for the mature wind industry. Also the visual quality of the landscape might be more important for large conventional wind turbines, which are more visually present with respect to airborne wind. Including the conventional wind energy weight factors, this framework could be applied for the nations selection of these systems.

Next to wind energy, the research framework could also be applied to other sustainable energy project at which many of the developed technical, economic, political and social criteria are also relevant. In example the grid system, the cost of electricity, the market size, the governmental targets and support for renewables, the political stability, the intellectual property right protection and the market acceptance are likely to be factor influencing the nation selection of for example small hydro power plants, solar plants, tidal-wave power plants and other sustainable energy technologies.

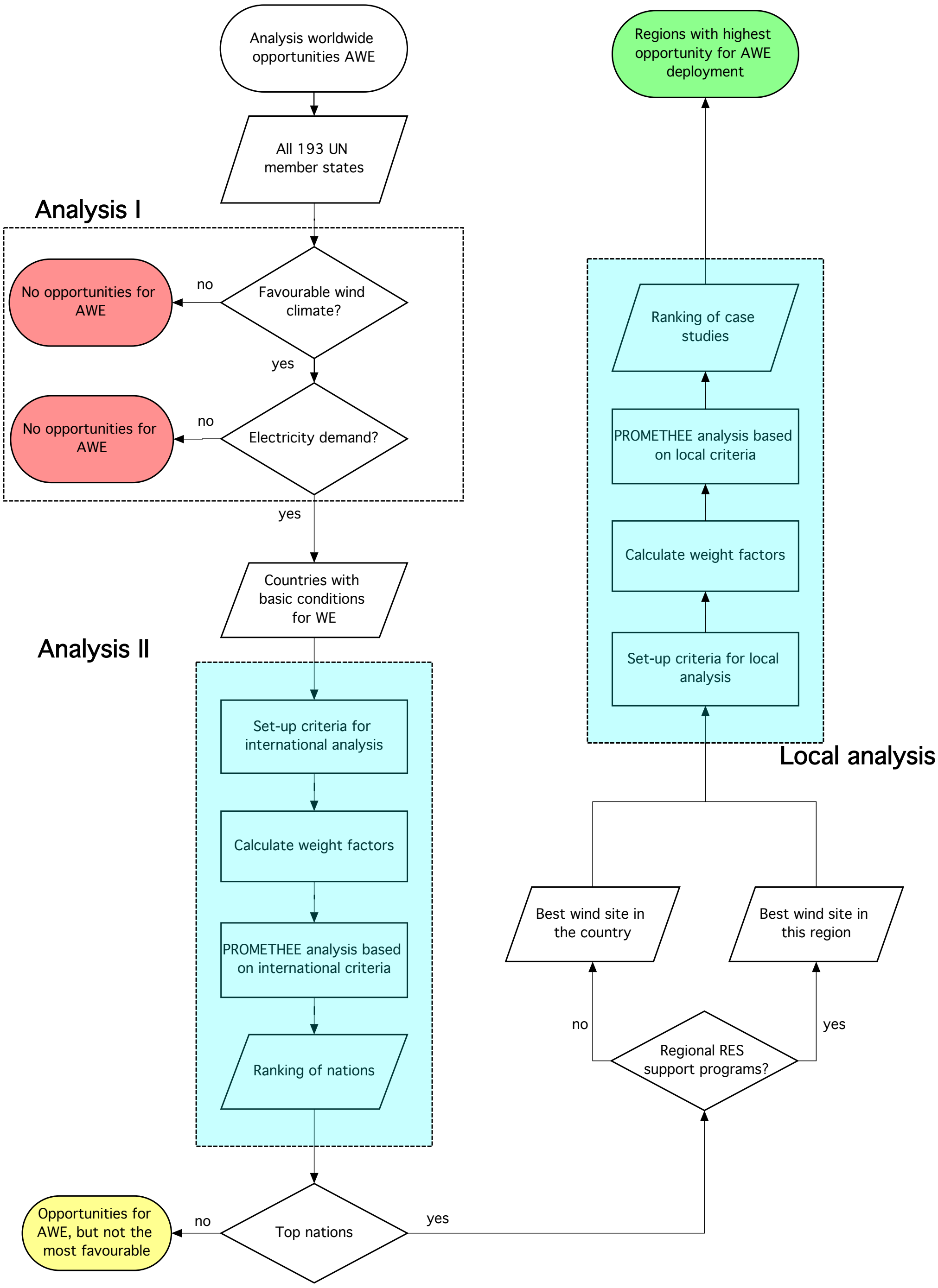


Figure 7.1: Flowchart of extended the research approach

References

[1] Enerdata, "Global energy statistical yearbook 2013," http://yearbook.enerdata.net/, 2013, online; accessed 02-Apr-2014.

[2] Dudley, B., *BP energy outlook 2030*, BP, 2013, http://www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/BP_Energy_Outlook_Booklet_2013.pdf, online; accessed 02-Apr-2014.

[3] Doman, L. E. and Arora, V., "International energy outlook 2013, with projections to 2040," Tech. rep., U.S. energy Information administration, 2013, Chapter 1 World energy demand and economic outlook, http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf, online; accessed 02-Apr-2014.

[4] Organisation for economic co-operation and development and international energy agency, *World energy outlook 2013*, WORLD ENERGY OUTLOOK, OECD, 2013.

[5] Sawin, J. L., "Renewables 2013, global status report," Tech. rep., REN21, 2013, http://www.ren21.net/portals/0/documents/resources/gsr/2013/gsr2013_lowres.pdf, online; accessed 02-Apr-2014.

[6] Stocker, T. F., Qin, D., Plattner, G. K., Alexander, L. V., Allen, S. K., Bindoff, N. L., Bréon, F. M., Church, J. A., Cubasch, U., Emori, S., Forster, P., Friedlingstein, P., Gillett, N., Gregory, J. M., Hartmann, D. L., Jansen, E., Kirtman, B., Knutti, R., Kumar, K. K., Lemke, P., Marotzke, J., Masson-Delmotte, V., Meehl, G. A., Mokhov, I. I., Piao, S., Ramaswamy, V., Randall, D., Rhein, M., Rojas, M., Sabine, C., Shindell, D., Talley, L. D., Vaughan, D. G., and Xie, S. P., "Technical summary," *Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report on the intergovernmental panel on climate change*, edited by T. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. X. andV. Bex, and P. M. Midgley, Cambridge university press, Cambridge, United

Kingdom and New York, NY, USA, 2013, http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf.

[7] "Kyoto protocol to the United Nations framework convention on climate change," Tech. rep., United Nations, 1998, http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[8] Ahrens, U., Diehl, M., and Schmehl, R., *Airborne Wind Energy*, Springer, Dordrecht, the Netherlands, 2013.

[9] Google, "Makani Power," 2014, http://www.google.com/makani/, online; accessed 26-Sep-2014.

[10] Zillmann, U. and Hach, S., "Financing Strategies for Airborne Wind Energy," *Airborne Wind Energy*, edited by U. Ahrens, M. Diehl, and R. Schmehl, Springer, Dordrecht, the Netherlands, 2013, pp. 117–137.

[11] Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., and Zhao, J.-H., "Review on multi-criteria decision analysis aid in sustainable energy decision-making," *Renewable and Sustainable Energy Reviews*, Vol. 13, No. 9, 2009, pp. 2263 – 2278. doi:10.1016/j.rser.2009.06.021.

[12] Diakoulaki, D., Antunes, C. H., and Martins, A. G., "MCDA and energy planning," *Multiple criteria decision analysis: state of the art surveys*, edited by J. Figueira, S. Greco, and M. Ehrgott, Springer, 2005, pp. 859–879.

[13] Mateo, J. R. S. C., *Multi-criteria analysis in the renewable energy industry*, Springer, London Dordrecht Heidelberg New York, 2012. doi:10.1007/978-1-4471-2346-0.

[14] Haralambopoulos, D. A. and Polatidis, H., "Renewable energy projects: structuring a multi-criteria group decision-making framework," *Renewable Energy*, Vol. 28, No. 6, 2003, pp. 961 – 973. doi:10.1016/S0960-1481(02)00072-1.

[15] Gamboa, G. and Munda, G., "The problem of windfarm location: a social multi-criteria evaluation framework," *Energy Policy*, Vol. 35, No. 3, 2007, pp. 1564 – 1583. doi:10.1016/j.enpol.2006.04.021.

[16] Mourmouris, J. C. and Potolias, C., "A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: a case study Thassos, Greece," *Energy Policy*, Vol. 52, No. 0, 2013, pp. 522 – 530. doi:10.1016/j.enpol.2012.09.074, Special Section: Transition Pathways to a Low Carbon Economy.

[17] Topcu, Y. I. and Ulengin, F., "Energy for the future: an integrated decision aid for the case of Turkey," *Energy*, Vol. 29, No. 1, 2004, pp. 137 – 154. doi:10.1016/S0360-5442(03)00160-9.

[18] Gigerenzer, G. and Goldstein, D. G., "Reasoning the fast and frugal way: Models of bounded rationality," *Psychological review*, Vol. 103, No. 4, 1996, pp. 650–669. doi:10.1037/0033-295X.103.4.650.

[19] van der Hoeven, M., *Technology roadmap, wind energy*, International energy agency, 2013, http://www.iea.org/publications/freepublications/publication/Wind_2013_Roadmap.pdf, online; accessed 02-Jun-2014.

[20] Zayas, J., "Wind turbine scaling enables projects to reach new heights," Office of energy efficiency and renewable energy, 2014, http://energy.gov/eere/wind/articles/wind-turbine-scaling-enables-projects-reach-new-heights, online; accessed 26-Sep-2014.

[21] Nixon, N., "Timeline: the history of wind power," 2008, http://www.theguardian.com/environment/2008/oct/17/wind-power-renewable-energy, online; accessed 02-Jun-2014.

[22] Global wind energy council, "Cumulative market forecast by region 2013-2018," 2013, http://www.gwec.net/wp-content/uploads/2014/04/2_29-2_cumulative-market-forecast-by-region-2003-2018.jpg, online; accessed 26-Sep-2014.

[23] Archer, C., "An introduction to meteorology for airborne wind energy," *Airborne Wind Energy*, edited by U. Ahrens, M. Diehl, and R. Schmehl, Springer, Dordrecht, the Netherlands, 2013, pp. 81–94.

[24] Ockels, W., Lansdorp, B., Breukels, J., and Spierenburg, G., "The laddermill: work in progress," *proceedings of European Wind Energy Conference, London*, European Wind Energy Conference & Exhibition, London, UK, 22-25 November 2004.

[25] Pocock, G., *The Aeropleustic Art or Navigation in the Air by the use of Kites, or Buoyant Sails*, W. Wilson, London, UK, 1827.

[26] Breukels, J., *An engineering methodology for kite design*, Ph.D. thesis, Delft University of Technology, 2010.

[27] Loyd, M., "Crosswind Kite Power," *Journal of Energy*, Vol. 4, No. 3, 1980, pp. 106–111. doi:10.2514/3.48021.

[28] Argatov, I., Rautakorpi, P., and Silvennoinen, R., "Estimation of the Mechanical Energy Output of the Kite Wind Generator," *Renewable Energy*, Vol. 34, No. 6, 2009, pp. 1525–1532.

[29] Williams, P., Lansdorp, B., and Ockels, W., "Optiimal Crosswind Towing and Power Generation with Tethered Kites," *AIAA Journal of Guidance, Control, and Dynamics*, Vol. 31, No. 1, 2008, pp. 81–93. doi:10.2514/1.30089.

[30] Diehl, M., "Airborne Wind Energy: Basic Concepts and Physical Foundations," *Airborne Wind Energy*, edited by U. Ahrens, M. Diehl, and R. Schmehl, Springer, Dordrecht, the Netherlands, 2013, pp. 3–22.

[31] Meijaard, J., Ockels, W., and Schwab, A., "Modelling of the dynamic behaviour of a laddermill, a novel concept to exploit wind energy," *proceedings of 3rd International Symposium on Cable Dynamics*, Trondheim, Norway, 16-18 August 1999, pp. 229–234.

[32] Ockels, W., "Laddermill a novel concept to exploit the energy in the airspace," *Aircraft Design*, Vol. 4, No. 2-3, 2001, pp. 81–97. doi:10.1016/S1369-8869(01)00002-7.

[33] van der Vlugt, R., Peschel, J., and Schmehl, R., "Design and Experimental Characterization of a Pumping Kite Power System," *Airborne Wind Energy*, edited by U. Ahrens, M. Diehl, and R. Schmehl, Springer, Dordrecht, the Netherlands, 2013, pp. 403–436.

[34] Makani Power, "Makani History," 2012, Accessed 10 January 2013.

[35] Makani Power, "MakaniPower How does it work?" 2012, Accessed 10 January 2013.

[36] Makani Power, "Makani Power Why Airborne Wind Power?" 2012, Accessed 10 January 2013.

[37] Google, "The solution, energy kites," 2014, `http://www.google.com/makani/technology/`, online; accessed 25-Sep-2014.

[38] Google, "The technology, meet the energy kites," 2014, `http://www.google.com/makani/solution/`, online; accessed 25-Sep-2014.

[39] Dijksterhuis, A. and Nordgren, L. F., "A theory of unconscious thought," *Perspectives on psychological science*, Vol. 1, No. 2, 2006, pp. 95 – 109. doi:10.1111/j.1745-6916.2006.00007.x.

[40] Nightingale, *Think smart - act smart: avoiding the business mistakes that even intelligent people make*, John Wiley & Sons, 2008.

[41] Simon, H. A., "Theories of decision-making in economics and behavioral science," *The American economic review*, Vol. 49, No. 3, 1959, pp. 523–283.

[42] Edwards, W., "The theory of decision making," *Psychological bulletin*, Vol. 51, No. 4, 1954, pp. 380 – 417.

[43] Ju, B., Junwen, F., and Chenglin, M., "Intuitive decision theory analysis and the evaluation theory," *Management Science and Engineering*, Vol. 1, No. 2, 2007, pp. 63–67.

[44] Klein, G., *The power of intuition: How to use your gut feelings to make better decisions at work*, Random House LLC, 2007.

[45] Scott, J., "Rational choice theory," *Understanding contemporary society: Theories of the present*, 2000, pp. 126–138.

[46] Schacter, D. L., Gilber, D. T., and Wegner, D. M., *Psychology*, Catherine Woods, 2009.

[47] Simon, H. A., "A Behavioral Model of Rational Choice," *The Quarterly Journal of Economics*, Vol. 69, No. 1, 1955, pp. 99 – 118.

[48] Maylor, H., *Project management*, Financial Times/ Prentice Hall, 4th ed., 2010.

[49] Popp, D., Newell, R. G., and Jaffe, A. B., "Chapter 21 - Energy, the Environment, and Technological Change," *Handbook of the Economics of Innovation*, edited by B. H. Hall and N. Rosenberg, Vol. 2, North-Holland, 2010, pp. 873 – 937. doi:10.1016/S0169-7218(10)02005-8.

[50] Moran, D. and Sherrington, C., "An economic assessment of windfarm power generation in Scotland including externalities," *Energy Policy*, Vol. 35, No. 5, 2007, pp. 2811 – 2825. doi:10.1016/j.enpol.2006.10.006.

[51] Kelman, S., "Cost-benefit analysis: an ethical critique." *Across the Board*, Vol. 18, No. 7, 1981, pp. 74–82.

[52] Zerbe Jr., R. O., "Is Cost-Benefit Analysis Legal? Three Rule," *Cost-Benefit Analysis and Public Policy*, edited by D. L. Weimer, Blackwell Publishing Ltd., 2009, pp. 275–308. doi:10.1002/9781444307177.ch25.

[53] Zerbe Jr., R. O., "Should moral sentiments be incorporated into benefit-cost analysis? An example of long-term discounting," *Policy Sciences*, Vol. 37, No. 3-4, 2004, pp. 305–318. doi:10.1007/s11077-005-5750-3.

[54] Söderholm, P. and Sundqvist, T., "Ethical limitations of social cost pricing: An application to power generation externalities," *Journal of Economic Issues*, Vol. 34, No. 2, 2000, pp. 453–462.

[55] Diakoulaki, D. and Karangelis, F., "Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece," *Renewable and Sustainable Energy Reviews*, Vol. 11, No. 4, 2007, pp. 716 – 727. doi:10.1016/j.rser.2005.06.007.

[56] European Commission, "Externe - external cost of energy," `http://www.externe.info/`, online; accessed 15-Apr-2014.

[57] Mamlook, R., Akash, B. A., and Mohsen, M. S., "A neuro-fuzzy program approach for evaluating electric power generation systems," *Energy*, Vol. 26, No. 6, 2001, pp. 619 – 632. doi:10.1016/S0360-5442(01)00015-9.

[58] Turoff, M., "The design of a policy Delphi," *Technological forecasting and social change*, Vol. 2, No. 2, 1970, pp. 149 – 171. doi:10.1016/0040-1625(70)90161-7.

[59] Linstone, H. A. and Turoff, M., *The Delphi method: Techniques and applications*, Addison-Wesley Publishing Company, Advanced Book Program Boston, MA, 1975.

[60] Pill, J., "The Delphi method: Substance, context, a critique and an annotated bibliography," *Socio-Economic Planning Sciences*, Vol. 5, No. 1, 1971, pp. 57 – 71. doi:10.1016/0038-0121(71)90041-3.

[61] Murray, T. J., "Delphi methodologies: A review and critique," *Urban Systems*, Vol. 4, No. 2, 1979, pp. 153 – 158. doi:10.1016/0147-8001(79)90013-5.

[62] Tichy, G., "The over-optimism among experts in assessment and foresight," *Technological Forecasting and Social Change*, Vol. 71, No. 4, 2004, pp. 341 – 363. doi:10.1016/j.techfore.2004.01.003.

[63] Welty, G., "Problems of selecting experts for Delphi exercises," *Academy of Management*, Vol. 15, No. 1, 1972, pp. 121 – 124. doi:10.2307/254805.

[64] Shiftan, Y., Kaplan, S., and Hakkert, S., "Scenario building as a tool for planning a sustainable transportation system," *Transportation Research Part D: Transport and Environment*, Vol. 8, No. 5, 2003, pp. 323 – 342. doi:10.1016/S1361-9209(03)00020-8.

[65] Czaplicka-Kolarz, K., Stańczyk, K., and Kapusta, K., "Technology foresight for a vision of energy sector development in Poland till 2030. Delphi survey as an element of technology foresighting," *Technological forecasting and social change*, Vol. 76, No. 3, 2009, pp. 327 – 338. doi:10.1016/j.techfore.2008.05.007.

[66] Terrados, J., Almonacid, G., and Pérez-Higueras, P., "Proposal for a combined methodology for renewable energy planning. Application to a Spanish region," *Renewable and austainable energy reviews*, Vol. 13, No. 8, 2009, pp. 2022 – 2030. doi:10.1016/j.rser.2009.01.025.

[67] Celiktas, M. S. and Kocar, G., "From potential forecast to foresight of Turkey's renewable energy with Delphi approach," *Energy*, Vol. 35, No. 5, 2010, pp. 1973 – 1980. doi:10.1016/j.energy.2010.01.012.

[68] Zack, M. H., *Knowledge and strategy*, Butterworth-Heinemann, 1999.

[69] Mehmood, F., Hassannezhad, M., and Abbas, T., "Analytical Investigation of Mobile NFC Adaption with SWOT-AHP Approach: A Case of Italian Telecom," *Procedia Technology*, Vol. 12, No. 0, 2014, pp. 535 – 541. doi:10.1016/j.protcy.2013.12.526, The 7th International Conference Interdisciplinarity in Engineering, INTER-ENG 2013, 10-11 October 2013, Petru Maior University of Tirgu Mures, Romania.

[70] Terrados, J., Almonacid, G., and Hontoria, L., "Regional energy planning through SWOT analysis and strategic planning tools: impact on renewables development," *Renewable and Sustainable Energy Reviews*, Vol. 11, No. 6, 2007, pp. 1275 – 1287. doi:10.1016/j.rser.2005.08.003.

[71] Markovska, N., Taseska, V., and Pop-Jordanov, J., "SWOT analyses of the national energy sector for sustainable energy development," *Energy*, Vol. 34, No. 6, 2009, pp. 752 – 756. doi:10.1016/j.energy.2009.02.006.

[72] de Souza, G. H. S., Lima, N. C., and Queiroz, J. V., "Marketing approach of Brazilian wind energy sector," *Journal of technology management & innovation*, Vol. 8, No. 4, 2013, pp. 46 – 58.

[73] Figueira, J., Greco, S., and Ehrgott, M., "Introduction," *Multiple criteria decision analysis: state of the art surveys*, edited by J. Figueira, S. Greco, and M. Ehrgott, Springer, 2005, pp. xxi–xxxvi.

[74] Amgoud, L., Bonnefon, J.-F., and Prade, H., "An argumentation-based approach to multiple criteria decision," *8th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty*, Vol. 3571 LNAI, Toulouse, France, Jul 2005, pp. 269–280.

[75] Franklin, B., "The complete works," 1887, Bigelow, J. ed., Putnam, New York.

[76] Pohekar, S. D. and Ramachandran, M., "Application of multi-criteria decision making to sustainable energy planning - A review," *Renewable and Sustainable Energy Reviews*, Vol. 8, No. 4, 2004, pp. 365 – 381. doi:10.1016/j.rser.2003.12.007.

[77] Iniyan, S. and Sumathy, K., "An optimal renewable energy model for various end-uses," *Energy*, Vol. 25, No. 6, 2000, pp. 563 – 575. doi:10.1016/S0360-5442(99)00090-0.

[78] Akash, B. A., Mamlook, R., and Mohsen, M. S., "Multi-criteria selection of electric power plants using analytical hierarchy process," *Electric Power Systems Research*, Vol. 52, No. 1, 1999, pp. 29 – 35. doi:10.1016/S0378-7796(99)00004-8.

[79] Georgopoulou, E., Lalas, D., and Papagiannakis, L., "A multicriteria decision aid approach for energy planning problems: The case of renewable energy option," *European Journal of Operational Research*, Vol. 103, No. 1, 1997, pp. 38 – 54. doi:10.1016/S0377-2217(96)00263-9.

[80] Afgan, N. H. and Carvalho, M. G., "Sustainability assessment of a hybrid energy system," *Energy Policy*, Vol. 36, No. 8, 2008, pp. 2903 – 2910. doi:10.1016/j.enpol.2008.03.040.

[81] Cavallaro, F. and Ciraolo, L., "A multicriteria approach to evaluate wind energy plants on an Italian island," *Energy Policy*, Vol. 33, No. 2, 2005, pp. 235 – 244. doi:10.1016/S0301-4215(03)00228-3.

[82] Jaber, J. O., Jaber, Q. M., Sawalha, S. A., and Mohsen, M. S., "Evaluation of conventional and renewable energy sources for space heating in the household sector," *Renewable and Sustainable Energy Reviews*, Vol. 12, No. 1, 2008, pp. 278 – 289. doi:10.1016/j.rser.2006.05.004.

[83] Papadopoulos, A. and Karagiannidis, A., "Application of the multi-criteria analysis method Electre III for the optimisation of decentralised energy systems," *Omega*, Vol. 36, No. 5, 2008, pp. 766 – 776. doi:10.1016/j.omega.2006.01.004.

[84] Rúdula, A. A. B. and Dia, N. K., "Application of a multi-criteria analysis for the selection of the most suitable energy source and water desalination system in Mauritania," *Energy Policy*, Vol. 38, No. 1, 2010, pp. 99 – 115. doi:10.1016/j.enpol.2009.08.057.

[85] Noori, M., Kucukvar, M., and Tatari, O., "A macro-level decision analysis of wind power as a solution for sustainable energy in the USA," *International Journal of Sustainable Energy*, 2013, pp. 1–16. doi:10.1080/14786451.2013.854796.

[86] Polatidis, H., Haralambopoulos, D. A., Bruinsma, F., Vreeker, R., and Munda, G., "Decision aid with the MCDA-RES software: a wind-hydro energy application for an Island of the Aegean, Greece," *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 4, No. 4, 2009, pp. 407–419. doi:10.1080/15567240701759826.

[87] Lee, A. H. I., Hung, M.-C., Kang, H.-Y., and Pearn, W. L., "A wind turbine evaluation model under a multi-criteria decision making environment," *Energy Conversion and Management*, Vol. 64, 2012, pp. 289 – 300. doi:10.1016/j.enconman.2012.03.029.

[88] Talinli, I., Topuz, E., and Akbay, M. U., "Comparative analysis for energy production processes (EPPs): Sustainable energy futures for Turkey," *Energy Policy*, Vol. 38, No. 8, 2010, pp. 4479 – 4488. doi:10.1016/j.enpol.2010.03.081.

[89] Boran, F. E., Boran, K., and Dizdar, E., "A fuzzy multi criteria decision making to evaluate energy policy based on an information axiom: a case study in turkey," *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 7, No. 3, 2012, pp. 230–240. doi:10.1080/15567240902839294.

[90] Sarucan, A., Baysal, M. E., Kahraman, C., and Engin, O., "A hierarchy grey relational analysis for selecting the renewable electricity generation technologies," *Proceedings of the World Congress on Engineering 2011, WCE 2011*, Vol. 2, 2011, pp. 1149–1154.

[91] Mourmouris, J. C., Potolias, C., and Jacob, F. G., "Evaluation of renewable energy sources exploitation at remote regions, using computing model and multi-criteria analysis: A case-study in samothrace, Greece," *International Journal of Renewable Energy Research*, Vol. 2, No. 2, 2012, pp. 307–316.

[92] Abdel Hamid, R. H., "A GIS-DSS for wind farms industry in Egypt," *Proceedings of the 2011 International Conference and Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia, ICUE 2011*, 2012. doi:10.1109/ICUEPES.2011.6497755.

[93] Noble, M. and Hester, P. T., "Why doesn't the united states have offshore wind farms? A multi-criteria decision analysis of european wind farm common attributes and potential U.S. sites," *Applications of Management Science*, edited by G. K. Kenneth D. Lawrence, Vol. 16, Emerald Group Publishing Limited, 2013, pp. 19–38. doi:10.1108/S0276-8976(2013)0000016005.

[94] Kaya, T. and Kahraman, C., "Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul," *Energy*, Vol. 35, No. 6, 2010, pp. 2517 – 2527. doi:10.1016/j.energy.2010.02.051, 7th International Conference on Sustainable Energy Technologies 7th International Conference on Sustainable Energy Technologies.

[95] Vagiona, D. G. and Karanikolas, N. M., "A multicriteria approach to evaluate offshore wind farms siting in Greece," *Global Nest Journal*, Vol. 14, No. 2, 2012, pp. 235–243.

[96] Ghaderi, S. F., Zakerinia, M. S., and Vaezi, E., "Optimal placement of wind turbine farms in Iran using new ranking method," *2012 2nd Iranian Conference on Renewable Energy and Distributed Generation, ICREDG 2012*, 2012, pp. 132–136.

[97] Aras, H., Şenol Erdoğmuş, and Koç, E., "Multi-criteria selection for a wind observation station location using analytic hierarchy process," *Renewable Energy*, Vol. 29, No. 8, 2004, pp. 1383 – 1392. doi:10.1016/j.renene.2003.12.020.

[98] Al-Yahyai, S., Charabi, Y., Gastli, A., and Al-Badi, A., "Wind farm land suitability indexing using multi-criteria analysis," *Renewable Energy*, Vol. 44, No. 0, 2012, pp. 80 – 87. doi:10.1016/j.renene.2012.01.004.

[99] van Haaren, R. and Fthenakis, V., "GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State," *Renewable and Sustainable Energy Reviews*, Vol. 15, No. 7, 2011, pp. 3332 – 3340. doi:10.1016/j.rser.2011.04.010.

[100] Sagbas, A., "An approach for the prioritization of wind energy production farms," *Energy Education Science and Technology Part A: Energy Science and Research*, Vol. 31, No. 3, 2013, pp. 1329 – 1340.

[101] Karakostas, S. and Economou, D., "Enhanced multi-objective optimization algorithm for renewable energy sources: optimal spatial development of wind farms," *International Journal of Geographical Information Science*, Vol. 28, No. 1, 2014, pp. 83–103. doi:10.1080/13658816.2013.820829.

[102] Erginel, N., Yalçinkaya, M., and Şenturk, S., "Fuzzy dea approach to solve the location selection of wind energy," *World Scientific Proc. Series on Computer Engineering and Information Science 7; Uncertainty Modeling in Knowledge Engineering and Decision Making - Proceedings of the 10th International FLINS Conf.*, Vol. 7, 2012, pp. 207–212. doi:10.1142/9789814417747_0034.

[103] Tegou, L. ., Polatidis, H., and Haralambopoulos, D. A., "Wind turbines site selection on an isolated island," *WIT Transactions on Ecology and the Environment*, Vol. 127, 2009, pp. 313–324. doi:10.2495/RAV090281.

[104] Simão, A., Densham, P. J., and Haklay, M., "Web-based GIS for collaborative planning and public participation: An application to the strategic planning

of wind farm sites," *Journal of Environmental Management*, Vol. 90, No. 6, 2009, pp. 2027 – 2040. doi:10.1016/j.jenvman.2007.08.032.

[105] Tegou, L.-I., Polatidis, H., and Haralambopoulos, D. A., "Environmental management framework for wind farm siting: Methodology and case study," *Journal of Environmental Management*, Vol. 91, No. 11, 2010, pp. 2134 – 2147. doi:10.1016/j.jenvman.2010.05.010.

[106] Hwang, G. H., Wei, L. S., Ching, K. B., and Lin, N. S., "Wind farm allocation in Malaysia based on multi-criteria decision making method," *2011 National Postgraduate Conference - Energy and Sustainability: Exploring the Innovative Minds, NPC 2011*, 2011. doi:10.1109/NatPC.2011.6136445.

[107] Lee, A. H. I., Chen, H. H., and Kang, H.-Y., "Multi-criteria decision making on strategic selection of wind farms," *Renewable Energy*, Vol. 34, No. 1, 2009, pp. 120 – 126. doi:10.1016/j.renene.2008.04.013.

[108] Janke, J. R., "Multicriteria GIS modeling of wind and solar farms in Colorado," *Renewable Energy*, Vol. 35, No. 10, 2010, pp. 2228 – 2234. doi:10.1016/j.renene.2010.03.014.

[109] Golabi, K., Kirkwood, C. W., and Sicherman, A., "Selecting a portfolio of solar energy projects using multiattribute preference theory," *Management Science*, Vol. 27, No. 2, 1981, pp. 174 – 189. doi:10.1287/mnsc.27.2.174.

[110] Mamlook, R., Akash, B. A., and Nijmeh, S., "Fuzzy sets programming to perform evaluation of solar systems in Jordan," *Energy Conversion and Management*, Vol. 42, No. 14, 2001, pp. 1717 – 1726. doi:10.1016/S0196-8904(00)00152-7.

[111] Ramanathan, R. and Ganesh, L. S., "Energy resource allocation incorporating qualitative and quantitative criteria: An integrated model using goal programming and AHP," *Socio-Economic Planning Sciences*, Vol. 29, No. 3, 1995, pp. 197 – 218. doi:10.1016/0038-0121(95)00013-C.

[112] Salah, C. B., Chaabene, M., and Ammar, M. B., "Multi-criteria fuzzy algorithm for energy management of a domestic photovoltaic panel," *Renewable Energy*, Vol. 33, No. 5, 2008, pp. 993 – 1001. doi:10.1016/j.renene.2007.05.036.

[113] Mutlu, S., Çabuk, A., and Güney, Y., "GIS based site determination model for productive solar farm: A case study in Eskişehir," *Proceedings of the International Offshore and Polar Engineering Conference*, 2011, pp. 499–505.

[114] Kavrakoğlu, I. and Kiziltan, G., "Multiobjective strategies in power systems planning," *European Journal of Operational Research*, Vol. 12, No. 2, 1983, pp. 159 – 170. doi:10.1016/0377-2217(83)90219-9.

[115] Pereira Jr., A. O., Soares, J. B., Gorini de Oliveira, R., and Pinto de Queiroz, R., "Energy in Brazil: toward sustainable development?" *Energy Policy*, Vol. 36, No. 1, 2008, pp. 73 – 83. doi:10.1016/j.enpol.2007.08.022.

[116] Mladineo, N., Margeta, J., Brans, J. P., and Mareschal, B., "Multicriteria ranking of alternative locations for small scale hydro plants," *European Journal of Operational Research*, Vol. 31, No. 2, 1987, pp. 215 – 222. doi:10.1016/0377-2217(87)90025-7.

[117] Lipošćak, M., Afgan, N. H., Duić, N., and da Graça Carvalho, M., "Sustainability assessment of cogeneration sector development in Croatia," *Energy*, Vol. 31, No. 13, 2006, pp. 2276 – 2284. doi:10.1016/j.energy.2006.01.024.

[118] Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., Shi, G.-H., and Zhang, X.-T., "A fuzzy multi-criteria decision-making model for trigeneration system," *Energy Policy*, Vol. 36, No. 10, 2008, pp. 3823 – 3832. doi:10.1016/j.enpol.2008.07.002.

[119] Patlitzianas, K. D., Ntotas, K., Doukas, H., and Psarras, J., "Assessing the renewable energy producers' environment in EU accession member states," *Energy Conversion and Management*, Vol. 48, No. 3, 2007, pp. 890 – 897. doi:10.1016/j.enconman.2006.08.014.

[120] Lee, S. K., Mogi, G., Kim, J. W., and Gim, B. J., "A fuzzy analytic hierarchy process approach for assessing national competitiveness in the hydrogen technology sector," *International Journal of Hydrogen Energy*, Vol. 33, No. 23, 2008, pp. 6840 – 6848. doi:10.1016/j.ijhydene.2008.09.028.

[121] Goumas, M. and Lygerou, V., "An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects," *European Journal of Operational Research*, Vol. 123, No. 3, 2000, pp. 606 – 613. doi:10.1016/S0377-2217(99)00093-4.

[122] Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., Zhang, X.-T., and Shi, G.-H., "Integrated evaluation of distributed triple-generation systems using improved grey incidence approach," *Energy*, Vol. 33, No. 9, 2008, pp. 1427 – 1437. doi:10.1016/j.energy.2008.04.008.

[123] Goumas, M. G., Lygerou, V. A., and Papayannakis, L. E., "Computational methods for planning and evaluating geothermal energy projects," *Energy Policy*, Vol. 27, No. 3, 1999, pp. 147 – 154. doi:10.1016/S0301-4215(99)00007-5.

[124] Barda, O. H., Dupuis, J., and Lencioni, P., "Multicriteria location of thermal power plants," *European Journal of Operational Research*, Vol. 45, No. 2–3, 1990, pp. 332 – 346. doi:10.1016/0377-2217(90)90197-J.

[125] Afgan, N. H. and Carvalho, M. G., "Multi-criteria assessment of new and renewable energy power plants," *Energy*, Vol. 27, No. 8, 2002, pp. 739 – 755. doi:10.1016/S0360-5442(02)00019-1.

[126] Suganthi, L. and Williams, A., "Renewable energy in India — a modelling study for 2020–2021," *Energy Policy*, Vol. 28, No. 15, 2000, pp. 1095 – 1109. doi:10.1016/S0301-4215(00)00096-3.

[127] Cormio, C., Dicorato, M., Minoia, A., and Trovato, M., "A regional energy planning methodology including renewable energy sources and environmental constraints," *Renewable and Sustainable Energy Reviews*, Vol. 7, No. 2, 2003, pp. 99 – 130. doi:10.1016/S1364-0321(03)00004-2.

[128] Zongxin, W. and Zhihong, W., "Mitigation assessment results and priorities for China's energy sector," *Applied Energy*, Vol. 56, No. 3–4, 1997, pp. 237 – 251. doi:10.1016/S0306-2619(97)00008-1.

[129] Georgopoulou, E., Sarafidis, Y., and Diakoulaki, D., "Design and implementation of a group DSS for sustaining renewable energies exploitation," *European Journal of Operational Research*, Vol. 109, No. 2, 1998, pp. 483 – 500. doi:10.1016/S0377-2217(98)00072-1.

[130] Beccali, M., Cellura, M., and Mistretta, M., "Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology," *Renewable Energy*, Vol. 28, No. 13, 2003, pp. 2063 – 2087. doi:10.1016/S0960-1481(03)00102-2.

[131] Chedid, R., Mezher, T., and Jarrouche, C., "A fuzzy programming approach to energy resource allocation," *International Journal of Energy Research*, Vol. 23, No. 4, 1999, pp. 303–317. doi:10.1002/(SICI)1099-114X(19990325)23:4<303::AID-ER479>3.0.CO;2-1.

[132] Begić, F. and Afgan, N. H., "Sustainability assessment tool for the decision making in selection of energy system - Bosnian case," *Energy*, Vol. 32, No. 10, 2007, pp. 1979 – 1985. doi:10.1016/j.energy.2007.02.006.

[133] Chatzimouratidis, A. I. and Pilavachi, P. A., "Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process," *Energy Policy*, Vol. 37, No. 3, 2009, pp. 778 – 787. doi:10.1016/j.enpol.2008.10.009.

[134] Chatzimouratidis, A. I. and Pilavachi, P. A., "Objective and subjective evaluation of power plants and their non-radioactive emissions using the analytic hierarchy process," *Energy Policy*, Vol. 35, No. 8, 2007, pp. 4027 – 4038. doi:10.1016/j.enpol.2007.02.003.

[135] Chatzimouratidis, A. I. and Pilavachi, P. A., "Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process," *Energy Policy*, Vol. 36, No. 3, 2008, pp. 1074 – 1089. doi:10.1016/j.enpol.2007.11.028.

[136] Chatzimouratidis, A. I. and Pilavachi, P. A., "Sensitivity analysis of the evaluation of power plants impact on the living standard using the analytic hierarchy process," *Energy Conversion and Management*, Vol. 49, No. 12, 2008, pp. 3599 – 3611. doi:10.1016/j.enconman.2008.07.009.

[137] Doukas, H. C., Andreas, B. M., and Psarras, J. E., "Multi-criteria decision aid for the formulation of sustainable technological energy priorities using

linguistic variables," *European Journal of Operational Research*, Vol. 182, No. 2, 2007, pp. 844 – 855. doi:10.1016/j.ejor.2006.08.037.

[138] Madlener, R., Kowalski, K., and Stagl, S., "New ways for the integrated appraisal of national energy scenarios: The case of renewable energy use in Austria," *Energy Policy*, Vol. 35, No. 12, 2007, pp. 6060 – 6074. doi:10.1016/j.enpol.2007.08.015.

[139] Burton, J. and Hubacek, K., "Is small beautiful? A multicriteria assessment of small-scale energy technology applications in local governments," *Energy Policy*, Vol. 35, No. 12, 2007, pp. 6402 – 6412. doi:10.1016/j.enpol.2007.08.002.

[140] Datta, A., Ray, A., Bhattacharya, G., and Saha, H., "Green energy sources (GES) selection based on multi-criteria decision analysis (MCDA)," *International Journal of Energy Sector Management*, Vol. 5, No. 2, 2011, pp. 271–286. doi:10.1108/17506221111146020.

[141] Wang, J. J., Zhang, C. F., and Jing, Y. Y., "Aggregation method of multi-criteria evaluations in new and renewable energy power plants: A case study," *Proceedings of the ASME 3rd International Conference on Energy Sustainability 2009, ES2009*, Vol. 1, 2009, pp. 461–466. doi:10.1115/ES2009-90103.

[142] Atmaca, E. and Basar, H. B., "Evaluation of power plants in Turkey using Analytic Network Process (ANP)," *Energy*, Vol. 44, No. 1, 2012, pp. 555 – 563. doi:10.1016/j.energy.2012.05.046.

[143] San Cristóbal, J., "Multi-criteria decision-making in the selection of a renewable energy project in Spain: The Vikor method," *Renewable Energy*, Vol. 36, No. 2, 2011, pp. 498 – 502. doi:10.1016/j.renene.2010.07.031.

[144] Kahraman, C., Kaya, I., and Cebi, S., "A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process," *Energy*, Vol. 34, No. 10, 2009, pp. 1603 – 1616. doi:10.1016/j.energy.2009.07.008.

[145] Stein, E. W., "A comprehensive multi-criteria model to rank electric energy production technologies," *Renewable and Sustainable Energy Reviews*, Vol. 22, No. 0, 2013, pp. 640 – 654. doi:10.1016/j.rser.2013.02.001.

[146] Ahmad, S. and Tahar, R. M., "Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia," *Renewable Energy*, Vol. 63, 2014, pp. 458 – 466. doi:10.1016/j.renene.2013.10.001.

[147] Ertay, T., Kahraman, C., and Kaya, I., "Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multicriteria methods: the case of Turkey," *Technological and Economic Development of Economy*, Vol. 19, No. 1, 2013, pp. 38–62. doi:10.3846/20294913.2012.762950.

[148] Wang, J. ., Jing, Y. ., and Zhao, J. ., "Multi criteria evaluation model of renewable energy power plants based on electre method," *Proceedings of the ASME 3rd International Conference on Energy Sustainability 2009, ES2009*, Vol. 1, 2009, pp. 467–473.

[149] Kabak, M. and Dağdeviren, M., "Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology," *Energy Conversion and Management*, Vol. 79, 2014, pp. 25 – 33. doi:10.1016/j.enconman.2013.11.036.

[150] Demirtas, O., "Evaluating the best renewable energy technology for sustainable energy planning," *International Journal of Energy Economics and Policy*, Vol. 3, 2013, pp. 23–33.

[151] Rezaei, J., Fahim, P. B., and Tavasszy, L., "Supplier selection in the airline retail industry using a funnel methodology: Conjunctive screening method and fuzzy {AHP}," *Expert Systems with Applications*, , No. 18, 2014, pp. 8165 – 8179. doi:10.1016/j.eswa.2014.07.005.

[152] Linkov, I., Varghese, A., Jamil, S., Seager, T., Kiker, G., and Bridges, T., "Multi-Criteria Decision Analysis: A Framework for Structuring Remedial Decisions at Contaminated Sites," *Comparative Risk Assessment and Environmental Decision Making*, edited by I. Linkov and A. Ramadan, Vol. 38 of *Nato Science Series: IV: Earth and Environmental Sciences*, Springer Netherlands, 2005, pp. 15–54. doi:10.1007/1-4020-2243-3_2.

[153] Rossi, P. E., Allenby, G. M., and McCulloch, R., *Case Study 4: A Choice Model with Conjunctive Screening Rules*, John Wiley & Sons, Ltd, 2006, pp. 253–267. doi:10.1002/0470863692.oth4.

[154] Cheng, C.-H. and Lin, Y., "Evaluating the best main battle tank using fuzzy decision theory with linguistic criteria evaluation," *European Journal of Operational Research*, Vol. 142, No. 1, 2002, pp. 174 – 186. doi:10.1016/S0377-2217(01)00280-6.

[155] Lee, J. W. and Kim, S. H., "An integrated approach for interdependent information system project selection," *International Journal of Project Management*, Vol. 19, No. 2, 2001, pp. 111 – 118. doi:10.1016/S0263-7863(99)00053-8.

[156] Al-helal, A. B. and Al-awadhi, J. M., "Assessment of sand encroachment in Kuwait using GIS," *Environmental Geology*, Vol. 49, No. 7, 2006, pp. 960–967. doi:10.1007/s00254-005-0134-8.

[157] Saaty, T. L., "A scaling method for priorities in hierarchical structures," *Journal of Mathematical Psychology*, Vol. 15, No. 3, 1977, pp. 234 – 281. doi:10.1016/0022-2496(77)90033-5.

[158] Saaty, T. L., *The analytic hierarchy process: planning, priority setting, resource allocation*, Advanced book program, McGraw-Hill, 1980.

[159] Saaty, T. L., "How to make a decision: the analytic hierarchy process," *European Journal of Operational Research*, Vol. 48, No. 1, 1990, pp. 9 – 26. doi:10.1016/0377-2217(90)90057-I.

[160] Roy, B., "Classement et choix en présence de points de vue multiples," *RAIRO - Operations Research - Recherche Opérationnelle*, Vol. 2, No. V1, 1968, pp. 57–75.

[161] Brans, J. P., Vincke, P., and Mareschal, B., "How to select and how to rank projects: The Promethee method," *European Journal of Operational Research*, Vol. 24, No. 2, 1986, pp. 228 – 238. doi:10.1016/0377-2217(86)90044-5, Mathematical Programming Multiple Criteria Decision Making.

[162] Murphy, C. K., "Limits on the analytic hierarchy process from its consistency index," *European Journal of Operational Research*, Vol. 65, No. 1, 1993, pp. 138 – 139. doi:10.1016/0377-2217(93)90148-G.

[163] Belton, V. and Gear, T., "On a short-coming of Saaty's method of analytic hierarchies," *Omega*, Vol. 11, No. 3, 1983, pp. 228 – 230. doi:10.1016/0305-0483(83)90047-6.

[164] Belton, V., "A comparison of the analytic hierarchy process and a simple multi-attribute value function," *European Journal of Operational Research*, Vol. 26, No. 1, 1986, pp. 7 – 21. doi:10.1016/0377-2217(86)90155-4.

[165] Macharis, C., Springael, J., Brucker, K. D., and Verbeke, A., "{PROMETHEE} and AHP: The design of operational synergies in multicriteria analysis.: Strengthening {PROMETHEE} with ideas of {AHP}," *European Journal of Operational Research*, Vol. 153, No. 2, 2004, pp. 307 – 317. doi:10.1016/S0377-2217(03)00153-X.

[166] Dawes, R. M. and Corrigan, B., "Linear models in decision making," *Psychological Bulletin*, Vol. 81, No. 2, 1974, pp. 95–106. doi:10.1037/h0037613.

[167] Aragonés-Beltrán, P., Chaparro-González, F., Pastor-Ferrando, J.-P., and Pla-Rubio, A., "An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based multi-criteria decision approach for the selection of solar-thermal power plant investment projects," *Energy*, Vol. 66, No. 0, 2014, pp. 222 – 238. doi:10.1016/j.energy.2013.12.016.

[168] Sónes, J., "Environmental quality indexing of large industrial development alternatives using AHP," *Environmental Impact Assessment Review*, Vol. 23, No. 3, 2003, pp. 283 – 303. doi:10.1016/S0195-9255(03)00004-0.

[169] Wang, J.-J. and Yang, D.-L., "Using a hybrid multi-criteria decision aid method for information systems outsourcing," *Computers & Operations Research*, Vol. 34, No. 12, 2007, pp. 3691 – 3700. doi:10.1016/j.cor.2006.01.017.

[170] Dağdeviren, M., "Decision making in equipment selection: an integrated approach with AHP and PROMETHEE," *Journal of Intelligent Manufacturing*, Vol. 19, No. 4, 2008, pp. 397–406. doi:10.1007/s10845-008-0091-7.

[171] Beim, G. and Levesque, M., *Country selection for new business venturing: a multiple criteria decision analysis*, Case Western Reserve University, 2003, http://weatherhead.case.edu/departments/operations/research-documents/technicalReports/Technical%20Memorandum%20Number%20776R.pdf, online; accessed 04-Jun-2014.

[172] The World Bank, "Foreign direct investment, net inflows (BoP, current US$)," 2014, http://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD, online; accessed 06-Jul-2014.

[173] Kobrin, S. J., "The environmental determinants of foreign direct manufacturing investment: an ex post empirical analysis," *Journal of International Business Studies*, 1976, pp. 29–42.

[174] Kumar, N., "Determinants of export orientation of foreign production by US multinationals: An inter-country analysis," *Journal of International Business Studies*, 1994, pp. 141–156.

[175] Zhao, H. and Levary, R. R., "Evaluation of country attractiveness for foreign direct investment in the e-retail industry," *Multinational Business Review*, Vol. 10, 2002, pp. 1–10.

[176] Hoffman, J. J. and Schniederjans, M. J., "A two-stage model for structuring global facility site selection decisions: the case of the brewing industry," *International Journal of Operations & Production Management*, Vol. 14, No. 4, 1994, pp. 79–96.

[177] Swoboda, B., Schwarz, S., and Hälsig, F., "Towards a conceptual model of country market selection: Selection processes of retailers and C&C wholesalers," *The International Review of Retail, Distribution and Consumer Research*, Vol. 17, No. 3, 2007, pp. 253–282. doi:10.1080/09593960701368820.

[178] Cook, W. D. and Hebner, K. J., "A multicriteria approach to country risk evaluation: With an example employing Japanese data," *International Review of Economics & Finance*, Vol. 2, No. 4, 1993, pp. 327 – 348. doi:10.1016/1059-0560(93)90008-E.

[179] Ehrman, C. M. and Hamburg, M., "Information search for foreign direct investment using two-stage country selection procedures: A new procedure," *Journal of International Business Studies*, 1986, pp. 93–116.

[180] Woodward, D. P. and Rolfe, R. J., "The location of export-oriented foreign direct investment in the Caribbean Basin," *Journal of international business studies*, 1993, pp. 121–144.

[181] Cosset, J.-C., Siskos, Y., and Zopounidis, C., "Evaluating country risk: A decision support approach," *Global Finance Journal*, Vol. 3, No. 1, 1992, pp. 79 – 95. doi:10.1016/1044-0283(92)90006-7.

[182] Doumpos, M., Zanakis, S. H., and Zopounidis, C., "Multicriteria Preference Disaggregation for Classification Problems with an Application to Global Investing Risk*," *Decision Sciences*, Vol. 32, No. 2, 2001, pp. 333–386.

[183] Brush, T. H., Marutan, C. A., and Karnani, A., "The plant location decision in multinational manufacturing firms: an empirical analysis of international business and manufacturing strategy perspectives," *Production and Operations Management*, Vol. 8, No. 2, 1999, pp. 109–132.

[184] Tvaronavičiene, M., Grybaite, V., and Korsakiene, R., "Foreign capital destinations: Baltic States versus India," *Journal of Business Economics and Management*, Vol. 9, No. 3, 2008, pp. 227–234. doi:10.3846/1611-1699.2008.9.227-234.

[185] Cabrera, L. R. and Giraldo, G. E., "A multiple criteria decision analysis for the FDI in Latin-American countries," *Proceeding of The 2009 Industrial Engineering Research Conference, University of Puerto Rico. Puerto Rico: June*, 2009.

[186] Daim, T., Bhatla, A., and Mansour, M., "Site selection for a data centre - a multi-criteria decision-making model," *International Journal of Sustainable Engineering*, Vol. 6, No. 1, 2013, pp. 10–22. doi:10.1080/19397038.2012.719554.

[187] Cheng, M.-Y., Tsai, H.-C., and Chuang, K.-H., "Supporting international entry decisions for construction firms using fuzzy preference relations and cumulative prospect theory," *Expert Systems with Applications*, Vol. 38, No. 12, 2011, pp. 15151 – 15158. doi:10.1016/j.eswa.2011.05.089.

[188] Dumludag, D., "An analysis of the determinants of foreign direct investment in Turkey: The role of the institutional context," *Journal of Business Economics and Management*, Vol. 10, No. 1, 2009, pp. 15–30. doi:10.3846/1611-1699.2009.10.15-30.

[189] Wu, D. D., "Supplier selection in a fuzzy group setting: A method using grey related analysis and Dempster?Shafer theory," *Expert Systems with Applications*, Vol. 36, No. 5, 2009, pp. 8892 – 8899. doi:10.1016/j.eswa.2008.11.010.

[190] Mekking, R., *International growth ambition. A country selection and market entry advice for HowTech B.V.*, Master's thesis, School of Management and Governance, University of Twente, Enschede, the Netherlands, 2008, `http://essay.utwente.nl/58720/1/scriptie_R_Mekking.pdf`, online; accessed 07-Jul-2014.

[191] Lu, X., McElroy, M. B., and Kiviluoma, J., "Global potential for wind-generated electricity," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 106, No. 27, 2009, pp. 10933–10938. doi:10.1073/pnas.0904101106.

[192] International Renewable Energy Agency, "Global atlas for renewable energy," `http://irena.masdar.ac.ae/`, online; accessed 05-May-2014.

[193] National renewable energy laboratory, "Mapsearch," http://www.nrel.gov/gis/mapsearch/, online; accessed 07-May-2014.

[194] International Renewable Energy Agency and International Energy Agency, "Studies on renewable energy potential," https://www.irena.org/potential_studies/index.aspx, online; accessed 05-May-2014.

[195] Morris, C., "Overview of grid reliability in EU," 2013, http://www.renewablesinternational.net/overview-of-grid-reliability-in-eu/150/537/75716/, online; accessed 06-Jul-2014.

[196] The World Bank, "Infrastructure," 2014, http://www.enterprisesurveys.org/data/exploreTopics/Infrastructure, online; accessed 06-Jul-2014.

[197] International Energy Agency, "World energy statistics and balances (2013 edition)," http://data.iea.org, online; accessed 01-May-2014.

[198] Deloitte, "Corporate tax rate 2014," http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Tax/dttl-tax-corporate-tax-rates-2014.pdf, online; accessed 01-May-2014.

[199] International Energy Agency, "Statistics, electricity and heat," 2014, http://www.iea.org/statistics/; online; accessed 06-Jul-2014.

[200] Bloomberg New Energy Finance, "Electricity demand growth, 2014-30," 2014.

[201] International Renewable Energy Agency and International Energy Agency, "IEA/IRENA joint policies and measures database," http://www.iea.org/policiesandmeasures/renewableenergy/, online; accessed 05-May-2014.

[202] Renewable Energy Policy Network for the 21st Century, "Renewables interactive map," http://www.map.ren21.net/, online; accessed 14-May-2014.

[203] Moccia, J., Arapogianni, A., Wilkes, J., Kjaer, C., Gruet, R., Azau, S., Scola, J., and Bianchin, R., "Pure power, wind energy targets for 2020 and 2030," Tech. rep., European Wind Energy Association, 2011, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf, online; accessed 14-May-2014.

[204] Boekhoudt, A. and Behrendt, L., "Tax incentives for renewable energy," Tech. rep., KPMG International, 2013, https://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/taxes-and-incentives-for-renewable-energy/Documents/taxes-and-incentives-for-renewable-energy-2013.pdf, online; accessed 01-May-2014.

[205] International Renewable Energy Agency, "30 years of policies for wind energy," 2012, https://www.irena.org/DocumentDownloads/Publications/IRENA_GWEC_WindReport_Full.pdf, online; accessed 05-May-2014.

[206] Enerdata, "Global energy statistical yearbook 2013," http://yearbook.enerdata.net/energy-consumption-data.html, online; accessed 01-May-2014.

[207] International Energy Agency, "Statistics," http://www.iea.org/statistics/, online; accessed 13-May-2014.

[208] Renewable Energy and Energy Efficiency Partnership and Renewable Energy Policy Network for the 21st Century, "Reegle, policy and regulatory overviews," http://www.reegle.info/policy-and-regulatory-overviews/, online; accessed 14-May-2014.

[209] Marsh, "Political risk trends and hotspots for 2014," http://usa.marsh.com/Portals/9/Documents/MRMR_Marsh-Maplecroft%20Political%20Risk_FINAL.pdf, online; accessed 01-May-2014.

[210] International Civil Aviation Organization, 2014, http://www.icao.int/, online; accessed 06-Jul2014.

[211] The World Bank Group, "Dealing with Construction Permits," 2014, http://www.doingbusiness.org/data/exploretopics/dealing-with-construction-permits, online; accessed 06-Jul-2014.

[212] The World Bank Group, "Protecting Investors," 2014, http://www.doingbusiness.org/data/exploretopics/protecting-investors, online; accessed 06-Jul-2014.

[213] Braynard Group, Inc., "2013 Report, international property rights index," http://www.internationalpropertyrightsindex.org/ranking, online; accessed 01-May-2014.

[214] Global wind energy council, "Global wind statistics 2013," 2014, http://www.gwec.net/wp-content/uploads/2014/02/GWEC-PRstats-2013_EN.pdf, online; accessed 02-May-2014.

[215] European Commission, "Public awareness and acceptance of CO_2 capture and storage," 2011, http://ec.europa.eu/public_opinion/archives/ebs/ebs_364_en.pdf, online; accessed 02-May-2014.

[216] Jacobe, D., "Americans want more emphasis on solar, wind, natural Gas," 2013, http://www.gallup.com/poll/161519/americans-emphasis-solar-wind-natural-gas.aspx, accessed 02-May-2014.

[217] Lombard, A. and Ferreira, S., "Residents' attitudes to proposed wind farms in the West Coast region of South Africa: A social perspective from the South," *Energy Policy*, Vol. 66, No. 0, 2014, pp. 390 – 399. doi:10.1016/j.enpol.2013.11.005.

[218] IRENA, "Renewable energy technologies: cost analysis series - wind power," 2012, http://costing.irena.org/media/2784/RE_Technologies_Cost_Analysis-WIND_POWER.pdf; online; accessed 21-Nov-2014.

[219] United States department of commerce, "Political & security risks," http://acetool.commerce.gov/political-security-risks, online; accessed 01-May-2014.

[220] Saaty, T. and Ozdemir, M., "Why the magic number seven plus or minus two," *Mathematical and Computer Modelling*, Vol. 38, No. 3?4, 2003, pp. 233 – 244. doi:10.1016/S0895-7177(03)90083-5.

[221] Saaty, T. L., "Decision making with the analytic hierarchy process," *International journal of services sciences*, Vol. 1, No. 1, 2008, pp. 83–98. doi:10.1504/IJSSci.2008.01759.

[222] 3Tiers, "Global Wind Speed Map," http://www.3tier.com/en/support/resource-maps/, online; accessed 08-May-2014.

[223] Arent, D., Sullivan, P., Heimiller, D., Lopez, A., Eurek, K., Badger, J., Jørgensen, H. E., Kelly, M., Clarke, L., and Luckow, P., "Improved offshore wind resource assessment in global climate stabilization scenarios," Tech. rep., National renewable energy laboratory, 2012, http://www.nrel.gov/docs/fy13osti/55049.pdf, online; accessed 08-May-2014.

[224] Mareschal, B., "The PROMETHEE-GAIA FAQ," 2012, http://www.promethee-gaia.net/faq-pro/, online; accessed 03-Jun-2014.

[225] Mareschal, B., "How to choose the right preference function?" 2012, http://www.promethee-gaia.net/faq-pro/?action=article&cat_id=003002&id=4&lang=, online; accessed 03-Jun-2014.

[226] International renewable energy agency, "IRENA renewable energy country profiles," 2014, http://www.irena.org/REmaps/, online; accessed 24-Sep-2014.

[227] Reegle, "Reegle country profiles," 2014, http://www.reegle.info/countries/, online; accessed 24-Sep-2014.

[228] World Economic Forum, "The global competitiveness report," 2009, http://www.weforum.org/pdf/GCR09/GCR20092010fullreport.pdf, online; accessed 24-Sep-2014.

[229] KPMG, "Corporate tax rates table," 2014, http://www.kpmg.com/global/en/services/tax/tax-tools-and-resources/pages/corporate-tax-rates-table.aspx, online; accessed 24-Sep-2014.

[230] Deloitte, "Corporate tax rates 2014," 2014, http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Tax/dttl-tax-corporate-tax-rates-2014.pdf, online; accessed 24-Sep-2014.

[231] Central Intelligence Agency, "The world factbook," 2014, http://www.photius.com/rankings/spreadsheets_2014/energy_2014.xls, online; accessed 09-Sep-2014.

[232] Bloomberg New Energy Finance, "H2 2014 LCOE Global Country Data," 2014.

[233] Ghazanfari, M. and Nojavan, M., "Educing inconsistency in fuzzy AHP by mathematical programming models," *Asia-Pacific Journal of Operational Research*, Vol. 21, No. 03, 2004, pp. 379–391. doi:10.1142/S0217595904000291.

[234] Tseng, T.-Y., Lin, S.-W., Huang, C.-L., and Lee, R., "Inconsistency Adjustment in the AHP Using the Complete Transitivity Convergence Algorithm," *Systems, Man and Cybernetics, 2006. SMC '06. IEEE International Conference on*, Vol. 4, Oct 2006, pp. 2808–2812. doi:10.1109/ICSMC.2006.385299.

[235] Heo, E., Kim, J., and Cho, S., "Selecting hydrogen production methods using fuzzy analytic hierarchy process with opportunities, costs, and risks," *International Journal of Hydrogen Energy*, Vol. 37, No. 23, 2012, pp. 17655 – 17662. doi:10.1016/j.ijhydene.2012.09.055.

[236] Heo, E., Kim, J., and Boo, K.-J., "Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy {AHP}," *Renewable and Sustainable Energy Reviews*, Vol. 14, No. 8, 2010, pp. 2214 – 2220. doi:10.1016/j.rser.2010.01.020.

[237] Erol, Ö. and Kilkiç, B., "An energy source policy assessment using analytical hierarchy process," *Energy Conversion and Management*, Vol. 63, No. 0, 2012, pp. 245 – 252. doi:10.1016/j.enconman.2012.01.040, 10th International Conference on Sustainable Energy Technologies (SET 2011).

[238] Mészáros, C. and Rapcs'ak, T., "On sensitivity analysis for a class of decision systems," *Decision Support Systems*, Vol. 16, No. 3, 1996, pp. 231 – 240. doi:10.1016/0167-9236(95)00012-7.

[239] Nekhay, O., Arriaza, M., and Guzmán-Álvarez, J. R., "Spatial analysis of the suitability of olive plantations for wildlife habitat restoration," *Computers and Electronics in Agriculture*, Vol. 65, No. 1, 2009, pp. 49 – 64. doi:10.1016/j.compag.2008.07.012.

[240] Kodikara, P. N., *Multi-objective optimal operation of urban water supply systems*, Ph.D. thesis, Victoria University, Australia, 2008.

[241] Sultana, A. and Kumar, A., "Ranking of biomass pellets by integration of economic, environmental and technical factors," *Biomass and Bioenergy*, Vol. 39, No. 0, 2012, pp. 344 – 355. doi:10.1016/j.biombioe.2012.01.027.

[242] Dhouib, D. and Elloumi, S., "A new multi-criteria approach dealing with dependent and heterogeneous criteria for end-of-life product strategy," *Applied Mathematics and Computation*, Vol. 218, No. 5, 2011, pp. 1668 – 1681. doi:10.1016/j.amc.2011.06.046.

[243] Mohamadabadi, H. S., Tichkowsky, G., and Kumar, A., "Development of a multi-criteria assessment model for ranking of renewable and non-renewable transportation fuel vehicles," *Energy*, Vol. 34, No. 1, 2009, pp. 112 – 125. doi:10.1016/j.energy.2008.09.004.

[244] Luk, J., Fernandes, H., and Kumar, A., "A conceptual framework for siting biorefineries in the Canadian Prairies," *Biofuels, Bioproducts and Biorefining*, Vol. 4, No. 4, 2010, pp. 408–422. doi:10.1002/bbb.233.

[245] Pilavachi, P. A., Stephanidis, S. D., Pappas, V. A., and Afgan, N. H., "Multi-criteria evaluation of hydrogen and natural gas fuelled power plant technologies," *Applied Thermal Engineering*, Vol. 29, No. 11?12, 2009, pp. 2228 – 2234. doi:10.1016/j.applthermaleng.2008.11.014.

[246] Afgan, N. H. and Carvalho, M. G., "Sustainability assessment of hydrogen energy systems," *International Journal of Hydrogen Energy*, Vol. 29, No. 13, 2004, pp. 1327 – 1342. doi:10.1016/j.ijhydene.2004.01.005.

[247] Dinca, C., Badea, A., Rousseaux, P., and Apostol, T., "A multi-criteria approach to evaluate the natural gas energy systems," *Energy Policy*, Vol. 35, No. 11, 2007, pp. 5754 – 5765. doi:10.1016/j.enpol.2007.06.024.

[248] Afgan, N. H., Pilavachi, P. A., and Carvalho, M. G., "Multi-criteria evaluation of natural gas resources," *Energy Policy*, Vol. 35, No. 1, 2007, pp. 704 – 713. doi:10.1016/j.enpol.2006.01.015.

[249] Alanne, K., Salo, A., Saari, A., and Gustafsson, S.-I., "Multi-criteria evaluation of residential energy supply systems," *Energy and Buildings*, Vol. 39, No. 12, 2007, pp. 1218 – 1226. doi:10.1016/j.enbuild.2007.01.009.

[250] Planning Commission (Government of India) , "Twelfth five year plan (2012-2017)," Tech. rep., 2013, `http://planningcommission.gov.in/plans/planrel/12thplan/pdf/12fyp_vol2.pdf`, online; accessed 15-Sep-2014.

[251] Global Wind Energy Council, "Global wind energy outlook 2012," 2012, `http://www.gwec.net/wp-content/uploads/2012/11/India-Wind-Energy-Outlook-2012.pdf`, online; accessed 09-Sep-2014.

[252] Rapoza, K., "The World's Riskiest Nations," 2013, `http://www.forbes.com/sites/kenrapoza/2013/03/19/the-worlds-riskiest-nations/`, online; accessed 15-Sep-2014.

[253] Schwab, K., "The global competitiveness report 2009-2010," Tech. rep., World Economic Forum, 2009, `http://www.weforum.org/pdf/GCR09/GCR20092010fullreport.pdf`, online; accessed 15-Sep-2014.

[254] Yardley, J. and Harris, G., "2nd Day of Power Failures Cripples Wide Swath of India," Tech. rep., The New York Times, 2012, `http://www.nytimes.com/2012/08/01/world/asia/power-outages-hit-600-million-in-india.html?pagewanted=all.pdf`, online; accessed 15-Sep-2014.

[255] International renewable energy agency, "Italy, market overview," 2013, https://www.irena.org/DocumentDownloads/Publications/GWEC_Italy.pdf, online; accessed 26-Sep-2014.

[256] The wind power, "Wind turbines and wind farms database, Italy," 2014, http://www.thewindpower.net/country_en_7_italy.php, online; accessed 26-Sep-2014.

[257] Maplecroft, "Country risk report - Russia," 2014, http://maplecroft.com/about/news/country-risk-reports-russia-may2.html. online; accessed 15-Sep-2014.

[258] Rice, B., Blomfield, A., and Rotar, A., "Russia's Second Renewable Energy Auction Gives Both Glimmer of Hope and Cause for Concern," 2014, http://www.kslaw.com/library/newsletters/EnergyNewsletter/2014/July/article1.html, online; accessed 15-Sep-2014.

[259] Clover, I., "Russia offers first ever subsidies for renewable energy," 2014, http://www.pv-magazine.com/news/details/beitrag/russia-offers-first-ever-subsidies-for-renewable-energy_100012889/#axzz3CAwG2R8v, online; accessed 15-Sep-2014.

[260] James, C. S., "Why Argentina's renewable energy programme has stalled," Buenos Aires Herald, 2013, http://www.buenosairesherald.com/article/132627/why-argentina%E2%80%99s-renewable-energy-programme-has-stalled, online; accessed 26-Sep-2014.

[261] The Wind Power, "Wind turbines and wind farms database, Argentina," 2014, http://www.thewindpower.net/country_en_48_argentina.php, online; accessed 07-Aug-2014.

[262] International renewable energy agency, "United States and the States of California and Texas, market overview," 2013, https://www.irena.org/DocumentDownloads/Publications/GWEC_USA.pdf, online, accessed 26-Sep-2014.

[263] The wind power, "Wind turbines and wind farms database, USA," 2014, http://www.thewindpower.net/country_en_4_usa.php, online; accessed 26-Sep-2014.

[264] American Wind Energy Association, "Wind energy facts at a glance," 2013, http://www.awea.org/Resources/Content.aspx?ItemNumber=5059, online; accessed 26-Sep-2014.

[265] International Energy Agency, "Canada," 2014, http://www.iea.org/publications/mtmr/countries/canada/, online; accessed 07-Aug-2014.

[266] Saskatchewan Environmental Society, "Yes they can: a 2020 vision for Saskpower," 2013, http://www.

environmentalsociety.ca/main/wp-content/uploads/2013/12/Bob-Hallidays-Final-Report-on-behalf-of-SES-to-SaskPower.pdf, online; accessed 29-Jul-2014.

[267] Canadian Solar Industries Association, "Provincial Consumer Incentives," 2011, http://www.cansia.ca/government-regulatory-issues/consumer-incentives/provincial.

[268] International renewable energy agency, "Hydro, renewable energy technology: cost analysis series," 2012, http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-HYDROPOWER.pdf, online; accessed 09-Sep-2014.

[269] International Energy Agency, "Projected costs of generating electricity," 2010, http://www.iea.org/publications/freepublications/publication/projected_costs.pdf, online; accessed 09-Sep-2014.

[270] International renewable energy agency, "China, market overview," 2013, https://www.irena.org/DocumentDownloads/Publications/IRENA_GWEC_WindReport_China.pdf, online; accessed 26-Sep-2014.

[271] The wind power, "Wind farms lists," 2014, http://www.thewindpower.net/windfarms_list_en.php, online; accessed 26-Sep-2014.

[272] Rogers, E. M., *Diffusion of innovations*, Simon and Schuster, 2010.

[273] Cooper, R. G., "Product innovation and technology strategy," *Research Technology Management*, Vol. 43, No. 1, 2000, pp. 38–41.

[274] Near Zero, "Energy high in the sky: expert perspectives on airborne wind energy systems," 2012, http://www.nearzero.org/reports/AirborneWind/pdf, online; accessed 13-Nov-2014.

Appendix A

Survey to prioritize criteria

Table A.1: Experts completed the survey

Field	Company	Name	Function
AWE industry	Makani	A. Woodrow	Business lead
	Makani	L. Casey	Engineer
	NTS X-Wind	U. Ahrens	CEO
	Airborne wind turbine	B. Lau	projectleader AWT project , technical manager CMC-Kuhnke
	Anonymous	Anonymous	CTO
	Anonymous	Anonymous	Director
	Anonymous	Anonymous	Head of Business Unit Power Industry
	Anonymous	Anonymous	CEO
	Flygenkite	B. Pierre	-
	Anurac	M. Bungart	Founder
	Daidaos	U. Zillmann	CEO of Daidalos Capital, a fund solely investing in AWE
	Kitenmergy	Anonymous	Managing Director
University	TU Delft	R. Schmehl	Assistant professor, lead kite power department
	TU Delft	G. van Bussel	Prof. Wind Energy group
	TU Delft	R. Kunneke	Prof. Economics of Infrastructures
	TU Delft	C. Grete	Mechanical Engineer in AWE project
	TU Delft	A. Cruz	PhD researcher, background in gas and oil industry
WE industry	Garrad Hassan	C. Faasen	Technical advisor solar and wind energy projects
	Siemens	D. Molenaar	Country division head wind power
	Eneco	F. Heijckmann	Project Manager
	Nuon	H. Kouwenhoven	Development manager WE
	Nuon	Anonymous	Project developer
	Nuon	M. Deimel	Head Wind Development NL
NGO	Anonymous	Anonymous	Broad macro investing coverage, including energy and renewables
	Anonymous	Anonymous	Senior scientist
Governmental	NASA	K. Antcliff	Aerospace Engineer, with background in AWE

Survey: Criteria prioritizing for AWE siting

Country selection and local siting of airborne wind turbines

Dear participant,

Thank you for taking some minutes to participate in this expert survey regarding country and site selection for the deployment of airborne wind energy (AWE) systems. The AWE industry is in its infancy, but commercial products will soon become available to this new and unexplored market. It is the goal of my TU Delft graduation research to explore the market, and determine the most appropriate nations (and regions within these nations) for AWE deployment.

Various technical, economical, environmental and political criteria influence the site selection of AWE systems, and some criteria might be more important than another. For a realistic analysis the relative importance of these criteria are of upmost importance. For this specific industry, the opinion of experts are most valuable and therefore about 20 experts from various backgrounds (government, industry, university and NGOs) are invited to participate in our expert survey to determine the relative importance of various criteria in country and site selection for the deployment of airborne wind energy systems.

In case you're unfamiliar with the airborne wind energy concept, please answer the questions from your wind energy expertise. It will take approximately 15 minutes to complete the questionnaire. Your participation in this study is completely voluntary and you can withdraw from the survey at any point. It is very important for us to learn from your opinions.

The next page contains questions about your background. Next you'll get an example question introducing the type of questions and answers. The remaining of the survey contains 70 questions related to the importance of various criteria relevant for country and site selection for the deployment of airborne wind energy systems.

If you have questions at any time about the survey or the procedures, you may contact Ir. Jelle Wijnja at +31(0)614600251 or by email at j.wijnja@student.tudelft.nl.

Thank you very much for your time and support. Please start with the survey now by clicking on the **Continue** button below.

What is your background? (multiple answers possible) *

- ☐ Industry, Wind Energy
- ☐ Industry, Airborne Wind Energy
- ☐ University, Wind Energy
- ☐ University, Airborne Wind Energy
- ☐ Governmental
- ☐ NGO
- ☐ Other ________

How many years of experience in Wind Energy?

____

How many years of experience in Airborne Wind Energy?

____

Other relevant experience:

What is your current function?

Name (not required)

Email address (not required)

Example

In this survey the pair-wise comparison method is applied. The importance of each criteria is determined with respect to the other criteria.

The following scale is applied:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Let's try this with an example. Let's say that for choosing a car, four criteria are of importance; **price**, **color**, **fuel consumption** and the **size**. In this example we determine the importance of all criteria with respect to the size of the car. The questions and answers in this survey are of the kind:

Give the relative importance of the following criteria with respect to the **size of the car**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Price *	○	○	◉	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Size

You should fill in one of the radio buttons according to the scale explained earlier. In this example, the radio button (6) is filled. This means that you believe, that for choosing a car, the price is a **strongly more important** criterion than the size.

In the next example, radio button (0) is filled. This means that you believe, that for choosing a car, the color and the size are **equally important** criteria.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Color *	○	○	○	○	○	○	○	○	◉	○	○	○	○	○	○	○	○	Size

In this example the (-7) radio button is filled. This means that you believe, that for choosing a car, the fuel consumption is **in between a very strongly less important and extremely less important** criterion with respect to the size of the car.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Fuel consumption *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◉	○	Size

Some last words before starting the pair-wise comparison part of the survey:

1) any comments/suggestions are welcome and can be given at the bottom of each page
2) an explanation of the scale is given at the bottom of each page

Start by ranking the main criteria, **technical, economic, political, social.**

Compare the **technical** criteria according to its relative importance with respect to the **economic**

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Technical *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Economic

And, compare the relative importance with respect to the **political** criteria.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Technical *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political
Economic *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political

And, compare the relative importance with respect to the **social** criteria.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Political *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social
Technical *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social
Economic *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social

Comments/Suggestions:

Scale:

---

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Next start the pair-wise comparison of the more detailed criteria

---

Compare the **wind climate** criterion according to its relative importance with respect to the **visual quality of the landscape at which the wind farm is planned**

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Visual.quality.of.the.landscape

---

Within the 'Wind climate' criterion, compare the **national wind energy potential** sub-criterion according to its relative importance with respect to the **local wind power density**

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
National wind energy potential *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Local.wind.power.density

---

Comments/Suggestions:

Scale:

---

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..

-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **ease of doing business**.

The ease of doing business is measured by (1) the number of procedures and time required for construction permits, (2) the level of investor protection and (3) the degree to which standardized aviation regulations are applied.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Visual quality of the landscape *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Ease of doing business
The wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Ease.of.doing.business

---

Within the 'ease of doing business' criterion, compare the sub-criterion **number of procedures and time required for construction permits** according to its relative importance with respect to the **level of investor protection**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Procedures and time required for construction permits *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Level.of.investor.protection

And, compare the subcriteria according to their relative importance with respect to **level of standardized aviation regulations**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Level of investor protection *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Standardized aviation regulations
Number of procedures and time required for construction permits *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Standardized.aviation.regulations

Comments/Suggestions:

Scale:

---

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..

-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **governmental financial support schemes for renewable energy (RE)**. Abbreviated to 'RE support schemes'.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Ease of doing business *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	RE support schemes
Visual quality of the landscape *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	RE support schemes
Wind climate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	RE.support.schemes

---

Within the 'governmental financial support schemes for renewable energy' criterion, compare the sub-criterion **specific wind energy financial support programs** according to its relative importance with respect to, the **general renewable energy support programs**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Specific wind energy *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	General.RE

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **political risk**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
RE support schemes *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political risk
Ease of doing business *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political risk
Visual quality of the landscape *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political risk
Wind climate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Political.risk

Comments/Suggestions:

___

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **social acceptance of (airborne) wind energy**.

The criterion 'social acceptance' is defined as the combination of public and market acceptance.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Political risk *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social acceptance
RE support programs *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social acceptance
Ease of doing business *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social acceptance
Visual quality of the landscape *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social acceptance
Wind climate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social.acceptance

---

Within the 'social acceptance' criterion, compare the **public acceptance** according to its relative importance with respect to the **market acceptance**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Public acceptance *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market.acceptance

---

Comments/Suggestions:

Scale:

___

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **level of intellectual property (IP) right protection**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Social acceptance *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP protection
Political risk *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP protection
RE support schemes *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP protection
Ease of doing business *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP protection
Visual quality of the landscape *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP protection
Wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	IP.protection

---

Comments/Suggestions:

:
Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to **the availability of a suitable grid system**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
IP protection *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
Social acceptance *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
Political stability *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
RE support schemes *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
Ease of doing business *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
Visual quality of the landscape *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid system
Wind climate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid.system

Comments/Suggestions:

Within the 'The availability of a suitable grid system' criterion, compare the **grid downtime** according to its relative importance with respect to the **electrification rate, the rate of buildings connected to the grid**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Electrification rate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Grid.Downtime

And, compare the subcriteria according to their relative importance with respect to the **distance between the wind farm and the grid**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Grid downtime *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Distance from grid
Electrification rate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Distance.from.grid

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **current and future electricity portfolio**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Grid system *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
IP protection *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
Social acceptance *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
Political risk *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
RE support schemes *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
Ease of doing business *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
Visual quality of the landscape *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity portfolio
Wind climate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Electricity.portfolio

---

Within the 'The current and future electricity portfolio' criterion, compare the subcriterion **specific wind energy target** according to its relative importance with respect to the **renewable energy target**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Specific wind energy target *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Renewable.energy.target

And, compare the subcriteria according to their relative importance with respect to **net import/export of electricity** .

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Renewable energy target *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Import/export of electricity
Specific wind energy target *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Import/export.of.electricity

And, compare the subcriteria according to their relative importance with respect to the **current share of renewables (excluding large hydro)**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Import/export of electricity *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Current share renewables
Renewable energy target *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Current share renewables
Specific wind energy target *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Current.share.renewables

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important

-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **cost of electricity**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Electricity portfolio *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Grid system *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
IP protection *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Social acceptance *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Political risk *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
RE support schemes *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Ease of doing business *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Visual quality of the landscape *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity cost
Wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Electricity.cost

---

Within the 'The costs of energy/electricity in this country and/or region' criterion, compare the subcriteria **the cost of local renewable electricity** according to its relative importance with respect to the **electricity cost from the grid**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Electricity from the grid *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	RE.electricity

---

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **corporate tax rate**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Electricity cost *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate

Energy portfolio *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Grid system *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
IP protection *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Social acceptance *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Political risk *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
RE support schemes *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Ease of doing business *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Visual quality of the landscape *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate tax rate
Wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	Corporate.tax.rate

---

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **airborne wind turbine's levelized cost of electricity (LCOE)**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Corporate tax rate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Electricity cost *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Electricity portfolio *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Grid system *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
IP protection *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Social acceptance *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Political risk *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
RE support schemes *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Ease of doing business *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Visual quality of the landscape *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE
Wind climate *	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	LCOE

Within the 'The airborne wind turbine's levelized cost of electricity specific for this country/region' criterion, compare the sub-criterion **grid connection cost** according to its relative importance with respect to the **operation and maintenance (O&M) costs**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Grid connection *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	O&M

And, compare the subcriteria according to their relative importance with respect to the **costs of land**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
O&M *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Land
Grid connection *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Land

And, compare the subcriteria according to their relative importance with respect to the **wind turbine investment costs**.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
Land *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Investment
O&M *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Investment
Grid connection *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Investment

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

Compare the following criteria according to their relative importance with respect to the **size of the market**.

The size of the market is a combination of the current electricity consumptions and the prospected future growth.

	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	
LCOE *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market size
Corporate tax rate *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market size
Electricity cost *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market size
Electricity portfolio *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market size
Grid system *	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Market size

IP protection * O O O O O O O O O O O O O O O O O Market size

Social acceptance * O O O O O O O O O O O O O O O O O Market size

Political risk * O O O O O O O O O O O O O O O O O Market size

RE support schemes * O O O O O O O O O O O O O O O O O Market size

Ease of doing business * O O O O O O O O O O O O O O O O O Market size

Visual quality of the landscape * O O O O O O O O O O O O O O O O O Market size

Wind climate * O O O O O O O O O O O O O O O O O Market.size

Within the 'Size of the market' criterion, compare the sub-criterion **current electricity consumption** according to its relative importance with respect to the **growth prospect of electricity consumption in 2020**.

8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7 -8

Current electricity consumption * O O O O O O O O O O O O O O O O O Growth.prospect

Comments/Suggestions:

Scale:

8 extremely more important
7 ..
6 very strongly more important
5 ..
4 strongly more important
3 ..
2 moderately more important
1 ..
0 equally important
-1 ..
-2 moderately less important
-3 ..
-4 strongly less important
-5 ..
-6 very strongly less important
-7 ..
-8 extremely less important

As a final ranking question:

Please drag and rank(1^{st} to 13^{rd}) according to their importance. The most important criteria on top.

- Market size
- LCOE
- Corporate tax rate
- Electricity cost

Electricity portfolio

Grid system

IP protection

Social acceptance

Political risk

RE support schemes

Ease of doing business

Visual quality of the landscape

Wind climate

If I've missed criteria important for the country and site selection of (airborne) wind farms, please indicate which below.

Any other comments/suggestions:
