Localising suitable areas for wind power development in Kiruna Municipality.

A spatial multi-criteria decision analysis.

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Abstract
Within the last decade, wind power has faced a strong expansion in Sweden, supported by national policies. However, when wind power projects are to be developed, a series of legal difficulties, opposing land-use interests and resistance often arise, hindering their implementation on a local level. To bypass such difficulties, the Swedish government has invited municipalities to localise suitable areas for wind power development in their comprehensive plans. By adopting this proactive approach, different interests and views can be implemented in an early stage of the planning process, possibly reducing the risk of land-use issues and local resistance.

The Municipality of Kiruna is currently updating its comprehensive plan and wind power is among the planning issues to be further investigated. Therefore, this thesis aims to combine GIS and multi-criteria decision making to support wind power spatial planning in Kiruna Municipality by exploring environmental, economic and social constraints and criteria under different planning scenarios.

Therefore, a spatial multi-criteria decision analysis is implemented to promote wind power localisation and at the same time, to prevent possible detrimental consequences. Swedish legislation, guidelines issued by national agencies and wind power planning practices are implemented to delimit areas feasible or unfeasible for wind power development. Then, the localisation process within feasible areas is guided by a set of social, economic and environmental criteria reflecting land-use interests typical of Kiruna Municipality. Weights, steering the relevance of the different criteria in the process, are then developed on the basis of three planning scenarios of future development for the Nordic Arctic.

The results of the analysis show that approximately 90% of the territory of Kiruna Municipality is not feasible for wind power development. In particular, low wind speeds and areas of interest for defence are constraints excluding large portions of the municipal territory. Among the feasible areas, it is particularly complex to identify locations which are not located within areas of interest for reindeer herding or national interest for undisturbed mountainous environment and that have an adequate distance from existing electric grids. Nevertheless, the planning scenarios pinpoint suitable locations for wind power development in northeastern Kiruna, in proximity of Karesuando.

Keywords: spatial multi-criteria decision analysis, wind power, localisation, GIS, land-use planning, Sweden.
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My interest is to approach spatial planning by seeking a combination of technical knowledge from the field of environmental engineering (derived from my Bachelor’s) with methodological and theoretical insights from the field of human geography. As student enrolled in the Master’s Program in Spatial planning and development, I had the opportunity to previously apply this approach in different assignments. The satisfying outcome led to the choice of pursuing this path for my master’s thesis. Over the years, I developed a special interest in renewable energy and geographic information systems (GIS). I believe that the combination of these spheres can provide meaningful applied knowledge to solve real-life planning issues. A field trip to Kiruna Municipality inspired me in narrowing down these spheres to a specific niche, such as wind power localisation to support land-use planning in a real life case.

Umeå, 31 May 2017

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1. Introduction

In the first place, this chapter provides background information for the planning problem to be tackled. Then the aim, research questions, limitations and ethical considerations guiding the research process are presented. Finally, a concise contextualization of the geographical dimension of the thesis is provided.

1.1 Problem background

Issues concerning international security, economic sustainability and environmental impacts arising from conventional energy systems have been advocating a shift towards the adoption of renewable energy sources (RES) for decades (Everett et al., 2012, p. 602). Among RES, wind energy can be exploited in a reliable and cost-efficient manner, by installing wind turbines translating kinetic energy into electricity (Wizelius, 2007, p. 3). Consequently wind power has experienced an intensive development in many countries, promoted by national policies and targets (Timilsina et al., 2013, p. 643-644). Despite the advantages and a general positive attitude on a global/national scale, wind power is often dubiously contemplated on a regional/local level (Pasqualetti, 2011a, p. 907-908). As a matter of fact, wind farms often generate trade-offs between infrastructural benefits on the one hand and environmental impacts and land-use conflicts on the other hand. Therefore, spatial planning is faced with the double challenge of promoting and restricting wind power through the localisation of suitable sites for wind farms that satisfy or compromise social, economic and environmental conditions (Wizelius, 2007, p. 167,221).

1.1.1 Wind power policy, planning and development in Sweden

The Swedish interest in wind power is rooted in the oil crises of the 1970s and in the nuclear power referendum of 1980, which pinpointed the need to provide an alternative to conventional energy sources (Åstrand & Neij, 2006, p. 278). However, until the early 2000s, national policies supporting this sector were unstructured and discontinuous, granting weak production stimuli (Söderholm et al., 2007, p. 370). Then, a first production target and an electricity certificate system for RES were introduced in 2002 (Pettersson et al. 2010, p. 3118-3119). This represented a turning point for wind power especially after 2006, when the system was prolonged until 2035 and re-formulated to raise the national production target (Wizelius, 2015, p. 156). On the side of these measures, the European Union directive 2009/28/EC 2020 established that at least 49% of the Swedish national energy consumption should be derived from RES by 2020. Consequently, the commitment to the strategy led to the establishment of a new wind power target of 30 TWh, of which 10 TWh offshore by 2020. Consequently, public authorities are entitled to identify potential locations hosting wind power projects to reach this production target (Wizelius, 2015, p. 156).

Besides national policies, the Swedish planning system (through the Planning and Building Act and the Environmental Code) supports wind power development and at the same time, it regulates its permitting to avoid detrimental issues. The Planning and Building Act has a restrictive character since it grants municipalities a veto right to the development of wind power projects according to their planning monopoly (Larsson et al., 2014, p. 293-294). On the other hand, the Act has a promoting character since it allows the possibility of including non-binding areas for wind power development in municipal comprehensive plans (Khan, 2003, p. 569). On the side of comprehensive
plans, municipalities develop detailed plans, giving local governments the possibility to regulate in detail the requirements of wind power projects; these plans are mandatory in areas displaying opposing land-use interests (Wizelius, 2007, p. 226). By including wind power projects in detailed plans, it is more likely to obtain a building permit, which is the last fundamental planning process steered by the Act (Söderholm et. al., 2007, p. 379) The Environmental Code steers land-use interests by defining areas of national interest, which determine sites that are of national importance for different scopes and legally protected against interferences (Pettersson et al., 2010, p. 3121). Areas of national interest have both a promoting and obstructing nature for wind power. If on the one hand, national power is listed as national interest and wind farms are prioritized in such areas, on the other hand, their implementation is limited when occurring in other areas of national interest. The Code further limit wind power by outlining specific geographic areas in which development may take place if no hindrance is caused to their ecological and cultural character (Pettersson et al., 2010, p. 3121). Finally, the localisation rule determines that sites for wind farms must be identified to reduce environmental impacts; in controversial cases, developers must evaluate other sites and if no alternatives are localised, permits may not be granted (Pettersson et al., 2010, p. 3121).

Wind power faced a strong expansion in the last decade because of the supportive national policies (Pettersson et al., 2010, p. 3117). As a matter of fact, the 90% of the 6422 MW national installed capacity in 2016 was developed only after 2006 when stronger policies were implemented (Swedish Energy Agency, 2016). However, this recent growth was geographically uneven and only a fraction of the available on-shore potential has been exploited (Ek et al., 2013, p. 136; Siyal et al., 2015, p. 456). On the one hand, certain municipalities host large wind farms while some other do not host a single turbine. Indeed, this uneven and limited development is partially justified by the displacement of good infrastructural conditions (Ek et al., 2013, p. 136). Nevertheless, a key factor behind municipal differences is the municipal veto established by the Planning and Building Act, since it enhances municipalities to refuse any wind power project in light of their political views, making void promoting national policies and planning as well as private initiatives (Larsson et al., 2014, p. 307). These negative views are influenced by local opposition groups striving to stop wind power development (Anshelm and Simon, 2016, p. 1548). The resistance of such groups is determined by specific demographics as shown by Söderholm et al. (2007, p. 378-384) or by a “not in my backyard” (NIMBY) reasoning, which sees wind power as superimposed and states that development should take place elsewhere (Ek & Persson, 2014, p. 201). The reduced willingness to accept wind power is also strongly eradicated in case of particular natural amenities or of specific land-use interests, which might be affected by wind power (e.g. reindeer herding, outdoor recreation) (Ek & Matti, 2014, p. 1332; Oles & Hammarlund, 2011, p. 480).

1.1.2 Localising wind power in Kiruna Municipality
To support the achievement of the national production target, the Swedish government invited municipalities to localise suitable areas for wind power within their comprehensive plans, on the side of areas of national interest for wind power (Larsson & Emmelin, 2015, p. 1363). By adopting this proactive bottom up approach, it may be possible to mild local resistance since local opposing interests would be involved in an
early stage of the planning process and at the same time, to enhance local self-
determination by allowing wind power localisation to be handled directly by
municipalities (Wizelius, 2015, p. 163).

GIS are useful to translate wind power planning in practice since they efficiently manage
and elaborate heterogeneous spatial data collected from various sources (Gigović et al.,
2017, p. 502). Swedish municipalities have therefore widely applied GIS for wind power
localisations and suitable areas have been identified through overlay analyses (Wizelius,
2007, p. 174). Within the comprehensive plan of Kiruna Municipality (2002), suitable
areas for wind power are identified. However, few planning criteria (e.g. wind
conditions) and constraints (e.g. noise annoyance) are included, as in the case of other
municipal GIS-based localisations developed at that time (Kiruna Municipality, 2002;
Wizelius 2007, p. 174-192). Nowadays, municipal planners in Kiruna consider this
localisation obsolete because few planning issues are contemplated and because
contemporary wind turbines have different requirements in terms of wind speeds,
harvesting altitude and land area. Furthermore, the previous localisation has not
promoted wind power development in Kiruna. In fact, only a single small-scale wind
farm was built within the identified areas, in proximity of the city of Kiruna. Despite of
the low development, wind power is perceived as a valuable opportunity for Kiruna
because of the high energy demands of the local mining industry. However, as shown in
Sub-chapter 1.5, at the same time, its implementation might be difficult because of the
many different land-use interests within Kiruna Municipality. For this reason, an
updated and comprehensive localisation analysis is necessary since multiple planning
factors and views have to be taken in account to promote sustainable land-use in a
longer period. The development of a new comprehensive plan in 2017 offers the
opportunity to implement this analysis (S. Aspvik-Thelin & M. Rosenfors, personal
communication, April 4, 2017).

To support wind power localisation in Kiruna Municipality, it might not be indicated to
apply traditional GIS overlay analysis. In fact, GIS do not provide sufficient analytical
support since they do not efficiently handle conflicting interests within geographical
data. Furthermore, the complex relationships underlying spatial decision problems
cannot be efficiently represented cartographically (Malczewski & Rinner, 2015, p. 11).
To deal with complex decision making problems, as the localisation of wind power in
Kiruna Municipality, GIS can be integrated with multi-criteria decision making (MCDM).
The integration of these two approaches gives birth to a methodology named spatial
multi-criteria decision analysis (spatial MCDA), defined as a process that transforms and
combines geographical data and value judgments to obtain information for decision
making (Malczewski, 2006, p.703). As shown in Sub-chapter 2.4., spatial MCDA has been
effectively applied and tested for wind power localisation in many geographical areas by
considering complex planning situation involving heterogeneous criteria, constraints
and stakeholders.

1.1.3 Research gap
On the contrary of many GIS applications carried out by private firms, governmental
agencies and municipalities, only few published studies investigate localisation of
suitable areas for wind power in Sweden trough GIS (Siyal et al., 2015; Siyal et al., 2016).
Consequently, the application of GIS wind power localisation in Sweden has been mainly
a domain of geographical practice rather than scientific research. Furthermore, to the
knowledge of the author, GIS and MCDM have not been previously integrated in Sweden for wind power localisation. In addition, this technique has never been applied on a municipal level in a global context.

1.2 Aim and research questions
This thesis aims to support wind power spatial planning in Kiruna Municipality by exploring environmental, economic and social constraints and criteria under different planning scenarios through the application of a spatial MCDA. Three research questions are set:

Q1. Where and how do planning constraints discourage wind power development?
Q2. Where and how do planning criteria favour wind power development?
Q3. Which locations are suitable for wind power development and to which extent, under different planning scenarios?

1.3 Limitations
The administrative borders of Kiruna Municipality represent the geographical boundaries of the thesis. Consequently, planning issues linked to bordering municipalities are not investigated. Furthermore, this thesis deals with potential on-shore wind power development; the localisation of wind power projects in inland waters is not explored. The selection of planning factors and constraint used in this analysis aims to be as complete as possible; nevertheless, the author acknowledge the unintended possibility of dismissing certain factors of interest for wind power planning. The analysis aims to develop wind power macro-siting, consequentially the detail level applied is accurate for pinpointing overall unfeasibility or suitability but not to ensure actual development for specific projects. Consequently, considerations on wind farms schemes as well as site-specific analyses are not included. Due to the lack of data, high-computational loads and in the light of the available resources, a limited deal of simplification might occur within the analysis. Lastly, marginal shortcomings linked to geodata and the author’s understanding, knowledge and judgement have to be taken in account. An in-depth discussion on limitations is provided in Chapter 5.

1.4 Ethical considerations
This study involves publicly available data and information on a municipal level, thus there are no expectations of violating privacy rights. Not publicly available cadastral geodata are retrieved from Kiruna Municipality. The author signed and respects an agreement to avoid the distribution of these data to third-parties and to limit their use for research purposes. Buildings and properties are displayed within this thesis; however, their exact location is protected by a Euclidean buffer. Concerning integrity, the outcome of this thesis is reported accurately in accordance with the analytical results.

1.5 Geographical dimension
As shown by Figure 1, the Municipality of Kiruna is located in the Swedish Norrbotten County, north of the Arctic Circle. Kiruna is a sparsely populated municipality, with an area of approximately 19.000 Km² and 23.000 inhabitants mainly residing in the city of Kiruna (SCB, 2017a,b). The mining industry is a major part of the history of Kiruna Municipality, since Kiruna city was established at the beginning of the 20th century to
support industrial production of iron ore. From being a land for reindeer herding for Sami communities, the area was redefined as a mining district (Granås, 2012, p. 127). Thus local development has been strongly linked to the fortunes of the mining company LKAB (Nyseth & Viken, 2016, p. 34-40). The iron mine is nowadays the world’s largest but Kiruna city represents a hinder for the expansion of the mining industry. As a matter of fact, the main iron vein stretches under the city and, if mining continues, parts of the city will collapse. Therefore, central parts of the city are being relocated a few kilometres to the north-west (Nilsson, 2010, p. 433-434). Furthermore, Kiruna Municipality, because of its geographical location, represents a defence hot spot, hosting military facilities since WWII (Schön, 2012, p. 171-222). Then, the space industry has established in Kiruna since the 1940s supporting the development of infrastructures such as the Esrange space centre (Nilsson, 2010, p. 433). Tourism has become a relevant sector too because of specific landmarks and natural amenities such as the midnight sun, aurora borealis and wild natural settings (Nilsson, 2010, p. 433; Nyseth & Viken, 2016, p. 41). The Sami communities in Kiruna Municipality still represent a vital reality thanks to reindeer herding and their contribution to the tourism industry (Nyseth & Viken, 2016, p.41). Finally yet importantly, Kiruna Municipality belongs to the so-called “Nordic Arctic”. In the light of its socio-economic and environmental conditions, this geographical region is already facing the consequences of global mega-trends such as climate change, economic restructuring and population ageing, posing threats and opportunities to local development in the near future (Nordregio, 2017, p. 13-20).

Figure 1: Overview map of Kiruna Municipality. Source: Lantmäteriet ©, 2017; own figure.
2. Theoretical framework

This chapter presents previous and current trends in geographic research concerning energy issues. In the second place, the relation between spatial planning and renewable energy is analysed with a focus on wind power. Then, the conceptualizations of space and spatial planning adopted within this thesis is argued. Finally, the role of GIS and multi-criteria decision analysis in localising sites for renewable energy production, such as wind farms, is presented.

2.1 Geography and energy

By applying a spatial approach to an energy issue, it is relevant to review previous and current links between geographical disciplines and the field of energy studies. Physical energy flows and societal energy demands co-produce spatial relations influencing both ecological and anthropogenic systems. Since the field of geography investigates spatial relations between humans and the environment, energy issues have been investigated according to different geographical perspectives and the study of energy is increasingly recognized as being at the heart of the geographic tradition (Calvert, 2016, p. 105-106). As argued by Pasqualetti (2011b, p. 972), the linkages between these disciplines are so common that it is possible to state that geography (always) matters in energy issues.

2.1.1 Previous research

The earliest body of geographical research concerning energy issues was developed between the 1930s and the 1950s; this body is focused on coal industries by applying descriptive and cartographic approaches (Solomon & Pasqualetti, 2004, p .2). The second body of research was established between the 1950s and the 1970s, on the side of the development of oil and natural gas industries and commercial nuclear power. Most studies adopted a descriptive approach to explain regional differentiations. The incorporation of location theory into the oil, gas, and nuclear power sectors was also of particular importance during this period (Solomon & Pasqualetti, 2004, p. 2). The third literature body was developed during the 1970s and the 1980s and it is characterized by the affirmation of quantitative methods. Mathematical and statistical techniques were applied to problems of energy resource development and transportation, power plant siting and socio-economic or environmental impact analyses (Solomon & Pasqualetti, 2004, p. 4). At the same time, a fourth body grew in between the 1980s and the 1990s, focusing on hazards, risks and decommissioning for nuclear power, as consequence of the Three Miles Island and Chernobyl accidents (Solomon & Pasqualetti, 2004, p. 5).

2.1.2 Current research

The current body of geographical research is steered by trends shaped in the early 1990s, such as increased scarcity of non-renewable resources, volatility of oil-based economies, evidence of global climate change and environmental issues linked to conventional energy production and use (Solomon & Pasqualetti, 2004, p. 6-8). However, it was only in the early 2000s that this new body of geographical research began to be consistent and witnessed a strong development (Huber, 2015, p. 2). Different research areas shape this research body. According to Zimmerer current geographical research within the energy field can be concentrated in the following areas: GIS modelling and assessment of energy flows, detailed evaluations of renewable energy sources and energy networks (2011, p. 709). On the other hand, Bridge et al. suggest a uniform cluster of geographic research under the umbrella of “geographies of
energy transitions” which have in common the achievement of a low-carbon transition by focusing on heterogeneous factors (2013, p. 334-339). Lastly, Calvert divides current geographical research by the themes of: advanced socio-spatial theory for understanding energy-society relationship, geopolitical and economic assessments of changing energy trade networks and advanced spatial decision support for energy planning (2016, p. 109-110).

As argued by Calvert (2016, p. 108), the constant geographical interest on energy led the establishment of “energy geography” as a sub-discipline incorporating a heterogeneous body of literature characterized by variegated theories and methods. However, because of the great heterogeneity of this research body, embracing the concept of “energy geographies” is a more indicated choice. Geographical approaches to energy can be considered as a field of study where disparate geographical sub-disciplines converge on the study of past, current, and future patterns of energy production, distribution and use at various geographical scales (Calvert, 2016, p. 107-108). The flexibility and pluralism proposed by energy geographies tackle the traditional and nowadays controversial separation of spheres of interest in research (Sheppard & Plummer, 2007, p. 2548). Consequently, the strength of energy geographies is in the lack of ties to some common theories or particular methodologies (Calvert, 2016, p. 107). This specific aspect provides the flexibility required to embrace the multidisciplinary of energy issues (Spreng, 2014, p. 66-69). As shown by Figure 2, energy geographies are able to capture the intrinsic nature of energy which is at the same time: a natural physical entity (under the domain of physical geography); a primary agent in the spatial organization of anthropogenic activities (under the domain of human geography); a link between environment and society (under both the previous domains); a space-dependent phenomenon (under the domain of GIS and cartography) (Calvert, 2016, p. 107-108).

Figure 1. Framework of energy geographies. Source: adapted from Calvert, 2016, p. 107; own figure.
Indeed, there might be difficulties in clearly implementing the framework of energy geographies. In the first place, it is necessary to dismiss the idea that everything related to energy is of geographical domain, because this would result in an unproductive generalization (Calvert, 2016, p. 105). In the second place, the heterogeneous nature of energy geographies should be combined according to a regulated and structured scheme to avoid inappropriate and confusing research approaches (Simandan, 2011, p. 569).

The multidisciplinary granted by energy has generated a consistent and heterogeneous body of research on wind power. As a matter of fact, geographic research on wind power has focused on different aspects of this renewable energy, taking advantages of heterogeneous theories and both qualitative and quantitative approaches. For instance, national policies and schemes for wind power, as well as development rates in different geographical areas are investigated (Söderholm & Pettersson, 2011; Liou, 2011; Timilsina et al., 2013). Certain studies focus on the economic development of the wind power industry in different nations (Corvellec, 2007; Fornahl et al., 2012; Simmie, 2012). In other cases, the socio-economic impacts of wind power development on local/regional scales are analysed (Brannstrom, 2011; Ek & Matti, 2014; Liljenfeldt & Pettersson, 2017). Geographical modelling is also applied to understand and predict wind conditions to support wind farm siting (Li, Stadler & Ramakumar, 2011). Furthermore, a consistent body of literature, arising from the traditional geographic competence in spatial planning, is focused on reviewing wind power planning systems and their implications (Khan, 2003; Phadke, 2013; Liljenfeldt, 2014), as well as developing models for localising of suitable sites for wind power development (Siyal et al., 2015; Siyal et al., 2016; Mentis et al., 2016).

2.2 Spatial planning and renewable energy

As previously argued, energy and its system of supply, distribution and use affects the spatial organization of society. Consequently, the geographical practice of spatial planning should include energy in its practice, especially by considering that neglecting its relevance might socio-economic and environmental issues. Specifically, land-use planning needs to take the lead within this issue. It might be questioned the necessity of land-use planning in the light of the acceptance over the need for public intervention, both in land-development and energy systems. As a matter of fact, it is sometimes suggested that market forces with minimal guidance will take care of the energy sector and produce an appropriate spatial structure. However, it is not granted that this mechanism would consider social and environmental discourses (Cullingworth, 1990, p. 53-55). This clashes with sustainable land-use planning, defined as the systematic assessment of land-use alternatives and social, environmental and economic conditions to adopt the best land-use options, therefore not providing desirable scenarios (FAO, 1996, p. 3-6).

2.2.1 Land-use conflicts and renewable energy

Many energy issues tackled by spatial planning originate from conflicting land use, since land use is the common link among various types of impacts generated by energy production (Pasqualetti, 1990, p. 127-130). The nature of such impacts varies considerably, including physical or visual intrusion, noise, ecosystem disturbance and in some cases air, water and land pollution (Walker, 1995, p. 3). However, the production
of electricity from renewable sources is often regarded as a land-use issue than production from conventional sources. Producing electricity from RES involves the use of larger land areas per unit of electricity generated than electricity production from conventional sources. Consequently the impact of renewable energy projects is perceived as more intruding and threatening by stakeholders and public opinion, since these are faced with noticeable land-use changes and graspable impacts if compared for instance with more intangible and complex issues generated by conventional energy systems on a global scale (Pasqualetti, 1990, p.127-130). In the case of wind power, the land-demand for energy production is higher if compared to conventional power plants (Jones, Pejchar & Kiesecker, 2015, p. 295). Furthermore, this demand is more problematic in comparison to other renewable energy production (e.g. solar, geothermal or biomass) since conventional wind power projects (not involving micro-turbines), as in the case of hydropower plants, require large areas of undeveloped land and can hardly be integrated in the built-environment (Balduzzi, Bianchini & Ferrari, 2012, p.163-164).

Negative attitudes towards renewable energy production usually arise as projects are proposed and developed. On a local level the environmental advantages of renewable energy are less clear and there is a low willingness to accept trade-offs (Kaza, & Curtis, 2014, p. 355-356). In the case of wind power, the reduction of greenhouse gases emission on a national/global scale is often not embraced by communities since these are not willing to accept the local social and environmental burdens of wind turbines (e.g. visual intrusion, landscape fragmentation) for the sake of hardly tangible and long-term common benefits (Firestone et al., 2012, p. 1371-1373). Renewable energy development has consequently caused some of the most intense land-use conflicts over the recent decades and planning systems struggle to deal with such issues because they have limited power in dealing with already approved or developed projects (Kaza, & Curtis, 2014, p. 355-356). This blind spot of land-use planning often make void sustainability efforts input at higher levels since many RES projects can be stopped on a local level. Consequently, more appropriate strategical approaches should be enhanced by planning systems (Owens, & Cowell, 2011, p. 18).

2.2.2 Proactive planning

Land-use conflicts can be embedded within the framework of “energy justice”, since they are generated from forms of inequality or vulnerability arising from transformations towards low-carbon societies trough policies and infrastructures implementation (Bickerstaff et al., 2013, p.7). Energy justice aims therefore to capture and prevent critical unbalances in the societal distribution of the burdens linked to the benefits of renewable energies, especially by considering the planning or decision making processes through the branch of procedural aspects (Jenkins et al., 2016, p. 175). However, it is relevant to observe that there will always be tension between development and maintenance of the status quo and unbalances are inevitable. Consequently spatial planning guided by energy justice may need to cast utopian aspirations of promoting even development and it should focus instead on the reduction of critical unbalances generating inequality, vulnerability and possibly leading to land-use conflicts (Pasqualetti, 1990, p.127-130)

To translate this theoretical approach in practice, within the context of renewable energy, the adoption of proactive spatial planning is often regarded as the most
appropriate approach. Proactive land-use planning does not consider the implications of renewable energy production on an ad hoc basis to each development proposal. On the contrary, it operates according to a structured process of prevision. A critical component of this approach is to carry out an explicit and early identification of sites, or more particularly, alternative sites, to host renewable energy projects that are promoted by national, regional or local energy policies or by private initiatives (Kaza, & Curtis, 2014, p. 355-356). This preliminary identification can be positive for renewable energy developers, which wish to have a pre-determined pool of sites to choose to avoid legal and planning difficulties (Kaza, & Curtis, 2014, p. 355-356). For instance, in the case of wind power, development is often allocated from public authorities to private actors that however, might have limited resources or expertise in local planning processes or strictly economic priorities and therefore have difficulties in localising sites which are effectively suitable in terms of sustainable land-use. Furthermore, if development is led mainly by private actors, then local communities can harsh their reluctance in accepting potential projects since they would see this as a superimposing and external intrusion in local issues (Ellis et al., 2009, p.524-529). Proactive planning can be also positive for local stakeholders that have a say in land use and the public opinion, since they might be involved with prepositive and constructive modalities (Kaza, & Curtis, 2014, p. 355-356). Accordingly, participation in wind power planning has been demonstrated to be a key-factor to reduce opposition and favour further development. When local stakeholders are considered in the planning process, a sense of fairness is promoted and therefore developers and political actors can more effectively implement their plans, without being perceived as external, intruding and super-imposing actors (McLaren Loring, 2007, p. 2649; Jamil & Walsh, 2014, p. 195-196). Furthermore, public authorities can benefit from this approach since they would be free of sudden projects and of protracted periods of uncertainty while a project proposal is evaluated by the planning system (Cope, Hills, & James, 1984, p. 289-292). Proactive land-use planning is therefore embracing the need of involving all stakeholders in the decision-making process as argued by the procedural aspects of energy justice; thus possibly reducing injustice and inequalities generated by lack of participation (Sovacool & Dworkin, 2015, p. 436-437). However, despite this recognition, participation has been often neglected in the planning process for wind power (Breukers & Wolsink, 2007, p. 2748). Consequently proactive planning has been carried out in certain cases but with reduced or ineffective public participation and by adopting an “ad-hoc” approach to prioritize the development of wind power projects considered to be of major importance over local interests (Liljenfeldt, 2017 p. 52).

2.3 Spatial conceptualization
Before engaging in empirical geographical issues, it is necessary to establish a theoretical definition of the fundamental unit of any spatial analysis: space. Geographic academia has expressed a shift from an absolute towards a relational conceptualization of space in light of tension between abstract concepts and phenomena (Khan et al., 2013, p. 290). Concisely, this shift suggests that rather than viewing space as “a container within which the world proceeds”, space should be considered as “a co-product of those proceedings” (Thrift, 2003, p. 96). Many geographers have further elaborated this proposition; in this case the conceptualization of relational space developed by Doreen Massey in her book “For Space” is reviewed (Massey, 2005).
2.3.1 Defining relational space

Three fundamental propositions summarize Massey’s conceptualization. First, space is “the product of interrelations; as constituted through interactions, from the immensity of the global to the intimately tiny” (Massey, 2005, p. 9). Consequently, space does not exist a priori or without interactions and identities and its form can be identified only in their light. There is no absolute space shaped within a coherent and seamless imaginary. Secondly, space is “the sphere of possibility of the existence of multiplicity in the sense of contemporaneous plurality” (Massey, 2005, p. 9). Multiplicity is therefore essential for the formulation of space but, at the same time, space is necessary to develop multiplicity. It is therefore not possible to conceptualize and define space according to an absolute trajectory and different trajectories shall always be considered at the same time. Finally, space is “as always under construction” (Massey, 2005, p. 9). Space is therefore a product of relations which are constantly carried out and it is always in the process of being made and it is never finished.

This conceptualization clashes with absolute approaches considering space as a uniform background or empty locations where activities would take part. Through a relational approach, space is, on the opposite, considered as constituting, rather than containing activities (Taylor, 2013, p. 807). Consequently when defining space it is necessary to consider that it is embedded in a wide number of social, economic and environmental processes. In the specific case of wind power, an absolute conceptualization of space would imply defining suitable locations as empty areas to be developed since they provide optimal conditions for this sector. On the contrary, a relational conceptualization implies the definition of these locations as the product of other processes and phenomena too, for instance the provisioning of ecosystem services. Thus, locations are not existing as a standing alone entities in the light of a single geographical dimension (e.g. wind conditions) but they present multiple dimensions at the same time (e.g. biodiversity, cultural values) that combined together determine their essence. These dimensions are shaped by trajectories involving stakeholders dispersed over time and space (i.e. current residents or visitors, previous local political administrations, national and international agencies, future wind power developers). Furthermore these trajectories can be material (e.g. physical fruitions and exploitations of euclidean spaces) or abstract (e.g. symbolical conceptualizations or landscape imaginaries), determining a multiplicity of spatial meanings for potential sites for wind power development (Liljenfeldt, 2017 p. 29-30).

2.3.2 A relational approach to spatial planning

Multiple actors involved in spatial planning, within and outside academia, often do not display a natural tendency to communicate or collaborate; thus fragmenting the field of spatial knowledge, policy and practice. This tendency is exacerbated by the increased specialization that separate the fields of knowledge and action, in many cases estranging theory from practice in spatial planning (Madanipour, 2013, p. 372). At the same time, spatial issues related to sustainability, climate change, social exclusion or economic deprivation require multidisciplinary and collaboration to be tackled (Khan et al., 2013, p. 290). These issues also require a demission of an absolute conceptualization of space in light of their constant evolution, multiplicity and interrelation (Graham & Healey, 1999, p. 624). Consequently, undermining a relational understanding of spatial dynamics determine scarce outcomes when engaging in spatial planning at different geographical
scales (Healey, 2006, p. 526-527). Moving towards a relational approach is a necessity in spatial planning (Khan et al., 2013, p. 290). A relational approach to space in planning implies an understanding of space as the union of social, cultural, economic, political, and ecological processes developed over multiple spatial and chronological scales. This understanding is based on the consideration that is ‘folded’ rather than ‘flat’, since it is construed by mutually interrelated hierarchical network topologies and inter-scalar processes that cut across wide territorial and temporal processes (Khan et al., 2013, p. 291).

Graham & Healey (1999) identifies a series of proposition that promote a relational approach to spatial planning. First, planning must consider relations and processes rather than objects and forms. In fact, it is not possible to assume as a universal generalization the extent to which a proposed action will lead to particular social, economic and environmental behaviours; this needs to be demonstrated for the relational dynamics of each specific case (Graham & Healey, 1999, p. 642). Second, planning practice must stress the multiple meanings of space and time. When setting and working with specific spatial and chronological frames it is necessary to consider that their conceptualization has different meanings for different actors (Graham & Healey, 1999, p. 642). Third, planning needs to represent places as multiple layers of relational assets and resources, which generate a distinctive power geometry of places. Different assets and processes shape places at the same time and their trade-offs can be fully understood by separating places in multiple planning layers (Graham & Healey, 1999, p. 642). Finally, planning should recognize how the relations within and between these layers are developed, to interpret them and promote conflict mediation and consensus building (Graham & Healey, 1999, p. 642).

In the case of wind power planning, the adoption of a relational approach would imply the consideration of the different relations and processes that concur in shaping the suitability or unsuitability of a geographical area. Therefore both physical and abstract trajectories, developed on different geographical (local/regional versus national/global) and temporal (previous, past and future) scales should be included in the planning process. By focusing on specific trajectories, such as the economic suitability, or by including only certain views, such as political agendas or production targets, then it is not possible to adopt a relational approach, thus increasing the risk of conflicts and undermining consensus building since geographical histories of production would be dismissed. Thus increasing the possibility of failures in the planning process (Liljenfeldt, 2017 p. 29-30).

Nevertheless, a relational approach to spatial planning determines also certain pitfalls. For instance, a relational approach is limited by the understanding of multiple spatial and temporal trajectories defining spaces. With limited geographical and historical knowledge and information, it is possible to exclude relevant trajectories and it is more difficult to implement this approach (Graham & Healey, 1999, p. 624). Furthermore, as discussed by Khan et al. (2013, p. 290) it should be avoided to collapse into the total relativism that could be promoted by a too stretched spatial reasoning. Pragmatism should be emphasized in relational spatial planning to focus only on trajectories and discourses that are of actual relevance for specific problems.
2.4 GIS and multi-criteria decision analysis

A relational approach to spatial planning to promote proactive land-use planning for renewable energy needs to be operationalized, meaning that the identification of suitable sites for renewable energy projects needs to be actually put in practice by applying the above-mentioned theoretical considerations. However, identifying suitable locations to harness RES is a complex task. In the first place, structural external factors, uncontrollable by decision makers and stakeholders, constantly affect the process. Furthermore, a number of conflicting criteria must be taken into account each time. In addition, decision makers and stakeholders brings along different points of view, which must be resolved within a framework of mutual compromise (Haralambopoulos & Polatidis, 2003, p. 962).

2.4.1 Spatial multi-criteria decision making problems

Because of these aspects, the localisation of sites suitable for renewable energy projects might be conceptualized as a spatial multi-criteria decision making problem (MCDM). As a matter of fact, spatial MCDM problems typically involve a set of feasible alternatives and multiple, conflicting evaluation criteria. The alternatives are ranked or evaluated by decision makers according to different criteria and their perceived importance (Malczewski, 2006, p. 703). Spatial MCDM problems can be classified into spatial multi-attribute (MADM) and spatial multi-objective (MODM) decision-making problems. The distinction between spatial MADM and spatial MODM problems is based on the classification of evaluation criteria into attributes and objectives. An attribute is a measurable quantitative or qualitative property of elements of a real-world geographical system. On the other hand, an objective is a statement about the desired state of the system under consideration (Malczewski, 1999, p. 82). Spatial MADM are focused on the choice from a moderate/small size set of feasible alternatives determined by the attributes in a spatially explicit context. On the contrary spatial MODM deals with the problem of design (finding the best solution) to maximize the objectives declared in a spatially implicit context bounded by the state of the environment (Colson & De Bruyn, 1989, p. 1201-1204). Spatial MCDM problems are in most cases classified as spatial MADM problems when they involve the localisation of sites suitable for renewable energy projects (Pohekar & Ramachandran, 2004, p. 376).

Spatial MADM and spatial MODM decision problems can further be categorized into single-decision maker’s problem and group decision maker’s problems. If there is a single goal-preference structure, the problem is referred to as individual decision-making. On the contrary, if stakeholders are characterized by different goal-preference structures, the problem becomes that of a group decision making. Finally, spatial MCDM problems can be categorized into decisions under certainty and decisions under uncertainty, depending on the amount of information or knowledge available to the stakeholders and analysts. If there is perfect knowledge of the decision environment, the decision is made under conditions of certainty. However, many real-world decisions involve some aspects that are unknowable or very difficult to predict; this type of decision-making is referred to as decisions under conditions of uncertainty (Malczewski, 1999, p. 88-90). For this reason, the siting of renewable energy projects takes place under conditions of uncertainty (Pohekar & Ramachandran, 2004, p. 376). Nevertheless, uncertainty may come from various sources and therefore, decisions under uncertainty may be further subdivided into two categories: probabilistic (based on probability
theory) and fuzzy (based on possibility theory) decision-making (Malczewski, 1999, p. 88-90).

2.4.2 Spatial multi-criteria decision analysis
To deal with spatial MCDM problems such as the siting of renewable energy projects, it is necessary to adopt a specific approach. In fact, it is not possible to handle these problems in light of their spatial nature or in light of their multi criteria decision aspect. In many cases GIS have been applied to guide the siting of renewable energy projects, for instance trough overlay analysis (Resch et al., 2014, p. 663-664). However, as Carver (1991, p.326) argues, these attempts fail to embrace the multi-level nature of the issues. GIS overlay analysis assumes that objectives and criteria are equally important, dismissing the multi-level aspects of decision making. Consequently, it is not possible to embrace the different views of stakeholders concerning certain objectives and criteria as well as acknowledging the different nature of criteria (Ferretti & Montibeller, 2016, p. 42-43). In addition, GIS overlays produce outputs that are hard to comprehend when they include many objectives and criteria and it is therefore not recommended for handling complex problems (Carver, 1991, p. 326). At the same time spatial MCDM problems cannot be approached with techniques suggested by traditional MCDA since these assume spatial homogeneity within a study area; these are obviously in contrast with spatial MCDM problems, involving space dependent features (Malczewski, 1999, p. 90). To tackle spatial MCDM problems, it is therefore necessary to adopt spatial multi-criteria decision analysis (spatial MCDA) deriving from the meeting between the two different areas of research (Jankowski, 1995, p. 251). This method can be conceived as an analytical approach to structure and break down spatial MCDM problems to perform a logical and comprehensive analysis aiming to produce a solution, as shown by Figure 3. Practically, a spatial MCDA can be considered a process that combines and transforms geographical data (input) into a result decision (output) thanks to a series of procedures steered by decision makers’ preferences and limited by a set of constrains. This implies that the results of the analysis do not depend only on the geographical distribution of data but also on the value judgment involved in the decision making process. Spatial MCDA therefore embraces the advantages provided by GIS in terms of data acquisition, storage, retrieval, manipulation and analysis as well as the MCDA capabilities of incorporating different data and decision maker’s preferences into unidimensional values of alternative decision (Malczewski, 1999, p. 91).
However, it is necessary to carefully handle the MCDM nature of this method. In fact, the selection of constraints or criteria and the input of preferences from both analysts and stakeholders can radically alter the outcome of the analysis. The subjectivity implied by these tasks makes it hard to avoid certain pitfalls of spatial MCDA. For instance by selecting too few constraints or criteria then a poor modelling would be provided. Then by selecting overlapping criteria the output of the analysis would be biased. Furthermore, by including preferences it is possible to cause misspecifications since analysts and stakeholders might have imprecise information and knowledge in setting priorities within the decision making process. (Malczewski & Rinner, 2015, p. 194-196). Lastly, if only certain stekholders are involved in selecting constraints and criteria or setting priorities in the process, then excluded actors may perceive that the output is unfavorable to their interests and therefore claim that the whole process is biased. This outcome naturally leads against consensus building therefore making the application of spatial MCDA void (Bojórquez-Tapia et al., 2011, p.544). Therefore, sensitivity analysis is a fundamental step of spatial MCDA since it critically assesses how the results are dependent on subjective tasks; thus increasing the overall objectivity of the process and ensuring a critical approach that might avoid pitfalls (Malczewski & Rinner, 2015, p. 192).

2.4.3 Siting wind power projects through spatial MCDA

The localisation of wind power projects is usually associated with several planning constraints. Furthermore, the localisation process has to take in account criteria that both promote and restrict wind turbines implementation. In addition, the opinion of different stakeholders is required within the planning process. Consequently, spatial MCDA has been widely applied for wind power localisation. These applications are carried out in different geographical areas and by different types of spatial MCDA, and in the majority of the cases led to a successful identification of suitable sites.
Baban and Parry (2001) developed one of the first spatial MCDA to test the effectiveness of this approach in localising suitable sites for wind power in the U.K. The authors consulted with wind power stakeholders to identify constraints and criteria relevant for wind power planning. Among the others, topography, wind speeds, land-use, infrastructural accessibility and protected nature were included to limit and steer the localisation process. The authors implemented these criteria and constraints in forms of vector geodata through the IDRISI GIS. To make these data comparable, then the authors manually reclassified them on the base of a common scale expressing suitability for wind power. Finally, the geographic layers were combined through a weighted linear combination, in which the relevance of each criterion over the localisation process was expressed according to two different planning scenarios. The outcome of the study demonstrated the suitability of spatial MCDA for the localisation of wind power.

Spatial MCDA was further applied by Hansen (2005) to identify potential sites for new wind farms in the Northern Jutland County in Denmark. In the first place, the author carried out interviews with spatial planners in the Baltic Sea region to determine factors relevant for wind power planning. Then a list of planning constraints and criteria was developed. Among these, it is possible to mention proximity to coast, distance from infrastructures (e.g. airports, roads, grids, radio masts) and wind potential. The author operationalized these constraints and criteria in ArcGIS by generating different layers, made comparable by the application of fuzzy mathematical functions. The author personally established the relevance of these planning factors by assigning different decision weights to implement in a simple additive weighting operation. The result of the study confirmed the effectivity of spatial MCDA and highlighted limited possibilities for further development in the County.

On the side of these European applications, Van Haren and Fthenakis (2011) applied an algorithm in ArcGIS to verify wind farm site selection in the state of New York (USA). The study consisted of three main steps. In the first place, sites that were infeasible for wind power because of conflicting land-use issues and geological factors were excluded. Then, the best feasible sites according the expected net value from four major cost and revenue categories (generated electricity, costs from access roads, power lines and land clearing) were selected. Finally the ecological impacts on birds and their habitats was assessed to determine the ultimate suitability of the locations previously identified. The results were then compared with the locations of existing wind turbine farms, proving their good locations.

Despite few applications in the early 2000s, the implementation of spatial MCDA for wind power planning bloomed within the last years. Atici et al. (2015) developed a spatial MCDA to determine feasible sites for wind power development in two Turkish districts. Planning criteria and constraints were determined through a literature review. Factors depending on safety issues, wind farms development and environmental aspects were selected. These criteria and constraints were transformed in raster geographical layers using ArcGIS. Then, stakeholders preferences, local experts in wind power planning were asked to rank the chosen criteria on the basis of a comparison matrix. Finally geographical information and decision making preferences were combined through different techniques. The outcomes of the study revealed suitable area available for wind power development in the region and provided insights on the use of different approaches to combine the elements of spatial MCDA.
Furthermore, Latinopoulos and Kechagia (2015) carried out a spatial MCDA based on simple additive weighting to provide a decision tool for wind power planning on a regional level in Greece. The analysis evaluated previous wind power development by verifying if licensed wind farms met a series of social, economic and environmental factors and by identifying further suitable locations. The evaluation criteria and constraints to steer the analysis were established on the basis of previous literature and Greek legislation. The analysis was then performed through Vertical Mapper and by using raster data, made comparable through linear fuzzy functions. The geographical layers expressing planning criteria and constraints were then weighted by the authors according to three contrasting planning scenarios. The results showed that all of the licensed wind farms in the study area were developed in suitable locations and further locations could be identified.

Noorollahi et al. (2016) combined GIS and multi-criteria decision making to identify potential sites for wind farms in the Markazi province in western Iran. A literature review was carried out by the authors to identify planning criteria and constraints of interest for the analysis. Furthermore, Iranian planning and environmental legislation was consulted to implement case-specific legislative constraints. The planning criteria and constraints were then implemented in ArcGIS by creating raster layers. The relevance of each layer in the localisation process was established on the basis of the authors’ personal judgments and expertise in the field. The results of the analysis were then organized in a suitability map displaying different degrees of suitability for wind power development in the province, assessing an overall good potential for wind power development.

Sánchez-Lozano et al. (2016) applied different MCDM techniques based on the fuzzy theory to perform a spatial MCDA for onshore wind farm site selection on the coast of the Murcia Region in Spain. Ten different constraints were included in the analysis to limit the selection process; among others it is possible to mention: avoidance of urban areas, protected nature and cultural heritage sites. The authors then involved different experts in renewable energy to develop a set of criteria to steer the localisation process towards optimal locations. Among these criteria, it is possible to mention slope, distance from infrastructures and average wind speed. These criteria were then normalized through linguistic fuzzy functions. Weights were generated through a survey to incorporate the opinions of the same experts in the process. The study was successful in identifying suitable sites for wind farms in the study area.

Lastly, Gigović et al. (2017) carried out a case study based on the combination of GIS and MCDM in the province of Vojvodina, in Serbia, to develop a reliable model for the identification of suitable locations for wind farms. The proposed model considered 11 constraints and 11 evaluation criteria which were grouped into economic, social and environmental clusters. These clusters were then prioritized to different extents by implementing statistical techniques leading to the development of weights expressing the importance in the localisation process. A weighted linear combination was then applied to combine the planning clusters. The results of the analysis displayed high suitability for wind power in the study area and different locations were pinpointed as suitable. A sensitivity analysis to verify model reliability was then carried out with successful outcomes.
3. Method

This chapter describes the methodological considerations applied to perform a spatial MCDA for wind power localisation in Kiruna Municipality. In the first place, the methodological choice is explained. Then, the chapter systematically follows the steps proposed by the spatial MCDA framework of Malczewski (1999), previously presented in Sub-chapter 2.4.

3.1 Methodological choice

The aim of this thesis is to provide a decision support tool to tackle spatial MCDM problem such as the localisation of areas suitable for wind power development in Kiruna Municipality. As previously argued, a spatial MCDM problem cannot be solved by exclusively applying GIS or multi-criteria decision-making (Malczewski, 1999, p. 90). Furthermore, this planning problem is a sustainability issue since it involves the balancing of social, economic and environmental interests (Thygesen & Agarwal, 2014, p.1013-1014). This is particularly evident in the case of Kiruna Municipality since different land-use interests of heterogeneous nature are coexisting. Consequently, it is advisable to adopt a relational approach to spatial planning as argued by Khan et al. (2013, p. 290). In the light of these two aspects, a spatial MCDA is a suitable method to tackle this planning problem. In fact, a spatial MCDA allows to overcome the limits of individually applying GIS or MCDM and at the same time promotes a relational approach to spatial planning.

For instance, by applying a GIS overlay analysis it would be hard to produce meaningful and understandable outputs to support decision-making. The cartographic display of the large number of planning constraints and criteria required by wind power would be hardly understandable. Furthermore, some of the planning criteria to take in account represents opposing land-use interests in Kiruna Municipality and therefore their nature cannot be discerned through overlay analysis, thus requiring the implementation of MCDM. Through MCDM it is possible to express preferences in the planning process to regulate opposing land-use interests as real-life planning issues, which constantly demand choices and trade-offs. On the other hand, it is not possible to tackle this problem by applying only MCDM since there is a fundamental spatial component, which would not be efficiently handled.

Furthermore, a spatial MCDA allows to process data of qualitative and quantitative nature reflecting social, cultural, economic, political, and ecological processes through its evaluation criteria, therefore incorporating heterogeneous spatial trajectories. Then, a spatial MCDA embraces spatial relational dynamics typical of each specific case by allowing the inclusion of local planning factors and preferences, therefore promoting a case-specific approach for Kiruna Municipality. Finally, a spatial MCDA allows representing places as multiple layers of relational space by separating them in multiple planning layers and allows to recognize how the relations within and between these layers are developed through weights.

3.2 Problem definition

The first step to implement a spatial MCDA requires the definition of the problem to be tackled. The problem has therefore to be defined and implemented according to both
its MCDM and its GIS nature to calibrate appropriate techniques to incorporate in the further stages of the analysis.

### 3.2.1 MCDM definition

The localisation of areas suitable for wind power development in Kiruna Municipality is a spatial MCDM problem. In fact, it involves a stakeholder (Kiruna Municipality) with a goal to achieve (wind power localisation) by handling a set of constraints (planning limitations), criteria (planning factors) and preferences on how to achieve it (planning priorities), on the basis of which alternatives (suitable areas) are evaluated. This spatial MCDM problem involves a localisation process and therefore it is classified as a spatial multi-attribute decision making (MADM) problem. In effect, it focuses on the choice of a defined and limited set of explicit geographical alternatives according to a set of constraints and to a ranking based on a set of criteria (Malczewski & Rinner, 2015, p. 46). In this case, this spatial MADM problem is an individual decision maker problem because, the planning process shall reflect the unitary preferences of Kiruna Municipality in the light of the Swedish planning monopoly. Furthermore, as a real world-planning problem, this spatial MADM problem is embedded in an uncertain environment. This uncertainty is characterized as fuzzy since it is associated to imprecisions in understanding and interpreting spatial phenomena (Malczewski, 1999, p. 100).

### 3.2.2 GIS definition

The spatial MADM problem is implemented in GIS through raster data because of major processing simplicity in supporting spatial modelling (Malczewski, 1999, p. 27-28). The territory of Kiruna Municipality is conceived as a grid of 25 m x 25 m cells representing individual patches of land. The grid size is determined by the accuracy of the coarsest raster geodata available according to the guidelines provided by Hengl (2006, p. 1297-1298). This minimum grid size is considered to provide an appropriate detailed level for the geographical scale of this analysis considering that previous GIS investigations on wind power on a regional level in Sweden adopted a grid size of 1 Km x 1 Km (Siyal et al., 2015; Siyal et al., 2016). A finer resolution would call for higher computation capabilities, possibly impeding the analysis (Hengl, 2006, p. 1283-1290). The land patches have to be identified as suitable (and to what degree) or not feasible for wind power according to a suitability index (SI) developed through the spatial MCDA. The SI ranges from 0, identifying unfeasible patches, to 1, identifying most suitable land patches. Patches receiving a SI score of at least 0.5 are considered to be suitable for wind power according to the threshold set by Latinopoulos & Kechagia (2015, p.555).

The localisation process aims to identify areas suitable for the establishment of wind turbines such as the one displayed by Figure 4. Adopting an idealized turbine model is helpful for implementing the problem in GIS and to calibrate some of the planning constraints and criteria. Turbines, such as the one displayed in Figure 4, represent an idealized model and do not correspond to a specific model available on the market. The choice of this relatively large turbine model is led by the consideration that wind power developers in Kiruna Municipality would be interested in promoting larger projects leading to robust production rates (S. Aspvik-Thelin & M. Rosenfors, personal communication, April 4, 2017).
Despite providing accuracy to the analysis, individual land-patches of 25 m x 25 m do not represent appropriate locations for wind power development. In fact the ideal model of turbine previously presented does not fit in a land patch of 625 m². Consequently, locations appropriate for wind power development require a larger area. According to the national strategy for wind power development, the minimum permissible area for onshore wind power in Sweden is set to 5 km² for Electricity Bidding Zone 1 (Siyal et al., 2015, p. 451). Consequently, clusters of suitable land patches covering an area of at least 5 km² are suitable locations.

3.3 Identification of constraints and criteria
The second step of the spatial MCDA involves specifying a comprehensive set of criteria that reflects concerns relevant to the decision problem and constraints which determine where the objective cannot be met. Finally, geographic measures to describe and implement criteria and constraints are required. Identifying constraints and criteria is a flexible step since they are problem-specific and there is no universal technique to determine them (Malczewski, 1999, p. 97). In the first place, a literature review is performed to determine a set of constraints limiting the localisation process. Swedish legislation, guidelines issued by national authorities and previous spatial MCDA for wind power localisation are consulted to identify conditions determining unfeasible locations. Secondly, a field trip to Kiruna Municipality takes place to identify case-related criteria to steer the localisation process. A preliminary list of constraints and criteria is developed and then it is refined through an un-structured consultation with the Planning Department of the Municipality of Kiruna. This consultation is useful in order to cross-reference the preliminary set of constraints and criteria s with the expertise of planners that usually deals with land-use issues in the area. A drawback of this approach is that an un-structured consultation does not guarantee a schematic cross-referencing. In addition, there is a risk to bias the analysis towards issues that are perceived as of stronger importance by the Municipality itself. Nevertheless, the author maintains a critical view towards the inputs received. In the following paragraphs, the chosen constraints and criteria are listed. In the end of the Sub-chapter, Table 1 presents an overview of the selected constraints and criteria.
3.3.1 Constraints

**National parks.** According to 2 §, Ch. 7 of the Environmental Code, national parks are the strongest form of nature protection since they preserve large state-owned areas in an unchanged state (SFS 1998:808). There are two national parks within Kiruna Municipality, Abisko and Vadvetjäkka, aiming to preserve mountainous landscapes and ecosystems in a pristine status (Swedish EPA, 2017). Wind power development in these national parks may clash with their objectives. In first place, roads and electric grids, as well as noise and lighting emitted by wind turbines may annoy or stress wildlife in remote and unspoiled landscapes (Helldin et al., 2012, p. 5-6). Furthermore, birds and bats may collide with wind turbines and larger projects may negatively affect migration patterns, breeding areas and hunting grounds (Rydell et al., 2012, p. 4-6); these issues may be particularly critical in mountainous biotopes (Falkdalen et al., 2013, p. 4-6; Hipkiss et al., 2013, p. 7-8). Lastly, unbroken landscapes may be crucial to a particular experience at a site, such as a national park, and wind turbines may have a negative impact towards landscape integrity (Waldo et al., 2013, p. 9-10).

**Areas of interest for defence.** According to 9-10 §, Ch. 3 of the Environmental Code, certain areas are defined as of national interest for defence; within these areas priority, over other conflicting land-use interests, should be granted to military operations (SFS 1998:808). Wind power can negatively affect military operations since turbines may affect aviation and technical systems, by posing physical hinders and radio interferences (Lindgren et al., 2013, p. 105-106). Different areas of national interest for defence are located in Kiruna Municipality, mainly as training sites, but also to ensure no disturbance to the ESRANGE space centre (County Administration Boards, 2017). Furthermore, military radars can be located outside of these areas, such as in Kiruna Municipality, and their operations should not be hindered by turbines located within a radius of 5 Km (National Board of Housing, Building and Planning, 2012, p. 77).

**Air transportation.** According to the Planning and Building Code, 1-2 §, Ch. 6, building permits are required for turbines, such as the ones applied in this analysis (SFS 2010:900). The issuing of building permits is strictly regulated in certain areas, such as the so-called “no-hinder zones” (ICAO Annex 14 areas) which are established to guarantee safety for air transportation by setting maximum heights for buildings and infrastructures in proximity of airports (Swedish Transport Administration, 2014, p. 19). The ICAO Annex 14 area of Kiruna airport is a constraint since the height of the turbine applied in this analysis would exceed maximum heights allowed in this no hinder zone.

**Distance from buildings.** Wind turbines emit noise, shadows and reflections that can cause annoyance and in some cases, health issues (Henningsson et al., 2013, p. 30-39). To prevent such issues, national guidelines are set: acoustic pollution from turbines should not be higher than 40 dB in residential areas while exposure to shadows and reflections should not overcome 30 minutes per day, for a total of 8 hours per year (National Board of Housing, Building and Planning, 2012, p. 34-38). To fulfil the guidelines a protective buffer of 800 m was applied for the identification of areas of national interest wind power (Swedish Energy Agency, 2013, p. 34). The same buffer is applied in this analysis. Considering the applied turbine model, acoustic pollution guidelines are expected to be fulfilled according to the noise propagation model developed by the Swedish EPA (Swedish EPA, 2013, p. 5). However, shadows and reflections can be perceived as far as 2 Km from a turbine and their intensity and
occurrence depend on many site-specific factors (Wizelius, 2015, p. 206). Therefore, the chosen buffer does not ensure a complete fulfilment of the national guidelines but reduces annoyance possibilities. By setting this buffer, it is also ensured that buildings and churches listed as national cultural heritage are preserved against possible changes in the character of their immediate surroundings as established by the Law on Cultural Environment (SFS 1988:950) (National Board of Housing, Building and Planning 2012, p. 92-93).

**Distance from infrastructures.** Wind turbines, shall not represent a hinder to roads and railways; consequently they should be surrounded by protective a buffer corresponding to their total height (National Board of Housing, Building and Planning, 2012, p. 75). Considering the applied turbine model, this buffer measures 200 m. Turbines should be not placed on the side of electric grids for safety reasons. A safety distance of 200 m is recommended for these infrastructures too (Swedish electric grid, 2016). This buffer would also protect infrastructures and their users from possible ice throws from blades. Furthermore, according to the Law on Electronic Communication (SFS 2003:389) and the Law on Electromagnetic Compatibility (SFS 1992:1512), if an activity or project can possibly affect telecommunication systems, then approval is required from the Swedish Post and Telecom Authority (National Board of Housing, Building and Planning, 2012, p. 73-74). Turbines’ disturbance over radio masts varies according to different factors (e.g. signals frequency, topography) (National Board of Housing, Building and Planning, 2012, p. 73-74). By setting a buffer distance of 500 m from radio masts, it might be possible to reduce or avoid most of the negative impacts (Vindlov, 2015a).

**Wind speed.** Wind farms require appropriate wind conditions; these are usually determined according to average yearly wind speeds at a certain altitude. An average wind speed of at least 7.2 m/s at an altitude of 100 m was chosen to identify areas of national interest for wind power (Swedish Energy Agency, 2013, p. 34). The same speed is applied in this analysis, but the applied turbine model requires an altitude of 140 m.

**Unsuitable land.** Lakes and rivers do not offer suitable conditions for wind power development and a buffer of 5 m around their shores is necessary to avoid unstable ground. Glaciers or névé also provide unsuitable topographic conditions. Land allocated for recreational and leisure purposes such as ski-slopes or sports facilities is also considered unsuitable. Graveyards are also excluded. In addition to these features, areas used for mining, dump sites as well as for commercial and industrial activities are excluded. Sites already occupied by wind turbines are not feasible and a buffer of 200 m around each turbine is required. Lastly, the city centre of Kiruna is being relocated. Areas that will be developed are not suitable and a buffer of 800 m is required to ensure safety conditions for future buildings and infrastructures.

**Terrain slope.** Steep slopes affect the development of wind power projects since they can alter wind conditions and require higher infrastructural investments. According to van Haaren & Fthenakis (2011, p. 3336) and Wizelius (2007, p .230) slopes steeper than 10° are not recommended for the establishment of wind power projects.

### 3.3.2 Criteria

**Good wind conditions.** Turbines require cut-in speeds to start their production; once this critical threshold is passed, production is directly proportional to wind speed up to a rated output speed after which it is stabilized determining a constant output (Wizelius,
It is assumed that optimal production starts with an average cut-in speed of 7.2 m/s at 140 m from ground and stabilizes at a rated output speed of 10 m/s. These thresholds are chosen according to production curves provided by Wizelius (2015, p. 300-302).

**Adequate distance from electric grids.** Wind farms require grid connection to input their production; the type of grid required depends on the installed capacity of a specific project (Wizelius, 2015, p. 284-289). In this analysis, different grids are considered equally. Connection costs are therefore proportional to distances to cover to reach grids of interest and they are usually charged to developers (Wizelius, 2015, p. 284-289). Locations located far from transmitting grids implies higher costs and are therefore less suitable than locations sited in proximity of grids. A distance of 10 Km is established as the threshold after which connection costs become too high. This distance is based on localisation studies of Baban and Parry (2001, p. 61) in the U.K. and of van Haaren and Fthenakis (2011, p. 3335) in the USA.

**Adequate distance from roads.** Wind power projects require roads for construction and for maintenance. If no suitable infrastructures are located nearby, these have to be upgraded or built, requiring investments whose cost depends on road type and distance to cover (Wizelius, 2007, p. 242). In this analysis different road types are considered equal, consequentially road investments depend on distance from existing infrastructures. A distance of 10 Km is established as the threshold after which construction costs become too high. This distance is based on the localisation studies of Baban and Parry (2001, p. 61) in the U.K. and of van Haaren and Fthenakis (2011, p. 3335) in the USA.

**Avoidance of protected nature.** Ch. 7 of the Environmental Code establish different types of protected nature (SFS 1998:808). Among these, nature reserves, natural monuments, wildlife and plant sanctuaries, Natura 2000 and RAMSAR areas are located in Kiruna Municipality (Swedish EPA, 2017). These areas are protected for different objectives and benefit of different degrees of protection. From a legal perspective developing wind power projects in these areas might be possible if projects would not clash with protection objectives (Swedish EPA, 2011; Vindlov, 2015b). However, because of the impacts possibly caused by wind power projects there is a concrete possibility that protection objectives would not be met and other locations should be prioritized (National Board of Housing, Building and Planning, 2012, p. 59). In addition to legally protected areas, there are wetlands in Kiruna Municipality protected according the Mire Protection Plan (Swedish EPA, 2007). Wetlands can be important biotopes for different bird species and therefore wind power development in such areas might be particularly detrimental (Rydell et al., 2012, p. 4-6). Wind power should also not be localised in the surroundings of protected nature since ecosystems can be disturbed even though turbines are located outside of its established borders (National Board of Housing, Building and Planning, 2012, p. 59). Therefore a buffer zone of 2 Km from the borders of protected nature should be established, especially in order to reduce birds and bats collision (National Board of Housing, Building and Planning, 2012, p. 63).

**Shoreline protection.** According to Ch. 7, § 13-14 of the Environmental Code, land and water areas shall be protected from 100 m up to 300 m from shorelines to assure public access to outdoor recreation and to maintain good ecological conditions. Within these
areas, according to § 16, construction should be avoided but special permits might be issued to clusters of three turbines with a total output of not less than 10 MW (SFS 1998:808). Therefore it might be possible to develop wind farms in the immediate surroundings of lakes and rivers in Kiruna Municipality but other locations should be prioritized (National Board of Housing, Building and Planning, 2012, p. 59).

**Reduced impacts on reindeer herding.** According to Ch. 3, § 5 of the Environmental Code, areas of national interest for reindeer should be protected against interfering measures (SFS 1998:808). Furthermore, the Reindeer and Herding Act protects reindeer herding against different forms of development, grants the recognition of this activity within spatial planning and ensures rights for land and water use to Sami communities (Lawrence, 2014, p. 1047). Wind power projects can be considered an interfering measure but despite its legislative status, reindeer herding is not entirely protected; this often results in conflicts that are embedded in a complex history of land dispossession and Sami resistance (Lawrence, 2014, p. 1037-1046). Wind power projects may alter topographies and fragment grazing areas and corridors acting as physical and behavioural barriers for reindeer (Helldin et al., 2012, p. 5-6). Furthermore, wind power projects may have a cumulative effect on sites that are already affected by roads, electric grids, scooter tracks or cottages (Larsen et al., 2016, p. 8-10). Reindeer displacement may result in overgrazing in other areas, potential conflicts with other Sami communities and necessity to provide additional fodder (Ek & Matti, 2014, p. 1332). Impacts are particularly clear during construction, when reindeer tend to avoid construction sites (Colman et al. 2012, p. 367-368; Skarin et al. 2015, p. 1539-1540). On the other hand, long term effects and their degree of disturbance is hard to determine. According to Skarin & Åhman (2014, p. 1050) reindeer may be affected up to 5 Km from wind turbines. Consequently localising wind power within and in proximity of areas of national interest for reindeer herding might be detrimental. Nevertheless, areas of national interest for reindeer herding do not fully incorporate land use by Sami communities in Kiruna Municipality; these geographical areas are integrated with routes, gathering areas, difficult passages, nurseries and comfort zones for reindeers (N. Inga, personal communication, March 1, 2017).

**Reduced impacts on tourism/recreation.** Wind turbines may alter the perception and fruition of certain areas for touristic or recreational purposes because of their landscape intrusion; however, wind farms schemes, personal beliefs, landscape features, types of touristic or recreational activities determine the degree of affection (Henningsson et al., 2013, p. 49-54). There is a lack of research assessing specific impacts of wind power in northern Sweden over tourism. However, it is possible to apply insights from the Jämtland County, which presents environmental settings similar to the ones of Kiruna Municipality. According to Hörnsten (2002, p. 21) and Bodèn (2009, p. 33-37) tourism might be particularly affected by wind power if large scale projects are developed within areas with a high natural and scenic value which are perceived as unspoiled such as the mountain range. On the contrary, impacts might be lower if projects are developed in non-scenic landscapes, such as woodlands, or far from touristic landmarks. Furthermore, in a Swedish context, acceptance might be higher if wind power is localised far from areas relevant for recreational purposes (Ek & Persson, 2014, p. 201; Ek & Matti, 2014, p. 1332). Ch. 3, § 6 of the Environmental Code, localise certain areas as of national interest for their natural or cultural value for outdoor recreation (SFS
Wind power localisation should be avoided in such areas in Kiruna Municipality, since they mostly cover mountainous and scenic landscapes and allow many different recreational activities (Swedish EPA, 2017). However, the fruition of such areas may be disturbed even though turbines are located outside of their borders; consequently, a buffer of 4.5 Km should be established to reduce wind power dominance (Wizelius, 2015, p. 214).

Avoidance of cultural landscapes. Cultural landscapes are portrayed as an important foundation of a collective identity and an anchorage in national history; consequently, landscapes issues brought by wind power development might be negatively perceived in such landscapes (Anshelm and Simon, 2016, p. 1551). Turbines, roads and grids are powerful intrusive elements within cultural landscapes and they can alter the perception and experience of these sites (Häggström, 2013, p. 55-57). In Kiruna Municipality, cultural landscapes are identified by the Regional Cultural Landscapes Programme of the Country Administration Board of Norrbotten (County Administration Board of Norrbotten, 2010, p. 17-67). This Programme includes areas identified as of national interest for their cultural value according to Ch. 3, § 6 of the Environmental Code as well as supplementary sites (SFS 1998:808). Wind power localisation should be avoided in these areas and in their surroundings, for a buffer of 10 Km to allow turbines to melt into landscapes and lose their dominance (Wizelius 2015, p. 214).

Reduced visibility from major settlements. Turbines visibility from major settlements might not be ranked as a pressing issue such as visibility in other sensitive landscapes (Ek & Persson, 2014, p. 201). However, the threat of constant exposure might increase local resistance to wind power development (Söderholm et al., 2007, p. 379). Furthermore at northern latitudes, shadows and reflections can be of particular annoyance from October to February when the sun is low on the horizon ranging from south-east to south-west. This factor is particularly relevant since many inhabited places of Kiruna Municipality are oriented towards south and are sited in lowlands surrounded by hilly terrain, thus increasing possible annoyance (L. Solbär, personal communication, March 4, 2017). Areas where turbines would be particularly intrusive within a radius of 10 Km from major inhabited places should be therefore avoided.

Avoidance of undisturbed mountainous environment. According to Ch. 4, § 5 of the Environmental Code, within the mountainous areas of Kebnekaise-Sjaujna, Rostu and Pessinkin in Kiruna Municipality, buildings and structures may only be established where necessary for reindeer herding, resident population, scientific research or outdoor recreational exercise; other measures may only be taken if not affecting the character of these areas (SFS 1998:808). Establishing wind power in such areas might be problematic since it is unlikely that their character would not be affected (National Board of Housing, Building and Planning, 2009, p. 25-27). Furthermore, public opinion is discouraging wind power development in mountainous areas (Söderholm et al., 2007, p. 383-384; Ek & Persson, 2014, p. 201). Consequently, areas of national interest for undisturbed mountainous environment and their surroundings within 10 Km are less suitable for wind power development in Kiruna Municipality.
### Table 1 Constraints and criteria selected for the analysis:

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>National parks</td>
<td>Not in national parks</td>
</tr>
<tr>
<td>Areas of interest for defence</td>
<td>Not in areas of national interest for defence and within 5 Km from radars</td>
</tr>
<tr>
<td>Air transportation</td>
<td>Not within ICAO Annex 14- areas</td>
</tr>
<tr>
<td>Distance from buildings</td>
<td>Not within 800 m from buildings</td>
</tr>
<tr>
<td>Distance from infrastructures</td>
<td>Not within 200 m from roads, railways and electric grids and within 500 m from radio masts</td>
</tr>
<tr>
<td>Wind speed</td>
<td>Not in areas with average yearly wind speeds lower than 7.2 m/s at 140</td>
</tr>
<tr>
<td>Unsuitable land</td>
<td>Not in lakes, rivers, glaciers, névé, industrial or commercial units, mines, dump sites, sport and leisure facilities, graveyards, existing wind farms and areas of future development for Kiruna city</td>
</tr>
<tr>
<td>Terrain slope</td>
<td>Not in areas with steeper slope than 10º</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Minimum suitability</th>
<th>Maximum suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good wind conditions</td>
<td>Wind speeds at 140 m</td>
<td>7.2 m/s</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Adequate distance from electric grids</td>
<td>Distance from electric grids</td>
<td>10 Km</td>
<td>200 m</td>
</tr>
<tr>
<td>Adequate distance from roads</td>
<td>Distance from, roads (public and private)</td>
<td>10 Km</td>
<td>200 m</td>
</tr>
<tr>
<td>Avoidance of protected nature</td>
<td>Distance from national parks, nature reserves, Natura 2000 areas (habitat and wildlife directives), RAMSAR areas, wildlife and plant sanctuaries, natural monuments, Mire Protection Plan areas</td>
<td>0 m</td>
<td>2 Km</td>
</tr>
<tr>
<td>Shore protection</td>
<td>Distance from water bodies</td>
<td>100 m</td>
<td>300 m</td>
</tr>
<tr>
<td>Reduced impacts on reindeer herding</td>
<td>Distance from areas of national interest for reindeer herding, routes, gathering areas, difficult passages, nurseries, areas used all-year around.</td>
<td>0 m</td>
<td>5 Km</td>
</tr>
<tr>
<td>Reduced impacts on tourism/recreation</td>
<td>Distance from areas of national interest for tourism and outdoor recreation</td>
<td>0 m</td>
<td>4.5 Km</td>
</tr>
<tr>
<td>Avoidance of cultural landscapes</td>
<td>Distance from areas listed in the Norrbotten cultural landscape programme</td>
<td>0 m</td>
<td>10 Km</td>
</tr>
<tr>
<td>Reduced visibility from major settlements</td>
<td>Visibility of turbines from major settlements within 10 Km in south-west direction</td>
<td>Not visible</td>
<td>Visible</td>
</tr>
<tr>
<td>Avoidance of undisturbed mountainous environment</td>
<td>Not within areas of national interest for undisturbed mountainous landscape.</td>
<td>0 m</td>
<td>10 Km</td>
</tr>
</tbody>
</table>

### 3.4 Generation of constraints and criteria maps

Within this step of the spatial MCDA, the chosen constraints and criteria are implemented in a GIS. The chosen GIS software is ArcMap 10.4, belonging to the ArcGIS package developed by ESRI. In the first place, the set of constraints needs to be organized to create constraints maps, which are geographical layers representing areas where the chosen objective can or cannot be achieved. Once that the different constraints maps are developed, it is necessary to create a new geographical layer which combines them according to a logical conceptualization (Malczewski, 1999, p. 150).
Secondly, the set of criteria needs to be organized in ArcMap too, to create criteria maps, which are geographical layers representing the spatial distribution of criteria. However, before being plotted over maps, criteria need to be normalized to a comparable unit of measure. The application of fuzzy sets, derived from the fuzzy theory, allows this standardization and at the same time allows incorporating the uncertainty characterizing this planning problem (Malczewski, 1999, p. 100). The fuzzy theory assumes that judgement over spatial issues should be characterized by a degree of uncertainty to avoid the common practice of establishing fixed definitions and boundaries concerning spatial phenomena, which do not reflect reality since they are biased by human judgment (Leung, 1983, p. 65). For instance, it might be difficult to accurately assess and determine the impact of a wind farm over protected nature and most often by avoiding the localisation within the boundaries of these areas it is assumed that detrimental issues would be avoided. However, excluding the localisation process in these areas does not ensure the avoidance of impacts. It is not possible to define a sharp boundary determining where wind farms would not represent a harm. Consequentially a certain degree of uncertainty is always present. This uncertainty is incorporated by establishing fuzzy sets, which are classes of geographical features in which there are no sharp boundary between features belonging to the class and features that do not. Fuzzy sets are formulated trough fuzzy membership functions, defining the membership value of a feature within a geographical class on a continuous scale ranging from 0 to 1 (Bellman and Zadeh 1970, B-43). In this case, a trapezoidal fuzzy membership, also interpretable as the union between the ascending liner fuzzy membership \( \alpha \) and a descending linear fuzzy membership \( \beta \) is implemented, as shown by Figure 5.

Figure 5 shows that the first point (a) marks the location where the membership function begins to rise above 0. The second point (b) indicates where it reaches 1; the third point (c) indicates the location where the membership grade begins to drop again below 1, while the fourth point (d) marks where it returns to 0. The transition zones in between the points a and b or c and d the membership functions assume values in between 0 and 1 determining and indicating if the function is closer to have a membership either of 0
either of 1. The points a and b or c and d are selected according to critical threshold, also known as crisp value according to the nature of the data and knowledge about their spatial behaviour (Malczewski, 1999, p. 131). Mathematically, the linear ascending fuzzy membership function of Figure 3 can be expressed by the following three equations:

1. \( MF(z) = 0 \) for \( z < a \)
2. \( MF(z) = \frac{z-a}{b} \) for \( a < z < b \)
3. \( MF(z) = 1 \) for \( z > b \)

Similarly, the linear descending fuzzy membership function of Figure 5 can be expressed by the following three equations:

1. \( MF(z) = 0 \) for \( z > d \)
2. \( MF(z) = \frac{z-c}{d} \) for \( c < z < d \)
3. \( MF(z) = 1 \) for \( z < c \)

For instance by applying an increasing fuzzy function to capture the reduction of wind power impacts on protected nature, it is established that suitability for wind power is null (0) for land patches located within protected nature. Then suitability proportionally increases (assuming values between 0 and 1) with the distance from protected nature until 2 Km, after which land patches are classified as mostly suitable for wind power (1) since then possible impacts are most likely to be avoided. The same reasoning is applied for the planning criteria of the analysis by using the thresholds reported in Table 1. Accordingly, it is possible to standardize criteria and at the same time incorporate fuzzy uncertainty in the spatial MCDA.

### 3.4.1 Data mining and management

Geodata are retrieved from various sources, consequently, they are available in different formats, covering heterogeneous geographical extents and they are projected in different coordinate systems. Appendix 3 and Appendix 4 provide information concerning the geodata used for the GIS processing. Before proceeding with the development of constraints and criteria maps, it is necessary to make the data comparable in ArcMap. In the first place, all of the geodata have to use the same coordinate system. The coordinate system chosen for the analysis is SWEREF 99 TM since most of the data are already projected according to it. Consequently, data with other coordinates system have to be projected to this system. Furthermore, the XY coordinates of weather radars in Sweden are used to create a new shapefile. Then it is necessary to delimit the geo-data to the areas of interest; data with a different geographic extend are clipped to a shapefile covering the Municipality of Kiruna. Furthermore, the map in TIFF format displaying the areas of future expansion for the city of Kiruna is georeferenced and transformed into a shapefile.

### 3.4.2 GIS Processing

The constraint maps are developed in ArcMap according to the flowchart displayed in Figure 6. Some common steps are carried out. In first place, when converting to raster format, the processing extent is set according to the digital elevation model (DEM) and the cell size is set to 25. Furthermore, raster reclassifications give a value of 0 to unsuitable land patches and a value of 1 to suitable land patches. These reclassifications follows the constraints description previously provided in Table 1. Once that the individual constraint maps are created, a final constraint map determining
feasible and unfeasible alternatives is created by implementing the Boolean operator “OR” in the tool “Raster calculator”. This logical operator is applied since it is assumed that locations suitable for wind power development shall not fulfil any of the formulated constraints. The final constraint map gives land-patches values of 1 (suitable) when they do not fulfil any constraint and values of 0 (unsuitable) when they fulfil at least one of the constraints.

After having retrieved and managed the data, criteria maps are developed and then individually standardized according to the fuzzy theory. To develop criteria maps, three main ArcMap tools are used. “Euclidean distance” allows the development of raster surfaces displaying distance from certain feature. “Viewshed” allows performing visibility analysis by inputting visibility points (requiring complementary fields to determine the range of the analysis, its orientation, the height of the observer and the height of a hypothetical turbine) and a surface composed by a digital elevation model plus a vegetation canopy obtained from land-cover. Finally, “Fuzzy suitability” allows the transformation of the different criteria according to the fuzzy theory. A linear fuzzy function is chosen and minimum and maximum values are presented in the criteria descriptions in Table 1. Figure 6 displays the GIS processing while Appendix 1 displays the transformation of criteria into fuzzy functions. For the development of the criteria map for reduced visibility from major settlements a binary fuzzy function is manually applied through a reclassification of land patches as visible (1) or not visible (0).
Figure 5 GIS processing in ArcMap for the development of constraints and criteria maps.
3.5 Weights development

This step of the spatial MCDA allows the implementation of preferences in the process simulating real-life planning situations. The relevance of each criterion in the spatial MCDA is expressed by weights. The pairwise comparison method is a common technique when dealing with spatial MADM problems. This method involves pairwise comparison to create ratio matrices expressing preferences towards criteria that are accounted in the final judgment. This approach reduces complex decisions to a series of pairwise comparisons and then it synthesizes the results in order to support the analyst in setting priorities. The pairwise comparison method can be implemented in three steps: generation of the pairwise comparison matrix, computation of criterion weights and consistency ratio estimation.

3.5.1 Pairwise comparison

The development of the pairwise comparison matrix employs judgement over the relative importance of each criterion over the other. The relative importance is quantified according to a scale ranging from 1 (equal importance) to 9 (extreme importance). Based on this scale the judgement is carried out and the comparison matrix is filled (Malczewski, 1999, p. 182). In this case, the author personally develops this judgement by considering different planning scenarios. This choice is led by three reasons. In the first place, the timing and resources available did not allow the author to carry out interviews with the extremely broad and fragmented body of stakeholders involved in wind power planning for the Municipality of Kiruna. Then, by applying scenarios reflecting real life planning situations it is possible to efficiently test the effectiveness of spatial MCDA as decision support tool for Kiruna Municipality. Finally by implementing scenarios it is possible to adopt a relation approach to spatial planning since multiple spatial and temporal trajectories are included. The computation of criterion weights and the consistency ration are derived by the pairwise comparison matrix. The consistency ration is a key element of the process, since it checks the consistency of the decision maker’s evaluations, thus reducing the bias in the decision making process. If the ration displays values higher than 0.10, then the judgment is incorrect and it is advisable to reconsider and revise the original values in the pairwise comparison matrix (Malczewski, 1999, p. 186). To carry out weighting directly in ArcMap it is possible to implement an open source Python plug-in toolbox (Digital Geography, 2015). The toolbox demands the user to weight the different criteria according to the pairwise comparison method. Then the toolbox automatically carries out the calculations required for the development of the weights as well as providing the consistency ration. The output is a text file from which the weights can be extracted and further implemented.

3.5.2 Scenarios

Two scenarios are applied: the “Green road” and the “Highway”. These scenarios were developed through a workshop organized by the Mistra Arctic Sustainable Development research programme and arranged in 2015 in Pajala Municipality. A heterogeneous group of actors was invited to the workshop in order to shape trajectories for future development in the Nordic Arctic in light of current and future social, economic and environmental processes reflecting both local and global trends (Nilsson et al., 2015, p. 5-6). The “Green road” scenario pictures highly independent communities in the Nordic Arctic accepting slow growth and development to enhance nature preservation and
traditional rural lifestyles. On the contrary, the “Highway” scenario conceptualizes globalized communities eager to accept trade-offs in natural amenities and traditional lifestyles to embrace fast growth and strong development based on both subsidies and private initiatives. A more detailed summary of these scenarios is provided in Appendix 2. On the side of these two scenarios, a third scenario is applied. This scenario is developed by the author and it is named “Baseline”. This scenario implies equal importance among the criteria, simulating a situation in which decision makers tend to balance different opposing interests to the maximum extent. In the following paragraphs, the reasoning behind development of weights according to the chosen scenarios is provided.

As shown by Table 2, the weighting for the “Baseline” scenario lead to the development of equal weights. Each criterion has a weight of 10% to determine areas suitable for wind power development. This outcome is driven by the assumption that criteria have equal importance in the decision making process and therefore they receive a score of 1. The weighting for the “Baseline” scenario provides a consistency ration higher than 0.1 therefore assessing bias in the judgement. This scenario to a certain extent violates the assumption of a spatial MCDA since it excludes uneven preferences that are always stated in decision making, however it is useful as mean of comparison for the other two scenarios.

Table 2, displays the weights generated for the “Green road” scenario. In the first place, reindeer herding is a relevant activity, highly regarded for the local economy; therefore when identifying areas suitable for wind power development, the interests of reindeer herding are highly valued. Secondly, a green ideology favours a strong identification of communities with their natural settings; thus, areas of national interest for undisturbed mountainous environment represent a vital asset that is highly regarded and there is low willingness to trade it off for wind power. In the light of this ideology, the avoidance of protected nature is the third most influential factor in steering wind power development. Following the same reasoning, shore protection is promoted on a minor scale because of the large availability of water bodies. Strong community identities lead also to a higher consideration of cultural landscapes that receive a substantial weight to avoid their alteration by landscape intrusion. Reduced visibility from major settlements is also pursued since local dwellers are assumed to highly value the wilderness of their surroundings. The avoidance of areas of national interest for tourism and outdoor recreation is not highly weighted since tourism does not represent a vital economic sector; furthermore, because of nature protection efforts, there are other areas available for outdoor recreation for the local dwellers. The slow-down of climatic changes and the development of alternative renewable energy projects for local consumption determine that wind power shall be localised by prioritizing the above-mentioned factors. Priority is not set upon seeking the best wind conditions, or choosing locations which might reduce the economic costs for the development of road networks and electric grids. Since wind power development is not a pressing issue, identifying areas that do not offer the best economic and infrastructural conditions is acceptable. The weighting for the “Green road” scenario provides a consistency ration lower than 0.10, thus, assessing logical judgement.

As it is possible to observe from Table 2, the weighting for the “Highway” scenario leads to different weights. In the first place, strong energy demands to supply both local
industry and the national energy market steer the development of wind power projects. Localising areas suitable for wind power is a priority in local planning, which is influenced by corporations and national agencies. However, economic profitability is a key-factor and therefore conditions, such as good wind conditions and proximity to infrastructures, represent the most relevant criteria for the localisation process. If these conditions are not met then wind power development might take place elsewhere. Opposing interests that do not deliver high profits are considered on a minor scale since communities are eager to embrace economic growth. Reindeer herding becomes a marginal activity because of the reduction of Sami people willing to embrace traditional life-styles and hinders determined by mining expansion and climate change. Therefore, areas of interest for reindeer herding are not highly valued. Nature protection and shore protection face a decrease in their importance: communities are willing to trade-off certain natural amenities in order to favour growth. On the contrary, communities highly value undisturbed mountainous landscapes. In fact, winter-tourism (favoured by climate change in the Alps) is a profitable sector and therefore it is protected to guarantee tourists the untouched and wild landscape they would expect from the remote Nordic Arctic. Furthermore, a shift in local attitudes is experienced, the in-migration of foreign workforce and the partial outmigration of elderlies lead to a decreased perceived importance for landscapes of cultural importance. Part of the local cultural heritage can be lost together with traditional outdoor activities. A more industrialized landscape leads to an adaptation to anthropogenic impacts and therefore the visibility of wind projects from settlements does not represent a particularly relevant issue for the local population. Lastly, changes in the landscape and a major focus on winter tourism make areas of national interest for tourism and outdoor recreation not vital for this sector. The weighting for the “Highway” scenario provides a consistency ration lower than 0.10, thus assessing logical judgement.

Table 2: Comparison of the weights given to each criterion under the three scenarios
3.6 Problem solution

The ultimate aim of a spatial MCDA is to combine criteria, constraints and weights to determine a set of solutions. This step is based on multi-criteria decision rules, which are procedures ordering alternatives, in this case potential locations. Weighted linear combination (WLC) is one of the most often used techniques to solve spatial MADM problems. The WLC is based on the concept of a weighted average, since solutions are determined according to the weights of relative importance that they receive. The WLC allows determining an overall suitability index (SI) for each alternative. The SI is based on the sum of the products of each individual criteria multiplied by its relative weight. This process is calculated only for feasible alternatives designated by constraints (Malczewski, 1999, p. 199). This method is displayed by the following formula:

\[ SI = \prod B_{ij} \sum w_j x_{ij} \]

SI represents the suitability index that determines how each alternative is suitable; \( x_{ij} \) is the score of the ith alternative with respect to the jth constraint, and the weight \( w_j \) is a normalized weight, so that criteria can be compared and their sum is equal to 1. The operator \( \prod B_{ij} \) allows the process to be carried out only for feasible alternatives determined by constraints (Malczewski, 1999, p. 199).

3.6.1 Weighted linear combination

The WLC is implemented in ArcMap through the “Raster calculator” tool. In the first place, the final constraint map is input as first operator to proceed only with the evaluation of feasible alternatives. The second operator of the combination is the sum of the ten evaluation criteria multiplied by their respective weights. The two operators are related by a multiplication factor according to the following formula:

\[ SI = \text{Constraints} \ast [(\text{Criteria1} \ast \text{Weight1}) + (\text{Criteria2} \ast \text{Weight2}) \ldots] \]

The output of the WLC provides a layer displaying the SI of each land patch expressed from 0 to 1, in which values closer to 0 shows a lower suitability while values closer to 1 shows higher suitability. The WLC is carried out three times in order to input the weights generated under the three different scenarios.

3.6.2 Selection of suitable locations

It is possible then to classify the land patches into different categories revealing their suitability for wind power development. The classification of the patches is led by the author personal judgement. Land patches with a SI equal to 0 are categorized as unfeasible since they do not allow wind power development, revealing constraints. Land patches with a SI <0.5 are feasible but display a too low index to be considered suitable alternatives. Land patches with a SI> 0.5 and <0.6 are suitable. Land patches with a SI> 0.6 and < 0.8 are highly suitable while patches with a SI> 0.8 are the most suitable for wind power development. In order to identify suitable locations, the three maps are converted from raster format to polygon. From the attribute tables of the newly created shape files it is possible to select feature with a SI > 0.5 and an area larger than 5 km².

3.7 Sensitivity analysis

Sensitivity analysis is required to investigate how model choice, system understanding, weighting and human judgment, contribute to the results of a spatial MCDA (Malczewski, 1999, p. 272). There is no common procedure to follow in order to perform
a sensitivity analysis; its level of complexity and varies according to the aim of a spatial MCDA (Pianosi et al., 2016, p. 214). In the light of these aspects, different tasks are usually carried out to perform sensitivity analyses. These tasks can be of quantitative nature or of qualitative nature. Through correlation analysis it is possible to test different forms of sensitivity. For instance, it is possible to investigate the presence of geographical overlaps among the chosen criteria determining ontological redundancy in the model and biasing the results of the spatial MCDA (Mitchell, 2012, p. 23). On the side of correlation analysis, it is possible to perform results analysis, which modifies criteria weights and investigates changes in the results; this is one of the most widely applied quantitative approaches to verify model sensibility towards weighting (Delgado & Sendra, 2004, p. 1177-1180). Finally, on the side of quantitative analysis, it is possible to perform a qualitative analysis qualitative nature, through visual inspection and judgment of the results; this procedure helps to visualize and compare how results vary over space and differ from each other (Pianosi et al. 2016, p. 216).

3.7.1 Correlation analysis
Correlation analysis is performed for the 10 criteria within ArcMap. To perform this task, the tool “Band collection statistics” is applied. The output of this task provides a report that is then elaborated in Microsoft Excel 2016.

3.7.2 Results analysis
In this analysis, three different scenarios implying three different weighing are implemented. To investigate the spatial MCDA sensitivity to weighting, changes in suitability classes under the three scenarios are compared. By exporting the attribute tables of the raster layers displaying the results from ArcMap to Microsoft Excel 2016 it is possible to carry out this operation.
4. Results

This chapter presents the maps displaying the findings of the spatial MCDA according to the research questions. Their interpretation is supported through descriptive statistics obtained from the GIS analysis. Furthermore, the outputs of the sensitivity analysis are presented.

4.1 Research question 1: constraints to wind power development

The first research question investigates where and how planning constraints discourage wind power development in Kiruna Municipality. Figure 7 shows the constraints maps developed to answer this question. Constraint Map 6 shows that wind speed is the most limiting condition for wind power development. Wind speeds lower than 7.2 m/s are experienced in large contiguous areas, accounting approximately for 56% of the territory of Kiruna. As shown by Constraint Map 2, areas of interest for defence cover around 15% of the territory. The high degree of unfeasibility generated by this constraint is mainly determined by the large safety zone required by the ESRANGE space centre in the centre of the Municipality. Training areas and the buffer zone around the weather radar exclude minor areas in proximity of the city of Kiruna. The combination of these two constraints limit wind power feasibility to approximately two-thirds of Kiruna Municipality.

Both steep slopes and insufficient distance from buildings individually exclude approximately 10% of the land from wind power siting. As shown by Constraint Map 8, steep slopes can be found especially in proximity of mountain ranges along the Norwegian border. Constraint Map 4 shows that larger concentrations of buildings can be found in the southern and southeastern part of Kiruna Municipality where the degree of urbanization is higher. Furthermore, higher concentrations of buildings can be found along major roads and in proximity of Karesuando in the northeast and around the Abisko area.

Constraint Map 6 shows that unsuitable land covers around 5% of the territory. Large lakes such as Torneträsk and ski-resorts such as Björkliden and Riksgränsen limit wind power localisation in the western part of the Municipality while mines, dump sites and industrial or commercial units can be found in proximity of the city of Kiruna. The constraints contributing the least to unfeasibility for wind power development are: distance from infrastructures (=3%), air transportation (=1%) and national parks (=0.5%). Constraint Map 5 shows that roads, railways and electric grids, as well as radio masts, cover a limit surface of Kiruna Municipality and are not widely diffused. These are mainly concentrated in the southern part of the Municipality and along two major communication axis heading west to Norway and north to Finland. Constraint Map 3 shows that there is only one commercial airport in the Municipality and this is located in proximity of the city Kiruna. Finally, constraint map 1 shows that only two national parks, Abisko and Vadveitjäkkä do not cover a large portion of the Municipal territory.

According to the Final Constraint Map, approximately 90% of the municipal territory is not feasible for wind power development. Most of the central and southern areas around the city of Kiruna are unfeasible for wind power development as well as bordering areas bordering Norway. In particular, the surroundings of Abisko are not feasible for wind power because they present many overlapping land-use interests.
Figure 6: Constraints maps. Source: Lantmäteriet ©, 2017; own figure
4.2 Research question 2: criteria for wind power development

The second research question aims to investigate where and how planning criteria encourage wind power development in Kiruna Municipality according to the identified planning factors. Figure 8 shows the different criteria maps developed to answer this question. Criterion Map 9 shows that there are many areas allowing to reduce visibility of wind turbines from major settlements. This criterion shows the average highest suitability index for wind power development. The limited number of major settlements and the large extension of the Municipality support the achievement of this criterion. However, within the 10 Km limit, most areas would be visible because of topography and the considerable height of the hypothetical turbines implemented in the visibility analysis.

The avoidance of cultural landscapes is the second criterion that on average can be best fulfilled in Kiruna Municipality. Cultural landscapes are limited and their extension is relatively small, since they mainly aim to cover specific anthropogenic landmarks, a part from the city of Kiruna, which is listed in its integrity as cultural landscape. However, especially in the western area of the Municipality, the buffers surrounding such landscapes tend to overlap, increasing potential visual intrusion.

According to Criterion Map 5, it is possible to ensure shore protection in many areas despite of the large amount of water bodies. Areas in which suitability is reduced by the 300 m buffer are limited if compared to the large extension of the Municipality. Suitability concerning avoidance of protected nature is limited. In fact, as shown by Criterion Map 4, there are many protected areas. In particular, in the middle of the Municipality there is a cluster of nature reserves (e.g. Torneträsk-Soppero fjällurskog, Alajaure, Rauta fjällurskog) and Natura 2000 areas (e.g. Tavvavuoma, Sautusvaara).

Despite the low degree of urbanization, the road network grants a certain degree of suitability, especially in the southern and partially the eastern areas. However low suitability for adequate distance from roads is displayed in the northern and western parts as shown by Criterion Map 3. Criterion Map 6 shows that reduced impact on tourism and outdoor recreation can be achieved in the eastern part of Kiruna since areas of national interest are relocated in the western mountainous area of the Municipality and around the Torne River. Within these contiguous areas, low suitability to wind power development is displayed.

The criteria that on average display the lowest suitability are avoidance of undisturbed mountainous environment, adequate distance from electric grids, reduced impacts on reindeer herding and good wind conditions. Criterion Map 10 shows that the Kebnekaise-Sjaunja, Rostu and Pessinkin mountains and their 10 Km buffer cover a wide area of the Municipality of Kiruna. Furthermore, as shown by Constraint Map 2, electric grids are not widely diffused and they follow the main roads and railways. Many large areas of the municipality are located more than 10 Km from electric grids and thus low suitability for wind power development is displayed by this criterion. As shown by Criterion Map 7, only few areas display high suitability to reduce impacts on reindeer herding: suitability for wind power concerning this criterion is extremely low. Finally, Criterion Map 1 shows that, good wind conditions can be found in in isolated spots in the northern and western parts of Kiruna. On the contrary, the southern and western areas display an extremely low degree of suitability.
Figure 7: Criteria maps. Source: Lantmäteriet ©, 2017; own figure
4.3 Research question 3: suitable locations for wind power development

The third question aims to localise suitable areas for wind power development under different planning scenarios and to explore their degree of suitability. As previously stated, only around 10% of Kiruna Municipality is feasible for wind power development. The combination of criteria and weights determines the degree of suitability of feasible areas developed through the output map of the spatial MCDA (see Figure 9). The “Baseline” scenario displays the highest average suitability among its land patches, followed by the “Green road” and the “Highway” scenarios. The majority of suitable patches is located approximately in the same area under the three scenarios, in the northeastern part of Kiruna Municipality. It is possible to recognize few other suitable clusters of land patches in the western and southern areas of the Municipality. However, the majority of land patches receive a suitability index lower than 0.5 therefore being considered unsuitable for wind power localisation under the three planning scenarios. The combination of unfeasible and unsuitable land patches determine that it is not possible or advisable to develop wind power respectively in ≈98% and ≈98% of the Municipal territory under the “Baseline” and “Green road” scenarios and the “Highway” scenarios. This leads to the suitability for wind power development in approximately 380 Km² under the “Baseline” and “Green road” scenarios and in 190 Km² and the “Highway” scenarios.

However, few clusters of suitable land patches cover a contiguous area larger than 5 Km². As it is possible to observe in Figure 10, these clusters are located in northeastern Kiruna, in proximity of the inhabited places of Idiuvuoma, Karesuando and Kuitannen and of the border with Finland. As shown by Figure 10, the suitable locations cover open woodlands and hilly terrain surrounded by mires, without overlaying any built environment. The area is served by the European road E45 and the national road 99, as well as few private roads and local electric grids. The “Baseline” scenario identifies ten locations, five of which highly suitable. The “Green road” scenario identifies fourteen locations, six of which are highly suitable and two of which are most suitable. The “Highway” scenario identifies only one location characterized as suitable. Appendix 6 provides information concerning the suitability index, the area and the geographical coordinates of the identified locations.

The “Baseline” scenario identifies an area of approximately 297 Km² suitable for wind power development. The “Green road” scenario identifies an area of approximately 204 Km² as suitable for wind power development and the “Highway” scenario identifies an area of approximately 11 Km² as suitable for wind power development. The scenario which displays highest suitability for wind power is the “Green road” since it provides a discrete amount of suitable location characterized by higher suitability indexes. On the contrary, the scenario that displays lowest suitability is the “Highway”, since it provides only one suitable locations. However only few locations are characterized as most suitable. This suggest that land-use issues arising from the dissatisfaction of certain planning criteria cannot be entirely dismissed in this area. As shown by Figure 10, there are different opposing interests in the area such as protected nature, areas of national interest for undisturbed mountainous environment, areas of national interest for tourism and outdoor recreation and areas of interest for reindeer herding. Furthermore, the localised areas located in a visible range from inhabited places.
Figure 8: Output of the spatial MCDA. Source: Lantmäteriet ©, 2017; own figure
Figure 9: Suitable locations for wind power development. Source: Lantmäteriet © 2017; own figure
4.4. Sensitivity Analysis

The correlation analysis for the different criteria shows if certain criteria overlaps. For the sake of this analysis, it is considered that Pearson’s correlation coefficients $> \approx 0.3$ display a weak correlation, coefficients $> \approx 0.5$ display a moderate correlation and coefficients $> \approx 0.8$ display a strong correlation. According to Table 3 a low degree of correlation can be found among the criteria, therefore assessing a limited bias in the final output. Most of the criteria are in fact covering different spatial aspects and do not concur in over-promoting or discouraging suitability. Only two criteria display strong or moderate correlations. The criterion “Adequate distance from electric grids” is moderately positively correlated with “Adequate distance from roads” because of the actual locations of such infrastructures, which are often overlapping, and to the application of a similar fuzzy function. The, criterion “Adequate distance from roads” is strongly positively correlated with “Avoidance of undisturbed mountainous environment”. However, this is determined by the limited urbanization occurring in the mountainous areas of Kebnekaise-Sjaunja, Rostu and Pessinkin.

Table 3: Correlation matrix for criteria. Significant correlations are highlighted in different shades of green and red

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>/</td>
<td>-0.2</td>
<td>-0.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>-0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Grids</td>
<td>-0.2</td>
<td>/</td>
<td>0.5</td>
<td>-0.1</td>
<td>-0.1</td>
<td>0.1</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Roads</td>
<td>-0.3</td>
<td>0.5</td>
<td>/</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>-0.2</td>
<td>-0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Nature</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.1</td>
<td>/</td>
<td>0.0</td>
<td>0.1</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Shore</td>
<td>0.1</td>
<td>-0.1</td>
<td>-0.1</td>
<td>0.0</td>
<td>/</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Herd.</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>/</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Tourism</td>
<td>-0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>-0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>/</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Culture</td>
<td>0.1</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>/</td>
<td>0.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>Visib.</td>
<td>0.1</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>-0.1</td>
<td>0.1</td>
<td>/</td>
<td>-0.2</td>
</tr>
<tr>
<td>Mount.</td>
<td>-0.3</td>
<td>0.4</td>
<td>0.8</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2</td>
<td>0.4</td>
<td>-0.1</td>
<td>-0.2</td>
<td>/</td>
</tr>
</tbody>
</table>

To understand how suitability for wind power changes according to the different scenarios it is necessary to compare the number of land patches by suitability category under each scenario. Table 4 shows the results of this task. It is possible to observe minor changes in suitability among the “Baseline” and the “Green road” scenarios while the “Highway” scenario displays higher differences. These differences are somehow limited if compared in terms of share of the territory but considering the large extension of Kiruna Municipality, they can be more crucial since even a reduced change can determine the suitability or unsuitability of many squared-kilometres of land.

Table 4: Results analysis

<table>
<thead>
<tr>
<th>Suitability Classes</th>
<th>The “Baseline” scenario</th>
<th>The “Green road” scenario</th>
<th>The “Highway” scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfeasible (SI = 0)</td>
<td>90,29%</td>
<td>90,29%</td>
<td>90,29%</td>
</tr>
<tr>
<td>Unsuitable (SI &lt; 0.5)</td>
<td>7,65%</td>
<td>8,00%</td>
<td>9,48%</td>
</tr>
<tr>
<td>Suitable (SI= 0.5-0.6)</td>
<td>1,29%</td>
<td>0,93%</td>
<td>0,18%</td>
</tr>
<tr>
<td>Highly suitable (SI= 0.6-0.8)</td>
<td>0,75%</td>
<td>0,75%</td>
<td>0,05%</td>
</tr>
<tr>
<td>Most Suitable (SI&gt;0.8)</td>
<td>0,01%</td>
<td>0,02%</td>
<td>0,00%</td>
</tr>
</tbody>
</table>
5. Discussion

In the first place, this chapter presents a discussion over the application of a spatial MCDA as tool to implement a relational approach to spatial planning to promote proactive land-use planning for renewable energy. In the second place, the results of wind power localisation in Kiruna Municipality are discussed. Finally methodological uncertainties and limitations are reviewed.

5.1 Planning approaches

Applying a spatial MCDA allows the implementation of the theoretical approaches to spatial planning presented in Chapter 2. In fact, suitable areas for wind power in Kiruna Municipality can be proactively identified by applying the principles determined by relational planning. The adoption of a relational approach to space and its translation within the practice of planning is relevant to tackle spatial issues related to sustainability as argued by Khan, Moulaoert and Schreurs (2013). In fact, this conceptualization leads to the choice of spatial MCDA as a method to solve this planning problem over a traditional GIS approach and it consequentially enhances to better implement the three dimensions of sustainability in spatial planning by balancing heterogeneous opposing interests. Furthermore as argued by Kaza, & Curtis (2014), many land-use planning systems are limited and ineffective in tackling renewable energy development. As briefly reviewed in Chapter 1, the Swedish planning system has been so far unsuccessful in this task too. Consequently, in a Swedish perspective, applying a proactive approach through spatial MCDA might help in partially covering this “blind spot” over wind power planning.

5.1.1 Implementing a relational approach to spatial planning

By applying a spatial MCDA for wind power localisation in Kiruna Municipality, it is possible to apply a relational conceptualization of space such as the one provided by Massey (2005). In fact, the identified locations are a product of interrelations, such as the one established between constraints, weights and criteria. In the second place, these locations represent spheres of possibility since they entail different geographical entities co-existing over space and time. In third place, these locations as always under construction since they are not fixed entities but change according to different planning scenarios.

Through this approach, it is possible to shift from an absolute conceptualization of space according to which areas are suitable for wind power development if the display sufficient wind speeds or they do not fall within protected nature. Space was therefore considered to be ‘folded’ rather than ‘flat’ as argued by Khan et al. (2013). The propositions on relational spatial planning proposed by Graham & Healey (1999) steer the spatial MCDA. In the first place, a set of case-specific criteria helps in dismissing a universal generalization according to which suitability for wind power development is determined by focusing only absolute rules irrespectively of the geographical area to investigate. Without this proposition, it would not be possible to fully understand and solve a localisation problem since relevant factors would be missed out, possibly supporting land-use conflicts. It would not be productive to exclude defence, tourism and reindeer herding in planning discourses in municipalities such as Kiruna. Secondly, it is possible to stress the multiple meanings that space and time can have for different stakeholders. Even though stakeholders have not been directly involved in the analysis,
through the application of scenarios it is possible to test the effectiveness of spatial MCDA in embracing different planning perspectives. Consequentially it is possible to implement possible views and preferences arising from different stakeholders. For instance, the same flatland can be considered an empty space by newly arrived wind power developers while at the same time it can be seen as an important gathering point by reindeer herders belonging to Sami communities living in the area for centuries. Furthermore, it is possible to separate space in multiple geographical layers and this process helps in recognizing the assets, trade-offs and processes shaping locations. In this way the localisation process is based on a more solid multi-dimension framework highlighting multiple geographical information at the same time. Finally, power geometries among these layers are incorporated through the selection of a series of objectives and criteria to promote conflict mediation, (e.g. inclusion of tourism and reindeer herding) as well as through the weighing process.

Furthermore, by adopting a relational approach, it is possible to embrace the union of social, cultural, economic, political, and ecological processes developed over multiple spatial and chronological scales, which constitute fundamental elements of energy geography as shown by Calvert (2016). In fact, through this spatial MCDA disparate geographical sub-disciplines are contemporarily applied. By investigating wind speeds and topographical aspects, the domain of physical geography is applied. By investigating the built environment, tourism and reindeer herding the domain of human geography is applied. By investigating nature protection, the domain of natural resource geography is applied. Then on an overarching level, GIS and cartography are used to implement and combine all of these different aspects to produce the results of the analysis. The flexibility and transdisciplinary nature of energy geographies is consequently enforced and the intrinsic nature of wind energy can be better understood.

5.1.2 Embracing proactive land-use planning

The implementation of a spatial MCDA allows to proactively approach land-use planning for renewable energy. The implications of renewable energy production are not analyzed on an ad hoc basis and it is possible to carry out an early identification of sites to host renewable energy projects promoted by national energy policies. As in many other cases, spatial MCDA is effective in localizing suitable areas for wind power development and is a suitable method for this goal.

The identification of suitable locations in Kiruna Municipality can be considered helpful for public authorities as argued by Cope, Hills, & James (1984). In fact, the Municipality of Kiruna, can benefit from this approach by clearly pinpointing its intentions concerning wind power in an early stage of the planning process; thus reducing the risk of contestations and conflicts with local stakeholders, possibly resulting in land-use issues and legal appeals. Furthermore, by identifying areas which are actually suitable for wind power development, the County Administration Board of Norrbotten, as representative of national interests, would gain advantages since could promote more easily wind power development steered by policies and targets. Also wind power developers can effectively gain advantages from having to choose from since they would avoid dealing with a complex localisation process. Finally the inclusion of stakeholders’ planning views through scenarios, allows the application of energy justice; thus possibly reducing injustice and inequality in the planning process generated by lack of participation as argued by Sovacool & Dworkin (2014)
Lastly, as argued by Pasqualetti (1990) it is relevant to consider that no matter, how well the localisation process is developed, it is necessary to cast utopian aspirations. There will be always tension between development and maintenance of the status quo. Furthermore, by having to deal with confined geographical spaces and resources, the total compatibility of different land uses without any trade-off is highly unlikely. Despite of its extremely large extension, it might be tricky to find locations that actually do not interfere with the many different land-use interests of Kiruna Municipality. Nevertheless, the framework developed by this spatial MCDA can help to deal with such issues in a more structured manner, possibly supporting the achievement of compromises.

5.2 Wind power in Kiruna Municipality
5.2.1 Planning constraints and criteria
The chosen constraints limit feasibility to ≈ 10% of the territory of Kiruna Municipality. Consequently, already from the first step of the spatial MCDA it is possible to observe that there are “limited” possibilities for wind power development even though Kiruna is the largest Municipality in Sweden by land area. Insufficient wind speeds concur the most in reducing possibility for wind power development; this finding is in-line with previous GIS studies over Sweden (Siyal et al., 2015; Siyal et al., 2016) which assesses how wind speed is a crucial factor in steering wind power localisation. Obviously, without wind it is not possible to develop wind power projects.

Furthermore, areas of interest for defence exclude large parts of the Municipality from the localisation process. In line with the findings of Lindgren et al. (2013) defence represent a strong hinder to wind power development in Sweden. However, military have an exclusionary character for many other land-use interest and consequentially might be suitable locations for wind power development to avoid further impacts. The actual degree of disturbance from turbines should be assessed since it might be possible that if placed in certain parts of the areas of interest for defence, wind power development would not be detrimental. However the confidentiality of information concerning land-use of areas of interest for defence and the priority ensured by the Environmental Code are hindering factors and it might be argued that wind power development should take place elsewhere to avoid endangering national security.

Because of low population density and scarce urbanization in Kiruna Municipality, maintaining a safety distance from buildings does not represent a strong hinder to wind power development. It might be even considered to extend the 800 m buffer to 1000 m to reduce chances of noise and shadow annoyance and to soften possible claims about the intruding character of wind turbines. In addition, it might be possible to establish a stronger protection buffer for inhabited places. On one hand, low degree of urbanization in Kiruna Municipality can be considered as a “blessing” for the siting of wind turbines. On the other hand, it represents a “curse” since limited roads and electric grids dramatically reduce the possibility for wind power in light of the high economic costs associated with the development of these infrastructures as shown by Wizelius (2015). The current grid covers only a small fraction of the territory and this is justified by the low population density and degree of urbanization of the Municipality. Grid development might increase possibilities for wind power development in Kiruna. However due to the high costs associated to grid
strengthening, it is unlikely to observe such development only because of wind power expansion. Kiruna is not experiencing a growth phase, which might justify major infrastructural investments, such as the ones that occurred to support the mining industry during the 20th century as shown by Granås (2012). If mining would be expanded in more remote locations then it might hypothesized that electric grids would be developed upgraded to support this energy intensive sector. Without major infrastructural investments, the costs to connect wind farms to the grid would rely on wind power developers and in some cases, the large distances to cover might be discouraging. On the other hand, roads do not represent such a strong constraint. In fact, more than public roads, a high number of private roads is developed, even in more remote areas of the Municipality. The possibility of using, upgrading or extending these roads to construct and access wind power projects would be relevant for potential wind power developers as argued by Wizelius (2007).

Kiruna Municipality covers a territory, which is organized according to another territorial system. In fact, municipal borders are drawn over herding areas of different Sami communities. Consequently the high coverage of area of interest for reindeer herding can be linked to the consideration that, in a Sami perspective, land has the right to be fully allocated to this sector. Localising areas suitable for wind power development is a complex and delicate matter when considering possible land-use conflicts with reindeer herding as shown by Lawrence (2014). If on one hand development is naturally seek and justified, it is also relevant to consider that this should not be carried out on the shoulder of Sami communities, which despite the rights they are entitled to, are often poorly represented and respected in planning issues as argued by Lawrence (2014). To favour wind power implementation in Kiruna Municipality, Sami communities should be consulted and a constructive dialogue is required. Indeed, further research to assess the actual long-term impacts of wind farms on reindeer herding could support better land use planning.

As shown, areas of national interest for undisturbed mountainous landscape cover a large portion of Kiruna Municipality. This represent a strong limiting condition for wind power development because of the strong protection status granted to these areas by the Environmental Code. Furthermore, it should be considered the potential impact form wind turbines located outside of these areas since they would alter landscape fruition. This argument is also valid for areas of national interest for tourism and outdoor recreation. In mountainous areas, the implementation of wind power might be particularly complicated, while the large availability of forested landscapes, rivers and lakes might not be considered detrimental factors as shown by Hörnsten (2002) and Bodèn (2009)

If on one hand national parks cover a limited portion of Kiruna Municipality, on the other hand there are large areas classified as nature reserves or Natura 2000 areas discouraging wind power development. However, it is relevant to underline how the Environmental Code only forbids development in such areas if this would clash with the single objective established for protected areas as argued by the Swedish EPA (2011). For instance, for Natura 2000 area aiming to protect aquatic ecosystems then there might be some possibilities to develop wind power projects However if in light of potential impacts for birds and baths it might be harder to develop wind power projects in Nature 2000 areas established according to the bird an habitat directive. The
implementation of wind power in proximity of such areas or in proximity of protected nature aiming to preserve wetlands should be carefully investigated as argued by Rydell (2012).

5.2.2 Suitable locations
Despite of the constraints and the mostly restrictive character of the criteria, it is possible to localise 380 Km² under the “Baseline” and “Green road” scenarios and 190 Km² under the “Highway” scenario for wind power development. However, the minimum permissible area for onshore wind power set by Electricity Bidding Zone 1 is a crucial factor in determining which of these areas can be actually developed. If on one hand this conditions aims to allow the development of larger and more economically attractive projects, on the other hand it limits the localisation to areas that would have been otherwise suitable, especially in southern Kiruna. Consequently, all of the suitable locations occur in the same area of Kiruna Municipality under the three scenarios applied. This suggests that this area is particularly suitable for wind power development since it was pinpointed despite different planning priorities.

According to these results, there might be better possibilities for wind power development if the best economic and infrastructural conditions are not pursued. The implementation of the only location identified by the “Highway” scenario might be a double-sided coin for wind power developers and stakeholders supporting wind power implementation. As a matter of fact, only few or a single project could be realised in Kiruna Municipality, therefore limiting the expansion of this sector. However, by supporting the development of this location, the best conditions for wind power development would be ensured. On the other hand, the implementation of locations identified by the “Green way” scenario might represent a more inviting solution since more projects could be developed and at the same time possible impacts over protected nature and reindeer herding could be reduced. Nevertheless the production output and the economic costs of such projects might not be extremely attractive for wind power developers. These scenarios seem to pinpoint a planning dilemma. This dilemma entails on the one hand the possibility of developing more areas, with reduced impacts, but at higher costs and on the other hand the possibility of developing less projects, with a higher impact but at a lower cost. Nevertheless it should also considered the cumulative effect played by wind power projects and their require infrastructures. If more projects are developed there are more likely to cause social and environmental impacts.

However, as previously shown, the suitable locations identified do not exclude the possibility of arising land-use issues, due to the proximity to Karesuando, protected nature, areas of national interest for undisturbed mountainous environment, areas of national interest for tourism and outdoor recreation and areas of interest for reindeer herding. The large extension of the identified areas might favour specific micro-siting schemes to reduce possible arising conflicts but further investigations and assessments are indeed required.

5.3 Uncertainties in the localisation process
It is crucial to discuss and review uncertainties that might influence and affect the framework developed by this spatial MCDA. These uncertainties are derived from both limitations determined by the author’s choices and judgment and from technical aspects of the data and methods implemented.
5.3.1 Limitations

Certain land-use aspects are not included within the set of constraints and criteria applied within this spatial MCDA. For instance, areas that might contain potential mineral deposits are not analysed. Because of the importance of this sector in Kiruna and on a national or global level, it might be possible that potential deposits would question wind power development if localised in potentially conflicting areas. Factors concerning soil structure and stability are also not included. Unstable soil might hinder the development of solid foundations for wind turbines and should be therefore carefully assessed. Furthermore, future areas that might established as national parks are not included in the analysis. Consequentially it would be necessary to understand if suitable locations are located within these areas.

A 5 Km buffer applied to avoid interferences to the weather radar in Kiruna; however, the National Board of Housing, Building and Planning (2009) recommends a buffer of 20 Km in case of a large group of turbines. Then the application of the ICAO Annex 14 area as “no-hinder zones” is a precautionary measure but it is possible that hinders to air transportation are not totally dismissed. Then the buffer distance of 500 m from radio masts can reduce the degree of disturbance but it is not totally ensured that detrimental impacts from wind power might not affect telecommunication systems. Consequently, consultations with military, communication and transport agencies should be carried out to verify if effectively such constraints dismiss potential disturbances possibly determined by the localised areas in Kiruna Municipality.

The geo data used within this thesis represent different land uses or geographical phenomena and are selected according to the author’s view on such matters. For instance, in absence of more accurate data, areas of national interest for tourism and outdoor recreation are chosen to reduce impacts on tourism and recreation. These data capture the geographical identity of tourism in Kiruna Municipality according to the author’s personal judgement and it could be argued that they dismiss more specific aspects of the local tourism industry. Furthermore, the choice of applying linear fuzzy functions and the establishment of their values by the author can steer the results of the analysis. The personal judgement of the author also accounts for weight development. Indeed the localisation process might take different paths if carried out according to a different weighing technique or by another analyst.

This spatial MCDA develops a geographical study on an overarching level aiming for macro-siting and not for micro-siting of wind power development. Consequentially landscape issues and visual impacts have been handled with a certain deal of simplification. To ensure a more accurate degree of visual disturbance in case of development within the identified locations it would be necessary to perform accurate visibility and landscape analyses. This is particularly relevant since the identified locations are not far from inhabited places and from areas of national interest for undisturbed mountainous environment. Such analyses cannot be carried extensively in a preliminary stage of wind power planning since they require high computation capacities and specific expertise within the field. In fact, to implement a more accurate visibility analysis in GIS it would be necessary to develop a vegetation canopy based on LIDAR data and more observer points should be identified. However, this implies extremely high computational capacities that can be hardly handled over large territories. The performed visibility analysis is also steered by a limited range of 10 Km
and it’s carried out towards a specific direction and this might bias the actual degree of visibility.

Setting the threshold of the suitability index to 0.5 is also an arbitrary choice of the author, even though supported by a previous spatial MCDA for wind power development developed carried out by Latinopoulos & Kechagia (2015). By increasing or decreasing this threshold, it is possible to alter the requirements to define locations as suitable or unsuitable. Indeed many localised areas display suitability indexes laying just above of this threshold. Is a location with a suitability index of 0.48 much less suitable than a location with a suitability index of 0.51? Indeed, there is no absolute answer to this question and it is relevant to maintain a certain criticism towards the results of the analysis also in the light of the insights provided by the fuzzy theory presented in this thesis.

5.3.2 Sensitivity analysis and GIS pitfalls
The chosen criteria, as shown by correlation analysis, display on average low degree of correlation. Consequently, this component of the spatial MCDA is not expected to bias the results of the analysis by over representing certain geographical feature. The results analysis carried out display low differences among the scenarios in terms of share of the territory allocated to each suitability class. However, considering the large extension of Kiruna Municipality, these changes can be crucial since even a reduced change can determine the suitability or unsuitability of many squared-kilometres of land. This form of sensitivity analysis does not ensure the robustness of this spatial MCDA on a statistical level. To do so, it should be further elaborated by including for instance Monte Carlo simulation for weight generation. However, the applied form of sensitivity analysis is considered to be sufficient for the aim of the thesis. In fact, the thesis aims to propose a framework suggesting suitable locations to be further investigated and not to determine an exact site for wind power development.

Inaccuracy among the geodata used cannot be dismissed. Furthermore, certain steps of the processing in ArcMap might bias the results of the analysis. In the first place, by converting data from raster format to shape format certain pitfalls can occur. Small polygons can be excluded and contiguous polygons can be divided in separated polygons during the conversion. Furthermore, by converting the final suitability maps from raster format to vector format a certain deal of generalization takes place. Then data with different coordinate systems are used and projected to SWEREF 99 TM. Within the re-projection process, it is possible that the shapes of certain features are altered. This issue is more likely to occur when feature are on the edge of the area of use of the coordinate system. Since Kiruna Municipality borders both Norway and Finland this possibility should not be excluded.
6. Conclusion

This concluding chapter summarizes the major findings and provides a series of considerations on planning implications, policy recommendations and further research concerning issues touched upon this thesis.

6.1 Main findings

There are limited possibilities for wind power development in Kiruna Municipality. Approximately 90% of the territory is not feasible for wind power development. In particular, low wind speeds and areas of interest for defence are constraints excluding large areas from wind power localisation. On the contrary, already developed land, national parks, safety distances from infrastructures and hinders to air transportation are not strong constraints to wind power development. Constraints maps show in an early stage that areas such the ones surrounding Abisko and Kiruna do not provide good conditions for wind power development since they entail many overlapping land-use interests. Among the feasible areas, it is particularly complex to fulfil good suitability when considering criteria such as to reduce impacts on reindeer herding, areas of interest for reindeer herding or undisturbed mountainous environment and that have an adequate distance from existing electric grids. These are the most limiting conditions that determine suitability for wind power development. On the contrary it is less difficult to identify locations to avoid protected nature and to avoid landscape intrusion terms of visibility from major settlements and avoidance of cultural landscape. Different scenarios regulate these planning criteria. The “Baseline” scenario assumes that planning criteria have the same importance within wind power localisation. The “Green road” scenario supports wind power localisation to limit social and environmental impacts. The “Highway” scenario supports wind power localisation to find the best economic and infrastructural conditions. According to these scenarios, suitable areas for wind power development can be mainly found in the northeastern part of Kiruna Municipality. Within this area, locations, with a suitability index higher than 0.5 and a surface of at least 5 Km² are found. Under the different scenarios, these locations are located in the same area, in proximity of the inhabited place of Karesuando. Consequently this area might be considered the most suitable for wind power development since it is pinpointed by different planning approaches. The scenario which displays highest suitability for wind power is the “Green road” since it provides a discrete amount of suitable location characterized by higher suitability indexes. On the contrary the scenario that displays lowest suitability is the “Highway”, since it provides only one suitable location. Nevertheless, opposing land-use interests are present in this area and should be therefore carefully assessed by specific investigations.

6.2 Planning implications and policy recommendations

This spatial MCDA incorporates different land-use interests of Kiruna Municipality. Nevertheless, consultations and participatory planning should be implemented to ensure that the identified locations are actually suitable for different stakeholders. Consequently, to actively propose and engage in a constructive planning dialogue concerning wind power development, local residents and interest groups, Sami communities, wind power developers, military, telecommunication and transport agencies as well as County Administration Board of Norrbotten should be consulted. In addition, the identified locations lie in proximity of the Finnish border. In case of interest in developing larger scale projects, consultations should be extended to Finnish
authorities and stakeholders. More detailed studies and investigations should be also carried out to ensure the suitability of the identified locations in detail. This is particularly relevant since these locations lies in proximity of inhabited places and areas of national interest for undisturbed mountainous environment (thus advocating more detailed visibility and landscape analysis) and protected nature (thus advocating environmental impacts assessments). Furthermore, the actual capacity of the roads and electric grids should be assessed to identify development possibilities. By including scenarios it is advocated that local decision makers should approach planning by focusing also on past and future and not only current issues. The localisation of wind power should be therefore framed within a more holistic approach, especially in a municipality such as Kiruna. Wind power planning in Kiruna Municipality is tied to wider planning issues and cannot be isolated. In this case, the inclusion of stakeholders’ preferences is individually carried out by the author. However, it would be extremely valuable to include the actual preferences of Kiruna’s stakeholders. The framework developed should be sent out to the inhabitants of Kiruna and other stakeholders to include their opinion on the matter of wind power development. This could be carried out through public meetings and consultations. However, participation and engagement in such occasions might be difficult to obtain. A fruitful idea could be to implement this framework in an open source WebGIS that would allow the anonymous inclusion of personal views. A series of policy recommendations can be established from this thesis:

- Wind power planning should not be carried out as a standing alone process but should be integrated within wider discourses on past, current and future development as well as with local land-use interests.

- The integration of GIS and multi-criteria decision analysis offers a solid framework and can be successfully applied on a municipal level in Sweden to implement a proactive land-use approach for the localisation of areas suitable for wind power development.

- Consultations with local stakeholders and specific investigations are required once that suitable locations for wind power are identified since an overarching localisation process does not entirely ensure local acceptance and specific feasibility issues.

6.3 Further research
The spatial MCDA applied in this thesis underline certain research gaps. In particular, long terms impacts of wind power over reindeer herding and tourism should be assessed with a more systematic approach and with a focus on northern Sweden. This thesis adopts linear fuzzy functions to standardize the chosen criteria. It might be possible to investigate how different fuzzy functions would alter the output of the standardization process. Furthermore, the use of other techniques in order to develop weights could provide useful insights on how the results are influenced by the chosen approach. It might be possible to carry out consultations and surveys with planning stakeholders in order to incorporate external judgment to weight development. In addition, statistical analyses (i.e. Monte Carlo simulations) could be performed to test and compare the outputs of different weightings. Lastly, the application of spatial MCDA in other Swedish municipalities could provide further insights on the suitability of this technique for wind power localisation on a local level. In addition, in case of municipalities hosting areas of national interest for wind power or wind farms, it could be possible to verify if these areas and projects are suitable according to other localisation techniques.
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Appendix

Appendix 1: Fuzzy functions
Appendix 2: Scenarios descriptions

The “Green Road”

Environmental degradation and inequality contribute to an ideological shift towards more sustainable values. Politics focus on enforcing green policy goals, both through incentives and by criminalizing environmentally, damaging activities and a more sustainable path is gradually taken in society. As a result of this shift, climate changed is partially tackled: sub-arctic regions warm only by 2ºC before stabilizing. This focus on environmental preservation leads to careful management of ecosystems. Furthermore, forestry becomes the major primary industry and it its predominance is strengthened by the necessity to provide carbon-storage to mitigate climate change and to produce biofuels to supply local energy demand, which is otherwise served by small scale biogas, wind and hydropower plants. Growing forests is encouraged since, on a political level, local decision-making powers are strengthened and municipalities have a stronger hand in the management of natural resources. Circular economies are strengthened and recycling is prioritized over extraction of raw materials. Consequently few productive mines remain in operation. There is also a strong focus on favouring locally produced goods or ethically sourced imports. The efforts towards preservation, recycle and reduction of consumption lead several pockets of society to accept lower salaries and to seek higher self-sufficiency livelihoods by remaining in rural areas. The rate of urbanization slows down in all of northern Fennoscandia, because of reduced out-migration from smaller municipalities and increased in-migration by people who seek a rural lifestyle. The permanence in these areas is also favoured by improved IT that support better educational and employment opportunities, since nature-based industries become more reliant on technology and need qualified professionals. Despite some in-migration, communities continue to face an ageing population requiring a heavy burden of caretaking (Nilsson et al., 2015, p.8).

The “Highway”

Climate change is exacerbated due to intensive fossil fuel use. Sub-arctic regions experience stronger changes than the global average: temperature increase more than by 2ºC, precipitation patterns are altered, the snow season is shorter and extreme weather events occur. These changes have harsh impacts. Icing events make reindeer herding difficult and there is a need for additional fodder. Tourism increases, as people increasingly look north for winter tourism when Alpine destinations experience less snow; however in increasingly warm and shorter winters, snow disappears more suddenly. Despite of global issues linked to climate change, economic growth continue at high rates. Consequently, global, national and local demands for resources and energy increases and sub-arctic regions become more and more attractive. Investments and infrastructure development is supported by national governments to gain access to resources and energy. Mining grows and new jobs are created through complementary industries, which are located in proximity of large scale wind and hydropower plants aiming to take advantage of the best available resources. Resource extraction and energy production are prioritized, but this increase environmental and health risks as well as generating land-use conflicts. Migration of workers and higher educated people is supported by new job opportunities. Population grows along with local healthcare, transportation and education grow along. In addition companies invest part of their revenues in local development. In light of the difficult conditions for herding and other job opportunities, new generations of Sami seek different types of lifestyle and reindeer herding as a livelihood declines. Changes in demography and population lead to a partial reorientation towards the value given to ecosystem services; certain activates remain popular but landscape fruition changes (Nilsson et al., 2015, p.9).
## Appendix 3: Geodata Constraints

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<tr>
<th>Constraint</th>
<th>Data-description</th>
<th>Source</th>
<th>Format</th>
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<th>Coordinate system</th>
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<td>Areas of national interest for defence</td>
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## Appendix 4: Geodata Criteria

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### Appendix 5: Weighting matrixes

**Scenario 1: Baseline**

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