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SPATIAL MULTICRITERIA DECISION ANALYSIS FOR SITING OF ON-SHORE WIND POWER IN KEMIÖNSAARI

MSc Thesis

Key words: Analytic hierarchy process, geographic information, multicriteria decision analysis, wind power

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OKSMAN, SONJA: Spatial multicriteria decision analysis for the siting of on-shore wind power in Kemiönsaari

MSc thesis, 134 p., 6 appendices 10 p.
40 ECTS
Geography
November 2012

Wind power is a low-carbon energy production form that reduces the dependence of society on fossil fuels. Finland has adopted wind energy production into its climate change mitigation policy, and that has lead to changes in legislation, guidelines, regional wind power areas allocation and establishing a feed-in tariff. Wind power production has indeed boosted in Finland after two decades of relatively slow growth, for instance from 2010 to 2011 wind energy production increased with 64 %, but there is still a long way to the national goal of 6 TWh by 2020.

This thesis introduces a GIS-based decision-support methodology for the preliminary identification of suitable areas for wind energy production including estimation of their level of risk. The goal of this study was to define the least risky places for wind energy development within Kemiönsaari municipality in Southwest Finland. Spatial multicriteria decision analysis (SMCDA) has been used for searching suitable wind power areas along with many other location-allocation problems. SMCDA scrutinizes complex ill-structured decision problems in GIS environment using constraints and evaluation criteria, which are aggregated using weighted linear combination (WLC). Weights for the evaluation criteria were acquired using analytic hierarchy process (AHP) with nine expert interviews. Subsequently, feasible alternatives were ranked in order to provide a recommendation and finally, a sensitivity analysis was conducted for the determination of recommendation robustness.

The first study aim was to scrutinize the suitability and necessity of existing data for this SMCDA study. Most of the available data sets were of sufficient resolution and quality. Input data necessity was evaluated qualitatively for each data set based on e.g. constraint coverage and attribute weights. Attribute quality was estimated mainly qualitatively by attribute comprehensiveness, operationality, measurability, completeness, decomposability, minimality and redundancy. The most significant quality issue was redundancy as interdependencies are not tolerated by WLC and AHP does not include measures to detect them. The third aim was to define the least risky areas for wind power development within the study area. The two highest ranking areas were Nordanå-Lövböle and Påvalsby followed by Helgeboda, Degerdal, Pungböle, Björkboda, and Östanå-Labböle. The fourth aim was to assess the recommendation reliability, and the top-ranking two areas proved robust whereas the other ones were more sensitive.

Key words: Analytic hierarchy process, geographic information, multicriteria decision analysis, wind power

TURUN YLIOPISTO
Matemaattis-luonnontieteellinen tiedekunta
Maantieteen ja geologian laitos

OKSMAN, SONJA: Spatiaalinen monikriteerianalyysi maatuulivoiman sijoittamisesta Kemiönsaarelle

Pro gradu -tutkielma, 134 s., 11 liites.
40 op
Maantiede
Marraskuu 2012

Tuulivoima on energiantuotantomuoto, jolla on matalat hiilipäästöt ja joka vähentää yhteiskunnan riippuvuutta fossiilisista polttoaineista. Se on suomessa otettu osaksi ilmastonmuutoksen torjuntaa, mikä on johtanut muutoksiin lainsäädännössä, ohjeistuksiin, maakunnallisten tuulivoima-alueiden selvittämiseen sekä syöttötariffin käyttöönottoon. Tuulivoimatuotanto onkin Suomessa lisääntynyt voimakkaasti kahden vuosikymmenen suhteellisen hitaan kasvun jälkeen. Esimerkiksi vuosien vuoden 2011 aikana tuulivoiman tuotanto kasvoi 64 % vuodesta 2010, mutta kansallinen 6 TWh tavoite vuoteen 2020 mennessä on vielä kaukana.

Tässä pro gradussa sovelletaan paikkatietopohjaista menetelmää, jolla voidaan alustavasti selvittää tuulivoimatuotannolle soveltuvat alueet ja arvioida niihin kohdistuvien riskien voimakkuutta. Analyysin tavoitteena oli määrittää tuulivoiman kannalta vähäriskisimmät alueet Kemiönsaarella Varsinais-Suomessa. Spatiaalista monikriteerianalyysia (SMCDA) on sovellettu tuulivoima-alueiden etsimiseen monien muiden sijoittumisongelmien ohella. Menetelmä tarkastelee monimuotoisia ja rakenteeltaan vaikeasti määriteltäviä ongelmia rajoittavien ja arvottavien kriteerien avulla paikkatietoympäristössä. Arvottavat kriteerit laskettiin yhteen painotetun lineaarisen kombinaation avulla (WLC), ja painot niihin saatiin analyyttisella hierarkiaprosessilla (AHP) yhdeksän asiantuntijahaastattelun avulla. Seuraavaksi soveltuvat vaihtoehdot laitettiin arvojärjestykseen suosituksen tuottamiseksi, ja lopuksi tehtiin herkkyysanalyysi, jolla selvitettiin suosituksen vakaus.

Tutkimuksen ensimmäinen tavoite oli tarkastella olemassa olevien aineistojen soveltuvuutta ja tarpeellisuutta tähän SMCDA-tutkimukseen. Suurin osa saatavilla olevista aineistoista oli tarpeeksi laadukkaita ja niiden resoluutio oli tarpeeksi korkea. Aineistojen tarpeellisuus arvioitiin aineistokohtaisesti mm. rajoittavien kriteereiden peittoalueen sekä arvottavien kriteereiden saamien painoarvojen perusteella. Toisekseen, attribuuttien eli kriteerien laatu arvioitiin pääosin kvalitatiivisesti sisältöpitoisuuden, toimivuuden, mitattavuuden, kattavuuden, hajotettavuuden, minimaalisuuden ja päällekkäisyyksien perusteella. Merkittävin laatuongelma oli attribuuttien päällekkäisyys, koska WLC ei sitä siedä eikä AHP havaitse. Kolmas tavoite oli määrittää vähiten riskialttiit tuulivoimalle soveltuvat alueet tutkimusalueelta. Kaksi korkeimmalle sijoittuvaa aluetta olivat Nordanå-Lövböle ja Påvalsby, joiden jälkeen sijoittuivat Helgeboda, Degerdal, Pungböle, Björkboda sekä Östanå-Labböle. Neljäs tavoite oli arvioida suosituksen luotettavuutta, ja kaksi parhaiten sijoittuvaa aluetta osoittautuivat vakaiksi, mutta muut mainitut alueet olivat herkempiä.

Asiasanat: analyyttinen hierarkiaprosessi, paikkatieto, monikriteerianalyysi, tuulivoima

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1 Introduction

There is a global concern of anthropogenic climate change and apprehension about how energy availability could be guaranteed in a new energy crisis. This has caused fast growth in wind power production (Kaldellis & Zafirakis 2011). Several nations have adopted wind energy as a means to mitigate climate change as it is renewable and does not cause any direct carbon dioxide emissions. For example, The EU plans to reduce greenhouse gas emissions by 20 % from the levels of 1990 by 2020 (European Commission 2008), and some of the reduction will be achieved by increasing the proportion of renewable energy. According to the European Commission (2008: 17), wind energy will be the fastest growing electricity production sector due to increasing efficiency and number of wind turbines.

Finland has an ambitious target to produce 38 % of its energy using renewable sources by 2020 (MEE 2010). Wind energy production capacity is planned to be increased up to 2000 MW by 2020, which means that the annual energy production rate would be about 6 TWh (MEE 2010). Some drastic measures are necessary for the achievement of this goal as in 2011 the total wind energy production was only 481 GWh (VTT 2012a).

Finland has introduced new policies and economic tools since the 6 TWh aim was announced. A feed-in tariff guarantees 83.5 €/MWh price for the first installed 2500 MW of wind power for 12 years (The Act on Production Subsidy… 6 & 23 § 1396/2010), and National Land-Use Guidelines impose that regional land use plans must indicate suitable wind power development locations (Finnish Government 2008). In addition, recent changes in the Land Use and Building Act has made the confusing and non-uniform statutory land use planning system more comprehensible as described by Jääskeläinen (2010): now construction license for wind power plants can be admitted based on master plan (see LUBA 77 § 132/1999), which can replace the previously used local master plan. Local master plan is a combined effort by the municipality and project developer. Wind power master plan designates locations to each wind turbine and related infrastructure. Together with the national guidelines for wind energy planning (see ME 2012), these improvements have recently made project development easier.

Wind energy is generally accepted as a carbon free form of energy production. Nevertheless, not all places are suitable for wind energy production, and often it faces opposition from environmentalists and public. The NIMBY phenomenon, acronym for “Not In My Back Yard”, is a common issue in wind energy development. For wind energy NIMBY means that in principle people are not against wind energy, they may even support it, but they are not willing to have wind turbines in their neighborhood. Wind energy faces stronger NIMBY than other energy production forms because of its visibility, although other arguments are used against wind power as well (Pasqualetti et al. 2002: 178).

The study area is located in Southwestern Finland, Kemiönsaari. The area was selected because the Regional Council has recognized wind energy potential of the area (Klap et al. 2011) and the Egentliga Finlands Energi (efe), which is the co-operation company for this thesis, has concentrated its development efforts there. Some local inhabitants and regular visitors in Kemiönsaari have concerns about wind energy development on the area. The public is worried about for instance effect on landscape, flickering, audible and low-frequency noise, nature, birds, bats, health, Finnish Defence Forces and tourism (ELY 2012, Rouhiainen 2012). Landscape impact is the most critical and widespread influence wind energy production (Wekman 2006). Apart from human impact, wind turbines may cause direct bird and bat death, habitat change and possibly changes in animal behavior. In order to tackle these concerns, it is necessary to conduct a variety of detailed studies and carefully consider the potential influence of wind parks on nature and humans. Many of these issues can be mitigated by carefully considering location of wind parks and individual turbines.

Wind power production suitability estimations can begin from the local perspective: often land-owners contact wind energy actors and offer their properties for project development. After this the project developer gradually estimates viability of the area using both internal and external expertise. Spatial multicriteria decision analysis (SMCDA) is a more systematic approach for finding the best locations. It is quantitative and produces comparable estimations on site suitability over large areas. Tegou et al. (2010) have conducted a SMCDA for the Greek island of Lesvos, and Baban and Parry (2001) used SMCDA already 10 years ago for finding wind power locations. In this study, a SMCDA method described for instance by Malczewski (1999), is implemented on a case study attempting to locate the least risky wind energy production sites in Kemiönsaari. SMCDA includes defining a set of attributes, which are elements that affect decision-making. Each alternative, in this case 25 m cell, receives a desirability value for each attribute. Finally, these values are aggregated and the least risky locations can be recommended based on the decision outcome. The analysis is conducted in ArcGIS 10 software environment.

The goal of this thesis is to apply a GIS-based model for the identification of least risky locations for wind power development. The risk for a project not becoming realized is estimated based on existing spatial data. The study aims are:

1. Estimating data suitability and necessity for the analysis. Suitability is related to data quality and necessity how the data set was used in the analysis.

2. Estimating the quality of attributes using quality criteria described by Malczewski (1999).
3. Defining least risky areas for wind power development within the study area.
4. Estimating reliability of the resulting recommendation with the means of sensitivity analysis.

This GIS method is proposed to be employed before initiating actual project development and investing on studies and turbines. It should be noted that by no means is this study supposed to replace detailed surveys, it merely points out places where further investigations may be directed at. Detailed studies should always take preference over the preliminary study. However, this study includes expert opinions and provides recommendations, which detailed surveys often are not able to do.

2 Study area: Kemiönsaari

Kemiönsaari main island is the largest island in the Southwest Finland with its area of 524 km^2 (Statistics Finland 2001). Land surface of the municipality covers 687 km^2 (The Regional Council of Southwest Finland 2010). The municipality is located in the inner archipelago of the Southwestern Archipelago about 40 km southeast from Turku. Only a narrow strait crossed by two bridges separates the main island from the continental Finland. The study area is typical inner archipelagic environment with narrow and sheltered inlets, yet inner areas of the island resemble continental environment with cultivated breach valleys and forested ridges (Klap et al. 2011). Agricultural and forestry landscape on the main island is complemented by numerous small villages. Kemiönsaari has approximately 7200 inhabitants (The Regional Council of Southwest Finland 2010) and more than 10 000 summer inhabitants, which use 4500 summer houses (Kemiönsaari 2012a). In fact, there are already three wind turbines installed with the combined production capacity of 6 MW in Högsåra, which is one of the small inhabited islands within the municipality (Turku Energia 2008).

Geologically the Southwestern Archipelago is a part of the very old Fennoscandian shield. It was formed 4 600–570 millions of years ago during the Precambrian (Turunen 2007). On the contrary, soil of the archipelago is rather young: when the last glaciation ended 10 000 years ago, glacial deposits were formed (Eklund 2007). Since then, bedrock has risen gradually from the sea, and this isostatic uplift continues even today (Hakala 2007). Due to its glacial history, the archipelago is characterized by glacially eroded bedrock and glacial deposits such as end moraines and eskers (Eklund 2007).

Kemiönsaari has some significant natural and cultural values and protected areas. The Archipelago National Park extends to the southern parts of the municipality, and there are also several nature protection and Natura 2000 areas. In addition, the municipality has significant landscape areas, traditional landscapes and FINIBA areas for the protection of bird environments. Kemiönsaari has a colorful history of Viking trade in Rosala (Rosala Viking Centre 2011) and archaeological remains from Stone Age and Iron Age (NBA 2010a).

Kemiönsaari was selected as the study area because this thesis is done in co-operation with efe, which is developing wind energy there. Efe focuses on wind energy development in cold climate and forested areas (efe 2012). There are also other companies, for example Taaleritehdas and Saba Wind developing projects in the municipality. In addition, Kemiönsaari has a strategy to become self-sufficient in energy production (Kemiönsaari

2011) and to increase the share of renewable energy (Kemiönsaari 2010). Supportive authorities, sufficient wind conditions, existing electric grid and sparse inhabitation along with other favorable factors make Kemiönsaari suitable for wind energy production.

The Regional Council of Southwest Finland has already found several locations within the main island suitable for industrial megawatt-scale wind energy development (Klap et al. 2011). They found six areas that received a wind power mark in the phased regional land use plan draft (Regional Council of Southwest Finland 2012a). The areal mark, which is reserved only for large parks that can accommodate more than 10 turbines, was given to Nordanå-Lövböle and Påvalsby (see appendix V for place name map). For Nordanå-Lövböle, a 31 turbine park is being planned by efe, and there have also been discussions on wind energy in Påvalsby (Venho 2012).

The Regional Council's wind power point mark for places that can accommodate less than ten turbines was given to Helgeboda, Degerdal, Pungböle, and Östanå-Labböle. Of these, Degerdal is the only one with contemporary project development. On the southern part of Degerdal is located the five-turbine Gräsböle project, which is also developed by efe. Pungböle and Helgeboda are Northeast and west from Gräsböle, and they have no published project plans. Östanå-Labböle is less attractive to potential project developers as Misskärr wind power project is being planned on the main wind direction.

There are also several project areas that did not receive any mark in the regional plan draft. Taaleritehdas is developing a nine turbine project in Misskärr (Kemiönsaaren kunta 2012) and it is in the statutory land use planning stage. There are also two smaller projects in Stusnäs and Kasnäs planned by Sabawind (Kemiönsaari 2012b). Statutory land use planning has been initiated for them as well. In addition, Konstsamfundet is planning a wind park of 20 turbines between Dalsbruk and Misskärr (Burman & Forsell 2012). This area was excluded from the regional plan draft due to impacts on birds (Regional Council of Southwest Finland 2011b). Furthermore, there already is a park of 3 2MW turbines in operation in Högsåra. Altogether, there are eleven areas developers are already interested in or determined as potential areas in the regional plan draft. These areas provide background for evaluating functionality of this method. The wind energy study database (Regional Council of Southwest Finland 2012c) provides reference for those areas that are not considered attractive and why.

The study area includes majority of the land areas of the municipality of Kemiönsaari, which consist of one main island and several smaller ones. It encompasses only those islands that have electricity and are accessible by ferry or bridges. Sea areas have been excluded because off-shore wind power requirements are different from on-shore requirements, and it is not practical to consider the both within this thesis. The study area consists of 22 islands ranging from 52140 to 4.8 hectares in size. Study area size is 58687 ha or 587 square kilometers, and it is divided into 938939 25 meters cells, each of them considered an alternative. The study area is depicted in Figure 1.

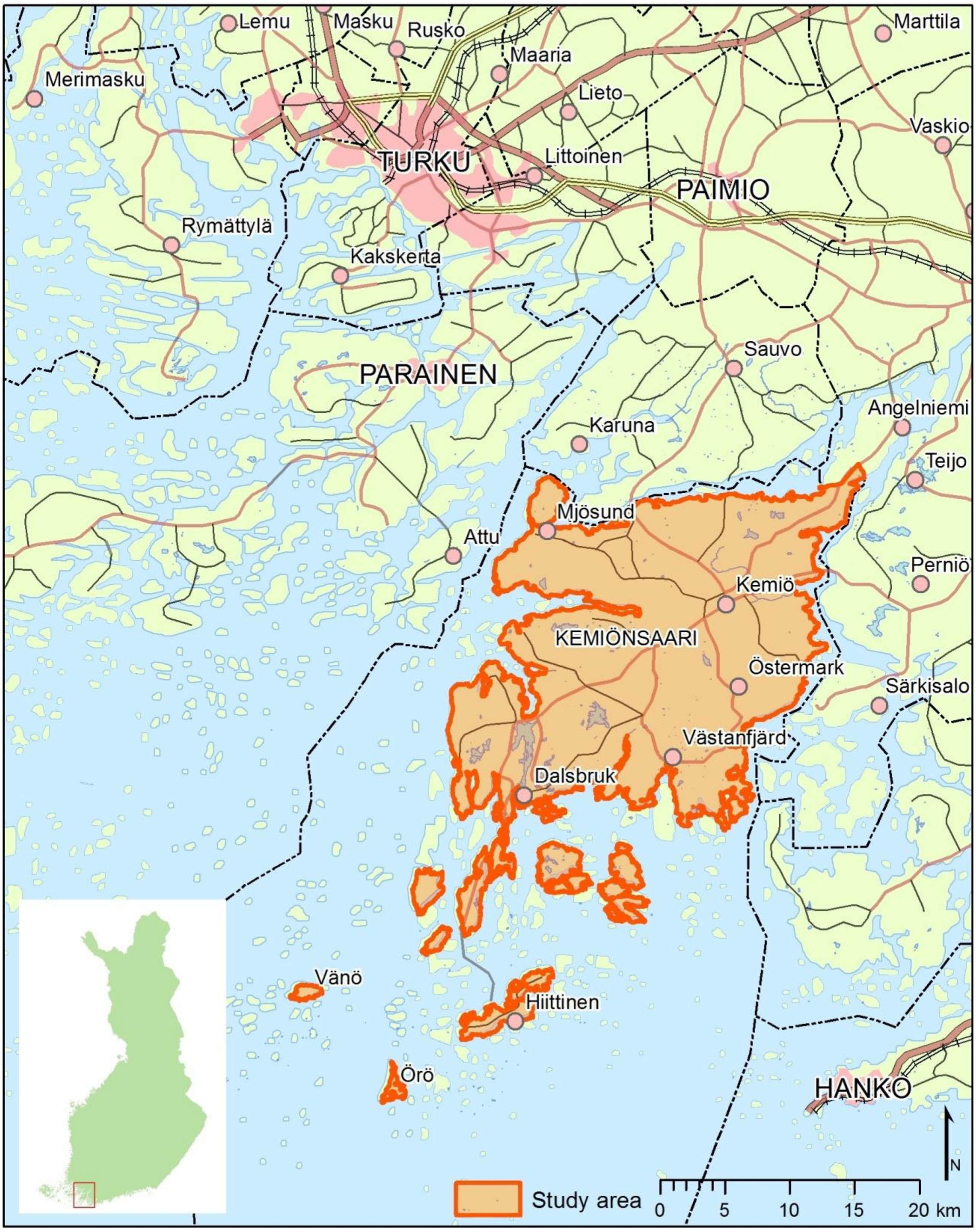

Figure 1. The study area consists of 22 islands. Background map data source: NLS Yleiskartta 1:1 000 000 2011.

3 Wind power in Finland

3.1 History and contemporary situation of wind energy

Wind energy has been used all over the world for different purposes. The earliest simple applications date thousands of years back. The first actual steps in utilizing wind energy took place in the Middle East about 2200 years ago with vertical axis windmills, which appeared in Europe during the medieval era. Those were commonly used for grinding crops. In the 1800's and 1900's, wind mills were used for water pumping as well. In 1888, the first electricity producing 12 kW wind turbine was installed in Cleveland, Ohio. In Europe, wind electricity production initiated during the world wars with kW-scale turbines. The oil crises in USA in 1973 caused a boost for wind energy, and in the 80's an enormous park with 16 000 turbines between 20 and 350 kW was established in California. During the 90's, the emphasis of new wind energy development shifted towards Europe. Nowadays the bulk of wind energy is produced in Europe while the USA and swiftly rising Asia are almost equally large producers. (Kaldellis & Zafirakis 2011.)

In Finland, the first wind mill was reported from 1463 nearby Turku. In Southwest Finland, there were already about 400 windmills in the end of 1500's but to the Eastern Finland they did not arrive until 1800's. In the 1700's wind mills were not used only for graining, but also for operating sawmills and water pumping. (FWPA 2012e.)

The first experimental electricity producing 300 kW wind turbine in Finland was constructed in Kopparnäs in 1986 (VTT 2005: 9). Industrial scale wind power production in Finland was initiated in 1991 when the first wind park consisting of four 200 kW turbines was built in Korsnäs (FWPA 2012c). After this Finland's wind energy production has increased as the number of turbines and their capacity has grown. In 2011, the total capacity was 199 MW with 131 turbines producing 481 GWh of electricity (VTT 2012a). The amount of energy produced can be illustrated by the following example. Figure 2 presents the growth of wind power production in Finland. The typical electricity consumption in a Finnish 120 m^2 house with four residents and other than electrical heating system is 7 kWh a year (Vattenfall 2012). Energy production of 2011, 481 GWh, would cover the consumption of 68 700 households. For comparison, the total electricity consumption of Turku, a city of about 179 000 inhabitants, in 2011 was 1527 GWh, of which housing and agriculture used 581 GWh (Finnish Energy Industries 2012a).

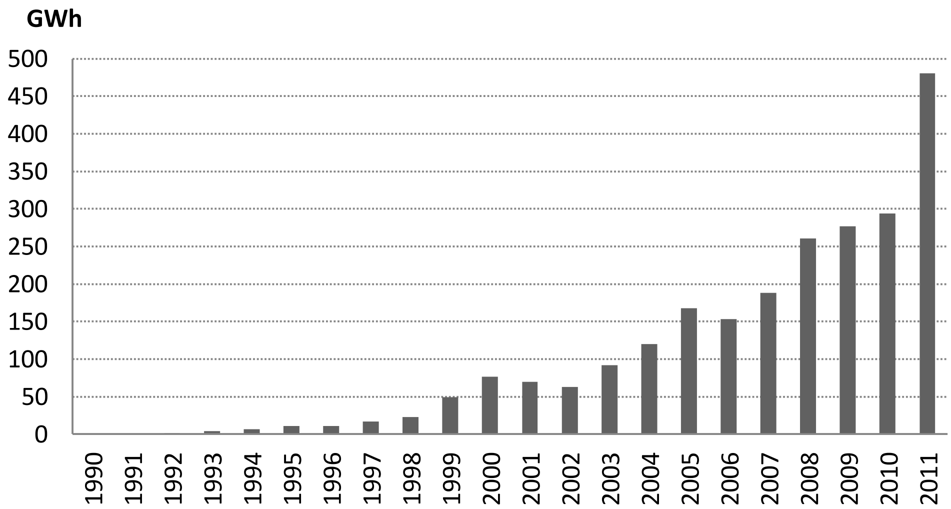

Figure 2. Wind energy production in Finland based on STV (2010), Stenberg & Holttinen (2011) and VTT (2012a).

In absolute terms, the increase of wind energy production has been significant in the national scale. Only in 2010, 17 new turbines of combined capacity of 50 MW were taken into use (Stenberg & Holttinen 2011). This is probably the cause for the rapid increase of wind energy production in 2011. Nevertheless, during 2011 only 3 MW increase in capacity occurred (VTT 2012a) possibly due to delays in tariff system and significant clampdowns in wind energy planning guidelines (FWPA 2012g). Despite of a slow year, it seems that in 2012 there will be again good rise in the capacity construction figures: during the first half of the year, already 21 MW have been constructed (VTT 2012a).

In EWEA statistics (2012) for 2011, the wind share of total electricity consumption was 0.5 % in Finland. In this statistics, Finland was dwarfed by for instance Denmark with 25.9 % share, Portugal with 15.6 % and Estonia, where 4.4 % of electricity consumption is covered with wind energy. In this European statistics, only Slovakia, Slovenia, and Malta were behind Finland (Figure 3). In order to catch up with the others, Finland has taken up the target of developing 6000 GWh by 2020.

The tools to improve Finnish wind energy production include for instance research, changes to legislation, introducing feed-in tariff and studying reasons for Finland's slow development in wind power production. One of the most significant research efforts has been to produce an interactive Wind Atlas map service describing windiness, production and icing conditions. The first Wind Atlas was produced in 1991, but it was based on measurements from 10–30 meter heights (Laatikainen & Jussila 2008). The new Wind Atlas was published in March 2009 (FMI 2010). In 2010, Swedish and English languages were added to the map service and resolution was improved to 250 m in selected areas (FMI

2010). According to the development manager Bengt Tammelin, there were no similar services of this resolution anywhere in the world at that time (FMI 2010). In March 2012, the service was further improved with the publication of the Icing Atlas (FMI 2012). The contemporary Wind Atlas provides information on 50–400 meters height with up to 250 m horizontal resolution (Finnish Wind Atlas 2012d).

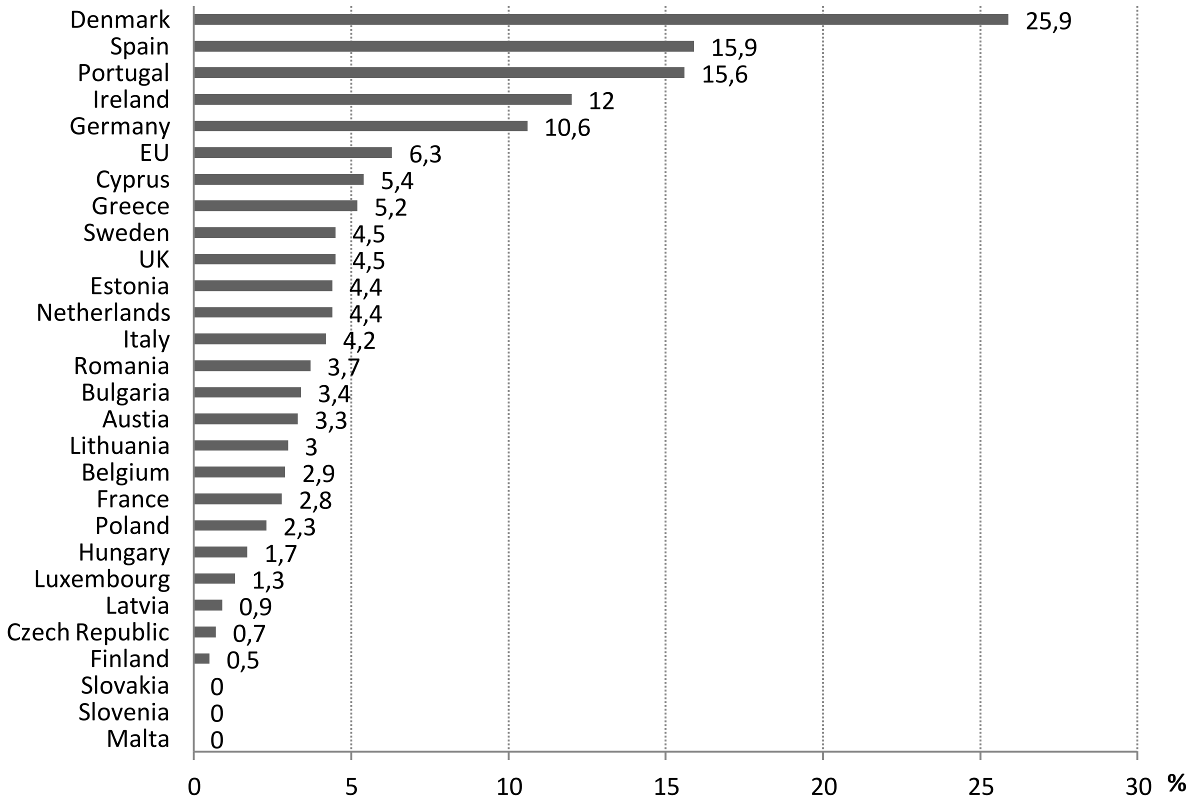

Figure 3. Wind share of total electricity consumption in various European countries in 2011. Adapted from EWEA 2012.

The Finnish statutory land use planning scheme has been changed in the end of last decade in order to encourage wind energy development. In 2008, the Finnish Council of State inserted an obligation for regional councils into the national land use objectives to search the most suitable areas for wind energy production (Finnish Government 2008). The restriction of locating wind turbines to fjeld and coastal areas was removed (Jääskeläinen 2010). Since then the Regional Councils have conducted wind power studies, and now many of them are in the process of adding wind power marks to their regional land use plans. It is yet to be seen how strongly these markings will influence licensing of new wind power projects.

In February 2011, a new paragraph of law was inserted to the Land-Use and Building Act (LUBA). The change simplified wind energy statutory land use planning process by allowing admitting construction license based on local master plan (LUBA 77 § 134/2011). This implicated that no local detailed planning would be necessary anymore. The new paragraph left room for interpretation, and there have been efforts to supplement i by giving guidelines for wind energy planning. This guideline document (ME 2012) that was released by the Ministry of the Environment in the summer 2012, attempts to formulate consistent practices for wind energy statutory land use planning in Finland. In the preface, the Ministry of Environment expressed a wish that these guidelines would encourage wind energy development in Finland but according to the FWPA (2012g), it might have had an opposite impact.

An important encouragement for wind energy development in Finland has been the renewal of subsidy system. The Act on Production Subsidy for Electricity Produced from Renewable Energy Sources, which includes also feed-in tariff for wind-energy, came into effect in 25.3.2011 (MEE 2011). The law guarantees 83.5 €/MWh price for 12 years for the first 2500 MW connected to the grid. Before the tariff, there were investment and tax subsidies, which were insufficient to encourage wind energy development (FWPA 2012b). In Germany and UK, feed-in tariff has proved more efficient than quota and auction mechanisms as it focuses competition on obtaining good sites instead of maximizing profit, and it enables concentration on initial planning instead of financing, and as consequence fewer projects fail in the licensing phase (Butler & Neuhoff 2008).

When the economical barrier was eased, it became apparent that there are also other barriers for wind energy development. In order to reach the 6 TWh aim, these have to be removed. In November 2011, the Ministry of Employment and Economy invited Lauri Tarasti to explore administrative barriers of wind energy development. He returned his report on April 2012, and it included 16 main problems and solution proposals (Tarasti 2012). These include among other things changing the planning guidelines of the Ministry of Environment, combining statutory land use planning and environmental impact assessment (EIA) processes, removing barriers by the Defence Forces and increasing real estate tax in order to improve local acceptability.

In order to encourage wind energy development, substantial efforts have already been made. Finnish legislation and statutory land use planning scheme has gone through changes local authorities are just beginning to learn how to implement. Some administrative barriers by for instance TraFi (Finnish Transport Safety Agency) and Finavia (the former Finnish Civil Aviation Administration) have already been slightly alleviated, but there is still pressure to remove remaining barriers. It is important to continue solving these problems as the effort made so far may not be enough to carry Finnish wind energy production to the 6 TWh goal.

3.2 Typical phases of wind power project development

Phases of wind park development usually include at least land acquisition, preliminary studies, statutory land use planning, EIA for large wind parks, licensing, wind measurements, grid negotiations, geological survey, technical planning, financing, turbine procurement, park design and construction, and finally the start of operation. Depending on the project, it takes several years to go through these phases, which are largely overlapping and may be in different order in different projects. There are no two projects alike, and therefore project development adapts to the purpose.

Somewhat similar pathways of project development are presented by Pöyry (2010) and FWPA (2012f) (Table 1). Pöyry's approach assumes that land-owners contact wind energy companies or start developing projects themselves without conducting thorough analysis in order to compare different location alternatives. FWPA included an additional phase before land acquisition: project development begins with locating suitable areas and comparing them. Both descriptions are correct and suitable for different projects.

Table 1. Comparison of two wind park development pathways.

Pöyry 2010	FWPA 2012f
1. Land acquisition	1. Preliminary studies (comparing several locations)
2. Preliminary studies	2. Finding suitable wind park location
3. Licensing	3. Land-owner negotiations
4. Wind measurements	4. Preliminary negotiations with grid owner and electricity buyer
5. Statutory land use planning	5. Wind measurements
6. Geological studies	6. ELY decision on the necessity of EIA
7. Technical planning and infrastructure construction	7. EIA If necessary
8. Financing	8. Statutory land use planning
9. Turbine acquisition	9. Negotiations with grid owner and electricity buyer
10. Start of operation	10. Licensing
	11. Excavation work
	12. Ordering turbines and construction work

Regional councils and some municipalities have started to provide studies for finding suitable locations. Methodologies vary greatly, but most of the studies employ a combination of GIS analysis and feasibility estimation (e.g. Paakkari 2011, Regional Council of Central Finland 2012), while others utilize also preliminary landscape analysis and expert interviews (e.g. Klap et al. 2011), and some concentrate merely on the feasibility analysis (e.g. Paakkari 2010). The analysis-based approach is becoming more and more popular in Finland due to recent changes in the national land-use guidelines that obligate regional councils to study and point out the most suitable locations for wind energy project planning. In addition, many companies actively search for suitable areas, and consulting companies provide GIS–based services for them as well.

In the beginning of project development, land-owners are contacted and lease-agreements signed. Property owners can be identified from the property register provided by the Finnish National Land Survey (NLS). Land-owners must agree with the plans as expropriation is not allowed for wind energy purposes apart from grid connection (Klap 2012).

Preliminary studies include for instance estimation of windiness, production, preliminary plans of turbine layout, necessary constructions, and external grid connection, as well as analyzing the most essential environmental factors from licensing perspective (Pöyry 2010). If those do not introduce barriers for development and the investment seems profitable, wind measurements and statutory land use planning may be initiated. Parallel to the statutory land use planning, EIA can be initiated. EIA is necessary if the project size is more than 10 turbines or 30 MW (Government decree, 6 § 259/2011). EIA and statutory land use planning require extensive environmental studies. For instance landscape, nature types, traffic impacts and protected species are often surveyed.

Some studies are not required for the EIA but may be beneficial to conduct. For instance, Finnish Meteorological Institute (FMI) radars and data transfer links are sensitive to wind turbines and may cause rejection of construction license application or lead to complaints but studies on them are not always required. When the park layout has been completely determined, Finavia statement and TraFi license for high constructions should be applied for. During the planning procedure, also a military radar study should be initiated if requested by the Defence Command.

EIA and statutory land use planning are parallel processes in Finland. Statutory land use planning guarantees participation and environmental studies also for those projects that do not require EIA. The planning system is hierarchical and guided by the *national land use objectives*, which state that wind turbines should be positioned primarily in groups (Finnish Government 2008: 7). In addition, they state that the best suitable areas for wind power should be indicated in the regional land use planning. The Regional Council of Southwest Finland has initiated this process with a study for locating suitable sites (Klap et al. 2011), and now it is in the process of drafting a phased regional land use plan for wind power. The plan will indicate preferred locations for wind parks but will not exclude areas from small scale development (Regional Council of Southwest Finland 2012a).

Individual wind park planning requires a more detailed land use plan that is drafted at the municipality level. These plans should be in accordance with the higher level land use plans and objectives. The Ministry of Environment guidelines (ME 2012: 27) recommend that maximum 6 turbines should be planned using the light planning procedure of *planning requirement decision*; *local master plan* is necessary larger parks; and *local detailed plan* is used on areas that require very detailed planning such as ports, industrial areas and population centers. These plans define turbine and infrastructure locations and ensure participation and sufficient studies in the local level.

Construction license is admitted based on the land use plan of appropriate level of detail. Therefore studies, surveys, and comparisons of turbine types and infrastructure details are necessary already during the local master planning, and they become increasingly precise as the project proceeds. If necessary, water permit and environmental license are applied along with the construction license after the statutory land use planning. TraFi license determines acceptance from the civil aviation perspective and defines necessary aviation obstruction lighting. A feed-in license with the regional grid owner must be obtained as well.

This thesis concerns the preliminary study phase before initiating statutory land use planning, studies or wind measurements. Other project development phases are only briefly mentioned for context. For further information on overall wind energy project development in Finland, the reader is referred to the national guidelines for wind energy development (ME 2012), wind energy guide (Tuulivoimaopas 2012) and to the FWPA wind energy information website (FWPA 2012f).

3.3 Factors that affect wind power project siting

Wind power project locating is influenced by many different factors. In this study, they have been categorized into three classes: economical, environmental and societal factors. Economical factors include production and costs: production is impacted mainly by wind conditions whereas costs include a variety of factors such as construction of infrastructure and transportation costs. Environmental factors include those impacts that are assessed in the EIA, for instance impact on birds and landscape. Societal factors are a scattered group of aspects related to common practices, licensing and planning, for example potential detrimental impacts on radars and noise emission. The most important factors that can be geographically described are discussed in the following section.

3.3.1 Wind conditions

Firstly, the developer checks wind conditions in the area of interest. Wind speed is the main determining factor of the profitability of wind power, which is why wind power production in Finland is concentrated on the windy coasts (Figure 4). In fact, production is related to wind speed exponentially (FWPA 2012d), which means that even subtle differences in wind speed may be essential from the profitability perspective.

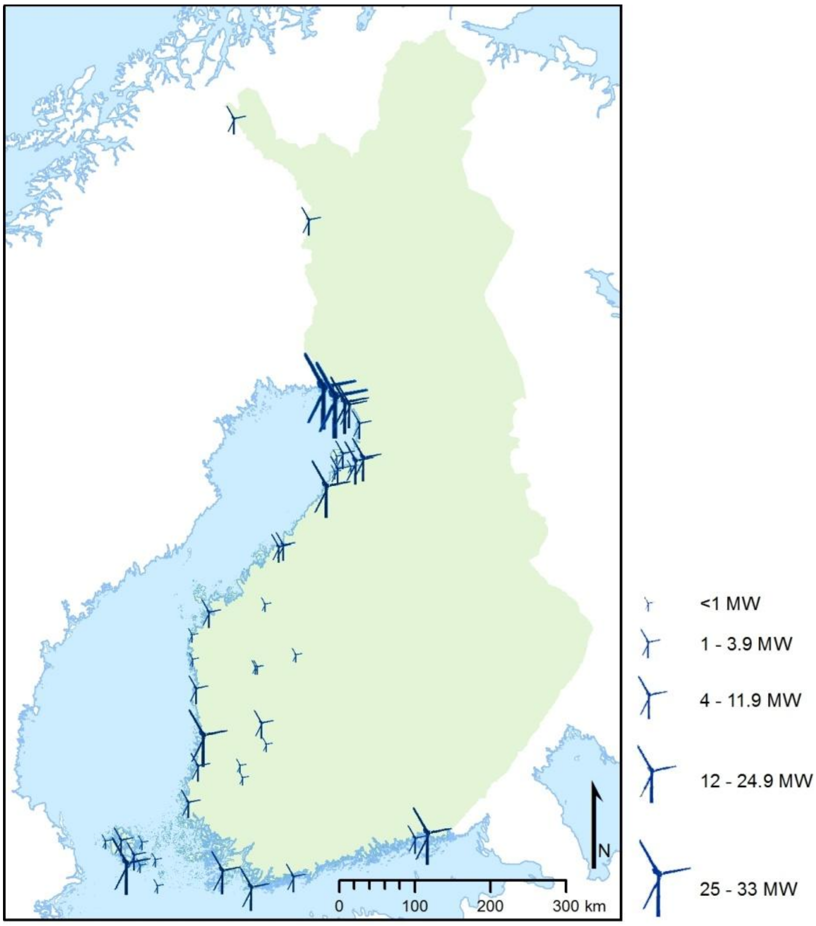

Figure 4. Wind power parks in Finland are often located on coastal areas due to high wind speed. Adapted from VTT 2012b. Background map data source: NLS Yleiskartta 1:1 000 000 2011.

A rule of thumb is that if wind speed is below 6.5 m/s in 100m, an area is not suitable for wind energy development (Klap et al 2011, p. 11). In practice, this threshold is flexible, and for instance low construction cost, large project size as well as turbine design may lower it. For example, in the wind power study for the Central Finland, the threshold value was 6.3 m/s (Paakkari 2011). It is probable that due to efficiency improvements of next generation wind turbines the threshold wind speed will soon decrease to 6 m/s (Klap et al 2011), which was used as a minimal value for the wind energy study for Pohjois-Savo (Regional Council of Pohjois-Savo 2010).

In Finland, the best source for preliminary wind information is the Finnish Wind Atlas (see Finnish Wind Atlas 2012d) that was published in 2009 by the FMI. Wind Atlas is a website and interactive map service that describes wind speed and directions, production estimations as well as icing conditions in 250 m or 2500 m resolution over Finland in several heights between 50 and 400 meters. It is based on the numerical weather forecast model AROME and the Danish Wind Application and Analysis Program WAsP. Wind Atlas utilizes weather simulations and statistical analysis of ERA40 and ERA-Interim atmospheric data sets. It does not consider climate change effects even though it is estimated that climate change could increase average wind speed with a few percentages (Finnish Wind Atlas 2012d).

It is necessary to point out some inherent inaccuracies of Tuuliatlas. No wind measurement data from the heights that the model describes was used directly for the production of the model (Finnish Wind Atlas 2012c). Wind measurement data was used indirectly through an iterative data assimilation procedure (Finnish Wind Atlas 2012c). When the model results were compared to mast measurements, the error was 0.24 m/s on average and varying between 0.01 and 1.09 m/s (Finnish Wind Atlas 2012a). When combined with roughness and calculated in WAsP, the model exaggerated measured windiness up to 12.3 % (Finnish Wind Atlas 2012a). It would seem that the highest overestimation of wind speed occurred close to the shoreline (Finnish Wind Atlas 2012c), and the study area is located at the coastal area.

As project feasibility is so sensitive to wind speed, it is necessary to conduct local wind measurements after the preliminary feasibility analysis. In addition, it is recommendable to conduct wind modeling especially in larger parks for extrapolating measurements to other heights and locations and for the estimation of park effect. Park effect is the reduction of power production caused by turbulence from other turbines within the wind park.

Apart from wind speed and park effect, production is affected for instance by turbine type, icing, and technical availability of components. The larger the rotor and higher the tower, the higher the production capacity often is. Moreover, turbines have different gear systems, pitch adjustment and other technical solutions that influence production. Sometimes turbines do not operate with their full capacity due to issues such as power failure. Interruptions of production may be caused by for example icing, maintenance and complications in turbine and electricity network functioning. On Kemiönsaari, icing conditions prevail even more than 1000 hours a year (Finnish Wind Atlas 2012b). Icing causes for instance measurement and control errors, power losses, mechanical and electrical failures and safety hazard (Parent & Ilinca 2010), and during icing conditions without deicing system production decreases or turbines have to be halted altogether. In 2010 the downtime (the time when turbine is not operational) in Finland was 10.6 % of the operation time (Stenberg & Holttinen 2011: 37). 33 % of this time was due to icing (Stenberg &

Holttinen 2011: 40). Deicing systems use about 2 % of the energy produced by the turbine but extend the time of use significantly in some areas (Finnish Wind Atlas 2012b).

It is not enough merely to consider wind speed and other atmospheric conditions when selecting a suitable location: it is also important to select a suitable turbine for local conditions. Some turbines are best suitable in high-wind areas, others are better when low winds are dominant. Production modeling should be conducted for several turbine alternatives considering deicing if necassry in order to find the best fitting options.

3.3.2 Investment costs

Economical feasibility of a wind energy project is defined by costs and production together with subsidies. Power production is directly proportional to wind conditions with regard to competent project planning. Cost is another aspect defining the financial feasibility of a wind project. The bulk of the cost of wind power production is the initial investment, which in 2010 was globally 1239 €/kW on average (Vaasa Energy Institute 2012). A 3 MW turbine with installation, infrastructure and planning would then cost about 3.7 million Euros. This investment price is not straightforward but affected by a plethora of factors ranging from the turbine manufacturer and capacity to park size, soil conditions and copper prices. 75–76 % of the initial investment is the turbine itself, 9 % goes to grid connection and 6–7 % for foundation. The rest goes to land acquisition, electricity installations, consultation, financing, road construction, and security systems (Vaasa Energy Institute 2012).

In order to define the most economical grid connection alternative, it is essential to compare alternative grid connection points nearby the project area. Grid connection points are substations or power lines that can be used for connecting a wind park to the national or regional power grid. Traditionally this is examined using maps and contacting the grid owner in order to find out the line voltage and available feed-in capacity for wind energy. For parks smaller than 12 MW, it may be possible to connect to 20 kV lines (Jarmo Saarinen, discussion 26.1.2012), but as the distance to the grid increases, electricity transfer losses grow. Parks smaller than 100 MW can be connected to 110 kV grid, whereas larger parks require higher voltage (FWPA 2012a). Distance to grid longer than 10 km is usually uneconomical, but with large parks longer distance may be tolerated (Klap et al. 2011, p.11). Distance to grid connection point has to be considered due to transfer losses and grid investment.

Modern turbines with rotors of 100 m diameter apply enormous forces on turbine tower and foundation on windy weather. Those forces must be transferred from the foundation into the ground. Suitable foundation type depends on soil and bedrock conditions. Turbine foundations can be divided into two main classes: spread foundation that is heavy and extends over a large area to support the turbine, and piled foundation that has pillars penetrating the ground beneath (see Svensson 2010). Rock anchor is a type of piled foundation and gravity foundation is the spread type. Rock anchor and gravity foundations are usually more economical solutions and suitable for firm soils such as till, gravel, sand, and bedrock whereas pillar foundations are more expensive and they are required on soft soils such as peat and clay (Kari Tuominen, discussion 29.8.2011).

Apart from investment costs, also operation costs, temporal degradation of turbine value, and requirements for the return of investments influence the profitability of a wind power project (Vaasa Energy Institute 2012). Operation costs are usually low when the turbine is new but they increase in time. They are 20–30 €/MWh if inflation over the turbine lifetime is considered (Vaasa Energy Institute 2012). Preliminary analysis of profitability should be included into the preliminary studies and the calculations ought to be revised as the project planning proceeds.

3.3.3 Noise and landscape affects on housing

Due to turbine noise it is not possible to build wind power close to housing areas. Decision of the Finnish Government on guide values for noise (993/1992) ordains that in housing areas noise should not exceed 55 dB during daytime and 50 dB during night. For holiday housing areas and recreation areas values are 10 dB lower. According to the guidelines for wind energy development (ME 2012: 57–60), these values are not applicable to wind turbine noise due to low-frequency and pulsating sound of turbines. The common safety distance in wind energy planning has been at least 500 m to houses (e.g. Aydin et al. 2010; Regional Council of Pohjois-Savo 2010; Klap et al. 2011; ME 2011b), but in order to keep to noise limits, it is often necessary to use noise reduction modification in turbines closest to housing. When there are several turbines, it is sometimes possible to hear the noise even up to 1500 m distance (Klap et al. 2011, p. 6). The final noise modeling can be made only after determining turbine locations and type, after which the park layout should be revised if necessary. Apart from noise, turbines cause flickering and visual impact that might disturb inhabitants in the vicinity of the park.

It may be necessary to consider nearby population centers separately from single houses (e.g. Baban & Parry 2001). Public acceptability of a wind park may suffer if it is too close to population centers due to landscape impact. In the fringes of population centers there is also often substantial pressure to use areas for housing, recreation or other purposes, which may not be compatible with wind energy production. In addition, proximity to a town may trigger need for a local detailed plan (ME 2012: 84). Therefore it is sometimes beneficial to keep longer distance to population centers than to single dwellings.

3.3.4 Environmental and cultural values

Environmental values should be considered at an early phase of project development. There is data available on for instance public and private protection areas, Natura 2000 areas, protection program areas, different landscape protection areas and protected buildings. National parks and nature parks and many other nature reserves are completely excluded from any construction. Most nature reserves in the Southwest Finland can be viewed in an interactive map service Lounaispaikka (see Lounaispaikka 2012) and nationally in Paikkatietoikkuna (see Paikkatietoikkuna 2012).

Most protection areas are not considered suitable for wind energy development. However, there are a few types of protected areas in which wind power production might be possible. Within the study area, there are three 2 MW turbines in Högsåra within a significant landscape area despite the fact that according to the contemporary guidelines significant landscape areas are should be avoided (ME 2012: 11). Another possibly usable protection areas type is Natura 2000 Sites of Community Importance (SCI). They are protected by the EU Habitats Directive (Council Directive 92/43/EEC). If the wind park does not threaten the protected values of a SCI area, wind energy development is not directly forbidden within the protected area (European Commission 2010). However, it is important to keep distance to Special Protection Areas (SPA), which are protected by the Birds Directive (Council Directive 09/147/EC), in order to avoid “killer turbines” for birds.

3.3.5 Other factors

Apart from economical, environmental and inhabitation-related factors, there are also other land use issues that must be studied locally. Local land use and property ownership should be investigated. Land use can be examined from existing plans, maps, and data sets like Corine Land Cover 2006, SLICES, or the Topographic database. Wind parks should not conflict with existing land use such as urban areas, military restricted areas, office areas, mines or some environmental types such as beaches.

Moreover, many other factors including turbine height limitations, tourism areas, bird migration routes, groundwater areas, railways, regional wind energy plans, White-tailed Eagles and other large predatory birds should be considered. Finavia’s height limitations are one of the limiting elements of wind power in Finland. These limitations have been imposed in order to secure safe and flowing aviation (ME 2012). Finavia revised the height limitation surfaces in 15.12.2011 in order to mitigate the influence of aviation on wind energy development and released a new data set on the limitation for the use of project developers (Finavia 2012).

In project development it is also necessary to find out where the closest weather radars are located as they may risk licensing. Turbines are visible as rain on weather radars even when they are far away (Erävuori 2012a). The FMI categorically complains about all turbines that are closer than 5 km from radar, and they have to study the potential impacts if it is closer than 20 km (B2B Uusiutuvat energiat 2012). It would be beneficial to request a statement from FMI already before the statutory land use planning procedure in order to confirm that the area can be used for wind energy production.

4 Spatial multicriteria decision analysis (SMCDA)

4.1 Multicriteria decision analysis – framework for solving complex decision problems

Multicriteria decision making (MCDM) is defined by Steuer (2002) as a body of methods and procedures by which the concern for multiple conflicting criteria can be formally incorporated into the analytical process. There are two main branches of MCDM: *multicriteria decision analysis* (MCDA) and *multiple-criteria optimization* (Steuer 2002). MCDA is often concerned with multicriteria problems that include uncertainty whereas multicriteria optimization is typically directed at problems formulated within a mathematical programming framework. This study utilizes basic methods of MCDA without entering the realm of programming while encompassing human decision-makers and considering uncertainty, which makes it namely more suitable to the branch of MCDA.

Another way to approach MCDA research is presented by Vincke (1986). He divides the field into three approaches: *Multiobjective mathematical programming*, which is similar to the multiple-criteria optimization by Steuer, *multiattribute utility theory* (MAUT), and *outranking relations approach*. MAUT attempts to represent decision-makers' preferences for criteria, which are aggregated into one unicriterion that ranks all the alternatives according to desirability. This study represents MAUT approach according to Vincke's definition. Unlike MAUT, outranking does not obtain complete ranking of feasible decisions, but instead it derives binary relations that determine if decision *a* is better than decision *b*. These relations are not necessarily obtained for each possible pair of decisions, and therefore the approach does not require ability to compare all pairs of objectives. However, this approach is not suitable for large amounts of alternatives (Joerin et al. 2001, Marinoni 2005) so it was not considered for this study.

MCDA sometimes refers to multicriteria decision assessment (Marttunen et al. 2008) or multicriteria decision aid (Ferretti 2011). All the terms are synonymous but perhaps emphasize different aspects of MCDA. *Analysis*, as referred by Malczewski et al. (1999), emphasizes the technical aspect, *assessment* may refer to the process structure and interactive character whereas *aid* implies that the results may be used for supporting decision-making.

Marttunen et al. (2008) define MCDA as a group of methods and approaches that can be applied for analyzing complex decision making problems that include various values, impacts, and uncertainty. They recommend that MCDA should be used to solve decision problems that have some of the features described in Table 2.

Table 2. Features of MCDA problem. Adapted from Marttunen et al. 2008.

- *Complexity*. The decision problem is so complex that it requires analysis.
- *Incommensurability*. Different aspects of the decision problem cannot be measured using the same scale, for instance money.
- *Immeasurability.* All factors cannot be measured.
- *Multiple objectives*. The decision should satisfy interested parties that have dissimilar goals.
- *Uncertainty*. Impacts and development forecasts have uncertainties making the decision outcome difficult to estimate.
- *Synthesis.* Necessity to organize the decision situation systematically and specify and combine related perceptions and knowledge to it.
- *Validity.* The outcome decision should be possible to justify transparently by the decision-maker. This requires information on for instance values of the decision-maker.

MCDA is not typically used for providing one right solution. Instead, it produces justifiable recommendations and helps comprehending the problem and interaction between interested parties. A Finnish manual for MCDA (Marttunen et al. 2008) emphasizes the communication and conflict solving aspects of the method, whereas Malczewski's compendium (1999) presents solution-centered approaches. Marttunen et al. assigns the key role to the perceptions of interested parties while Malczewski introduces also such methods that diminish the role of interested parties to the minimum. This study considers most interested parties indirectly through legislation, guidelines and expert opinions, and some through formal interviews of the decision-makers.

Spatial multicriteria decision analysis (SMCDA) is MCDA that includes spatial aspects, and therefore can be applied in GIS environment. According to Malczewski (1999: 96–99), there are some general steps in SMCDA. Firstly, decision problem is recognized and defined. In practice, raw data is acquired and examined in order to define the problem *goal* and what information is necessary and available for the problem solving. In the second phase, *constraints* and *criteria* are defined, and in the third one, *scores* are calculated for each criterion. *Alternatives* are defined by constraints. In SMCDA, *alternatives* can be areas or locations, but in other MCDA problems they can be for instance people, operating systems, cars or land-use forms. The fourth phase includes defining *criterion weights* and the fifth calculating *decision outcome* and *recommendation*. Decision outcome maps are analyzed with *sensitivity analysis* in order to estimate the stability of the result with different weights and inputs, and in the end, a recommendation for action is provided. The phases of SMCDA have been enlisted into the Table 3 (p.33).

MCDA has been applied on for instance hazard risk assessment (Rashed & Weeks 2003), ore exploration (e.g. Pazand et al. 2011), natural resource management (see Diaz-Balteiro & Romero 2008, Mendoza-Martins 2006), municipality solid waste facility siting (e.g. Ferretti 2011), land suitability analysis (e.g. Ascough et al. 2002) and of course for wind energy siting (e.g. Aydin et al. 2010, Ramirez-Rosado et al. 2008, Tegou et al. 2010).

4.2 MCDA structure

The structure of MCDA is hierarchical (Figure 5), and it described for instance by Marttunen et al. (2008) and Malczewski (1999). The top element is the *overall goal*, which in this case is finding the best locations for wind energy production. Decision problem involves one or several *decision-makers*, which define the criteria of the problem and their relative weights. *Criteria* are the elements that the decision-maker considers when making a decision.

Decision-makers define a set of *objectives* together with the person who executes the analysis. An objective defines what is desirable in terms of the related *attribute*. Objective expresses desirability of the related attribute by either maximizing or minimizing attribute values. Attribute measures the fulfillment of objective with for example money or meters. Attributes and the related objectives form criteria. Criteria can be described as GIS layers, whereas in non-spatial MCDA it can be for instance charm, age, and education of a job applicant. It should be noted that this is not the only way to describe the structure of MCDA: terminology and ways to structure the hierarchy vary from case to case.

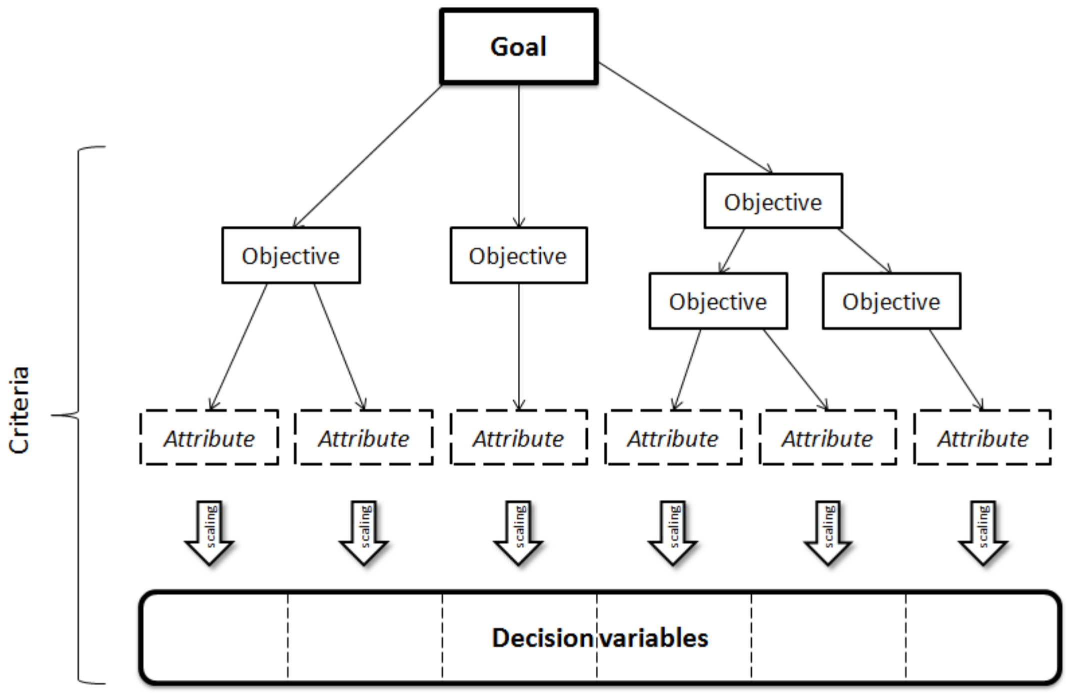

Figure 5. The structure of MCDA. Adapted from Marttunen et al. (2008)

Criteria include *constraints* that restrict *feasible alternatives* and *evaluation criteria* that describe preference. In MAUT each evaluation criterion is then *standardized* or *rescaled* between for instance one and zero, and the resulting layer can be called for instance *decision variable*. There are many methods for rescaling, and some of them are described by Malczewski (1999). In this study, *linear scale transformation* is used.

4.3 Analytic hierarchy process

When criteria have been identified and organized into a hierarchical structure, *weights* will be generated and incorporated into the model. These may be acquired from experts or decision-makers using several different methods such as rating, ranking, pairwise comparison and trade-off analysis (Malczewski 1999: 177–190). For instance, Robinson et al. (2002) utilized ranking methods so that the consulted experts gave the lowest ranking criterion value 1 and all the other ones values proportional to that. Then the mean of all expert groups was calculated. A pairwise comparison method called *analytic hierarchy process (AHP)* is utilized in this study. For SMCDA, AHP has been used by for instance by Pazand et al. (2011) for the exploration of copper porphyry as well as Rashed and Weeks (2003) for earthquake hazard assessment.

AHP is a way to derive relative significance of attributes. This method developed by Thomas L. Saaty includes three steps: 1) develop the AHP hierarchy, 2) pairwise comparison of attributes and 3) rating overall priorities (Malczewski 1999: 218–220). AHP hierarchy is similar to the conceptual structure of the MCDA problem in question (Figure 5).

Pairwise comparison is the second phase of AHP. It includes comparing each criterion on one level of hierarchy against the others by each selected decision-maker or expert. The scale of assessment is 1–9, 1 signifying equal value and 9 the extreme relative significance of the other (Saaty 1990). Pairwise comparison is often conducted during an *analysis interview.*

Attribute weights can be calculated from the pairwise comparison table using eigenvectors. It is also customary to calculate *consistency ratio* or *consistency measure* that reveals inconsistencies in the pairwise comparison table. The reader is referred to Saaty (1990) for further information on calculating weights and consistency ratio.

4.4 Aggregation of criteria

Overall priorities are rated after AHP with *weighted linear combination* (WLC). WLC is a practical implementation of SMCDA, and they are compared in Table 3. In WLC all the weighted criteria layers are aggregated for a *decision outcome*. It can be described as a function:

$$A_1 = \sum_j w_j x_{ij} \qquad (1)$$

, where the total score of an alternative is A_1, w_j is the criterion weight, and x_{ij} is the normalized criterion score (Malczewski 1999: 199). This is also the basic utility function of MAUT (Munier 2011: 57). The normalized criteria are multiplied with the weight acquired in the pairwise comparisons. Then the weighted criterion values are summed for each alternative, and the resulting map is the decision outcome score map. It orders all alternatives according to their level of preference. All values are between one and zero, one being the best and zero the worst. Finally, a *recommendation* is given for future action based on ranking of the alternatives.

Table 3. Comparison of SMCDA and WLC. Adapted from Malczewski 1999.

Phases in SMCDA (pp. 96–99)	WLC phases in GIS (p. 199)
1. Problem definition/goal 2. Definition of constraints and attributes 3. Definition of feasible alternatives 4. Incorporating criterion weights 5. Calculating decision outcome 6. Sensitivity analysis 7. Recommendation	1. Define the set of criteria 2. Standardize criterion map layers 3. Define criterion weights 4. Multiply normalized maps with weights 5. Generate overall score for each alternative 6. Rank alternatives according to the overall score

WLC has been commonly used in SMCDA. It was used by for instance Ramirez-Rosado et al. (2008) and Tegou et al. (2010) together with different applications of pairwise comparison for wind farm siting. Robinson et al. (2002) used WLC together with a ranking method. Ferretti et al. (2011) applied WLC with analytic network process (ANP), which is a non-hierarchical version of AHP. Jiang and Eastman (2000) have used it with fuzzy measures. WLC is flexible and it can be applied in many different situations, and it is intuitive and easy to accept and understand. In addition, it is compensatory meaning that low scores in one criterion can be compensated by high scores in another one, which is desired for this particular decision problem. For these reasons, WLC was selected as the method of aggregation.

4.5 Wind power location as a SMCDA problem

SMCDA has been used in many parts of the world for determining suitable locations for wind energy. The scale of analysis has usually been regional or national. Sets of criteria and their standardization methods are varying as well as weighing methods. Some articles that discuss wind energy siting in SMCDA context were selected for comparison of criteria, and they are enlisted in Table 4. All of these studies take windiness into consideration but it is merely one criterion among the others. On the contrary, Sliz-Szkliniarz & Vogt (2011) concentrate on modeling energy yield based on wind and turbine data. In addition to windiness, nature reserves, proximity to roads and grid, distance to houses and/or settlements, different topographical aspects and land cover was considered in most of the selected studies. Windiness is the only criteria common to all studies, but also the other criteria share thematical resemblance.

In this thesis, linear standardization was used for rescaling criteria layers. *Fuzzy logic* is another way to derive criteria layer, and for instance Aydin et al. (2010) and Hansen (2005) used *fuzzy set* methodology. Fuzzy sets describe the possibility of an alternative for belonging into a certain class. Aydin et al. (2010) apply fuzzy logic to all evaluation layers and do not separate between constraints and evaluation criteria. Instead, they define threshold values for the evaluation criteria, which cause the alternative to be excluded. Fuzzy sets can be aggregated using three methods: intersection, union, and averaging (Malczewski 1999, p. 233). If there are no constraint layers, only intersection method should be used in Finland as licensing is at the moment based on meeting every minimum requirement instead of weighing positive and negative aspects (Tarasti 2012). Aydin et al. (2010) compare examples of intersection and union methods and an aggregation method of all three called *ordered weighing averaging*. In contrast, Hansen et al. (2005) used WLC. Fuzzy sets are useful when class borders and thresholds are not clearly defined or for instance if the criterion score should not be linearly proportional to the values in unscaled criteria layers.

Baban and Parry (2001) used a simple method of classifying attribute values into categories instead of continuous scale criteria. Another methodological difference to this thesis is how they acquired criteria weights. Based on the perceived importance of each criterion, each criterion was assigned to one of four importance classes, after which a systematic pairwise comparison was conducted. In that study it is left unclear whether the decision-makers were directly involved, and who they were. Hansen et al. (2005) decided not to put much effort into assigning weights although they admitted that to be perhaps the most crucial part of the analysis. Indeed, it is necessary to consider weights carefully and explain where they originate from as they justify the applicability of the method into decision-making.

Gamboa and Munda (2007) took another approach on the location-allocation problem. Instead of trying to find feasible areas using constraints, they aspired to determine the best of seven pre-defined alternatives. All the alternatives included the same wind parks, but turbine position or size varied or some turbines or parks were excluded altogether. They were not seeking to determine the risk from the developer perspective or combine land uses from the planning perspective but aimed to find the most socially acceptable alternative. Social acceptability was defined based on a set of criteria including social, economic, socioecological and technological factors. This analysis is an outranking method, which is very different from MAUT used in this thesis.

Table 4. Comparison of criteria in selected articles. c: constraint criterion, e: evaluation criterion. Threshold distances are marked behind the letter code. Source articles: a) Aydin et al. (2010), b) Hansen (2005), c) Baban &Parry (2001), d) Janke (2010), e) Tegou et al (2010).

	a)	b)	c)	d)	e)
Wind	c, e	e	c (5 m/s)	e	c (4 m/s), e
Topography		e	c, e		c, e
Electricity demand					e
Grid		e	c (10 km)	e	e
Roads		e	c (10 km), e	e	c (10 km), e
Land value					e
Nature reserves	c (0.25/1 km), e	c	c (1 km), e		c
Water bodies	c (0.4 km), e (1.5/5 km)	e	c, e		
Shoreline		e			
Bird protection areas	c (0.3/0.5 km), e (1.2 km)	c			
Visual impact					e
Historical/religious buildings		e			c (0.5 km)
Historical/archeological sites			c (1 km), e		c (0.5 km), e
Land cover		e	c, e	e	c, e
Landowner			c (1 km), e	c	
Houses	c/e (0.4/ 0.5 km)		c (0.5 km)		
Settlements	c (2 km), e (1/2/3 km)	e	c (2 km), e	e	c (0.5/1/1.5 km), e
Population density				e	
Airports	c (2.5 km), e (3/6 km)	e			c
Gas pipes		e			
GSM/radio/TV		e			

Janke (2010) applied SMCDA to the state of Colorado. When the study area is large, it is necessary to use large-scale data. Computing power limits the level of detail for large-scale analysis. Distance to housing or population centers was a criterion in most other studies but due to the resolution of 1.5 km, population density was used instead in Janke's study. Low resolution masks detailed variance in the study area, and therefore studies of this scale are not suitable for finding locations for small parks. Population density may work on a coarse scale, but it may also cause errors when inhabitation is located unevenly throughout the cell. On the other hand, it may mistake areas with dispersed inhabitation for suitable areas.

Another factor to point out in the study is that all the criteria were assigned weights on a 1-3 cardinal scale, which lacks detail compared to AHP.

Some studies have used pairwise comparison element familiar from AHP but derive weights using other methods instead of calculating eigenvectors. For instance, Ramirez-Rosado et al. (2008) and Tegou et al. (2010) apply these alternative methods although the both use the same WLC model and pairwise comparison.

These studies are merely examples on the type of SMCDA studies that have been conducted for wind energy locating decision problems. They demonstrate some alternative ways of deriving criteria, standardizing them, deriving weights and aggregating criteria maps in addition to presenting a variety of criteria sets. As the following section shows, most Finnish wind power locating studies are based on point assignation without criteria weighing and are more simplistic than these studies.

4.6 GIS-based studies on locating wind energy production in Finland

Regional councils have used different GIS methods together with other methods in order to locate the best suitable areas for wind energy. Their studies have often been simplified forms of MCDA including only constraint criteria (Table 5). Often feasible alternatives are considered individually from the environmental, societal, and economical perspective outside GIS environment.

Regional Council of Southwest Finland has conducted a series of studies on finding suitable locations for wind energy production since the beginning of 2000’s. The first one was initiated in 2002, and it did not detect suitable areas for large wind parks (Pöyry 2007). The second study that complemented the first one, scrutinized smaller areas with potential for maximum ten turbines in the coastal areas of the Southwest Finland. The analysis was conducted cartographically excluding areas that were too close to inhabitation; environmentally, culturally or otherwise sensitive; or had water depth of over 10 m (Regional Council of Southwest Finland 2005). The remaining 88 areas were assigned points according to windiness and grid connection (Regional Council of Southwest Finland 2005), and six of them were selected for further studies including e.g. technical-economical, noise, and landscape aspects (Pöyry 2007). One of these six areas is located in Skallerfjärden, Kemiönsaari.

When the national land use objectives obligating regional councils to study also continental areas came into effect in 2008, Regional Council of Southwest Finland initiated a completely new study for the whole Southwest Finland. In the study, constraints were defined, and selected remaining areas were analyzed from e.g. technical, economical, environmental and landscape perspectives (see Klap et al. 2011).

Table 5. Criteria in Finnish wind power studies. c = constraint criterion, e = evaluation criterion. Source studies: a) Klap et al. (2011), b) Paakkari (2011), c) Council of Oulu Region (2011), d) Uusimaa Regional Council, Regional Council of Eastern Uusimaa, Regional Council of Häme & Regional Council of Päijät-Häme (2010), e) Pöyry (2012).

	a)	b)	c)	d)	e)
Windiness		c (6.3 m/s), e	c (6.25 m/s)	c (6 m/s), e	e
Relative elevation		e			e
Area size or turbine amount		c (3 km^2), e	c (2 km^2)	c , e	
Electric grid	c (10 km)	e		e	e
Roads		e		e	e
Nature reserves*	c	c	c (0.5/1 km), e	c	c
Valuable moraine, bedrock, and till areas			c (0.1 km)	c	
Ground water areas & protected water areas			c	c	
FINIBA/IBA	c	c	c (1 km), e		c
Protected bird nests**	c (2 km)		c (1 km), e	e	c (2 km)
Landscape areas	c	c	c (1 km), e		c
Cultural environments (RKY)		c	c (1 km), e		c
Traditional biotopes			c		
Archeological findings			c		c
Recreation areas & tourism services			c (1 km), e		c (2.5 km)
Land-use in regional/ other plan	c	c	c		c, e
Houses and summer houses	c (0.65/1 km)	c (0.5–2 km)	c (0.5 km), e	c (0.4–2 km)	c (1 km)
Population centers		c (0.5–2 km)	c (1 km)		c (1/2.5 km)
Airports	c (0–12 km)		c (3–10 km)		
Restricted areas of the Defence Forces		c	c		c

*includes private and program areas, regional land use plan, Natura 2000
** White-tailed Eagle, Osprey, Peregrine Falcon, or other threatened bird nests

A partially different approach was followed in the study for Central and Northern Ostrobothnia (Council of Oulu Region 2011). At first, areas were excluded based on a wide set of constraint criteria. Environmental risk was defined for each area by assigning points for different elements, and they were aggregated as an environmental risk index figure. This can be understood as a reduced form of SMCDA where alternatives are potential wind power areas and evaluation criteria are environmental factors. In the analysis for Southern

Finland and Southern Lapland, a similar point assignation system was applied for also other than environmental aspects (Uusimaa Regional Council et al. 2010; Pöyry 2012).

Six regional councils in Central and Eastern Finland conducted co-operative studies in order to find suitable wind energy sites (Paakkari 2011). At first, each regional council conducted their own GIS-based exclusion process. The criteria were determined by each regional council separately but some common criteria are enlisted in Table 5. More than 200 potential areas were found (Paakkari 2011). In the second phase common to all regional councils, points from zero to four were assigned to the areas for windiness, elevation differences, distance to grid, number of turbines and existing road network. Each factor was given a weight in percentages, and the scores for each potential area, alternative, were calculated. With the help of these scores, each regional council picked four areas for further technical and economical scrutiny.

To conclude, many regional councils adopted a point assigning approach, which can be viewed as a simplified form of MCDA. There are two things that must be considered carefully when using the point system. Firstly, what is the maximum amount of points in each criterion? If all the criteria can have the same maximum amount of points, then all of them are considered equally important. However, for instance distance to roads and windiness may not be equal. Another aspect to consider is where the threshold values lie. For instance, if 1–2 points are supposed to be designated to areas according to windiness, will the threshold between one and two be the average or median on the map or perhaps a fixed figure such as 6.5 m/s. Different analysts make different decisions, and that may lead to differing alternative ranking. An additional issue with these studies is that the methods are not identical, so comparing results over regional borders is challenging at best.

5 Materials

5.1 Data acquisition and preprocessing

Data sets described in the following chapter were acquired in order to estimate their suitability for the analysis. Not all of them were used. Most of the data sets were procured via PaITuli (CSC 2012), where university students, researchers and university staff can download data for educational and research uses. This spatial data service is maintained by CSC (IT Center for Science). Some data sets were delivered by Lounaispaikka, which maintains a regional interactive map service (Lounaispaikka 2012) and also delivers some spatial data upon request. SYKE has OIVA service (OIVA 2011) where many environmental data sets can be downloaded free of charge also for commercial use. Some data sets were requested directly from the producer.

Table 6 enlists the data sets. All of them required some preprocessing before they could be used for the analysis. Firstly, all data sets were reprojected into EUREF-FIN coordinate system, which is the Finnish realization of ETRS89 coordinate system. Secondly, they were merged or clipped to a suitable size and sometimes intersected with the study area definition in order to match the data extent of different data layers. All raster data sets were snapped to match together and then extracted by the study area mask. Sometimes extraction and clipping was conducted after the analysis if values of cells and features outside the study area would have influenced attribute values.

5.2 Data sets

5.2.1 Data for economical criteria and study area definition

Wind speed

Wind speed data were acquired from FMI, which sells model results in vector format for private use. For this study, wind speed in 100 meters was obtained. Windiness data are essential when determining an area potential for wind energy. Further description on the data production and inaccuracies is provided in the section 3.3.1.

Terrain data and digital elevation model

The Topographical database is an extensive vector data set of land cover variables in Finland. It is produced by the NLS. The data set includes for example roads, elevation contours, lakes, seas, administrative borders, land use and buildings. Many layers of the database wee used for the creation of criteria and the study area definition is based on the shoreline from the Topographical database as well.

In addition, raster format *digital elevation model (DEM)* was provided by the NLS. It was produced from the elevation contours of the Topographical database in the 1990's. This DEM has the horizontal resolution of 25 meters, and vertical accuracy is two meters on average.

Islands with electricity

This vector data set has been produced by the University of Turku and it is available upon request in the Department of Geography and Geology. It describes islands that have electricity network. The data set used in this study was updated by Timo Rantanen in 2011. It was used for the definition of study area, but not for the analysis itself.

Roads

The Finnish Transport Agency produces *Digiroad*, a detailed data set on roads and other transport connections. Digiroad is updated by the NLS, The Finnish Transport Agency, municipalities, and some other bodies of public administration. Unlike the Topographical database road layer, Digiroad includes an abundance of attribute data on for instance traffic direction, names and addresses as well as speed limitations. However, the Topographical database includes also small forest roads and paths that are not indicated in Digiroad.

Soils

Geological Survey of Finland (GTK) provides maps of *Quaternary deposits* on many scales and formats. There were no detailed deposit data available for the whole study area, so 1:200 000 vector data were selected for the analysis. In this scale, the minimum patch size is 6 ha. Grid size of this analysis is 0.0625 ha, so the coarse resolution is a significant source of error.

5.2.2 Environmental and cultural data

Valuable geological features

This data set includes bedrock areas that have significant geological, environmental or aesthetic values. It is based on national inventories further described by Heikkinen & Husa (1995). Areas are categorized in five classes of significance, and their legal importance is based on the Finnish Land Extraction Act (SYKE 2010c). This vector data set can be acquired via OIVA service.

Nature reserves, conservation programme areas, and Natura 2000

Nature reserves, *nature conservation programme* and *Natura 2000 area* data sets are provided by SYKE and they can be downloaded from OIVA. These three data sets are partially overlapping, and they may also overlap with the Topographical database and regional land use plan proposition marks. Nature reserves include areas on governmentally owned land, private land and wilderness areas in Lapland. Kemiönsaari has governmentally owned archipelagic national park and several small private protected areas but the data do not describe the reason for protection.

Nature conservation programmes are principle decisions by the Finnish Government. They include programs for the protection of old forests, eskers, groves, bird waters, shores and wetlands. Apart from protection programmes, the data also include information on significant landscape areas. Kemiönsaari has programme areas for the protection of eskers, groves, bird waters, landscapes, shores and wetlands. Natura 2000 depicts SCI and SPA areas, and it is partially overlapping with nature reserves and programmes.

Important bird areas

Finnish Important Bird Areas (FINIBA) is provided by SYKE and BirdLife Suomi. The database describes areas that are important for the protection of birds (BirdLife Finland 2012). It can be viewed in Lounaispaikka, but for downloading it must be requested from SYKE or BirdLife. There are no IBA areas of international significance in the vicinity of the study area, so only FINIBA-areas are used in this analysis.

Eagle nests

White-tailed Eagles are protected, and information about their nest location is confidential. In this study, *eagle nest data* are used only for excluding areas and, and the original data are disguised in order to avoid revealing the location nests. The data can be acquired from the local Centre for Economic Development, Transport and the Environment (ELY) or Metsähallitus, which is the forest-owning enterprise of the state. For this thesis, the nest data was received from Metsähallitus in an Excel spreadsheet format. It was imported to ArcMap and saved as a shapefile, after which a 2 km buffer was created around each nest. This buffer was manually edited in order to mask locations of the nests.

Cultural environments, protected built heritage, and traditional landscapes

Nationally significant cultural environments (RKY) is a data set published by the National Board of Antiquities (NBA). It includes areas larger than just a single building, and it is based on inventories that were finished in 2009. Kemiönsaari has 17 significant cultural environments including the fort of Örö, archipelagic villages, Dalsbruk historical industrial area and Sjölax mansion.

NBA maintains also a database of *protected built heritage*. Kemiönsaari has four protected built sites described in the database, all of which are churches. More protected buildings and built environments, including for instance mansions, old farms and parsonages, are described in the phased regional land use plan proposal.

Traditional landscapes is produced by the Southwestern Finland's ELY centre. Traditional landscapes inventory took place in 1992-1997, and it included classifying traditional landscapes in categories of local, regional and national importance. The ELY centre provides this data set upon request.

Archaeological heritage

Archaeological heritage is vector data mapped by the NBA. The data set consists of polygon and point layers. Point layers are not considered in this study because their spatial accuracy is 50 meters, which is lower than the resolution of the analysis. In addition, point features in real life are small findings that are avoided by moving the turbine a few meters so that it does not interfere with the finding. Polygon data is considered suitable for the spatial analysis as it describes extension of the heritage site and they often depict findings with larger coverage.

Recreational areas and routes

SYKE's vector database *VIRGIS* describes recreation routes, areas and services on a national scale. It has been produced in co-operation with Metsähallitus and the Faculty of Sports and Health Sciences in the University of Jyväskylä. There are just a few short recreation routes marked in Kemiönsaari, and almost all of the recreation areas are identical to the Archipelago national park. Therefore VIRGIS is not investigated further in this study, although it could be more useful in other areas. Recreation values for the analysis are extracted from the regional land use plan proposition.

Land-cover rasters SLICES and CLC2006

SLICES is a raster land cover data set with the grid size of 10 meters. The data set has been constructed by combining information from existing data sets and it was last updated in 2005. In the scope of this thesis, SLICES data set is an alternative to CLC2006. However, as it is subject to charge and does not hold more significant attribute data than CLC2006, it was not used in the analysis.

Corine Land Cover 2006 (CLC2006) encompasses the whole European Union area, and it is available in both vector and raster formats. Land cover types are categorized into four hierarchical levels. CLC2006 is produced by SYKE according to the European Union standards. IMAGE2006 satellite image mosaic has been used for the data production along with a variety of data sets acquired from for example The Finnish Forest Research Institute (Metla), Metsähallitus, and NLS. The resulting raster data set has the resolution of 25 m. The vector data have been generalized based on the raster data.

5.2.3 Data on land use and societal requirements

Regional council studies and land use plans

The Regional Council of Southwest Finland carried out a study for wind parks of at least eight or nine turbines (Klap et al. 2011: 11). The results of this *wind power study* are used in the regional wind energy planning procedure, which was initiated in 1.10.2011 and is planned to come to closure in 31.12.2013 (Regional Council of Southwest Finland 2012a). Based on the study results and some further investigations, the Regional Council published a *phased regional land use plan draft for wind power* in the spring 2012 (Regional Council of Southwest Finland 2012a). The study and plan draft can be acquired from the Regional Council upon request.

Regional land use plan proposition includes a great variety of spatial data on for instance land use, protection areas and future plans of regional importance. The plan proposition includes for example the borders of significant landscape areas that differ from the national definition in SYKE data. However, the definition of landscape areas is not significantly different in the study area, so significant landscape areas have been extracted from the SYKE data set for this thesis. The plan proposition also includes protected cultural environments that are identical to the SYKE definition and archeologically valuable areas. Those differ from the national data, so they are considered in the analysis as well.

Local master plan

Local master plans on the study area were acquired from the municipality. Master plan describes also existing building rights and areas where for instance holiday resorts and new summer housing is being planned. They were not used in this study due to partial coverage and overlapping with other data sets.

Aviation height limitation surfaces

Height limitation data set is produced by Finavia in order to anticipate obstruction authorization from TraFi. This data set and further information on the surfaces is available at Finavia web site (Finavia 2011; Finavia 2012). The data are used in combination with DEM in order to produce a grid that describes the allowed height of turbines in each grid cell. In practice, terrain elevation is subtracted from the limitation surface elevation.

Table 6. Data sets. Information from Paikkatietoikkuna 2012, Finavia 2011, Finavia 2012, Regional Council of Southwest Finland 2012b, NLS 2012, and Lounaispaikka 2012.

Data set	Description	Vector/ raster	Resolution/ scale	Updated	Producer	Acquisition	Preprocessing	Not used/ criterion/ constraint	Free/ subject to charge
Wind speed	Average annual wind speed in 100 m	Vector	250 m	2011	FMI	FMI	Interpolation from center point to 25 m grid	Criterion	Subject to charge
The Topographical database	Land cover & terrain	Vector	1:5000–1:10 000	Freq-uently	NLS	PaITuli, NLS download service	Merge, extract necessary feature classes	Criterion/ constraint	Free
DEM	Elevation	Raster	25 m	2007	NLS	PaITuli, NLS download service	---	Criterion/ constraint	Free
Islands with electricity	Islands with electric grid in Southwestern Archipelago	Vector	1:20 000	2011	University of Turku	Lounaispaikka, Department of Geography and Geology	---	Other: Study area definition	Free
Digiroad	Roads	Vector	1:10 000	2012	Finnish Transport Agency	Finnish Transport Agency	---	Criterion/ constraint	Subject to charge
Map of Quaternary deposits	Soils	Vector	1:200 000, 2–6 ha	2010	GTK	GTK	Rasterize, reclassify	Criterion	Subject to charge
Valuable geological areas	Protected bedrock areas	Vector	1:20 000	2008	SYKE	PaITuli, OIVA	---	Not used	Free
Nature reserves	Private & public nature reserves	Vector	1:20 000	2010	SYKE	PaITuli, OIVA	---	Criterion/ constraint	Free
Conservation programmes (LSO)	Thematical nature conservation programme areas and significant landscape areas	Vector	1:20 000	2008	SYKE	PaITuli, OIVA	---	Criterion/ constraint	Free
Natura 2000	Natura 2000 SPA & SCI areas	Vector	1:20 000	2010	SYKE	PaITuli, OIVA	---	Criterion/ constraint	Free

Table 6 continues.

Data set	Description	Vector/ raster	Resolution/ scale	Up-dated	Producer	Acquisition	Preprocessing	Not used/ criterion/ exclusive	Free/ subject to charge
FINIBA	Important Bird Protection Areas in Finland	Vector	---	---	SYKE, Birdlife	SYKE, Birdlife	---	Constraint	Free
Eagle nests	Locations of White-tailed Eagle nests	Vector, coordinat es	---	---	Metsähallitus	ELY, Metsähallitus	Coordinates to points, creation of 2 km buffer, manual masking	Constraint	Free
RKY	Cultural environments	Vector	1:20 000	2009	NBA	PaITuli, NBA	---	Criterion/ constraint	Free
Protected built heritage	Protected buildings	Vector	1:20 000	2010	NBA	PaITuli, NBA	---	Criterion	Free
Traditional landscapes	Traditional environments	Vector	1:20 000	2008	ELY	ELY	---	Criterion/ constraint	Free
Archaeological heritage	Archaeological findings	Vector	1:20 000	2010	NBA	PaITuli, NBA	---	Constraint	Free
VIRGIS	Recreation areas	Vector	1:20 000	2009	SYKE	PaITuli, OIVA	---	Not used	Free
SLICES	Land cover	Raster	10 m	2011	NLS	PaITuli, NLS	Reclassification, generalization to 25 m grid	Not used	Subject to charge
CLC2006	Land cover	Raster	25 m	2006	SYKE	PaITuli, OIVA	Reclassification	Constraint	Free
Regional land use plan	Existing and planned land use	Vector	1:100 000	2011	Regional Council of Southwest Finland	Regional Council of Southwest Finland, Lounaispaikka	---	Criterion/ constraint	Free

Table 6 continues.

Data set	Description	Vector/ raster	Resolution/ scale	Up-dated	Producer	Acquisition	Preprocessing	Not used/ criterion/ constraint	Free/ subject to charge
Wind power plan draft	Suitable sites for wind energy production	Vector	1:150 000	2012	Regional Council of Southwest Finland	Regional Council of Southwest Finland, Lounaispaikka	---	Criterion	Free
Wind power study	Suitable sites for wind energy production	Vector	---	2011	Regional Council of Southwest Finland	Regional Council of Southwest Finland, Lounaispaikka	---	Criterion	Free
Master plans	Existing and planned land use	Vector	1:10 000	2011	Kemiönsaari	Kemiönsaari, Lounaispaikka	---	Not used	Free
Finavia height limitation surfaces	Allowed heights for tall structures	Vector	---	2011	Finavia	Finavia web site	rasterize, subtract DEM	Constraint	Free

6 Methods

SMCDA was initiated by determining the goal, delineation of the study area and checking available spatial data, after which attributes were selected and organized into a hierarchical structure. Criteria were composed based on existing data within the study area. Evaluation criteria were rescaled between one and zero using linear standardization methods and feasible alternatives were defined by intersecting constraint criteria. It was necessary to review criteria composition and input data in this phase but hierarchical structure remained the same. Weights were defined for evaluation layers using pairwise comparison in AHP, and then all the weighted evaluation criteria were aggregated using WLC. Consequently, scores of feasible alternatives were extracted from the aggregation result and ranked for the recommendation. Finally, reliability of the recommendation was estimated using six selected sensitivity analysis scenarios, which required returning back to the earlier phases of the SMCDA process described in Figure 6.

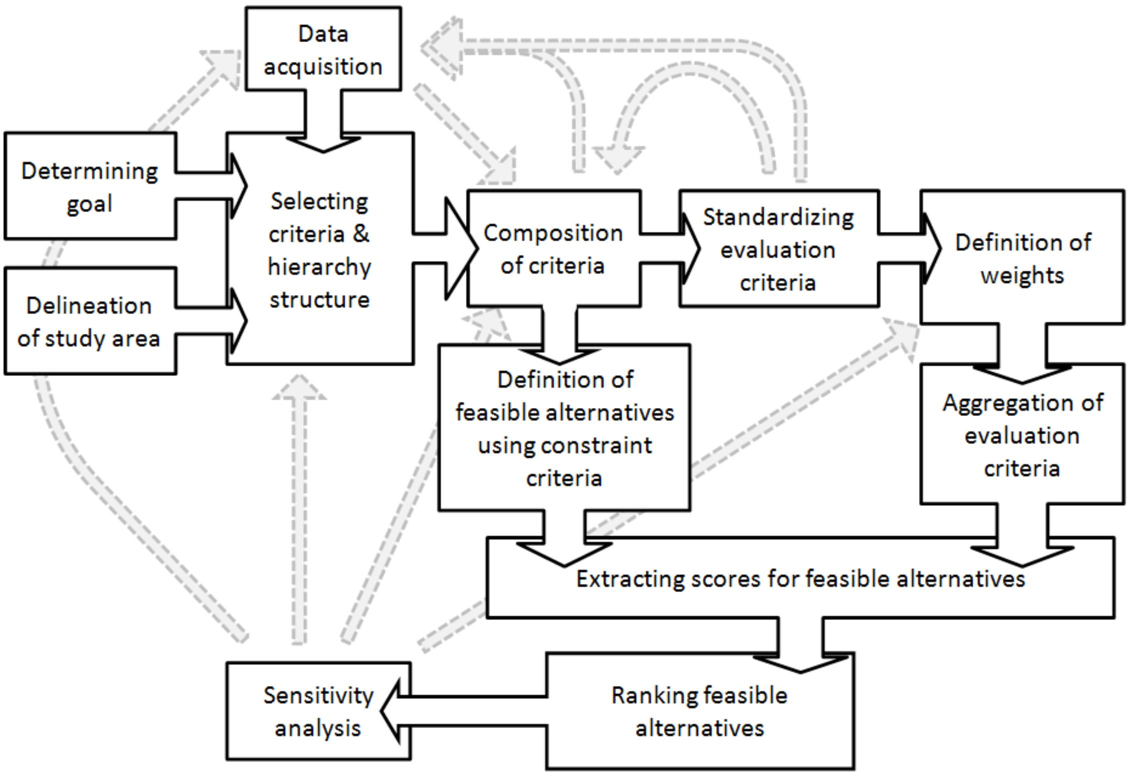

Figure 6. The process of SMCDA as it was used in this thesis. Dashed arrows signify places where it was necessary to return to earlier phases in the analysis.

6.1 Delineation of the study area

The study area was delineated using five different criteria: municipality, onshore location, island size, electricity grid on the island and connections to the main island. The first defining factor was administrative borders of Kemiönsaari and the second on-shore location. Off-shore parks are not discussed in this study because that would require separate analysis. Thirdly, the amount of turbines that should be positioned in one park was considered. National land use objectives state that wind turbines must be located primarily into units of several turbines (Finnish Government 2008). Centralizing is very important especially in areas with sensitive landscape (ME 2011a: 9) such as archipelago (ME 2011a: 16). This was interpreted so that outside the main island of Kemiönsaari, the minimum amount of turbines is three in one park.

In order to calculate the minimum area for three turbines, one turbine, WinWinD3, was selected as an example turbine. The same example turbine was used also for criterion definition when necessary. Its hub height is 120 m and rotor diameter 109 m. In general, the minimum distance between two turbines should be 5 times the rotor diameter (Mikko Niininen, personal communication, week 29/2011), which is 545 m in this case. The surface area was calculated so that 545 meters was used as the side of an equilateral triangle, and then overlaid circle radius was calculated. Based on the radius, circle surface area was computed. This resulted in as approximately 69 hectares: a circle just large enough to accommodate three example turbines. Smaller islands were excluded with the exception of small islands with a bridge connection to the main island.

The fourth factor restricting multi-megawatt wind energy development was the availability of electricity grid. When the study area was defined, those islands without electricity were excluded due to the high cost of constructing underwater power lines. For this purpose, the *islands with electricity* data set was used together with the Topographical database. Project cost on islands without electricity would approach to that of off-shore projects (Ansgar Hahn, personal communication 23.3.2011).

Many islands were excluded from the study area due to insufficient accessibility. Maintenance of a wind park requires sufficient road infrastructure so that the maintenance staff and equipment can reach the area within a reasonable time. Islands without bridge or a regular ferry connection were therefore excluded. Information on the connectivity of islands was acquired from Lounaispaikka (2012) and compared with Digiroad and the Topographical database.

6.2 Decision problem definition

The basic structure of the MCDA includes goal, objectives, attributes, and alternatives as described in the section 4.2. The overall goal of the analysis is to find areas that have least risk of failure for wind power projects. Main objectives were divided into sub-objectives which corresponded to the measurable attributes. Attributes and their connections were decided based on literature and discussions with some wind energy experts.

The structural model (Figure 7) includes three main objectives: minimize damage to environmental and cultural values, minimize impact on society and maximize profit. These objectives correspond to the first level criteria in pairwise comparison. They can be divided further conceptually into sub-objectives – second level criteria in AHP – that help to comprehend the relationship between attributes and main objectives as well as the formation of decision variables. Minimizing environmental and cultural damage includes minimizing impact on birds, nature, landscape and recreation. Each sub-objective relates to one or several attributes that can be used for measuring the potential influence of the decision on the above-mentioned aspects.

Objectives aim at maximizing or minimizing attribute values. Distance to bird protection area and shoreline is maximized in order to avoid detrimental effect on birds. Potential impact on nature is measured as distance to nature reserves. Potential landscape impact is measures in meters as well: it is described by distance to shoreline, landscape protection areas, and protected buildings. Impact on recreation is measured as distance to recreation areas.

The formula for maximizing profit includes minimizing costs and maximizing production. The three factors that affect turbine cost and are dependent on location are distance to roads and grid along with foundation price, so they were selected as attributes for the analysis. Production maximization was simplified here into two attributes: windiness and relative elevation.

The main objective of minimizing impact on society is the most abstract of the three. It includes common practices in wind energy development, some of which are superimposed by authorities. The law does not give strict regulations regarding these factors, but different authorities may give statements that potentially inhibit wind energy development in critical areas. The sub-objectives include minimizing impact on housing and military along with maximizing compliance to wind energy policy, in this case phased regional land use plan draft and its wind power marks. Impact on housing is described by distance to houses and population centers separately. Impact on Defence Forces can be described as distance to restricted zones of the Defence Forces.

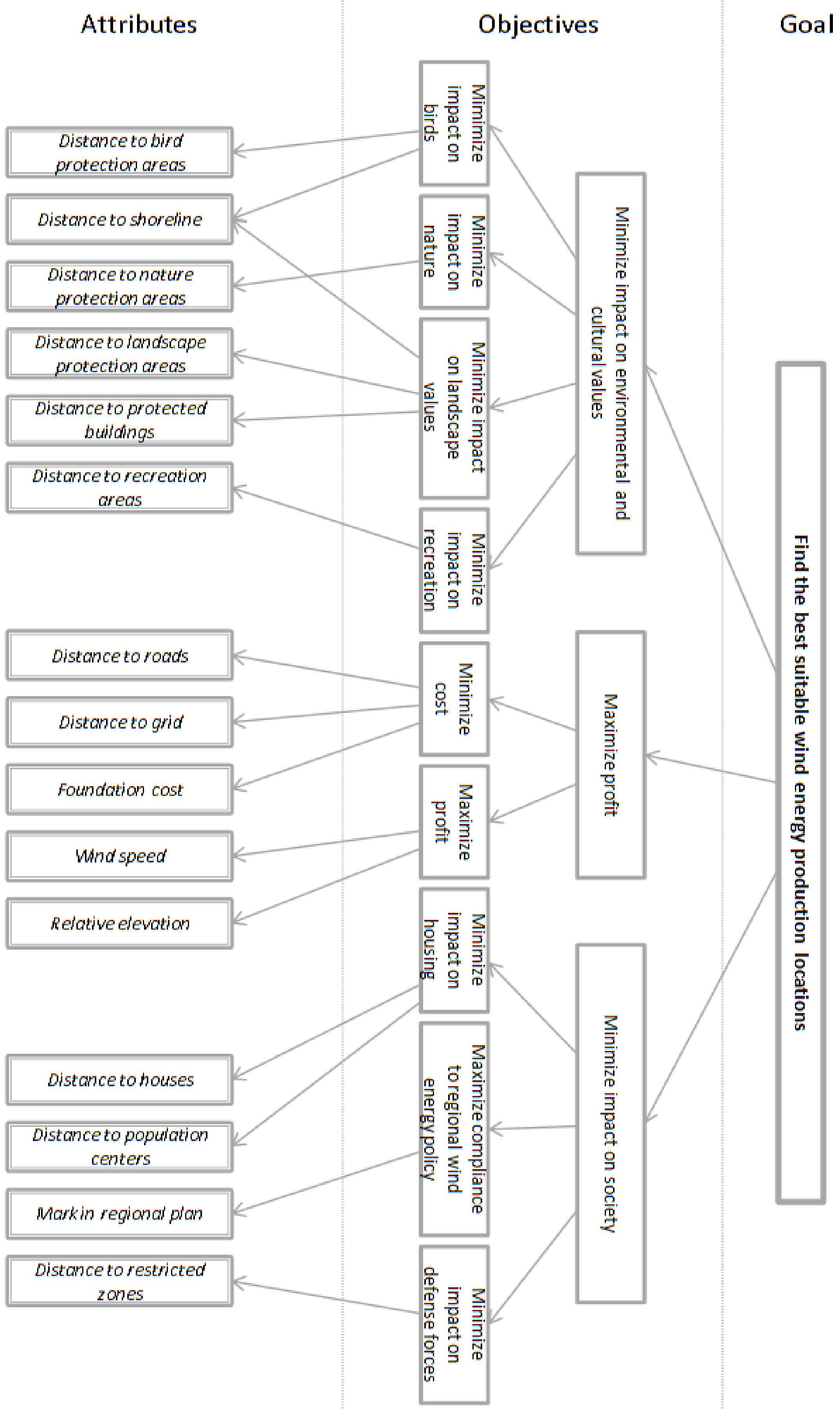

Figure 7: Structure of the decision problem

6.3 Composition of criteria

6.3.1 Economical criteria

Production maximization

Windiness is the main prerequisite for wind energy production. Windiness data was available in the study area only in 250 m resolution. The wind model considers roughness and topography in addition to weather model results. According to the Wind Atlas data, the lowest wind speed in the study area is 6.1 m/s at 100 m. It was assumed that this wind speed would be enough for wind energy production, and therefore no areas were excluded due to low wind speed. In order to interpolate wind data from 250 m to 25 m, center points were extracted from the original data. They were used for interpolation with ordinary kriging method with spherical radius search based on the values of 12 points. Kriging was selected after visual inspection of results from several different interpolation methods as it produced a realistic result without spatial patterning. The result of the interpolation as well as other data that was used for the creation for criteria is visible in the Figure 8. The interpolation outcome was standardized between one and zero using the linear standardization function (Function 2, p. 62).

Wind turbines are preferably placed on top of hills, as windiness is better there than in valleys. Often the 250 m Wind Atlas data fails to observe the subtle variation of Finnish landscape, and due to low resolution it averages out differences in roughness and topography. Similar to the wind power study for Interior Finland (Paakkari 2011), this study attempts to improve the resolution of windiness data with elevation data.

In order to create a raster layer describing relative elevation, DEM was first averaged using a circle-shaped moving kernel with 500 meters radius. 500 meters comes from the concept of wind-uptake area, which is a common approximation of the area where a turbine harvests winds. Then the averaged layer was subtracted from the original DEM. After all the figures were made positive by adding the positive counterpart of the lowest negative value to all cell values, the relative elevation map was standardized using Function 2.

Cost minimization

The three cost factors considered were distance to grid, foundation cost and distance to roads. Electric grid connection constitutes approximately 9 % of the total investment (Vaasa Energy Institute 2012). Price of the connection depends on the connection type – e.g. whether a new substation is necessary and on the power line voltage – and the length of the cable between wind park and external grid. When the distance increases, also costs rise. Therefore it is necessary to favor locations that are close to the grid.

At first, 110 kV grid data was extracted from the Topographical database. A Euclidean distance raster was calculated from the grid with the accuracy of one meter. All values above 10 000 meters were reclassified to 10 000 and all values below 263 meters were transformed to 263 in order to match the evaluation criterion with the corresponding constraint definition (see section 6.6.1). Standardization between one and zero was done using Function 5 (p. 62) for inverted linear transformation.

Turbine foundation cost depends on soil conditions. Ordinary gravity and rock anchor foundation costs about 300 000 € (Pöyry 2010). Soft soil adds another 100 000 € to the price as the turbine has to be piled (Kari Tuominen, personal communication 29.8.2011). In fact, foundation costs constitute 6–7 % of the total investment (Vaasa Energy Institute 2012).

GTK soil maps of the highest available resolution were used for the creation of the criterion map. The original vector data was reclassified in two classes based on base sediments: 1 symbolizing 300 000 € and 0 for 400 000 €. The classes were defined as follows:

1: bedrock classes, mixed grain size sediment classes and water
0: clay, peat, and muddy soils

Water was defined as 1 because resolution of the soil data is coarse and lakes and sea are more accurately described in the Topographical database. Lakes were ignored here in order to avoid duplication.

The third cost attribute was distance to roads. Turbines should not be placed nearby governmentally owned roads due to the Finnish Transport Agency regulations (2012b). However, wind parks require high quality road network for construction and maintenance. Roads must be approximately five or six meters wide and even wider in curves. They should also be able to carry heavy loads. In addition, long blades pose restrictions to road curvature and steepness. Road construction costs usually account for about one percent of the total cost (Vaasa Energy Institute 2012). Nevertheless, if only one or just a few turbines are built far from existing roads, costs may rise significantly, and those can be reduced by placing the turbine close to roads. Clever road planning may also reduce the cost of electric grid construction as internal power lines are often placed in connection with roads.

In this study, Digiroad was used for the road distance analysis. All roads were accepted into the analysis because even small roads are helpful in the planning phase and they can be upgraded. However, many smaller roads would require significant improvements in order to carry the weight of loaded trucks.

For the analysis, Digiroad was edited based on interpretation of an aerial photo and maps. Those islands that did not have road infrastructure but had a port and a regular ferry connection were manually added to the database. A Euclidean distance raster from roads of 25 m resolution was created with accuracy of one meter. The resulting layer was normalized between one and zero using inverted linear scale transformation (Function 3 p. 62).

6.3.2 Environmental and cultural criteria

Minimization of impact on nature

When a wind park is planned, a thorough nature study is required in order to ensure that no important nature values are destroyed irreversibly. Areas that hold significant nature values were excluded by constraints. The evaluation criterion includes only those nature values that were not described in the landscape or bird criterion. Therefore it mainly describes biological values, more precisely vegetation and animal habitats. The nature criteria layer includes private protected areas, SCI areas, programme areas apart from bird water protection programme, and the core areas of the Archipelagic National Park.

There are two ways how wind parks can reduce these biological values on nearby protection areas (Erävuori 2012b). Firstly, if the turbine is constructed in a forested environment close to the border of a protection area, forest clearings may cause edge effect to the protection area. Usually edge effect extends 50 meters from the clearing, but it can reach up to 250 meters. Secondly, average noise level should not exceed 40 dB in protection areas. In some cases the distance required may be up to 1000 m, which is considered to be a threshold after which the protection area does not influence the risk for wind power development. On a standardized criterion map this means that the risk decreases linearly away from nature reserves but reaches the level zero in 1000 m, after which it does not change anymore.

The criterion was composed by creating a Euclidean distance raster from nature protection areas. All cells that were further than 1000 meters were then assigned the value of 1000. Finally the layer was standardized with Function 2.

Minimization of impact on birds

Birds are protected in Finland with species and habitat protection. Species protection requires detailed studies but some important habitats are described in GI format. Natura SPAs are protected by at least EU legislation and bird water conservation programme areas by national legislation. The risk that a bird protection area might impede to the realization of a wind energy farm project is greatest close to them and decreases with distance. A Euclidean distance raster was created from SPA and bird water programme areas, and normalization Function 2 was used for standardization.

Minimization of landscape impact

Unfortunately it is not possible to construct a model that would acknowledge the real landscape impact in the scope of this thesis. A true estimation of landscape impact requires a landscape analysis for all the possible wind park areas. However, it can be assumed that in many cases the closer the park is to a valuable landscape element, the more severe is the impact.

Landscape impact is described here by two criteria. The first one includes landscape protection areas and the second protected buildings. Protected landscape areas include traditional landscapes, constructed cultural environments (RKY) and significant landscape areas. Traditional landscapes do not enjoy similar national protection as RKY and significant landscape areas but they are regionally valuable. Nevertheless, as the study scale is local, all the landscape areas are considered equal. Protected buildings include buildings from the regional land use plan proposal, churches from the protected built heritage layer, and one lighthouse from the Topographical database. Firstly Euclidean distance rasters were created and then the criteria were standardized using linear scaling (Function 2).

Minimization of impact on recreation

Regional land use plan proposition describes recreation areas of national or regional significance. Disturbance can be caused for recreation areas by noise and landscape impact (Klap et al. 2011: 9). Therefore it is recommendable not to plan parks inside recreation areas and it might be necessary to keep some distance to them as well. For the estimation of risk caused by recreation areas, a Euclidean distance raster was created and standardized using linear scale transformation (Function 2).

Maximization of distance to shoreline

Archipelagic shores have many landscapes that are especially vulnerable to wind energy development, and there is also significant land-use pressure for recreation and holiday housing. Avoiding places close to shoreline increases acceptability of wind energy (YLE 2010) and reduces impact on birds (Nordström 2011). A distance raster was first created based on the shoreline data from the Topographical database and then linear transformation was used for standardization (Function 2).

6.3.3 Societal criteria

Minimization of impact on housing

Impact on housing consists of two attributes: distance to single houses and distance to population centers. The minimum distance to housing is 500 meters, after which the impact on the risk for wind energy projects decreases gradually. Inhabitation information is based on the Topographical database, where houses and holiday houses are separated in attribute data. A 500 m buffer to houses and summerhouses was computed and used for the creation of a Euclidean distance raster. The criterion was standardized with the Function 2. Population center data were extracted from the regional land use plan proposal. There are two large population centers on Kemiönsaari: Kemiö and Dalsbruk. A Euclidean distance raster was created, and it was standardized using the Function 2.

Maximization of compliance to the regional wind power policy

A mark in the regional land use plan draft for wind power signifies that according to the studies of the regional council the area is a suitable location for wind energy production. Those were extracted from the phased regional land use plan draft and areas corresponding to the point marks were extracted from the preceding wind power study data set. The study area was categorized into two classes: 1 for areas that had a mark and 0 for areas that did not receive it.

Minimization of impact on Defence forces

The military restricted area delineation was derived from two sources: the Topographical database and regional land use plan proposal. If an area was defined as a restricted in either one, it was categorized as restricted area in this study. The study area has two restricted zones: Skinnarvik and Örö. A distance raster was derived from these areas and standardized using Function 2.

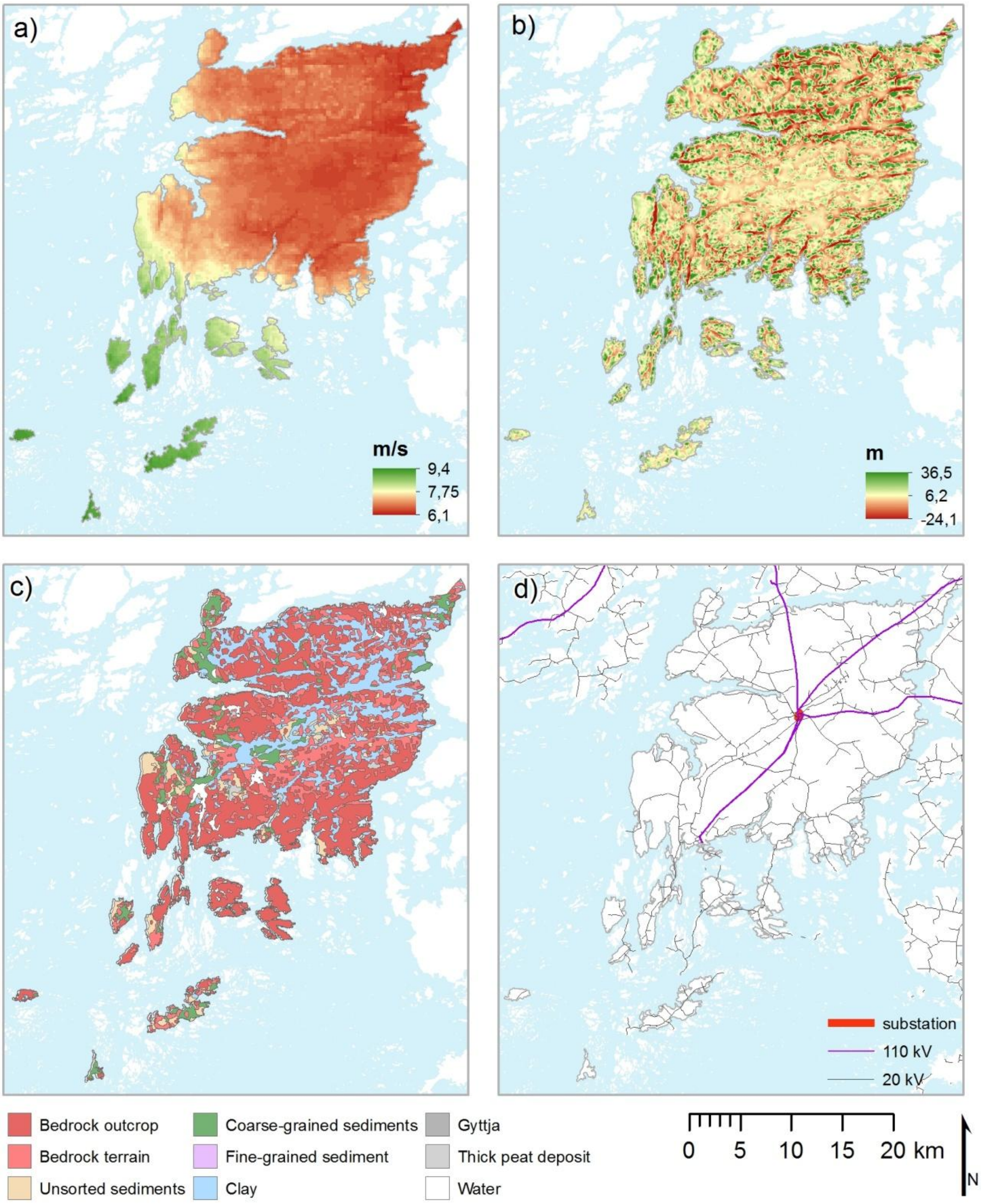

Figure 8. Visualizations of data that was used for the creation of criteria. a) Windiness in 100 m Wind Atlas model result (FMI 2011), b) Relative elevation is based on 25 m DEM (NLS 2007*)*, c) Soil conditions according to The Map of Quaternary deposits 1:200 000 (GTK 2010), d) Electric grid (NLS 2010).

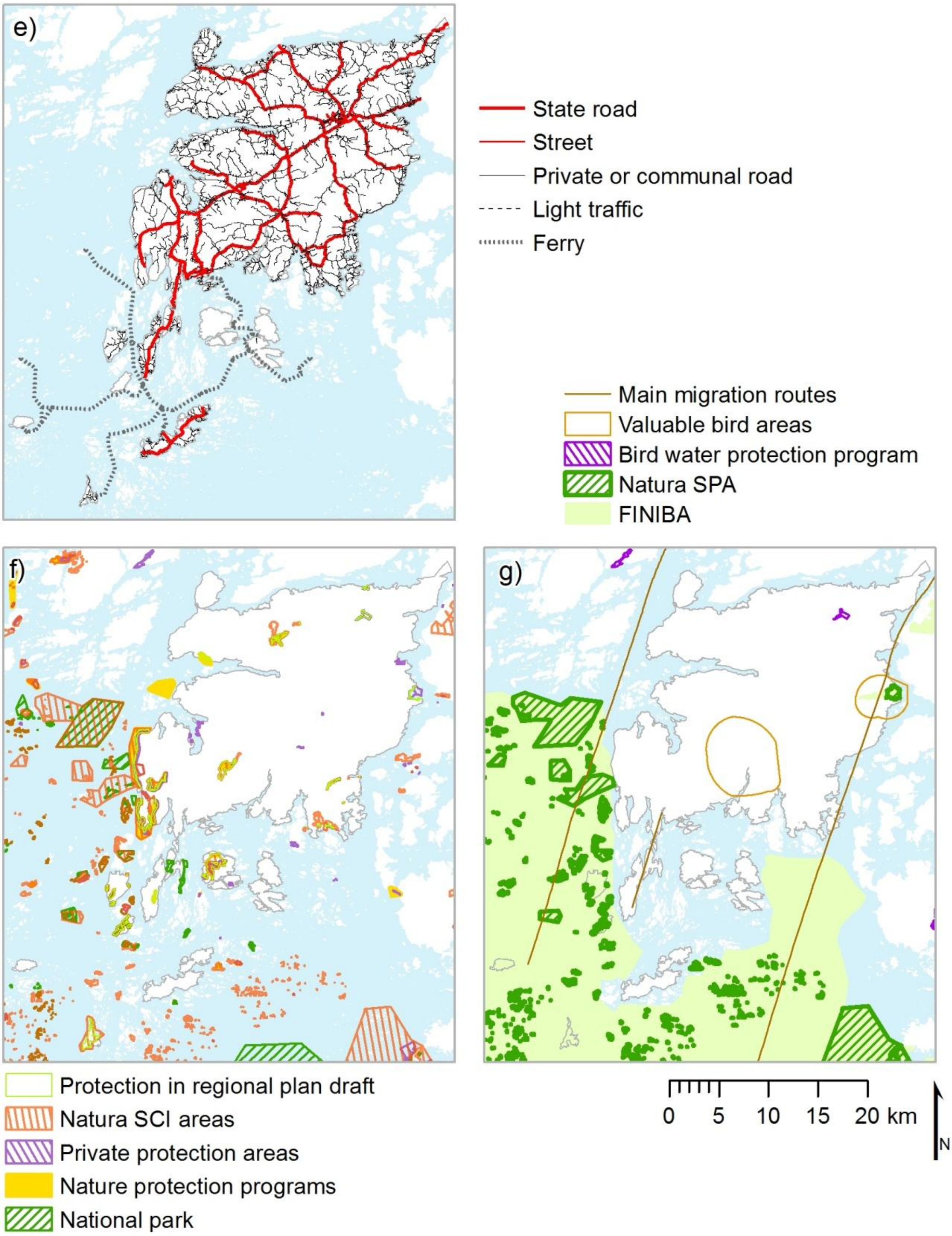

Figure 8 continues. e) Roads from Digiroad (Finnish Transport Agency 2012a), f) Nature reserves (SYKE 2008; SYKE 2010a; SYKE 2010b; Regional Council of Southwest Finland 2011a), g) Bird protection areas and other area important for birds (SYKE & BirdLife 2011, SYKE 2008; SYKE 2010a; Regional Council of Southwest Finland 2012a).

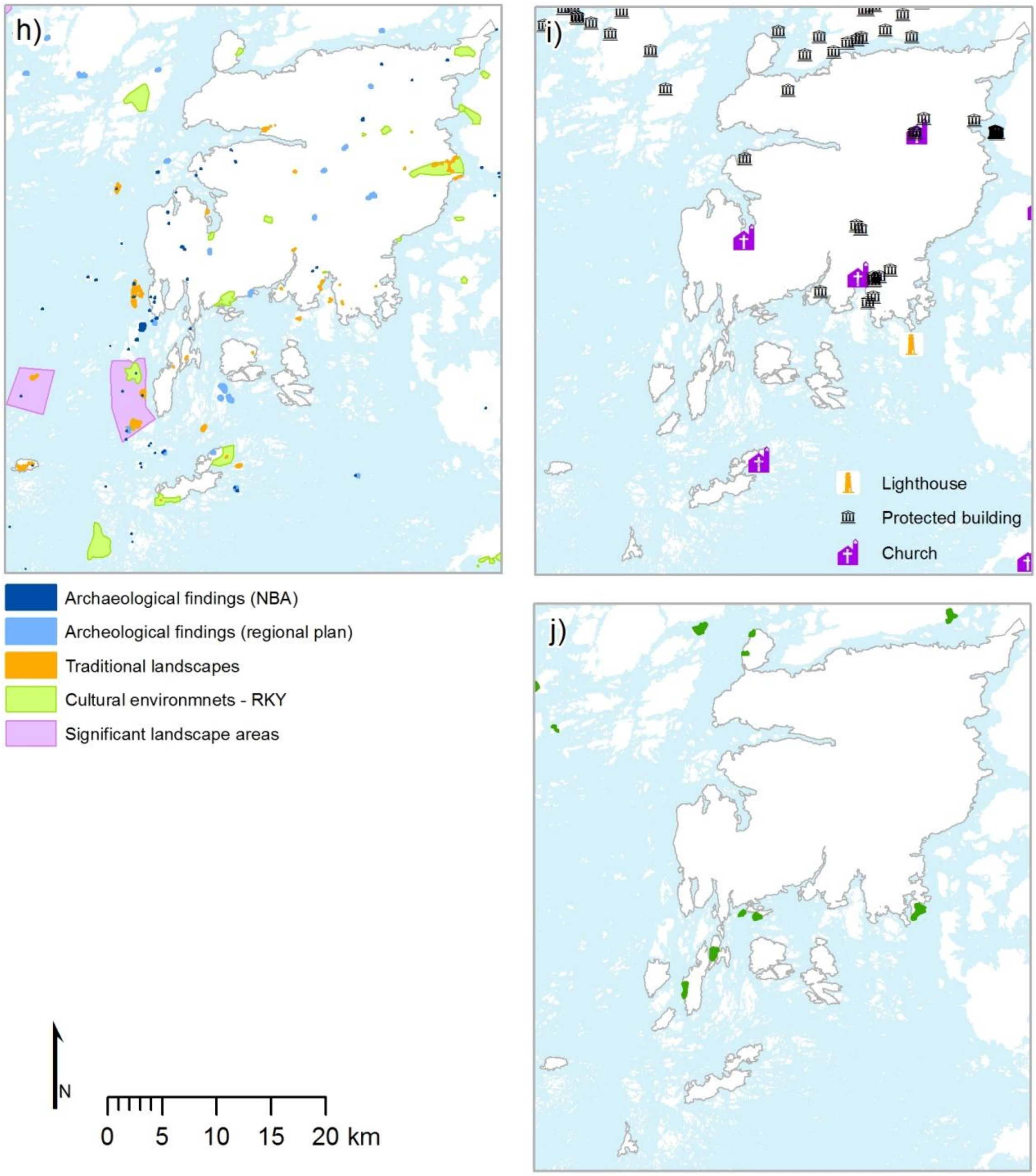

Figure 8 continues. h) Protected landscape conservation areas and historical sites (ELY 2008; NBA 2009; NBA 2010a; Regional Council of Southwest Finland 2011a), i) protected buildings (NBA 2009; NBA 2010b; NLS 2011), j) Recreation areas (Regional Council of Southwest Finland 2011a).

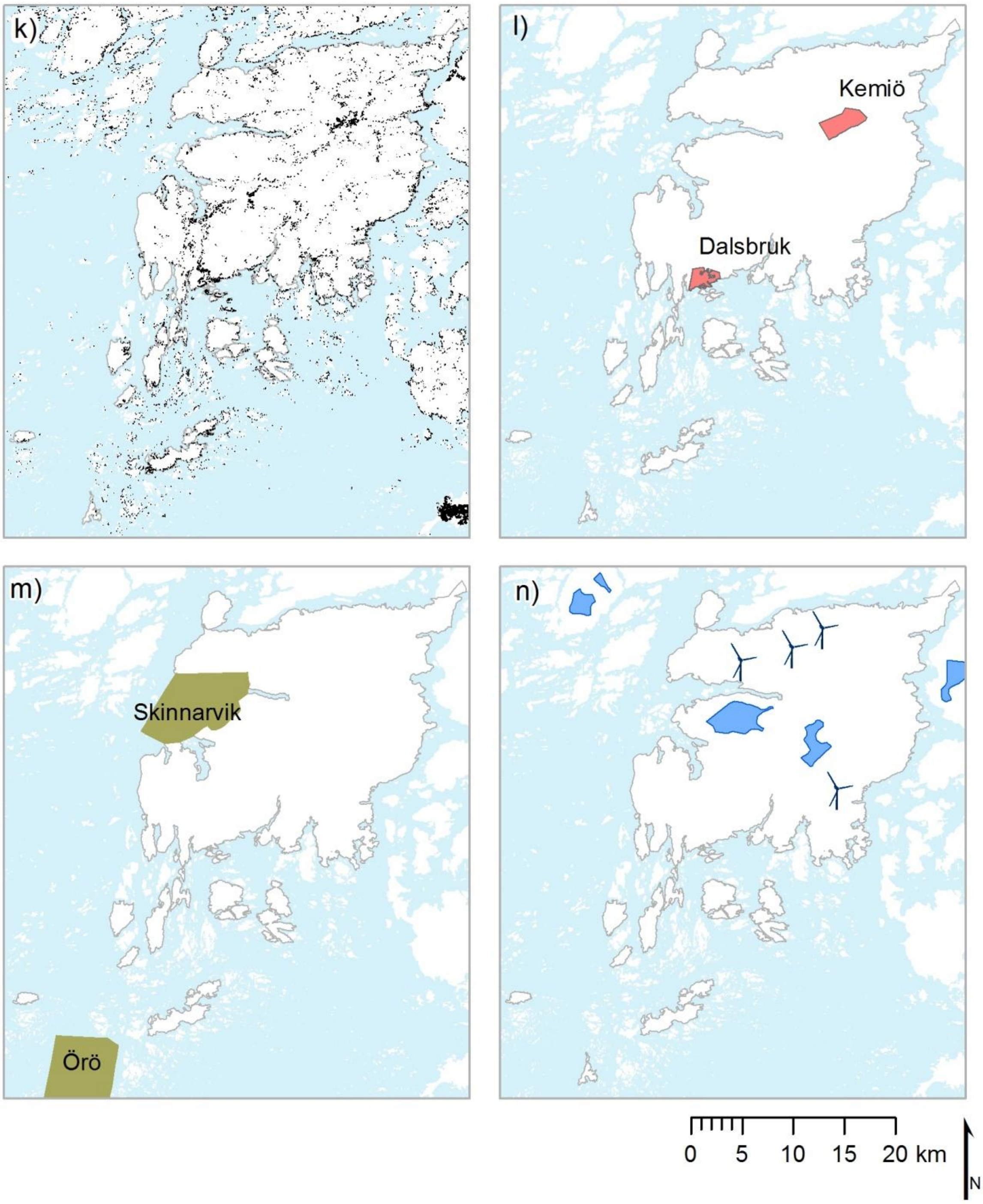

Figure 8 continues. k) Houses and holiday houses (NLS 2011), l) population centers (Regional Council of Southwest Finland 2011a), m) restricted areas of the Finnish Defence Forces (NLS 2011; Regional Council of Southwest Finland 2011a), n) Wind energy markings in the phased regional land use plan draft (Regional Council of Southwest Finland 2012c).

6.4 Criterion standardization

Transformation of attributes into 1–0 scale is called standardizing or rescaling. One is the desirable score. The following standardization functions are described in Malczewski (1999: 117). The simplest way of standardizing is *linear scale transformation*:

$$x'_{ij} = \frac{x_{ij}}{x_j^{max}} \tag{2}$$

, where x'_{ij} is the *standardized score* for the *i*th alternative, x_{ij} is the *alternative's raw score* in the attribute map before standardization, and x_j^{max} is the maximum score in the raw attribute map *j*. Standardized score is calculated by dividing the raw score with the maximum value in the attribute layer. This requires that the lowest value in the raw attribute map is zero and that the risk increases towards the object where the distance is measured from.

Sometimes risk decreases towards the object of interest, for instance when the distance to roads is considered. In that case, *inverted linear transformation* should be applied. The standardized score is subtracted from the maximum standardized score, which in this case is one.

$$x'_{ij} = 1 - \frac{x_{ij}}{x_j^{max}} \tag{3}$$

When the lowest raw score is higher than zero, the lowest score must be subtracted from all the raw scores before standardization so that the lowest standardized score will be no higher than zero.

$$x'_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{4}$$

, where x_j^{min} is the lowest raw value. When low raw value signifies low risk, the corresponding equation is

$$x'_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{5}$$

If there are only two or three categories, values can be assigned directly for categorical data – 0 for those that cause disadvantage, 0.5 for indifference, and 1 to those that cause advantage.

6.5 Definition of weights and execution of aggregation

Experts, which are a sample of decision-makers, include five planners and four wind energy developers. Developers know the criteria that make a location attractive for wind energy, and planners are experts of conflicting land use, and in this case also local or regional statutory land use planning of wind power. There are also other parties that are involved in location decisions, for instance municipality council and ELY centers, but they are not in charge of the planning of wind energy, they mainly present conditions and approve or disprove.

The hierarchical structure (Figure 9) for AHP corresponds to the structure of the problem definition (Figure 6, p. 49). Marttunen et al. (2008) recommend that the problem hierarchy should be defined preferably together with the interviewed experts or decision-makers but due to limited time resource, the structure was defined here without the assistance of those experts. Instead, hierarchy was discussed with selected experts.

Analysis interviews take place between the decision analyst and interested party, expert or decision-maker (Marttunen et al. 2008). It is also possible to use questionnaires or organize a conference in which the interested parties interact freely and form consensus on criteria (Marttunen et al. 2008). Pairwise comparison can be performed for instance by using questionnaires or internet service, but Marttunen et al. (2008: 12) recommend using interviews instead. In this study, structured interviews were used together with the internet MDCM service Web-HIPRE. Interviews were performed during the summer 2012, and they were preceded by an introductory presentation describing the study, AHP, and pairwise comparison. The presentation provided the context and introduced decision-makers to the criteria they would evaluate.

Web-HIPRE tool version 1.22 by the Systems Analysis Laboratory of the Helsinki University of Technology was used for the pairwise comparison (see Systems Analysis Laboratory 2012b). It is a web tool for multicriteria decision making that allows the user to create a customary hierarchical structure and calculate weights for criteria with different methods including AHP. More information and the tool itself can be found from the Web-HIPRE tool website (Systems Analysis Laboratory 2012c). The tool does not support SMCDA itself, but it can be used for defining the weights.

Decision-makers completed a pairwise comparison table for each first level attribute (environmental, economical, and societal) comparing all the related second level attributes pairwise (Figure 10). They viewed maps describing the original data for each criterion similar to those in Figure 8. They were also provided an opportunity to review their answers after viewing the resulting weights. The answers were checked by the decision-makers and interviewer together in order to reach the sufficient consistency measure of 0.2 (see Systems

Analysis Laboratory 2012a). The experts gave comments during the interviews, and some of them provided ideas for the discussion section.

After the weights had been acquired, the WLC formula (formula 1, p. 34) was applied using *Raster Calculator* in ArcGIS 10. In practice, the analysis was conducted separately for each first level attribute in order to obtain thematic maps for discussion. Finally thematic maps were aggregated together for the final score maps separately for the planners and developers and together for both of the groups. No standardizing was made for final score map, which means that it represents planners' opinions slightly more than the developers'. Constraints were excluded from the score maps, and those were ranked by categorizing alternatives into classes corresponding to a percent share of alternatives. Based on ranking, recommendations could be made on where to direct further development.

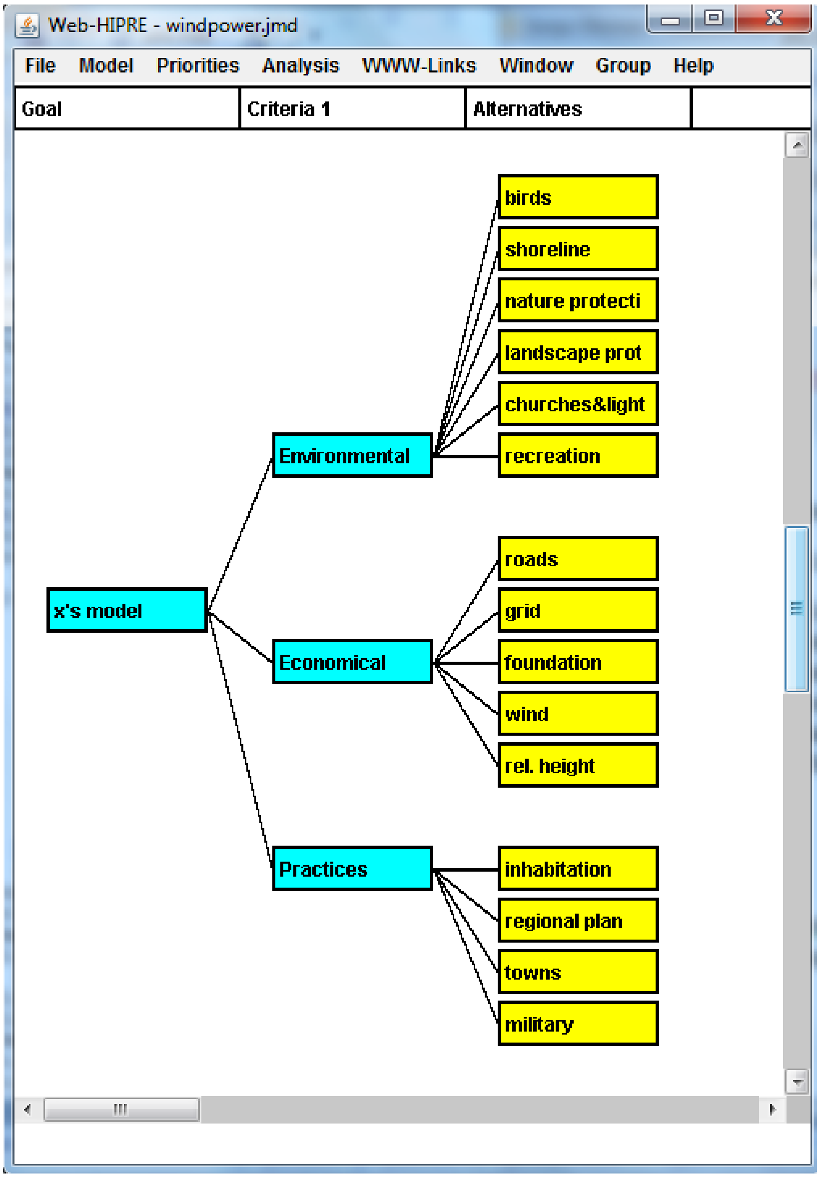

Figure 9. Web-HIPRE user interface with the study value tree. Automatic headings of the hierarchy are incorrect when it is used for SMCDA: in the place of "alternatives" there should be "criteria 2".

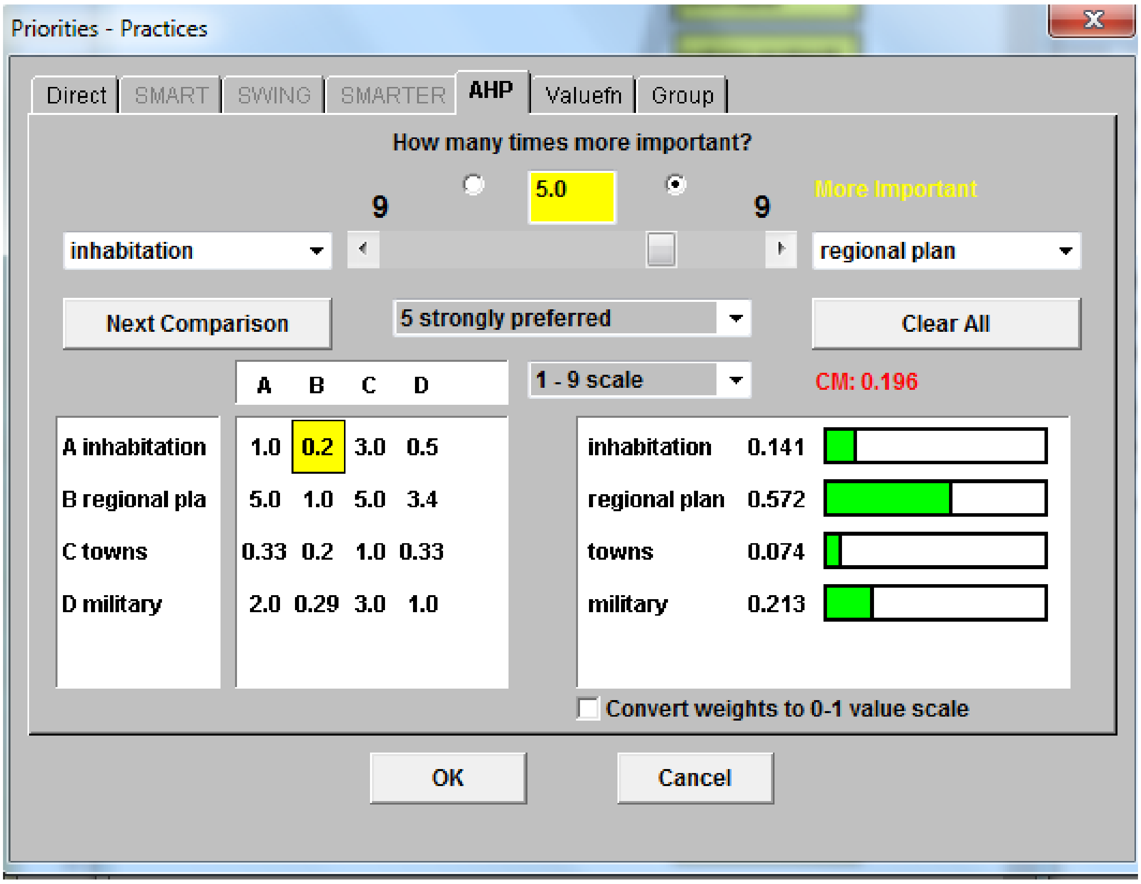

Figure 10. AHP pairwise comparison sheet in Web-HIPRE. The table in the left is the pairwise comparison table. Here phased regional land use plan wind energy mark is strongly preferred over distance to housing after 500 m (the yellow number). In practice the decision-maker assumes that it is strongly more risky to build wind turbines outside regional land use plan draft marks than close to inhabitation, however, exceeding 500 m minimum distance. CM is the consistency measure, and the chart and figures on the right describe resulting weights.

6.6 Definition of constraints

6.6.1 Economical and infrastructural constraints

Land-use restrictions by electric grid

In Kemiönsaari, there are two electric grid companies with 110 kV power lines: Fingrid and Fortum. Fingrid is the national grid company and Fortum is the regional grid owner. The both have transformer stations near Mattkärr on the main island. Fingrid's safety policy on wind energy is that no turbines should be located closer to their overhead power lines than 1.5 times the total height of the turbine (Länsi-Lapin maakuntakaavan… 2011: 8).

Regarding the example turbine that has the total height of 174.5 m, the Fingrid policy means that at least 262 m distance should be kept to power lines. On the contrary, according to Jarmo Saarinen (personal communication 26.1.2012) Fortum does not have strict distance policy as long as turbines are not located too close to the power line. However, here for simplicity it was assumed that Fortum lines cause similar constraint to Fingrid lines.

20 kV lines are relatively easy to move and they do not require safety distance. Therefore they were not considered to cause restrictions to turbine construction.

Maximum distance to the electric grid

In general, wind parks should not be located further than 10 km away from the grid (Klap et al. 2011; Jarmo Saarinen, personal communication 26.1.2012). This is just a simplification, and as the park size increases, it may become feasible to construct wind parks further from the grid. Grid connection voltage is also important: the lower voltage the line has, the higher the energy loss.

Table 7. Constraints and their definition.

Constraint category	Constraint	Buffer/selection
Economical and infrastructural constraints	Grid	10 000 >…≥162 m
	Roads	…≥195m
	Slopes	40 ° >…
	Lakes	
Environmental and cultural constraints	Natura 2000 areas	
	Nature reserves, national parks, protection in regional land use plan	
	Nature conservation programme areas	
	FINIBA	
	White-tailed Eagle nests	…> 2 km
	Significant landscape conservation areas	
	Traditional landscape conservation areas	
	Significant cultural environments	
	Archeologically valuable areas	
Land use and societal constraints	CLC2006 unsuitable land use	see section 6.6.3
	Houses and holiday houses	…> 500 m
	Population centers	
	The Defence Forces’ restricted areas	
	Finavia height limitations	…≥ 175 m

The type of external grid connection of a wind park depends on the park size. Wind parks larger than 25 MW must be connected to a substation (Fingrid 2010). Wind parks smaller than 25 MW can be connected directly to 110kV powerline (Fingrid 2010). Kemiönsaari main island has a stable 20 kV grid that can be used to connect maximum 12 MW of wind energy (Jarmo Saarinen, personal communication 26.1.2012). However, as the distance between a wind park and 20 kV grid increases, the amount of connectible megawatts decreases (Jarmo Saarinen, personal communication 26.1.2012).

The Topographical database depicts power lines but it does not define the voltage precisely. 110 kV lines are described in the regional land use plan draft report (Regional Council of Southwest Finland 2012a), and they mostly correspond to a certain class in the Topographical database. All the other lines in the Topographical database are assumed to be 20 kV lines. It is assumed that turbines are connected to the 110 kV line, and those areas more than 10 km away from 110 kV lines are excluded. The grid constraint as well as all the other constraints are described in appendix III and enlisted in Table 7.

Land-use restrictions around state roads

The Finnish Transport Agency (2012b) poses restrictions on locating wind turbines nearby roads and railways in order to secure the safety of traffic. On state-owned roads with speed limit of 100 km/h or more, the distance of wind turbine from a national road should be at least 300 meters. On Kemiönsaari, the highest speed limit is 80 km/h. For such roads the minimum distance is the width of the safety zone around the road and the total height of a turbine. The safety zone usually reaches 20–30 meters from the center of the outermost lane. In this study it is assumed that the safety zone is 20 meters around all state roads. The total height of the selected example turbine is 174.5 meters. Therefore the resulting safety buffer around roads is 194.5 meters. Digiroad has information on which roads are state roads, and areas closer than 196 m to them were excluded (Figure 11).

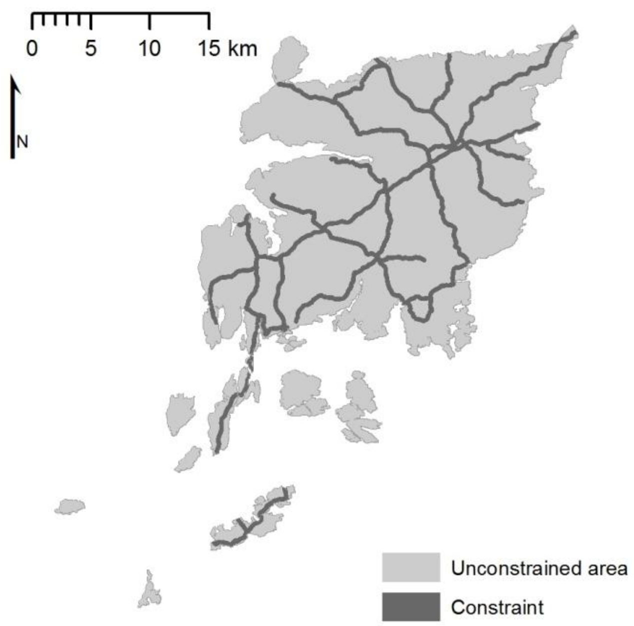

Figure 11. Example of a constraint: road constraint criterion.

Slope steepness

Each turbine needs an access road that should be relatively flat and straight as turbine blades require space during transportation. Furthermore, during turbine erection a flat surface at least approximately 25 meters wide and 40 meters long must be prepared for the crane in the direct vicinity of the turbine. A relatively flat area with enough space for one rotor blade or the whole rotor depending on the rotor montage method is also necessary.

Slope analysis feature in ArcGIS 10 identifies the largest elevation change from a cell to its neighbors. The resulting layer was vectorized and used as an exclusion layer. However, the analysis fails to find detailed-scale ruggedness in the landscape. Although 25 meter resolution elevation model can indicate some no-go zones, the resolution is not high enough in order to be useful in micrositing in such small-scaled landscapes as the study area.

Lakes

Sea has been excluded from the study area due to different requirements regarding grid and foundation. In addition, lakes smaller than 1 ha and some other aquatic environments are protected by the Finnish Water Act (11 § 587/2011). Lakes can be acquired from several data sources, but here the Topographical database was used due to its high spatial accuracy.

6.6.2 Environmental and cultural constraints

Natura 2000

There is no clear indication whether Natura 2000 areas should be excluded. The Finnish Nature Conservation Act (65–66 § 1096/1996) states that protected values of a Natura 2000 area should not be deteriorated, and if a project is likely to cause significant detriment to the protected values, a special Natura environmental impact assessment should be conducted. The Ministry of environment (ME 2012: 38) has stated that bird habitats are critical environments regarding wind energy. This implies that at least SPA areas should be excluded. European Commission recommends judging accommodating Natura 2000 areas and wind energy to the same area on a case by case basis (European Commission 2010: 5). In this study, all Natura 2000 areas have been excluded in order to keep to the safe side even though that might mean exclusion of some areas that actually might be suitable.

Nature reserves

There are both public and private nature reserves on Kemiönsaari. There is for instance the Archipelago national park, which consists of several small areas. No constructions can be built inside national park core areas (Nature Conservation Act 13 § 1096/1996) so they must be excluded. These core areas are depicted in the Nature reserve database by SYKE (Figure 8g). The Topographical database definition is substantially larger than the core areas, and it includes also the surrounding co-operation district where human influence is allowed. Co-operation zone should not be excluded, and therefore SYKE definition is used here.

Private nature conservation areas have a similar protection to public nature reserves (Nature Conservation Act 17 a § 1096/1996). Therefore it is assumed that construction is categorically prohibited on all private conservation areas. In addition, the guidelines for wind power planning (ME 2012: 11) state that nature conservation areas are not suitable locations. Also nature reserves in the regional land use plan were excluded.

Nature conservation programmes and landscape conservation areas

Representative habitat types are protected by six conservation programmes. They are partially overlapping with nature conservation and Natura 2000 areas. Programme conservation is not quite as strict as the protection of conservation areas because the Nature Conservation Act 50 § (1906/1996) states that execution of conservation should be determined case by case and more importantly, the means of protection should be primarily voluntary.

The study area has areas of all the other programmes apart from the conservation programme of old forests. The wetlands conservation programme goal is to conserve wetlands in their natural state. That means that wetlands protected with a programme cannot be used for wind energy as any construction would change their natural state. The same applies to the protected bird waters, groves and shores. Esker conservation programme areas could be used for some purposes that interfere moderately with their natural state. However, due to the landscape conservation agenda of the program, constructing 120 m tall turbines would probably not be allowed. To conclude, even though construction could be allowed to some conservation programme areas, in practice it is reasonable to exclude them all.

Conservation programme data is delivered by SYKE together with the significant landscape conservation area features. An archipelagic cultural landscape conservation area is located within the study area. Protection of significant landscape conservation areas is executed by a decision from the Ministry of the Environment or ELY, but the protection should not cause significant harm to the property owner. This implies that it might be possible to construct turbines on landscape conservation areas. This is also supported by the fact that the only existing turbines in Kemiönsaari are located on Högsåra within the protected landscape conservation area. However, Högsåra turbines are only about 60 m tall (Turku Energia 2008), and this study assumes that the protected values are too sensitive to endure 120 m wind turbines.

IBA and FINIBA

According to the Ministry of the Environment (2012b: 11), Important Bird Areas (IBA) are not suitable for wind energy development, but there are no IBAs on the study area. Finnish Important Bird Areas (FINIBA) should be studied and considered in statutory land use planning (ME 2012: 63–64), but they do not exclude areas categorically. However, as bird habitats are critical areas regarding wind energy, FINIBAs are excluded in this study.

Eagle nests

White-tailed Eagle and their nest trees are protected by the Finnish Nature Conservation Act (38–39 § 1096/1996). WWF recommends keeping at least 2 km distance from wind turbines to white-tailed eagle nests (WWF Suomi 2012). The Finnish ELY centers that steer the EIA process and give statements for licensing have adopted this guideline as a practice, and therefore this study excludes areas that are closer than approximately 2 km from a White-tailed Eagle nest.

Built cultural environments, traditional environments and archaeological findings

Landscape conservation areas such as built cultural environments and traditional landscapes are not considered suitable places for wind energy (ME 2011a: 43). In addition, it might be necessary to keep extra distance to them. Furthermore, archaeological findings are protected by the Antiquities Act, which states that they should not be damaged in any way (1§ 295/1963). Therefore they were excluded from the feasible alternatives as well.

6.6.3 Land use and societal constraints

Unsuitable land use

CLC2006 raster data set was used for creating an exclusion map by defining land cover classes that could not be used for wind power production. The excluded classes are:

- 1.1. Urban fabric
- 1.2.2. Road and rail networks and associated land
- 1.2.4. Airports
- 1.3.1. Mineral extraction sites

1.3.2. Refuse tips
1.3.3. Construction sites
1.4.2.1. Summer houses
3.3.1. Beaches, dunes and sands
4.1.1.2. Inland marshes in water
4.2.1.1. Salt marshes in water

Mineral extraction sites and refuse tips were excluded because such activities induce constant excavation and piling of ground materials, which makes these areas unsuitable for construction. When they are taken out of use, they might become suitable as infrastructure may be already at place and there are no special environmental values. For instance, there is a 3 MW wind park in Karlsruhe, Germany, on top of an old refuse tip (Energie Forum Karlsruhe 2012). Beaches, dunes and sands were excluded as they are protected environmental types (Nature Conservation Act 29 § 1096/1996). Marshes in water are excluded due to their environmental value and foundation costs.

Noise distance

Noise caused by wind turbines depends on the turbine type, its programming and surroundings. Therefore it is difficult to determine one distance that is both reasonable for the industry and sufficient. In this study, 500 meters distance to houses and summer houses is used as a minimum distance. In practice, a 500 m buffer is created around all inhabited buildings depicted in the Topographical database. Nevertheless, it is extremely important that noise levels are modeled separately for each park and layout considering its environment and wind conditions and using appropriate modeling software, modeling standards and case-specific parameters. In addition to 500 m noise buffer, the two largest population centers on the study area have been excluded based on the regional land use plan proposal definition.

The Finnish Defence Forces

All military areas are excluded from the alternatives. The needs of the Defence Forces are protected by the national land use objectives so that other land use should not deteriorate their ability to function or intolerable radar disturbances (ME 2012). Therefore restriction zones in the regional land use plan proposal and the Topographical database are excluded.

Finavia height limitations

Height limitations are posed by Finavia in order to prevent disturbance to safety and fluency of air traffic (ME 2012: 42). A 218 meter limitation surface is located over the northern part of the main island. In order to calculate how much space is left under the limitation surface for construction, terrain elevation was subtracted from it. The areas that did not have enough space for a 174.5 m tall turbine were excluded. However, in some cases these surfaces may be penetrated (Piispanen et al. 2011).

6.7 Sensitivity analysis

Linear scale transformation does not incorporate uncertainty as fuzzy membership functions or probability functions do. Therefore it is necessary to evaluate the result with *sensitivity analysis*, in which inputs are changed and influence on the outcome assessed. If the outcome does not change significantly, it is considered robust. In addition to sensitivity analysis, error related to input data is estimated in section 8.3.4.

Sensitivity to attribute values can be estimated by changing criteria weights or input layers and observing if alternative ranking changes. Analytical error propagation methods and Monte Carlo simulation require a great amount of iterations (see Malczewski 1999: 269–272) due to the amount of criteria and alternatives involved, which exceeds the scope of this thesis. Therefore sensitivity analysis was conducted similarly to many other SMCDA studies (e.g. Tegou et al. 2010; Ferretti 2011): by selecting a restricted number of scenarios and calculating results for them.

Estimation of sensitivity was done using 6 scenarios:

1) *Equal weight*s
2) *Multiple sources*
3) *Extensive bird protection*
4) *Unplanned*
5) *Högsåra*
6) *Low weight exclusion*

Equal weights, Multiple sources and *Högsåra* are based on manipulation of weights. *Equal weights* depicts the situation when all the weights are 0.67. For *Extensive bird protection,* one of the input layers was manipulated. *Unplanned* and *Low weight exclusion* exclude criteria and adjust the remaining ones accordingly. Only wind power marks criterion has been removed from the *Unplanned* scenario, whereas four criteria were removed from the *Low weight exclusion.*

Multiple sources includes a mixture of weights from different decision-maker groups and statistics. The economical criterion was divided into two sections: cost and production.

Weights for the cost section were derived from literature (Vaasa Energy Institute 2012). They are:

Grid connection 9 %
Foundation 6.5 %
Road construction 1 %

of the investment costs when total investment is 100 %. Production figures were equal to the developers' weights:

Windiness: 0.494
Relative elevation: 0.0165

The remaining cost attributes were then left with 34.1 % of the total weight. Percentage for cost factors was calculated according to the following function

$$w = \frac{w_s \cdot c}{\sum w_s} \quad (6)$$

, where w is the weight of an attribute, w_s is the statistical weight, and c is the share of cost factors from the economical criterion. The resulting relative weights were

Windiness: 0.494
Relative elevation: 0.165
Distance to grid: 0.186
Distance to roads: 0.021
Foundation cost: 0.134

, which are 1.000 in total. Because foundation cost criterion had been standardized between 1 and 0, it was necessary to change it in order to avoid exaggeration. In theory, road and grid price can be close to zero, but foundation must always be constructed. Foundation price ranges between 300 000 € and 400 000 €. In order to represent that range, the criterion was standardized between 0.75 and 1.

The planner view was used for environmental attributes, because the planners were assumed to have greater expertise on the environmental legislation in Finland and environmental impacts of wind power than the developers. Combined weights were used for the societal attributes as well as the first level criteria,

In *Extensive bird protection,* the bird protection criterion was manipulated by adding new features into the data layer that was used as the input layer for the Euclidean distance analysis. This data set was obtained from the Regional Council, and it describes main migration routes and other important bird areas. As the new bird data was not considered during the interviews and these routes and areas already have been considered in the phase regional land use plan draft, the scenario result is unreliable. Nevertheless, it is useful for the interpretation of results and detecting double-counting.

Högsåra simulates the case when the maximum park size is 12 MW or four 3 MW turbines. It is named after the existing 6 MW Högsåra wind park. The motivation for this scenario is to provide estimation of risk for small wind parks. It differs from the original analysis by input data, alternative definition and weights. The electric grid input layer was changed from 110 kV line to 20 kV line. In addition, restrictions posed by distance to 110 kV line were removed. Finally, the economical layer was manipulated in order to simulate the loss of mass benefits. Costs received 2/3 of the criterion weights whereas production had 1/3. Corresponding weights were calculated using Function 6.

Windiness: 0.250
Relative elevation: 0.083
Distance to grid: 0.397
Distance to roads: 0.139
Foundation cost: 0.131

For the other parts of the scenario, combined weights were used.

For the *Low weight exclusion,* lowest ranking criteria were eliminated and the remaining ones adjusted iteratively until all the weights were higher than 0.05. As a result, four weakest criteria were eliminated.

Wind 0.156
Relative elevation 0.058
Grid 0.055

Nature protection 0.072
Birds 0.174
Landscape protection 0.109
Protected buildings 0.066
Shore 0.053

Houses 0.103
Population centers 0.055
Regional plan 0.097

Results of the described sensitivity scenarios are presented in section 7.5.

7 Results

The seventh chapter consists of results of different analysis phases. Results are expressed in the form of maps and their interpretation is supported by text, charts and tables. Criterion maps are depicted in the first section and results of weight application in the second. In addition, weights are scrutinized and compared between each thematic group. The third section concerns constraints and alternatives, whereas the fourth one examines results of ranking. Finally, scenario maps from the sensitivity analysis are viewed.

7.1 Criterion maps

Fifteen criterion maps are depicted in Figure 12. Most of the maps describe distance to certain elements of interest, a few are derived from other continuous scale rasters, and two describe favorability of conditions based on categorical data.

The two criteria describing productivity objective, *windiness* and *relative elevation*, are rescaled continuous data maps. In the windiness criterion, alternatives with at least the score of 0.5 are located in the archipelago but scores in the main island are lower. Many high-ranking areas are excluded by environmental causes and inhabitation. Relative elevation criterion emphasizes valleys and hills whereas flat areas receive intermediate values. Most of the study area scores are slightly below 0.5, although peaks are visible in green and valleys in red.

Foundation price, distance to grid and *distance to roads* describe the cost factor. Foundation price is divided into two classes, 0 and 1. Most of the study area is included into the class 1, and only fields and wetlands are in the class 0. Many 0 areas are located under the housing buffer as people tend to live close to fields, not on rocky forested hills. Grid criterion induces the best scores for the internal and northeasterly parts of the main island. From the perspective of transportation, most of the study area receives high scores so the value range is negatively skewed.

For all environmental criteria, risk gets lower with distance. *Distance to nature reserves* differs from the other environmental criteria because the influence of a protected area extends no further than 1 km. Therefore most of the study area is not affected by nature reserves and the spatial transition between high and low scores is sharp.

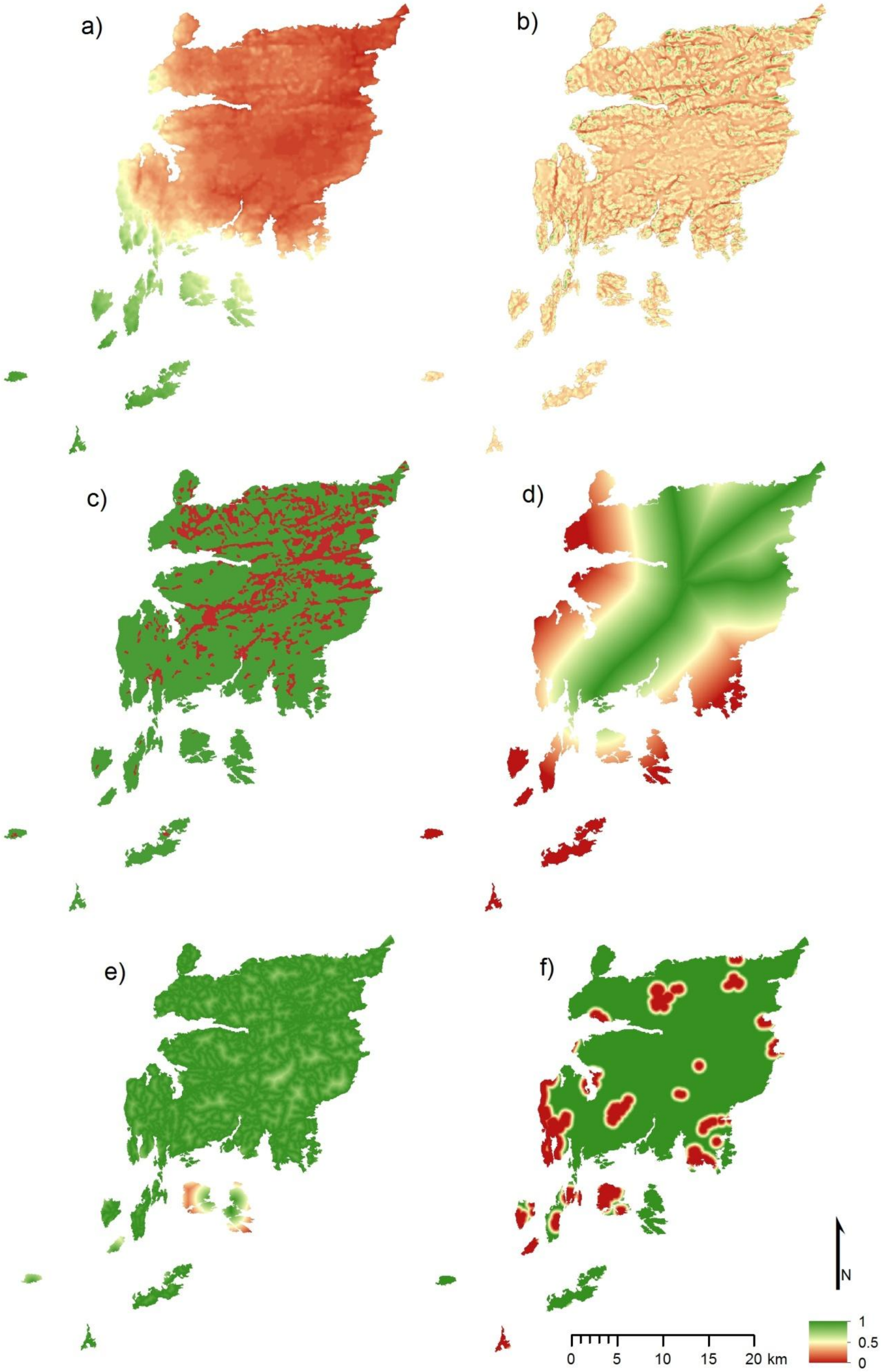

Figure 12. Evaluation criteria. a) Windiness, b) relative elevation, c) foundation price, d) distance to grid, e) distance to roads, f) distance to nature reserves.

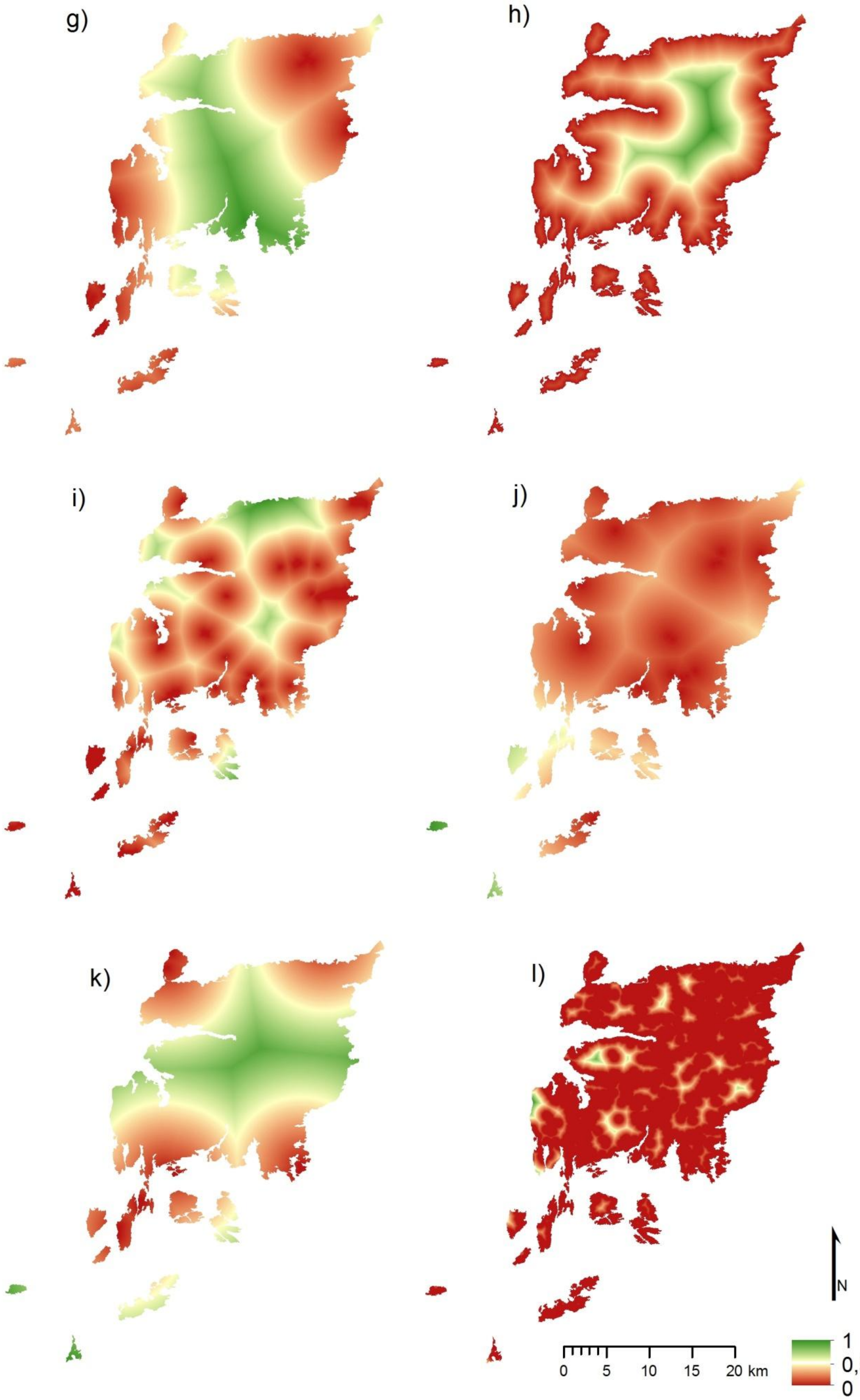

Figure 12 continues. g) Distance to bird protection areas, h) distance to shoreline, i) distance to landscape conservation areas, j) distance to protected buildings, k) distance to recreation areas, l) distance to housing.

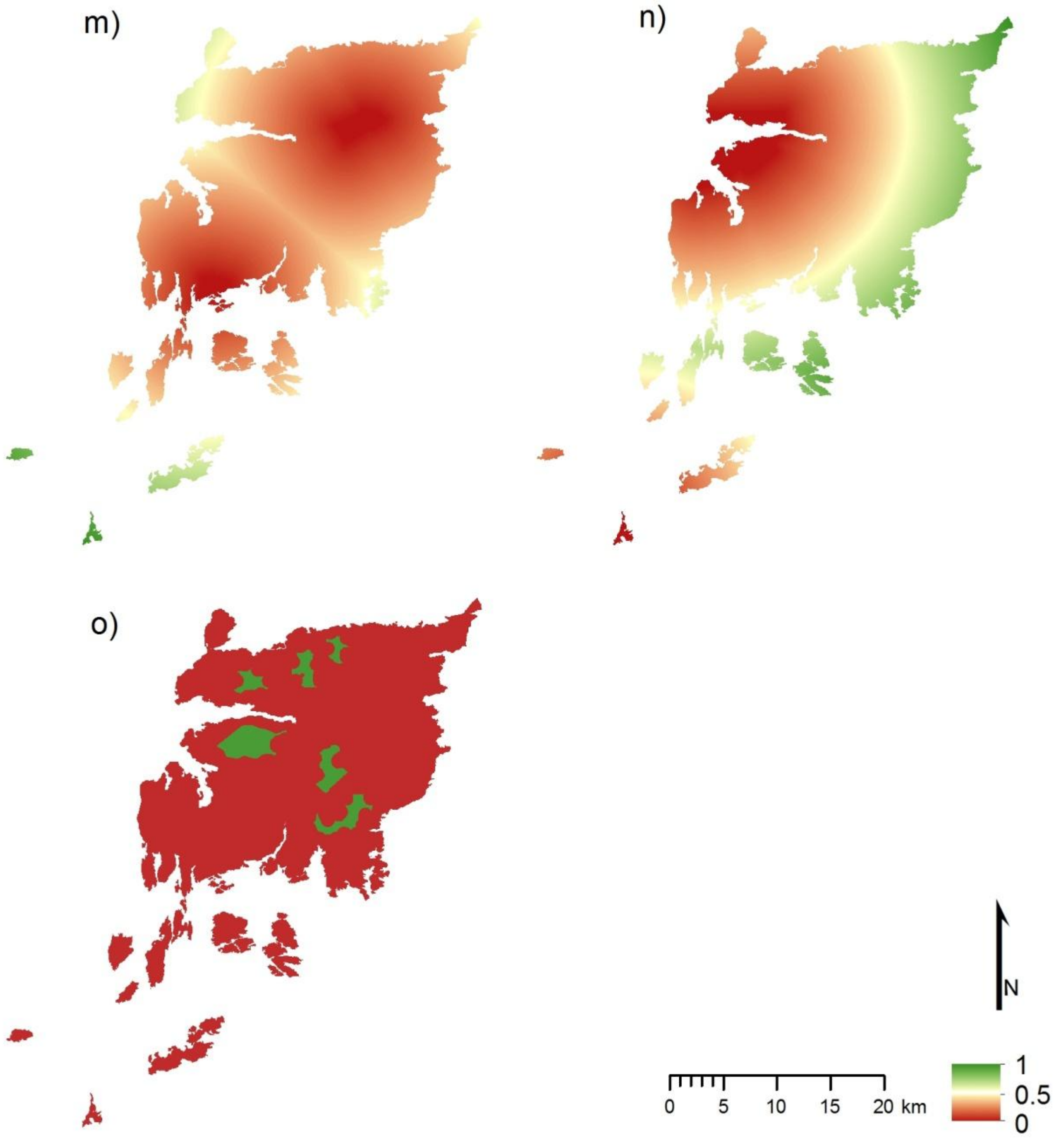

Figure 12 continues. m) Distance to population centers, n) distance to restricted areas of The Defence Forces, o) wind power marks in the phased regional land use plan draft.

Distance to bird protection areas and *distance to recreation areas* are similar in the sense that the areas with low scores are located around the edges of the study area. Internal areas of the main island receive the highest scores. *Landscape conservation areas* and *protected buildings* are scattered around the study area with just a few places that are relatively far from protected sites. Their range is positively skewed. *Distance to shoreline* leaves central areas of the main island with high scores and value distribution is positively skewed. The furthest point from shore is only 6.6 km away, which emphasizes the study area‘s archipelagic character.

Of the societal criteria all but one are distance rasters. *Distance to housing* has a range that is strongly positively skewed as much of the study area is covered by the 500 m housing buffer. The longest distance to the 500 meter buffer is about 1700 meters. The furthest *distance population centers* is about 25 km. The most distant areas are in the archipelago, whereas most of the main island is less than 12 km from one of the two population centers. *Distance to restricted areas* receives low values in the west and high values in the east. The Regional Council's wind power areas are described categorically with only values one and zero. Most of the island is belongs to the class 0.

7.2 Comparison of criterion weights and score maps

In this section, weights derived from the analysis interviews are scrutinized together as well as separated to the two decision-maker groups of developers and planners. The averaged weights are enlisted in the appendix I. The second level criteria weights were multiplied with the first level weights, which resulted in as absolute weights for each criterion. They are visualized in Figure 13. The both decision-maker groups agreed that windiness and distance to bird protection areas were very important criteria. Planners thought that also distance to landscape protection areas and housing were very important. Phased regional land use plan mark was more important to the developers than to the planners. Both groups agreed about the low ranking of distance to roads and foundation cost.

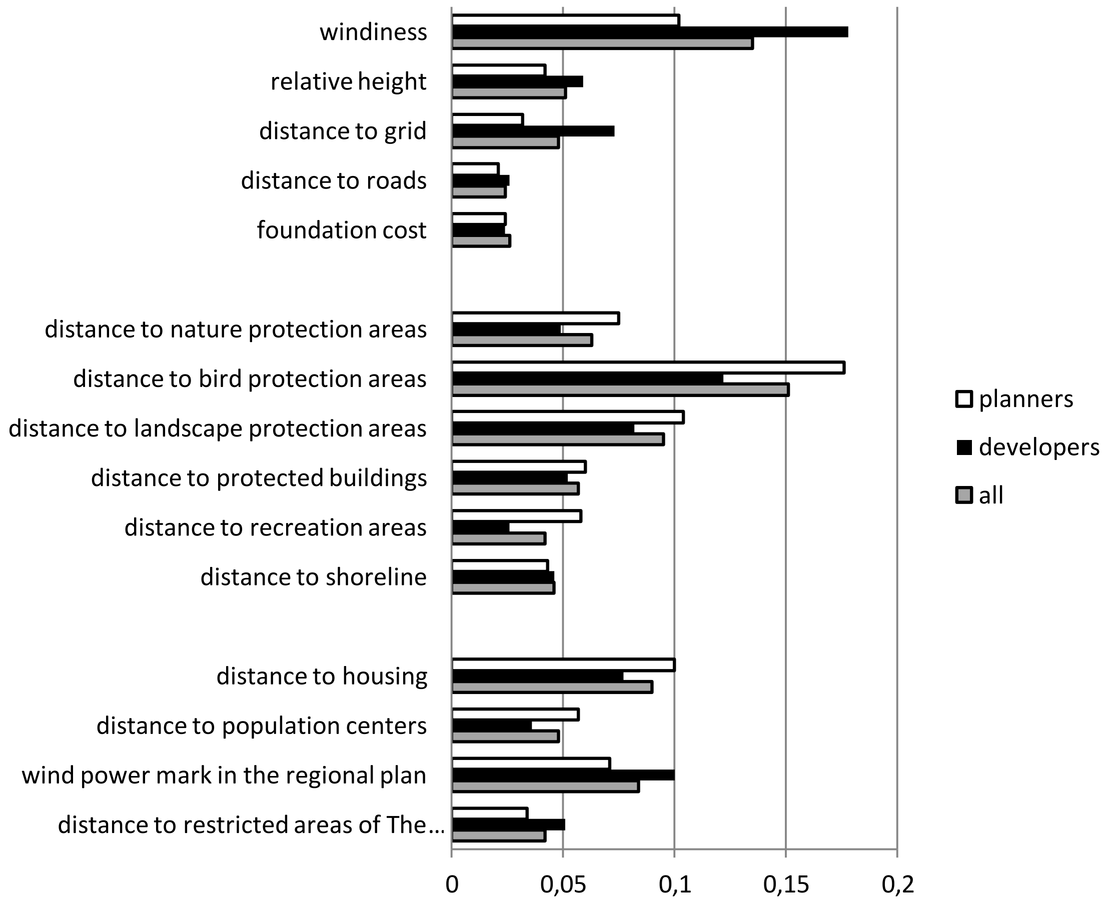

Figure 13. Second level criterion weights derived from the analysis interiviews.

The second level criterion weights are described in Figure 13 and the first level weights in Figure 14. Environmental values were the most important first level criterion for the planner group and it received more than 50 % of the total weight. For the developers, the environmental criterion was the most important also, but for them, the economical values were almost as important. The both interest groups agreed about the weight of the societal criterion: instead there was no agreement on the relative significance of environmental and economical values.

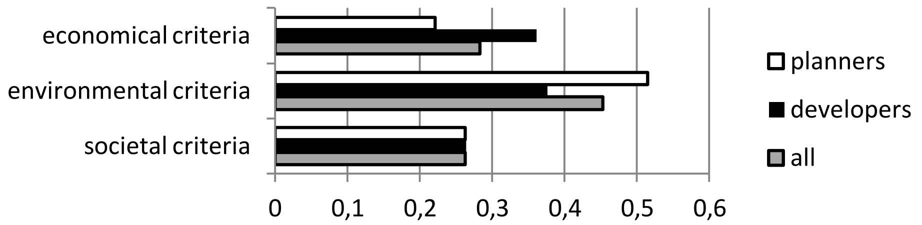

Figure 14. First level criterion weights derived from the analysis interviews.

Figure 15 describes the results of all nine decision-makers. In the economical criterion, windiness clearly dominates with its weight of 0.476, and the best areas are located in the archipelago. Poor soils are visible as slightly less attracting than their surroundings. Relative elevation causes only gentle patterning in the map. Distance to grid is evident as it increases the suitability of central areas of the main island. Impact of roads does not show in the map as it is has only 0.084 weight and road network is extensive in the main island.

The distribution of environmental scores is negatively skewed. The lowest values are in the archipelago and southeastern and northwestern archipelago, where many environmental values accumulate, especially bird and landscape values. The map indicates that interior parts of the island are least risky from the environmental perspective. Distance to bird protection areas dominates the map, although also shoreline impact is visible. Nature reserves are clearly visible due to the sharp transition from zero to one. The impact of landscape conservation areas, protected buildings and recreation areas do not show on the map.

The societal practices map is strongly positively skewed. Regional plan dominates and defines the best areas even though it has lower weight than distance to housing. Categorical definition creates a sharp transition to the map. Also distance to houses shows a clear pattern and enhances the impact of the Regional Council’s wind areas. Distance to restricted areas and population centers are not that explicit and are visible only as a slightly stronger red tone between population centers and Skinnarvik. In the rank map these two criteria are clearly visible: the worst 10 % is centered near towns and military.

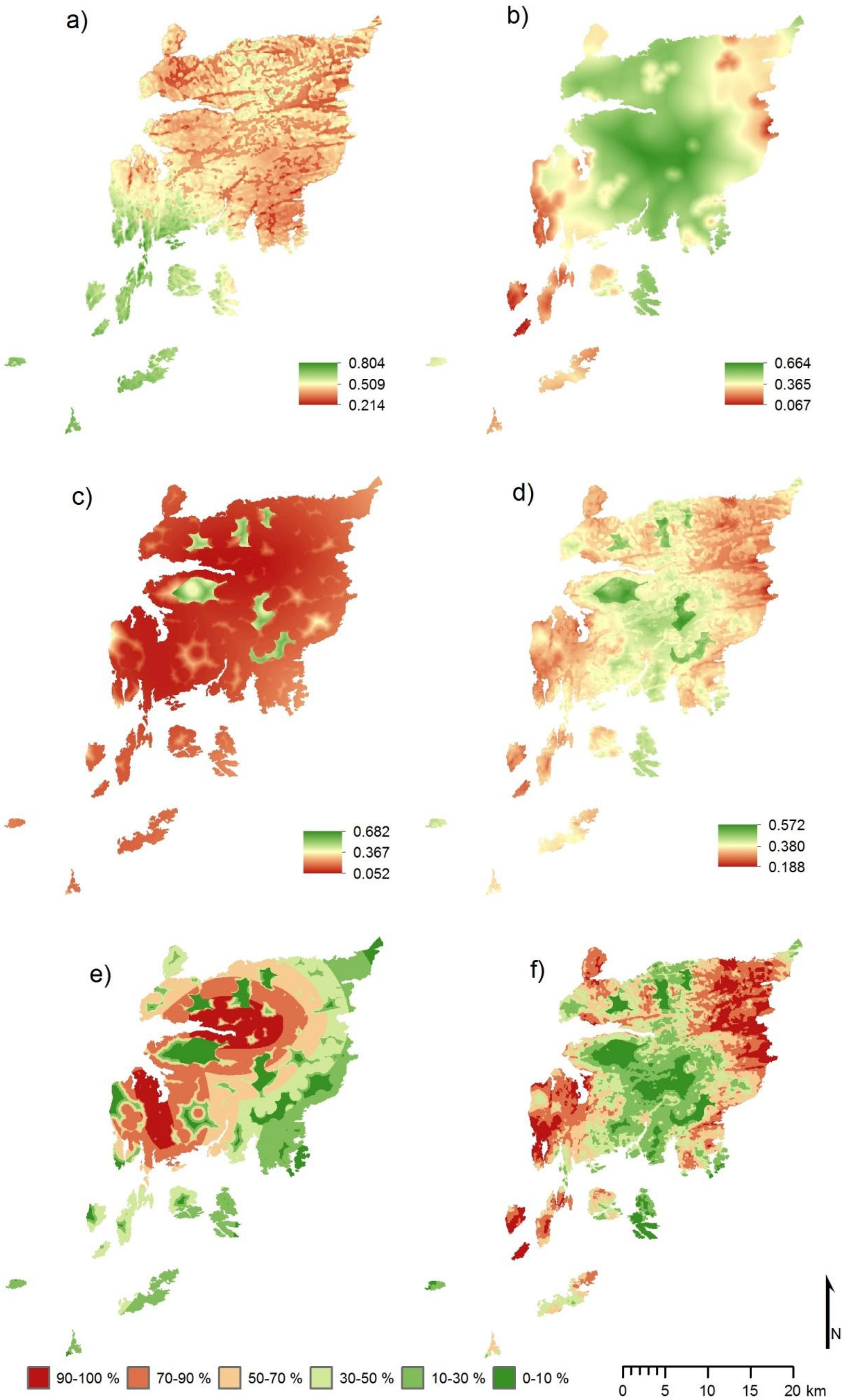

Figure 15. First level criterion score maps and resulting score and rank maps. Percentages in rank maps describe the share of alternatives that rank higher than the alternative in question.a) Economical score map, b) environmental score map, c) societal score map, d) decision outcome score map, e) societal rank map, f) decision outcome rank map.

In the decision outcome rank map, the most striking features are the wind park areas even though the criterion received only 0.084 as weight. Another distinctive resemblance is to the environmental map, which got 0.451 as weight. Windiness does not show directly despite of the 0.135 weight. Valleys are distinctive, perhaps because they are categorically defined in the criteria and relative elevation and wind data emphasizes them in some places. Despite of low wind conditions, most low-risk places are found in the interior parts of the main island.

The economical maps (Figure 16) are very similar apart from a slightly redder tint in the northwest and southeast corners in the developers' map. This is due to the impact of grid, which has slightly higher weight in the developers' map. On the contrary, foundation is slightly less pronounced in the developer's map.

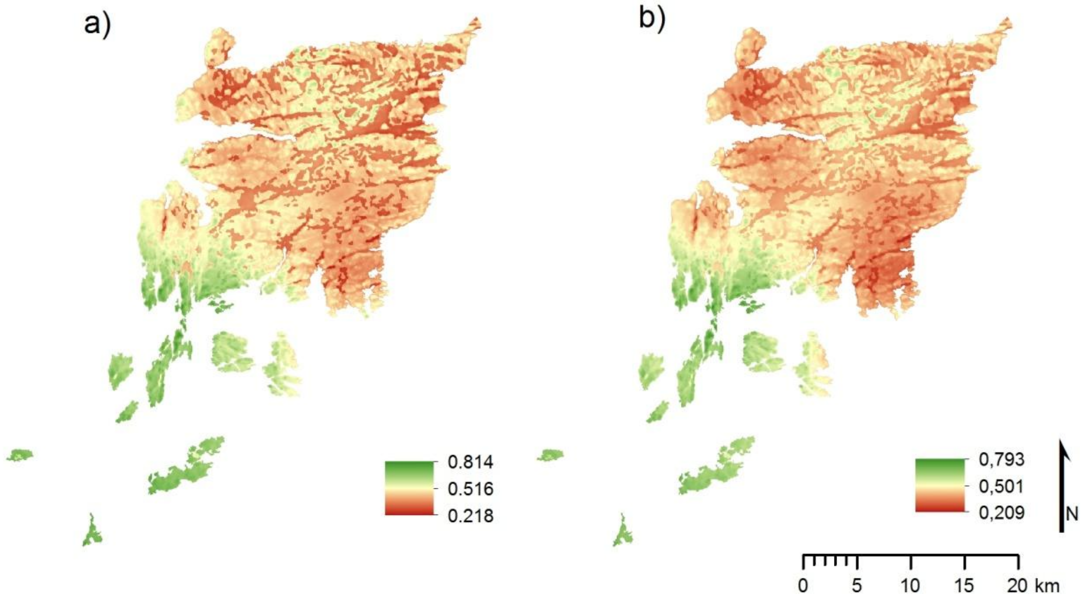

Figure 16. Economical score maps of a) planners and b) developers.

The difference between group maps is minimal when it comes to environmental values (Figure 17). All the other second level environmental weights of the groups are very similar apart from the distance to recreation areas and shoreline. However, their weights are relatively low and their difference is not large, so differences do not show clearly in the score maps.

The societal criterion score maps (Figure 18) look very similar but when the scores are ranked and ranks categorized. a new pattern is revealed. In the planners' map, the worst 10 % of area is centered on population centers and stretched towards the restricted areas. In the developers' map, they are centered on the restricted area and stretched towards population centers. This difference was caused by that planners weighed population center higher and developers restricted area. In the combined societal rank map, this results in as a pattern

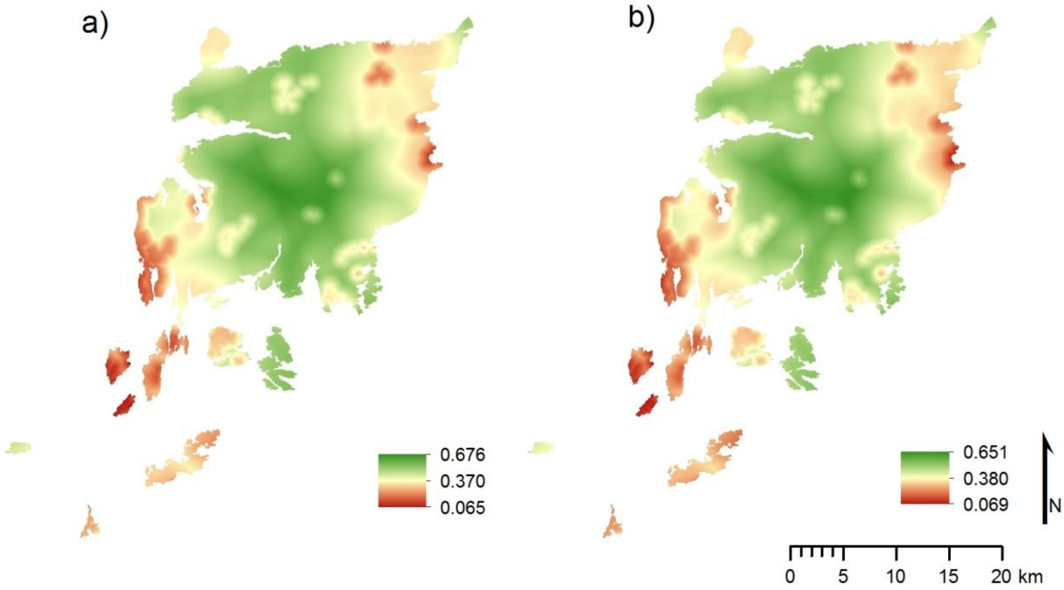

Figure 17. Environmental score maps of a) planners and b) developers.

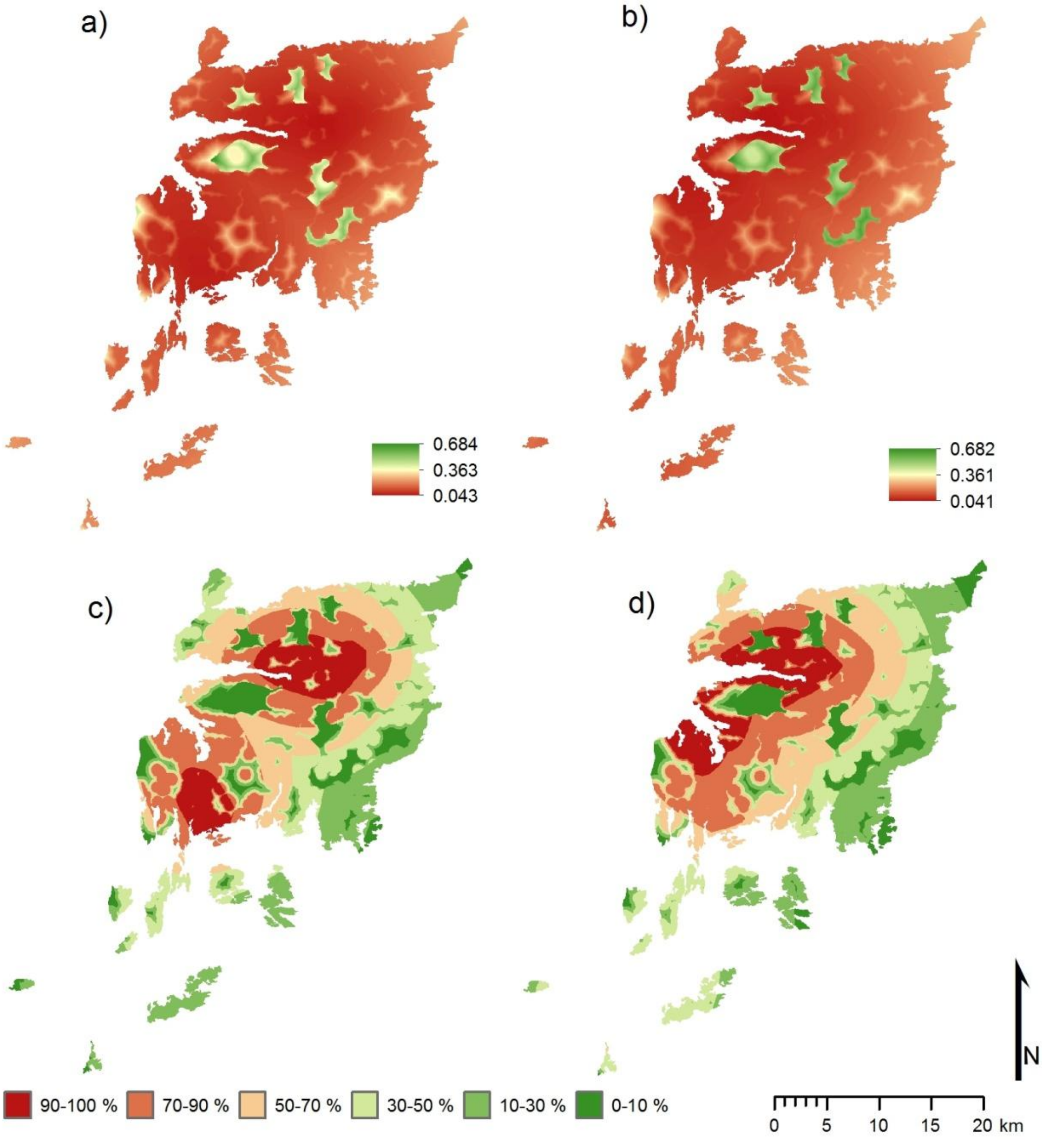

Figure 18. Ranking reveals new patterns from societal score maps. a) Planners' societal score map, b) developers' societal score map, c) planners' societal rank map, d) developers' societal rank map.

where the lowest weights are between Skinnarvik and population centers (Figure 14e). Distance to inhabitation was the strongest criterion in the planners' weights, so that is more evident also in their map than planners'. Regional plan is stronger in the developers' map.

Societal practices are almost equal in the both group result score maps (Figure 19). Because of the difference in first level criteria weighs, phased regional land use plan marks are more pronounced in the developers' map. The economical criterion is much more pronounced in the developers' score map and environmental criterion in the planners' score map. Internal parts of the island score higher in the planners' map due to high emphasis on the environmental criteria. Developers' map resembles more to the economical map showing lower values in the northwest and southeast.

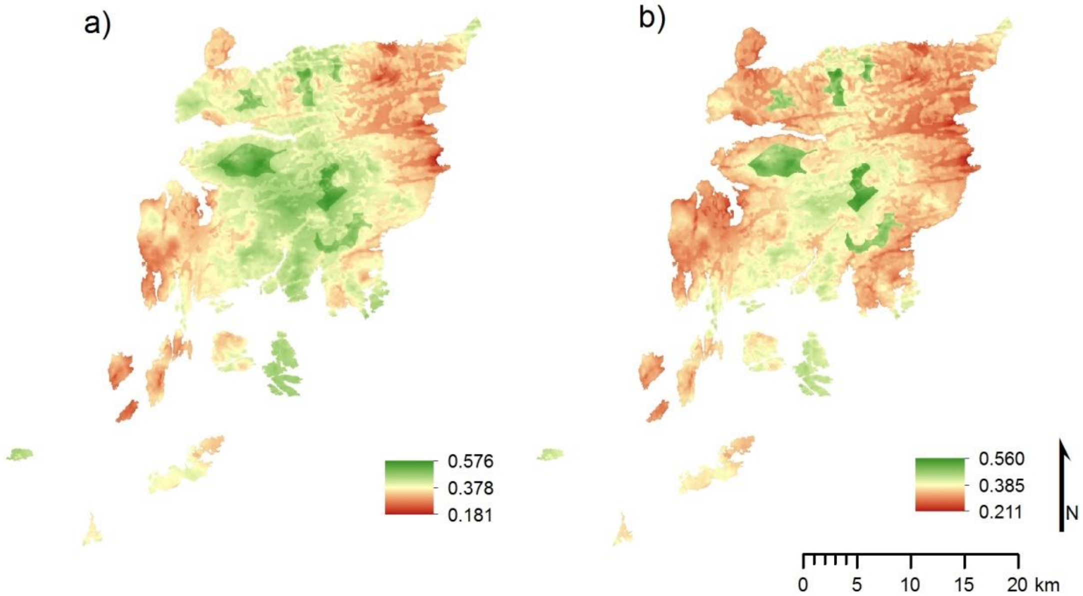

Figure 19. Decision outcome score maps were derived by aggregating all the evaluation criteria. a) Planners' scores, b) developers' scores.

7.3 Delineation of feasible alternatives by constraints

All the areas not restricted by constraints are feasible alternatives (Figure 20). 82.69 % of the study area is covered by at least one constraint, which leaves 10157 ha or 17.31 % for feasible alternatives. The largest patch of feasible alternatives is 1238 hectares. Each patch possibly together with the neighboring patches may be understood as a potential wind park area. All patches large enough for three or more turbines are located on the mainland. Most of the smaller islands were excluded altogether by constraints. 500 m housing buffer shows most clearly but also grid restriction is evident. In addition, few places are excluded by protection areas or White-tailed Eagle nests.

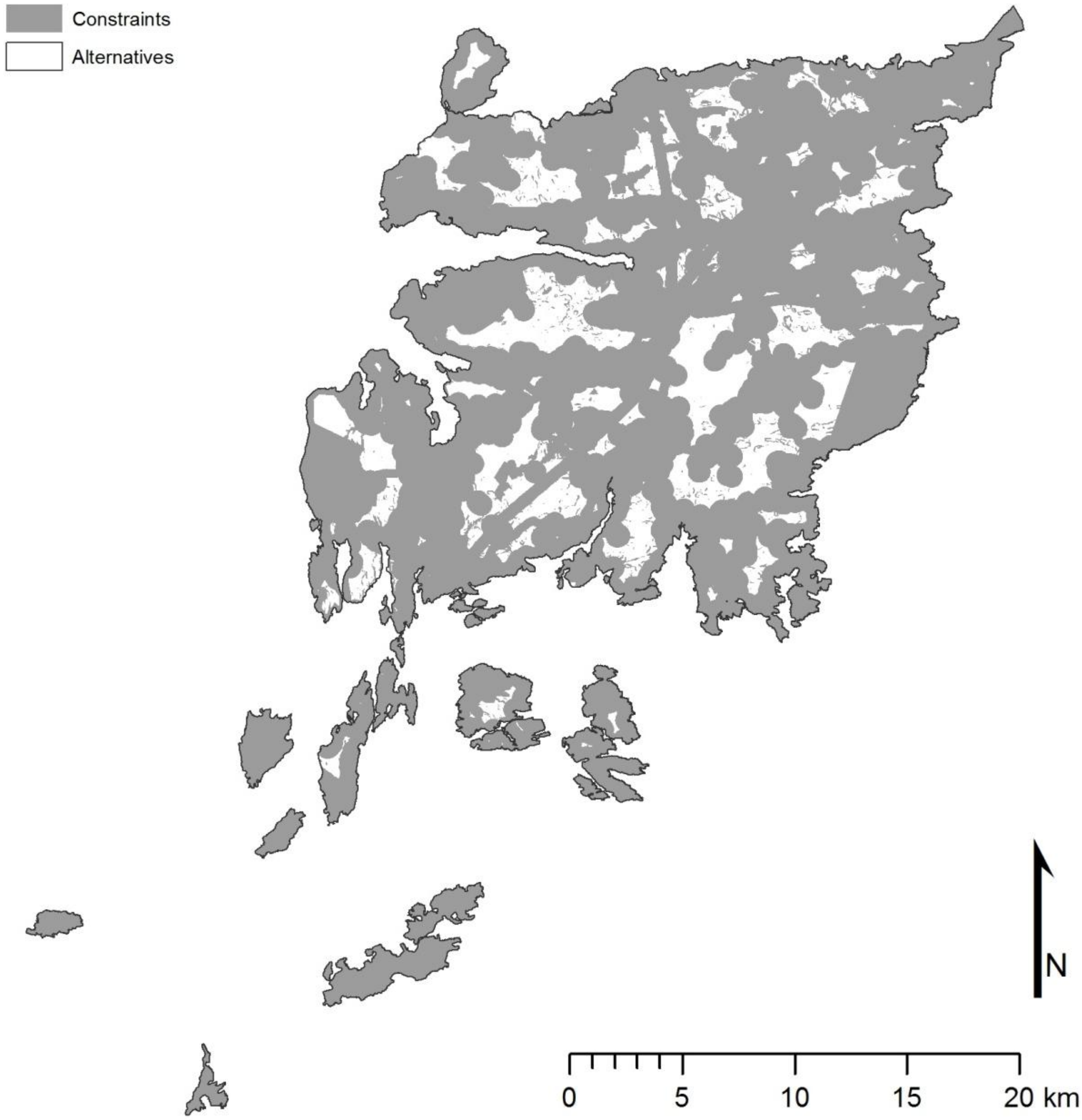

Figure 20. Intersection of all constraint layers leaves about 17 % of the study area for feasible alternatives.

Table 8 represents constraints according to the area they cover. The most restricting constraint is housing buffer, which excludes about three quarters of the study area. The next restricting constraints are roads and grid, which both exclude more than 10 %. Steepness, eagle nests and land use suitability from CLC 2006 exclude 5–10 %. All the rest exclusion criteria exclude less than 5 %, and below 1 % fall Finavia restrictions, archaeology and traditional landscapes. Even though the last mentioned criteria do not exclude large areas, they are important exclusive factors. They express locations that are not detected by other data layers: for instance land use layer detects mining activities and quarrying areas that cannot be used for turbine placement due to competing land use.

Table 8. Area of constraints. Inhabitation excludes majority of the study area.

Constraint criterion	Area ha	% of study area
Inhabitation buffer	42628	72.64
State roads	8118	13.83
Grid	7190	12.25
Steepness	5708	9.73
Eagle nests	4369	7.45
CLC 2006	4004	6.82
Restricted areas	2280	3.88
Natura 2000	1546	2.63
Cultural environments	1350	2.30
FINIBA	1329	2.26
Protection in the regional land use plan	1233	2.10
Towns	1125	1.92
Lakes	1083	1.85
Nature reserves	916	1.56
Protection program areas	837	1.43
Significant landscape conservation areas	722	1.23
Height restrictions	474	0.81
Archaeology (regional land use plan proposal)	109	0.19
Traditional landscapes	103	0.18
Archaeology (NBA)	17	0.03

7.4 Ranking feasible alternatives

In order to provide decision outcome, feasible alternatives were extracted from the results and then ranked based on their decision outcome score. Figure 21 presents the decision rank map. Most of the high ranking areas were not excluded by the constraints, perhaps partially because wind power areas in the phased regional land use plan are largely located within the feasible areas. In addition, many features that cause low scores cause also constraints. For instance, both protection areas and population centers were excluded, and they also cause evaluation criteria. Most areas in the central parts of the main island ranked high. The least risky areas are Nordanå-Lövböle and Påvalsby. The riskiest areas are scattered around the edges of the main islands. Many of them are rather small but there are also larger ones.

Planner and developer rank maps (Figure 22) look quite similar: the same areas have received highest and lowest ranking in both of the maps. The riskiest areas are generally located close to the shoreline. The least risky areas are the two large ones in the center of the main island that coincide with the Regional Council wind power marks, Nordanå-Lövböle and Påvalsby. North and south from them, there are other low-risk areas as well. However, there are especially in the north and southwest some areas on which the two interest groups do not agree. Degerdal and Pungböle rank higher in the developer scenario, which is due to higher appreciation of the Regional Council wind power mark. Also areas south of Björkboda have higher ranking in the developers' preferences.

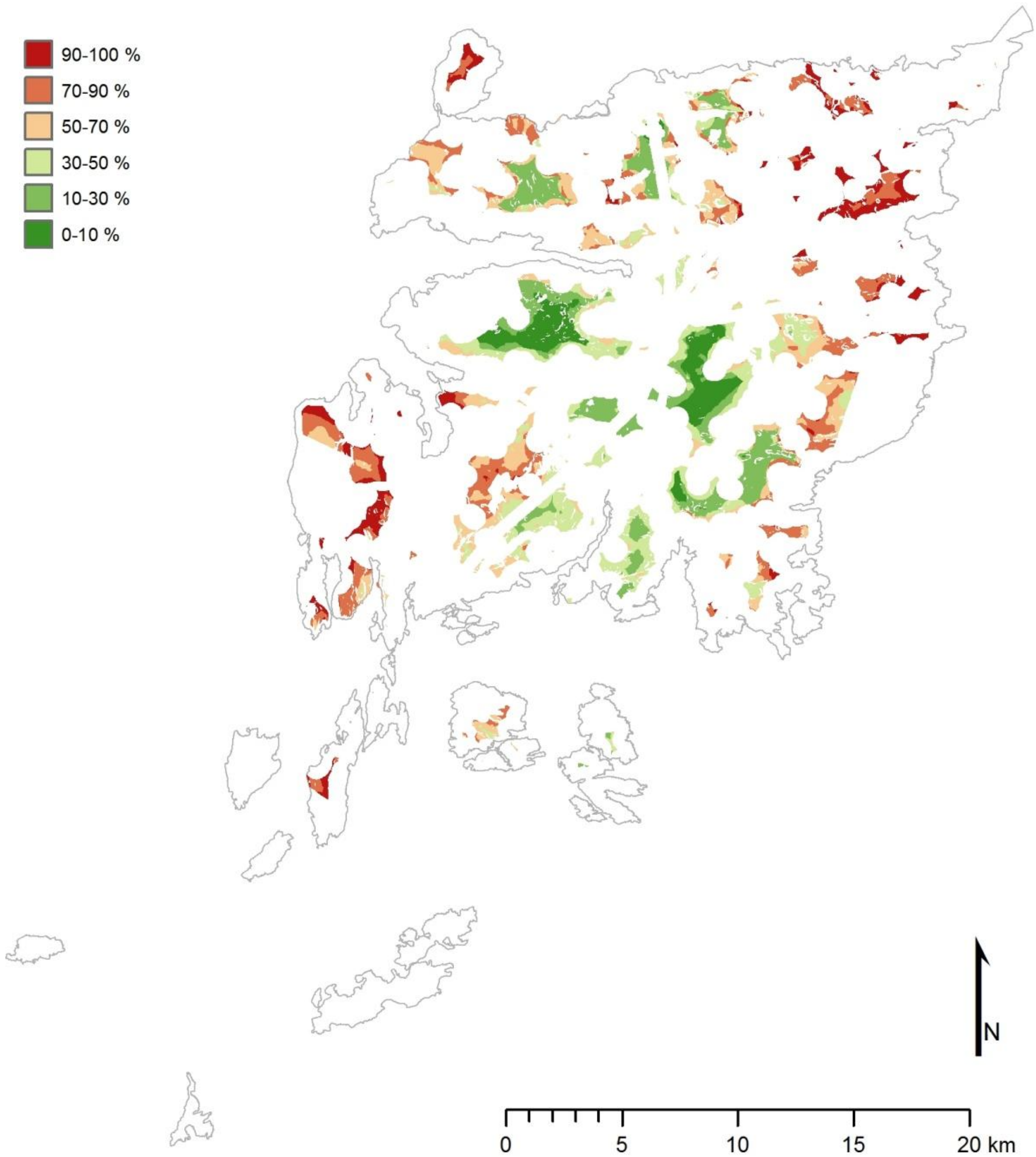

Figure 21. Decision outcome rank map. Percentages describe the share of alternatives that rank higher than the alternative in question.

Archipelagic areas rank slightly higher and northwestern and southeastern slightly lower for the planners because of their higher appreciation for economical factors. Nordanå-Lövböle and Misskärr rank higher for planners, but small northern areas and Påvalsby for developers. The lower ranking of western part of Nordanå-Lövböle for developers is caused by higher weight for the restricted area proximity. High ranking of northern areas and Påvalsby as well as low ranking of Misskärr is caused by high confidence on the phased regional land use plan. Nevertheless, differences in ranking between interest groups are rather subtle as the risk level does not differ radically in any suitable area.

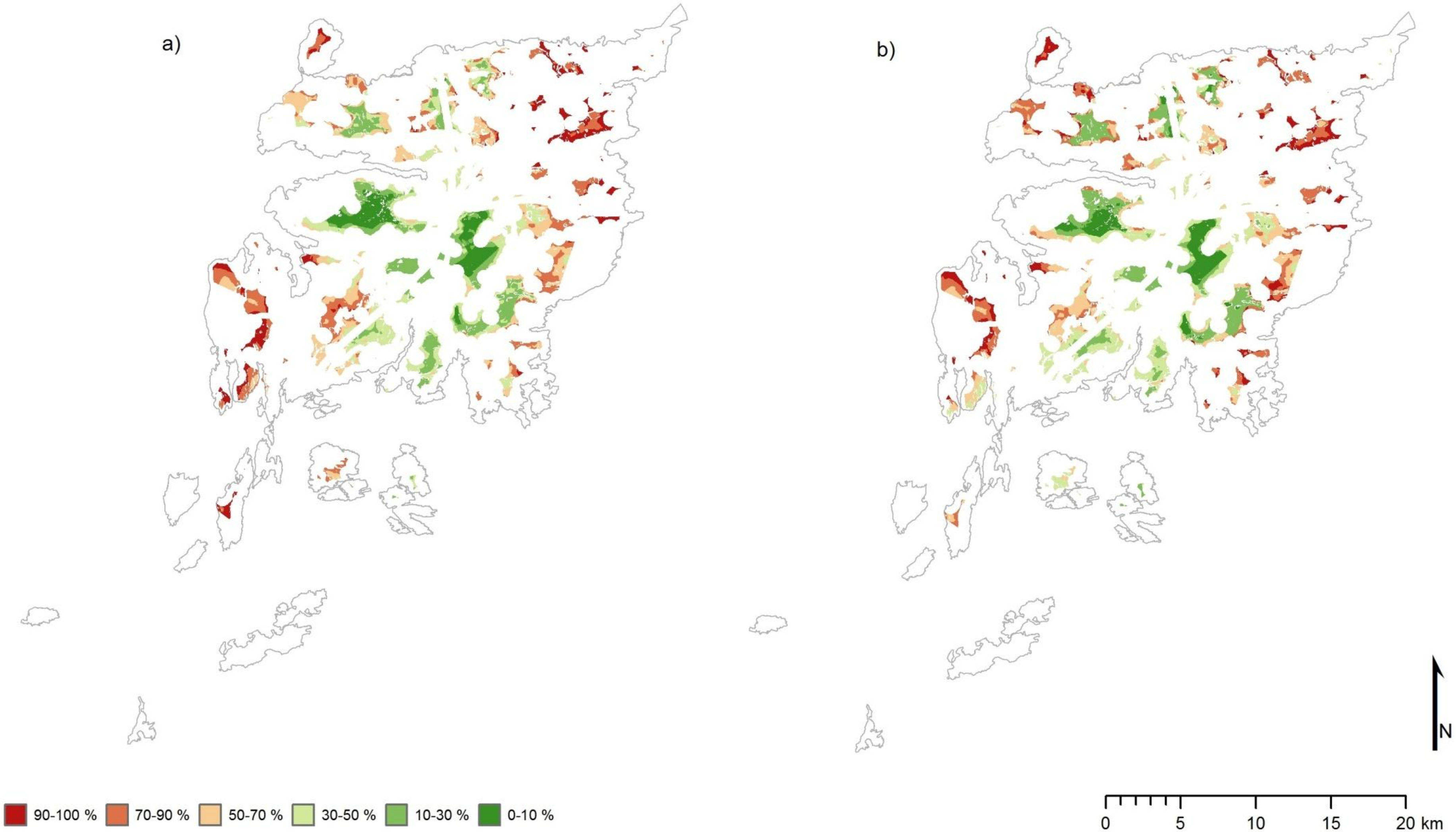

Figure 22: a) planner decision ranking, b) developer decision ranking

7.5 Scenario maps

Scenario score maps and rank maps are presented in Figure 25. Rank maps are categorized into six classes in order to ease interpretation and comparison. It is a compromise with accuracy, but this particular decision problem does not require high precision in the recommendation phase as it is sufficient to point out where the least risky areas are located.

In the *Equal weights* scenario, all the criterion weights are 0.067. Basically the scenario measures the number of risks in a location. As the original decision score map (Figure 15d, p. 81) and the map with equal values resemble each other in many ways, it can be said that the number of risk is an important factor in determining the total risk. However, northeast areas evidently receive low values on just a few criteria, namely windiness and birds. In addition, foundation cost is overly emphasized in the *Equal weight* map and central areas of the map have relatively higher values.

The *Equal weights* rank map resembles to the result rank map (Figure 21, p. 87) substantially. Yet the effect of lower windiness and bird protection area weights and higher foundation cost weight can be seen in the recommendations along with the lower significance of phased regional land use plan mark. Many of the potential areas also have much larger internal variance of quality and more intricate patterning for instance in Gräsböle area in the *Equal weights*.

The *Multiple sources* scenario includes a mixture of weights from the two decision-maker groups and statistics. The resulting score map is very similar to the original one (Figure 15d, p. 81), and the rank map is almost identical to the original rank map (Figure 21, p. 87). The largest difference in criterion weight occurred in distance to roads — reduction of 0.018 — which apparently is not sufficient to cause significant changes in the ranking. Borders between classes have shifted slightly in a few places, but there are no changes in the general character of any patch.

During analysis interviews, it proved necessary to review the distance to bird protection areas criterion. This criterion did not include study results provided by the Regional Council, and they had an influence on informants' views on the risk level of some potential wind energy areas. The Regional Council had ordered a bird study (Koskimies 2012) for the wind energy study, and that data became in a geographically referenced format. It was too late to add it to the analysis as the interviewees were not asked to consider it in their answers. However, because the bird criterion is the most important to the informants, it was used for the sensitivity analysis.

The bird criterion map looks very different with and without the bird study data (see Figure 23a and 12g, p. 77). In the new map, the southern side of the main island, where several projects have been planned, appear risky. When the new criterion was used instead of the old one in the environmental criterion map (Figure 23b), the outcome score map changed completely: skewness shifted towards positive, and the southern areas that previously scored high, scored now low. Recommendation changed completely: northern and southwestern areas ranked high and southerly areas low. Nevertheless, as regionally significant areas were not included into the bird criterion during the interviews, the scenario result is not reliable. In addition, there is significant double-counting present because the bird study was an important factor affecting the selection of the Regional Council's wind power areas.

For the *Unplanned* scenario, the wind power mark criterion was left out of the analysis and other criteria were stretched accordingly. The value range became more negatively skewed due to the elimination of extremely high values. The highest scores are in the south and in the interior parts, and clearly delineated low risk areas have disappeared. The highest scoring areas are located between Påvalsby, Nordanå-Lövböle and Misskärr. The northern areas that have been marked in the regional land use plan draft did not receive outstandingly high or low scores.

The *Högsåra* scenario simulates a case when the maximum park size is 12 MW or can include four example turbines. It was chosen for the sensitivity analysis in order to simulate the risk for small parks. Weight factors for the economical criteria are enlisted in the section 6.7. Constraints were also defined slightly differently due to the utility of 20 kV for small wind parks. The archipelago or fringes of the study area were not excluded from the decision outcome due to the distance to grid. Therefore some areas that are not available for projects larger than 12 MW are suitable for smaller projects.

Högsåra scenario utilized distance to 20 kV grid instead of 110 kV lines. This distance to grid criterion layer is described in Figure 24a). Kemiönsaari has an extensive 20 kV grid line network. The only island without it is Örö according to The Topographical database (NLS 2011), although it has been marked as an island with electricity (University of Turku 2011). The criterion map is negatively skewed because of Örö, which receives much lower values than any other part of the study area. As a result, the economical criterion map (Figure 24b) does not cause low scores for large areas in the southeast and northwest unlike in the original economical criterion score map (Figure 15d, p. 81).

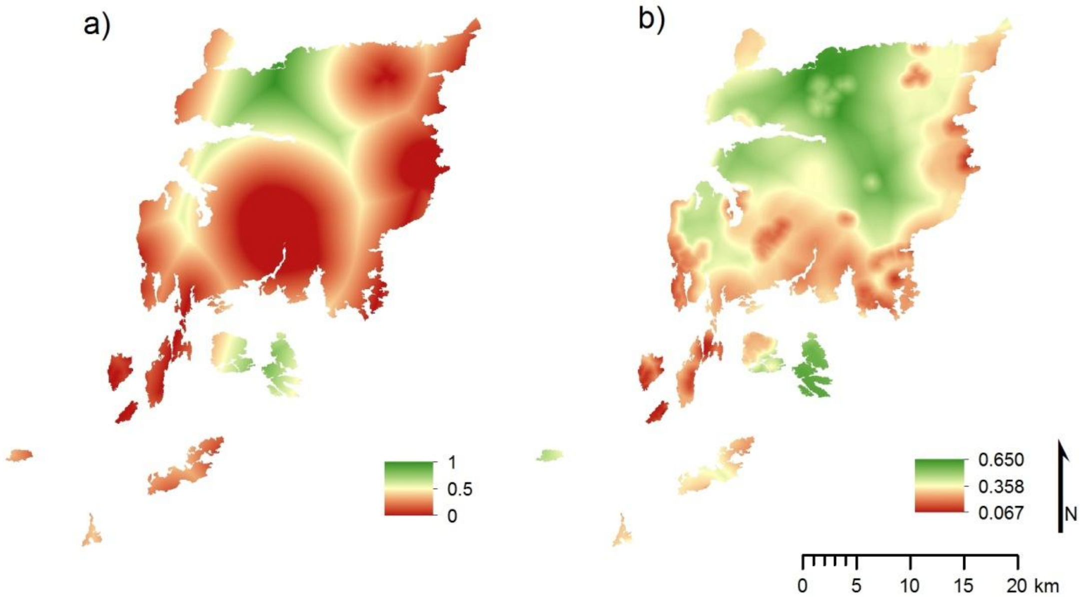

Figure 23. Changing input data within distance to bird protection criterion for the *Extensive bird protection* scenario causes significant changes in alternative scores. a) Altered distance criterion map, b) scenario environmental score map.

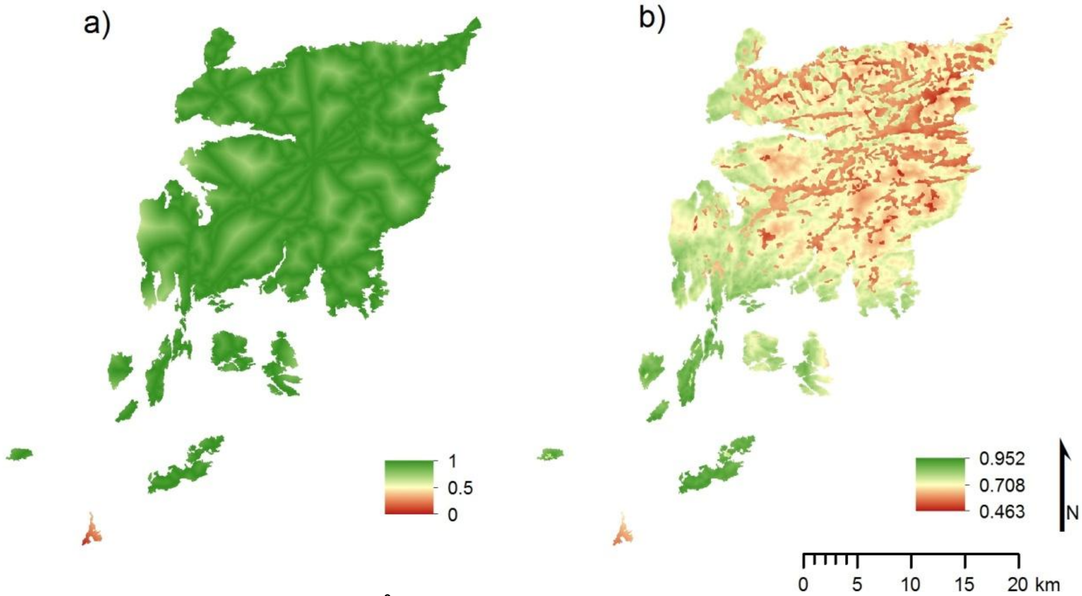

Figure 24. Changes in the *Högsåra* scenario input data. a) Distance to grid, b) economical criterion.

In the economical criterion map, internal areas of the main island are relatively more risky than with the 110 kV definition as 20 kV grid is available also on areas with high winds. Yet the score map is not very different from the original score map (Figure 15d. p 81). Archipelago, southwest and northeast score slightly higher in the *Högsåra* scenario. However, it is worthwhile to note that wind power marks only consider larger parks, and therefore the impact of regional land use plan should be excluded. Here it is not necessary because this scenario is meant only for the sensitivity analysis.

From the *Low weight exclusion* scenario, the criteria of distance to roads, foundation price, recreation areas and distance to restricted zones were removed. Removal of distance to roads is not visible but the influence of missing foundation price shows clearly from the score maps. Proximity to restricted zones and recreation areas show as slightly higher scores in the scenario map than in the original result map. These changes have only minimal effect on the rank map — the most significant difference occurs in the northwest as areas close to Sandö are slightly better in the scenario than in the original result.

When all the scenario score maps are compared, they look quite different: they have different skewness and some areas seem to have differing scores in all of the score maps. Nevertheless, they also have characteristics in common. For instance, northeast and southwest score always relatively low. The highest scoring areas are located in the central areas of the main island. Categorical data are clearly visible in all the score maps as scattered patches and clearly defined borders. Differences in the rank maps are not that pronounced apart from the *Extensive bird protection* scenario, which scores very low in the south.

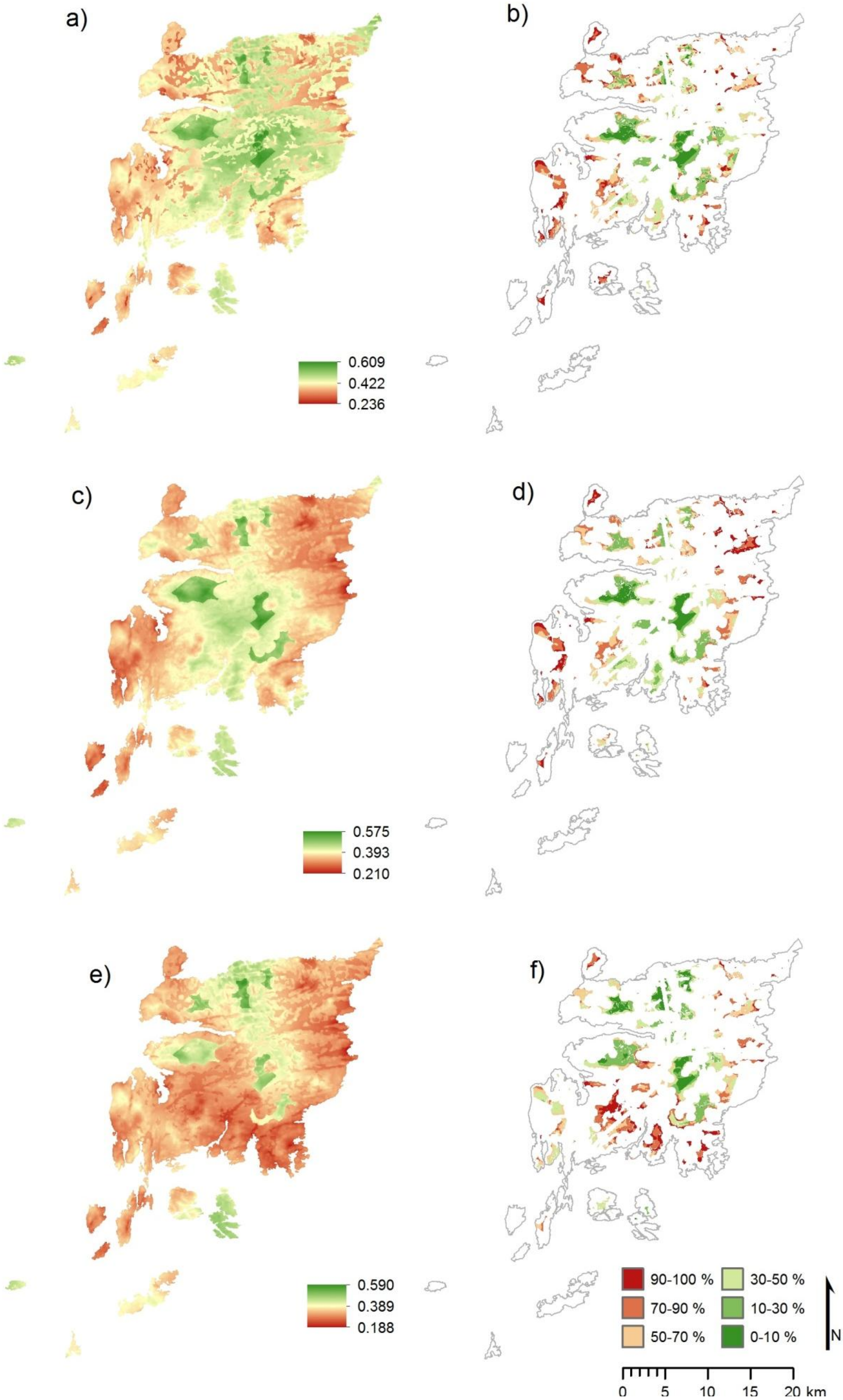

Figure 25. Scenario score and rank maps are used for the estimation of analysis relibility. a) *Equal weight* scenario result score map, b) *Equal weight* scenario outcome rank map, c) *Multiple sources* scenario result score map, d) *Multiple sources* scenario outcome rank map, e) *Extensive bird protection* scenario result score map, f) *Extensive bird protection* scenario outcome rank map.

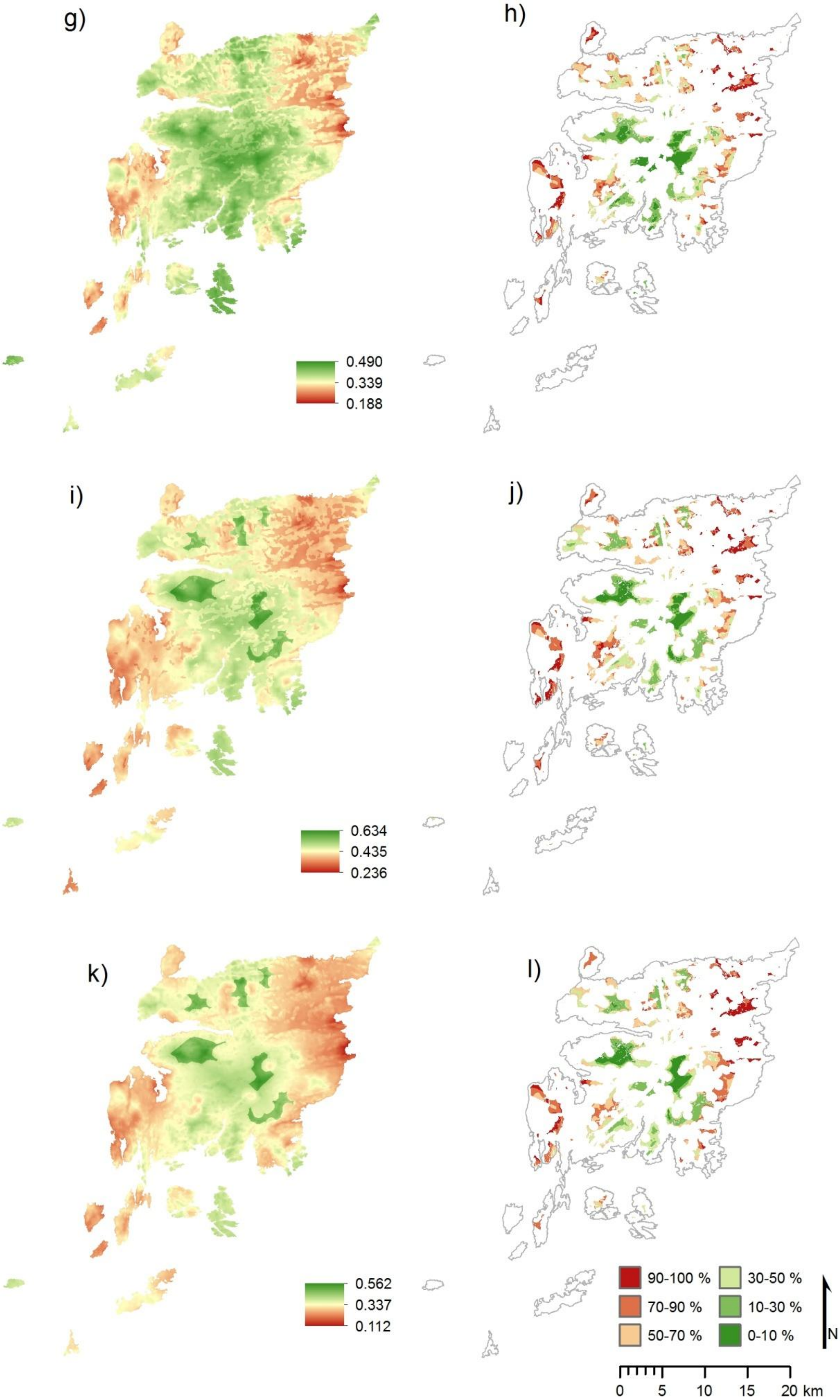

Figure 25 continues. i) *Unplanned* scenario score map, j) *Unplanned* scenario rank map, k) *Högsåra* scenario score map, l) *Högsåra* scenario rank map, k) *Low weight exclusion* score map, l) *Low weight exclusion* rank map.

8 Discussion

8.1 Input data suitability

8.1.1 Data quality issues

The first study aim was to evaluate the suitability of available data for this analysis. The second one was related to attribute quality, the third and fourth one considered results and their reliability. For the first study aim it is necessary to evaluate data quality, availability, and usability for this analysis. Data sets and their acquisition routes are described in the section 5. In the following section, specific issues related to data sets are discussed and data sets are classified according to their level of importance. The following subchapters discuss other study aims as well as other issues that have surfaced during the analyses.

One issue with data is whether *attribute data* is *sufficient* for criterion formation. For instance, private protection area data set lacks attribute information describing protected values, which means that they cannot be assigned correctly to either nature or bird protection criterion. Here all private protection areas were assumed to be nature reserves but that may not be the truth. In addition, protected buildings do not have any indication on the landscape value of the building. From wind energy perspective, it is clear that for instance ruins in a forest and a church close to shore are not of equal value but here they must be assumed to be so.

Another issue is that sometimes protection areas host *values that are related to several criteria*. For instance, national park core areas are not protected only because of their nature values but also due to landscape values. In this case, it was decided that the national park should go to the nature protection criterion as some of these areas were already described in landscape criterion by other data sets.

The data have not been designed to be used in this type of an analysis, and there are important *features classes missing*. For instance Digiroad, which is an extensive data set, does not describe ports sufficiently. This issue arises as some parts of the study area are not accessible by roads at all. In the archipelago, mere distance to roads would just depict proximity to an island that has roads or island remoteness but that information is not useful from the turbine transportation or maintenance perspective. Ports that regularly receive connection ferries can be viewed as extensions of the road network as they allow maintenance staff entrance to the island with maintenance vehicles. However, there is no guarantee that the ports are properly equipped or deep enough to facilitate turbine transportation. The data was manually complemented as described in section 6.3.1. The distance to roads criterion with and without modification are presented in Figure 26. The original map represents those islands that have roads with almost solid green. The modified criterion has more intermediate values but most of the area is well above 0.5. That is what the informants thought also: many mentioned that Kemiönsaari has an extensive forest road network.

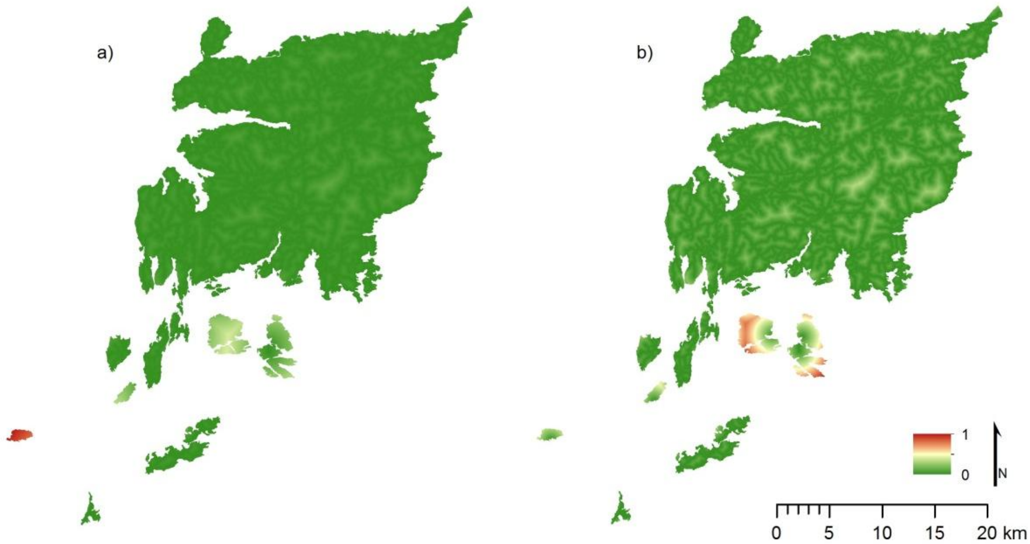

Figure 26. Distance to roads criterion map a) without manual modification, b) with manual modification.

Data availability may sometimes be an issue. For instance, the DEM used here is not the best existing quality. There is a 10 meter resolution model with slightly better vertical accuracy but it must be ordered directly from the NLS. In 2008, the NLS initiated the production of a new LIDAR (light detection and ranging) elevation model, which has the spatial resolution of two meters and the vertical accuracy of 30 cm (Nenonen et al. 2010). Unfortunately this model is not yet available from the study area. A higher resolution DEM could be used for instance for accurate estimation of slope steepness.

There is an extensive variety of spatial data describing Finland, which is exemplified by the fact that much of the data necessary for this analysis was readily available. In recent years, the situation has been improved by a trend of accumulating data into viewing and download services since the INSPIRE directive came into effect in 2007. The 24 data sets were obtained from 14 different web services or data producers. Many data sets could be downloaded directly from the producer's web sites but others were quite challenging to obtain because sometimes it is unclear within the producer organization, who was responsible for the data, especially if the person ordinarily in charge was on holiday. Differing coordinate systems also caused confusion, and especially inexperienced GIS users might face problems with coordinate transformation. Sometimes the coordinate system of data set was actually different from what was described by metadata. Furthermore, sometimes explanations for the attribute data had to be downloaded or requested separately. Data availability and ease of use could be improved by centralizing data spatial data infrastructure and having sufficient and up-to-date metadata readily available.

Data resolution caused issues in the analysis as well. For instance, the original wind map had the resolution of 250 meters and GTK's soils map was available only on the scale of 1:200 000 over the study area. The resolution of wind map was improved here with two methods: interpolating a 25 m windiness map and including relative elevation map that described the more detailed structure of the terrain. Windiness interpolation result may differ slightly from the actual wind conditions. Soil map resolution could not be compensated, which causes a large source of error in the analysis. As the original data was categorical, no interpolation could be done in order to increase the resolution, but also coarse-scale data provides an implication on what soil may be found in the area.

In addition, *errors and inaccuracies in the input data* had to be tolerated. The wind map is based on a model, not on systematic long-time measurements, and the model has inaccuracies, which are transferred to the resulting analysis. Further description of the wind data inaccuracies is in chapter 3.3.1. In addition, the Topographical database, Digiroad and other data sets include both *spatial and attribute errors*. Some features may not be accurately positioned and information could be missing or old. Attribute errors can include for instance mistaken classification of barn as house or private road as state road. Nevertheless, both the Topographical database and Digiroad are best available data sets and updated frequently.

Once that data issues have been discussed, it is important to carefully consider, which data is included and which excluded. Especially in those classes that receive high weights, alternative scores and ranking can substantially depend on input data. For instance Misskärr area and areas north and west from there, rank high in the original analysis but low in the *Extensive bird protection* scenario, where the only difference is additional data on the birds criterion (Figure 27). Distance to bird protection areas receives the highest environmental weight, so as anticipated by Malczewski (1999: 268), changes in the criterion layer inflict radical changes to the score map. That which data is available and included might change the attractiveness of an area completely. Therefore it is essential to gather all the available meaningful information and estimate its significance, not only in SMCDA but also in real-life wind energy project development.

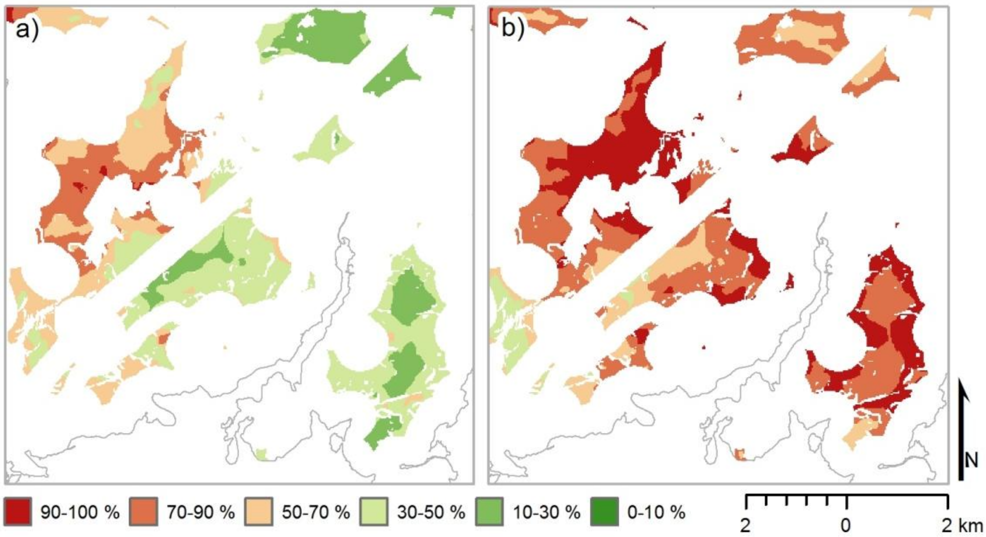

Figure 27. Impact of including the Regional Council's bird study data on Misskärr and neighboring areas. a) The original rank map, b) the *Extensive bird protection* scenario rank map.

Even though there were many issues with finding suitable data for the analysis, 15 criteria and 18 constraints were defined using existing geographical data. Therefore it can be argued that data available in Finland is sufficient for this analysis although there are still many challenges. Then again, the model can be modified in order to accommodate data-related error better by for instance changing analysis resolution, although that would introduce scale-related errors of such as averaging effects. For instance, when a raster includes only extremely low and high values, the score of a generalized cell would represent none of the high resolution cells correctly.

8.1.2 Legislation ambiguity in criterion formation

Some issues arise from ambiguity on how certain type of environmental protection affects wind power. Geologically valuable features were not considered in the analysis as it is not clear whether they have influence. For instance, in the Regional Council's studies for Southwest Finland (Klap et al. 2011) and North Karelia (Laitinen 2012) they were not considered, whereas BirdLife, The Finnish Association for Nature Conservation, and WWF recommend that these areas should be excluded from wind energy development altogether (BirdLife Finland et al. 2012). Yet in the statement by ELY on Gräsböle project, the underlying geologically valuable feature was considered (ELY 2012).

Legislation regarding Natura 2000 areas is not clear either. Natura SCI area does not necessarily mean that the area should be excluded from wind energy development: instead implications should be evaluated case by case (European Commission 2010). According to the wind power planning guidelines (ME 2012: 37–38), a special study should be conducted if the plan is expected to have impacts on the Natura 2000 area, but if no protected values are compromised, protection area does not prohibit construction. SPA areas are considered critical for wind energy development in the guidelines. However, for simplicity and in order to be on the safe side, all Natura 2000 areas were excluded in this study.

8.1.3 Comparison of data sets

Some data sets were used more frequently than others in the analysis. For instance, the Topographical database was used for many constraints and criteria as well as for the creation of study area definition, and also DEM was used for several constraints. On the contrary, some data sets were needed only for one criterion, and there are also few data sets that were excluded from the analysis altogether. Data sets and criteria are cross-tabulated in Table 9. Employed data sets were divided into three main classes: essential, useful and not used. In Table 10, the data are categorized according to the level of utility so that high and extremely high utility levels correspond to essential data sets and intermediate and low levels to useful data sets.

Table 9. Comparison of criteria and data sets used for their creation. Grey square signifies that the data set on the column has been used for the criterion on the row.

	DEM	The Topographical database	Wind speed	Islands with electricity	Quaternary deposits	Digiroad	Nature reserves	Program areas	Natura 2000	FINIBA	Eagle nests	Cultural environments	Protected built heritage	Traditional landscapes	Archaeological heritage	CLC2006	Wind power study	Regional and use plan draft	Regional land use plan proposal	Height limitation surfaces
Study area		X		X																
Constraints	X	X				X	X	X	X	X	X	X		X	X	X		X		X
Windiness			X																	
Relative elevation	X																			
Grid*		X																		
Foundation price					X															
Roads*						X														
Nature reserves*							X	X	X										X	
Bird protection areas*								X	X											
Shoreline*		X																		
Landscape conservation areas*								X				X		X						
Protected buildings*		X											X						X	
Recreation areas*																			X	
Houses*		X																		
Population centers*																			X	
Restricted zones*		X																	X	
Wind power areas																	X	X		

* Distance to…

When evaluating suitability of a site for wind energy production, it is necessary to acquire many data sets. In this analysis, the most important data set was the Topographical database. It includes information on for instance housing, grid, roads and topography. 77 % of the study area was excluded by constraints only with this data set, and it was used for the creation of five criteria. The Topographical database is therefore very useful in wind energy project development. It is available free of charge for the whole country and can be easily downloaded using web services.

Another highly useful data set was the regional land use plan proposal. It includes important information on for instance land use, protection areas, restricted areas and landscape values. Nevertheless, regional land use plans are not always readily available on GIS format, and in this case, the acquisition required contacting the Regional Council or Lounaispaikka in Southwest Finland. Some of the data, for instance protection areas and restricted zones, could be replaced by other data to some extent but for instance the same recreation areas are not described anywhere else.

Essential data sets

White-tailed Eagle nest locations are essential data in the archipelago and close to shoreline as eagles have become common and their protection issues are taken seriously by the Finnish authorities. 7.5 % of the study area was excluded by the 2 km buffer to eagle nests. Even though data acquisition might be problematic and data itself is confidential, it is necessary for any wind energy developer in the coastal Finland to check the locations of closest nests.

The Topographical database, regional land use plan proposal and eagle nests were the most essential data sets with which it was possible to conduct an analysis that excluded the majority of sensitive areas outside of development. Other important data sets included wind speed, nature conservation programme areas, Natura 2000 areas and cultural environments. Wind speed data was important from the economical perspective and it basically defined the economical suitability of an area. However, it is more important on continental areas than on the coast because on coastal Finland wind speeds are usually high enough for wind energy development. The downside of wind speed data is that it has to be purchased from the FMI and delivery might take time. Natura 2000 and conservation programme areas were considered important as they separated between nature, bird and landscape values unlike other nature protection data sets. Cultural environments were categorized significant because landscape values were considered very important by the experts interviewed for this study.

Useful data sets

The above-mentioned were the most important data sets but also many others proved useful during the analysis. Data sets of intermediate importance were DEM, Digiroad, nature reserves, FINIBA, traditional landscapes, and the wind energy study. DEM excluded more than 10 % of the study area and it was used to define slope angle, Finavia restrictions and relative elevation. Elevation can also be derived from the Topographical database. Digiroad includes very detailed information on roads but it is not free of charge and it can be replaced by the Topographical database. FINIBA excluded 2.3 % of the study area. The FINIBA area within the study area is rather small and the database was not used for any criterion, so it is considered useful but not essential. Nevertheless, in other areas it might be more important. Traditional landscapes are rather small areas, and their significance is lower than cultural environments or landscape conservation areas. On the other hand, landscape values were considered very important by the interviewees, so it was useful to acquire this data set as well.

Wind power study was used here in order to support the regional land use plan draft data. Before the draft was published, the wind power study data would have been essential because it provided for both planners and developers indication on which areas might be acceptable from the perspective of regional authorities. Here both phased regional land use plan draft and wind power study were classified as useful, not essential, as they were replaceable and the corresponding criterion received a rather low weight from the informants. However, from the results of the sensitivity analysis it can be seen that the criterion affects significantly the outcome score if not ranking, and thus even though this data may not be essential, it is highly useful.

Other useful although less important data sets included quaternary deposits, protected built heritage, archaeological heritage, CLC2006, Finavia height restrictions and in the Southwestern Finland islands with electricity. The deposit map was used for the estimation of foundation conditions, but the economical difference between different soil types was only 100 000 €. Protected built heritage describes protected buildings, which are often landmarks sensitive to landscape impact but it does not separate the degree of sensitivity. Archaeological heritage is in the low significance category because of the small coverage and impacts that can be mitigated with layout changes. CLC 2006 did exclude 6.8 % of the study area, but most of these areas were already excluded by inhabitation buffer. However, information on wetlands, soils extraction sites and mines is useful in project planning. Finavia restrictions were considered low importance only because the study area was not restricted by them. Even so, in many municipalities they exclude many, if not all, potential areas from wind power development. In fact, in 2011 62 % of projects were affected by the restrictions (Piispanen et al. 2011: 19). Even though the limitations have been alleviated slightly, they still pose issues for many projects.

Data sets not used

Some of the data sets did not increase the value of the analysis in this study are, although they might have been significant in other areas or used to replace other data sets. For instance SLICES land cover data set was not used. It has better spatial resolution than CLC2006 but since the spatial resolution of CLC2006 is sufficient, it is not necessary to have any higher resolution land-use data. SLICES was also slightly older than CLC2006 during the time of data acquisition. It has different classes than CLC2006 and more information on for instance power lines and roads but that information is trivial if the analyst has access to the Topographical database. Then again, the Topographical database has high resolution and it includes attribute data. SLICES might be useful in studies done with higher resolution and if there is no access to CLC2006 and the Topographical database.

Valuable geological features data set was excluded from the analysis because it is unclear whether or not geologically valuable areas actually impact on wind energy construction. However, if there is a geologically valuable site within any wind project area, it is beneficial to discuss with the local Centre for Economic Development, Transport, and the Environment during project planning on what might be the implications. It might be reasonable to take these areas into the analysis as a separate criterion layer once that experience on their impact on wind energy development is gained. The classification of different areas is from one to five, and this significance figure could be used for the creation of categorical criterion layer.

VIRGIS was excluded as it is overlapping with national park areas and does not provide extra information. In other areas, where there are many recreation routes and areas, it might be useful, and certainly it is worthwhile to check this database in the early phase of project development.

Local master plan data were acquired from Lounaispaikka and municipality. Data coverage was incomplete and information very detailed. Protected areas are already depicted in the regional land use plan and other data sets, so they were not extracted from the master plans anymore. On the study area, planned new housing does not cover extensive areas and unrealized building rights are also quite close to existing houses. Therefore a new layer describing intended inhabitation would mostly overlap with the housing constraint and cause unnecessary complication in the model.

Table 10. Data set classification. Constraint % signifies the percentage of area that the constraints derived from the data set in question exclude. Number of criteria is the amount of criteria that was derived from that data set. The criteria can be identified from the Table 9. Average criterion weight describes the average weight of these criteria.

	Constraint %	Number of criteria	Average criterion weight	level of utility
Wind speed		1	0.135	high
The Topographical database	77.05	5	0.057	extremely high
DEM	10.41	1	0.051	intermediate
Islands with electricity				low
Digiroad	13.83	1	0.024	intermediate
Soils		1	0.026	low
Valuable geological features				not used
Nature reserves	1.56	1	0.151	intermediate
Program areas	2.66	3	0.103	high
Natura 2000	2.63	2	0.107	high
FINIBA	2.26			intermediate
White-tailed Eagle nests	7.45			very high
Cultural environments	2.30	1	0.095	high
Protected built heritage		1	0.057	low
Traditional landscapes	0.18	1	0.095	intermediate
Archaeological heritage	0.03			low
VIRGIS				not used
CLC2006	6.82			low
SLICES				not used
Wind energy study		1	0.084	intermediate
Regional land use plan proposition	7.72	5	0.068	very high
Phased regional land use plan draft		1	0.084	intermediate
Master plan				not used
Finavia height restrictions	0.81			low

8.2 Defining attribute quality

The second study aim considered determining the quality of attributes. Malczewski (1999: 107–109) provides a set of quality requirements for criteria, which are used in this section as a framework for quality estimation. A set of attributes should be *comprehensive* to the decision-maker and clearly related to the objective as well as *operational* so that it can be used meaningfully in the decision making process. Without m*easurability* an attribute cannot be translated into a meaningful criterion. The set of attributes should be *complete* covering all the relevant aspects of the decision making problem. *Decomposability* signifies that the decision problem can be disaggregated into smaller parts. *Minimal* amount of attributes reduces the effort for conducting decision analysis. Finally, attributes should be *nonredundant* meaning that they are independent of each other.

8.2.1 Comprehensiveness – relationship between attribute and objective

A comprehensive attribute clearly indicates to what degree the associated objective is achieved (Malczewski 1999: 107). In other words, the attribute should indicate the related objective properly. Most of the attributes in this study are rather comprehensive, for instance grid and road construction costs depend on the length of power line or road that has to be constructed and can be represented by a simple Euclidean distance raster. However, in each attribute there are aspects that a simple GIS-based Euclidean distance analysis cannot grasp thoroughly. For instance, road price depends also on soil conditions and topography.

A similar issue of comprehensiveness occurs with many other attributes: distance-based attributes do not necessarily represent related objectives properly. For instance, impact on military does not depend only on distance but also on what functions there are in the restricted zone and future plans for the area. For nature reserves the risk might be dependent on for instance occurrence of a certain habitat type in a certain direction from the protection area. Distance to shoreline is an especially problematic attribute from the comprehensiveness perspective. Objectives that it should indicate include minimizing impact on birds and landscape. Shoreline itself is not an undisputable indicator of desirability as not all shores are used by the birds, and some are more open for viewing than others. Reality is always more complex than its attribute representations.

Landscape impacts are dependent on for example visibility of the turbine and characteristics of the landscape, which are very challenging if not impossible to represent in GIS format. Therefore criteria maps have to be *simplified*. For instance, landscape impact in real life is very complicated due to the varying visibility of turbines to sensitive places. If visibility would be considered, spatial analysis would require multiple iterations of viewshed analysis and consideration of several scenarios with regard to landscape values. Therefore landscape impact estimation is left for landscape analysts to conduct during detailed project studies, and in the spatial analysis only distance to the closest landscape protection area or protected building is being considered. For the preliminary site searching purposes, distance attributes are often the best way to describe objectives despite some comprehensiveness issues.

8.2.2 Operationality and measurability – understanding and measuring attributes

An operational attribute is understandable to decision-makers and they can comprehend consequences of alternative decisions (Malczewski 1999, p. 108). That means that the decision-makers should be familiar with the attributes or concepts used to explain them and understand how they may affect the suitability of a site for wind energy development. The interviewees were familiar with most of the attributes and could comprehend their usability in decision-making. Relative elevation often required explanation but once it was understood, it was also accepted. Distance to population centers was questioned by some interviewees as they could not see how distance to population centers would be different from distance to houses or they thought that there is no expansion pressure or landscape values close to the towns. In the first case they were informed about differing recommendations for distance to houses and population centers and of their differing spatial occurrence. Wind power marks in the phased regional land use plan draft also raised questions because contemporarily the plan is not legally binding. The interviewees were advised to consider contemporary situation and the guiding influence of the plan draft on statutory land use planning or project planning.

An attribute is measurable if it is practical to assign a number and preference value on alternatives (Malczewski 1999: 107). The number assigned can be for instance wind speed, distance from a feature or foundation price. Impact on nature, recreation or birds cannot be directly measured so a proxy measure of distance is used instead. Assigning raw values and preference values is not always straightforward. For instance, road criterion had to be considered carefully as some existing roads are good enough for transportation while others require different levels of improvements and others may not be of use at all. The first consideration was about which roads to include into the analysis: all or only roads of certain types. Here roads that can be traveled with a car or all those roads described in Digiroad, were accepted because all roads are helpful even if they are not sufficient for turbine transportation. Another issue was how to assign values on different types of roads. It is possible to give some roads the preference value of 1, and others for instance 0.5. Here all roads were assigned equal preference value because of simplicity and that there was no sufficient information readily available about road quality.

8.2.3 Completeness – including all essential attributes

A set of attributes should represent the decision making problem completely and so that no important factors are ignored. Unfortunately sometimes it is not possible to consider all known aspects due to reasons such as data availability, confidentiality or minimality requirement. For instance, data transfer links are not readily available in GIS format, and there are also confidentiality issues. A separate study is required for data acquisition. In areas without extensive fiber optic cable network such as Kemiönsaari, data transfer is conducted with optical links between link masts (Erävuori 2012a). The optical signal must be clear from disturbances such as turbines and their blades. However, links do not exclude areas from wind energy development, it merely affects micrositing.

Confidentiality restricts the use of eagle nests. Eagle nests should be considered up to 10 km distance from the nest (WWF Suomi 2012), so it would have been useful to add eagle nest to the bird criterion. The data was not used for this purpose in order to avoid revealing nest locations.

Due to minimality requirement, for instance geologically valuable features, roughness and hill shadow were excluded from this analysis. When some aspects are not considered, it always introduces inaccuracy. Even so, it is important to exclude those factors that have minimal impact or no impact at all so that the analysis remains comprehensible and meaningful, and 15 attributes provide a practical set of attributes. If there were more, minimality of the set of criteria would be compromised.

8.2.4 Decomposability and minimality for efficient analysis

If a decision problem can be disaggregated into smaller parts, a set of attributes is decomposable (Malczewski 1999: 108). This means that it should be possible to categorize attributes into groups that make understanding the problem easier. In this study, the decision problem was divided into three first level attributes – economical, environmental, and societal. Some of the second level attributes could perhaps belong to another first level attribute, for instance, distance to recreation areas might have been easier to comprehend to the decision-makers in the societal group. However, the problem is decomposed into smaller parts that ease understanding and reduce the number of necessary pairwise comparisons.

Decomposition has to be well considered or otherwise it may pose a risk to the model reliability. The structure of the value tree may cause inaccuracy in the pairwise comparison interviews. The societal first level attribute includes four second level attributes, the economical five, and the environmental six. If an interviewee assesses the relative significance of the first level attributes equal, the values of the second level societal attributes might end up larger than intended. This was considered in the interviews by reminding interviewees to take a look at what each theme contains before evaluating their significance. Furthermore, decomposability introduces error into the results, which is discussed in the section 8.3.4.

The set of attributes is minimal if it is not possible to determine a smaller set of attributes describing the problem (Malczewski 1999: 109). If several attributes can be represented adequately in just one attribute, it should be used, and if an attribute proves to be insignificant, it should not be a part of the analysis. Minimality reduces the effort for data collection and quantification of decision-makers preferences (Malczewski 1999: 109).

An issue with minimality is that aspirations to achieve it may lead to oversimplification of the decision problem. When several objectives are described in one attribute, decision-makers do not have an opportunity to differentiate their appreciations between criteria. If an attribute is removed altogether, the decision-maker cannot evaluate its importance at all. This may lead to a situation where the decision problem is not represented completely.

In order to achieve minimality, thematically similar data acquired from different sources was combined into one attribute. For instance, nature protection layer includes Natura 2000 areas, nature reserves, program protection areas and protection in the regional land use plan. In addition, geologically valuable areas were excluded from the analysis. To avoid oversimplification, thematically different data was not combined.

8.2.5 Redundancy as correlation

Definition of a good criterion includes independence from other criteria. In practice, criteria are often *connected* because in real world everything is connected one way or another. All the criteria and their source data was thematically selected so that the phenomena they describe would not be overlapping and data sets would repeat each other as little as possible. However, between criteria there are connections, which are described here utilizing correlation coefficients.

Redundancy means that decision consequences are counted twice during the analysis (Malczewski 1999: 208). In order to detect these situations, correlation matrix including all pairs of criteria was calculated as recommended by Malczewski. Yet he reminds that situation of complete nonredundancy is extremely unlikely in spatial decision making. Highly redundant attributes should nevertheless be excluded.

Correlation matrix including all criteria was calculated. Some criteria show correlation with each other (appendix VI). They are distance to shore, distance recreation areas, distance to population centers, distance to grid and windiness. It seems that these criteria are repeating a pattern where archipelagic and coastal areas receive high values and internal parts of the main island low values or the opposite. Indeed, they do have many overlaps: recreation areas are often located close to shoreline and also wind conditions tend to be rather good there. On the contrary, population centers and grid are located in the internal parts of the main island. The negative correlation between distance to towns and grid is especially high.

When extremely high correlations occur, Malczewski (2000) recommends combining or dropping criteria as correlating criteria may cause double-counting, which introduces error in the resulting score. Nevertheless, spatial correlation of the criteria maps does not necessarily mean that the same phenomenon has been double-counted as the spatial correlation may be thematically independent. In this case, it may not be beneficial to exclude spatially correlating criteria. If for instance distance to grid was dropped, it would fail to represent the decision problem accurately. The correlating criteria here are thematically so different, that completeness of the model would be compromised if the some of them were excluded.

Correlation calculations do not always correspond to what one would intuitively see as correlation when viewing the criterion maps. For instance, landscape, bird, and nature values accumulate to same areas, so they would be expected to correlate. The spatial overlap is partially due to the fact that many Natura areas have been marked as both SPA and SCI. Therefore these areas are considered twice: once in the bird criterion and the second time in the nature criterion. Nevertheless, correlation of these two environmental criteria is only moderate.

During attribute definitions it was considered whether the SPA and SCI and other similar overlapping environmental areas should be considered in one or several criterion layers. If they were in several, they would have more significance in the analysis than those described in only one criterion. In this case, a decision was made that if the overlapping protected areas share protected values, for instance Natura 2000 SCI area and nature conservation programme area, they would be considered in the same criterion and their significance does not accumulate in the WLC process. In contrast, those areas that have different protected values, for instance when national park and Natura 2000 bird protection area are overlapping, they are considered separately and the impact accumulates. This may be a source of error, and the capability of correlation matrix is limited in detecting it. Correlation analysis may be used for revealing repeating patterns among the criteria but it should not be used for eliminating redundant criteria without case specific consideration.

There was a potential redundancy issue also between windiness and relative elevation because elevation data was used for the generation of the wind model. Correlation between relative elevation and windiness was expected to be high as elevation data was used for producing them both. In the interpolated windiness map, elevation conditions were clearly visible (Figure 28). However, it did not reveal such a detailed pattern of landscape as the relative elevation due to low calculation resolution. Despite having similar data on the background, their correlation coefficient is only 0.17, which is moderate. This suggests that there is no significant double-counting.

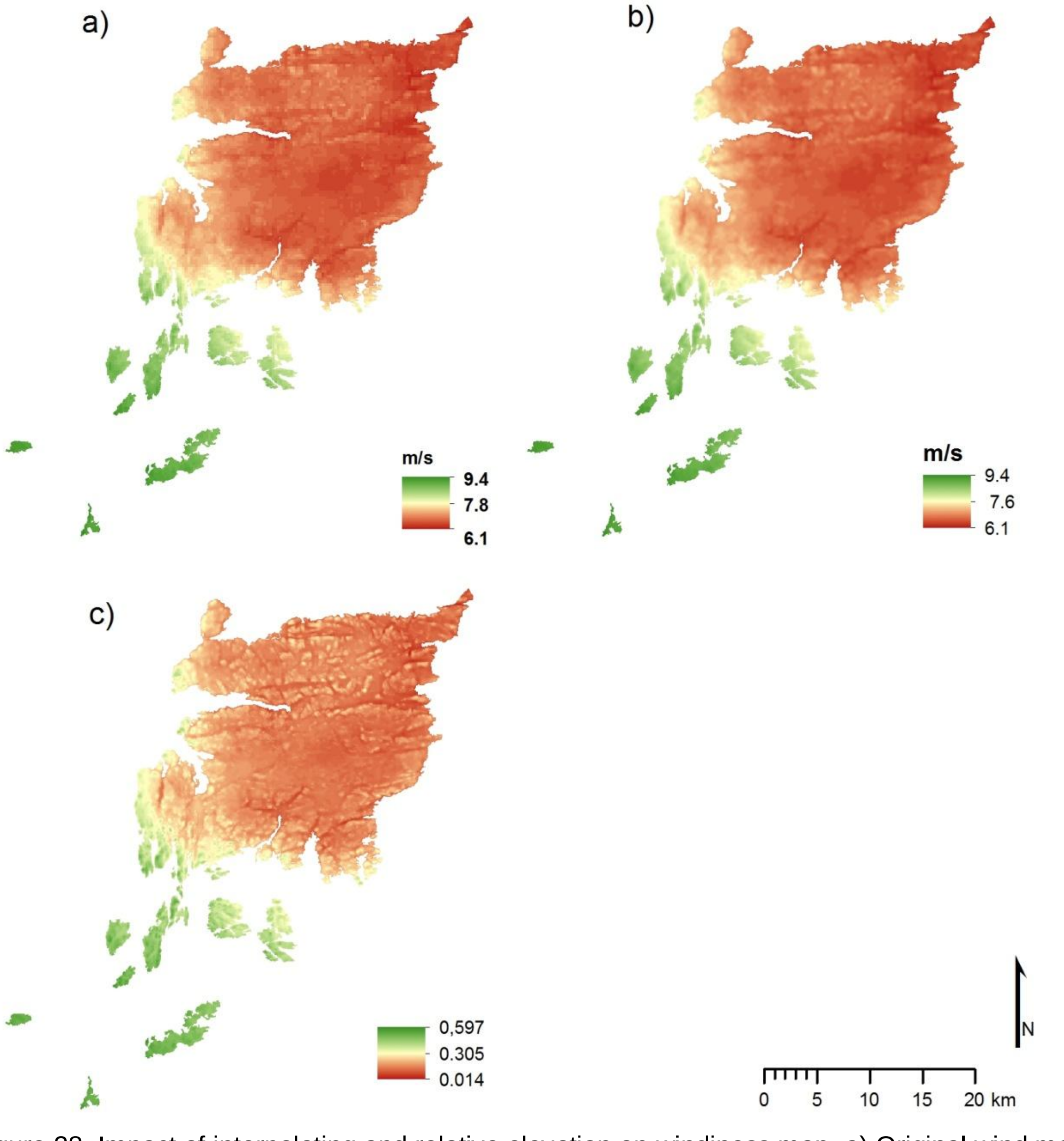

Figure 28. Impact of interpolating and relative elevation on windiness map. a) Original wind map by FMI, b) interpolated wind map, c) profit map, which includes relative elevation and wind criteria.

Criteria were selected in this study so that the level of interdependencies would be minimal but redundancies were not eliminated completely in order to maintain completeness of attributes. For further research, it would be interesting to see studies of wind energy siting that utilize such methods that can take interdependencies into consideration. One of them is the analytic network process (ANP), which is similar to AHP but accommodates interdependencies using a network value structure. Saaty and Vargas (2006) discuss the methodology and its application in their book *Decision making with the analytic hierarchy process*. Ferretti (2011) used ANP to resolve a landfill siting problem. Redundant criteria were named by decision-makers, which also defined connections between them. The drawback of ANP method is that it requires even more pairwise comparisons than AHP and is therefore more time-consuming.

Especially problematic criterion from the redundancy perspective is the Regional Council's wind energy mark. When these marks were determined, planners considered many different environmental and societal criteria. In the wind power study (Klap et al. 2011), two large areas east from Påvalsby and Östanå-Labböle were excluded due to landscape effects. The decision was made based on landscape studies, which were not considered in this thesis. Another place where exclusion has occurred is in the southern parts of the main island, this time due to bird impacts. The Regional Council's bird study is the reason for excluding these areas, and the study is not considered in this thesis apart from the sensitivity analysis. As landscape studies and bird study of the regional council were not considered here, double-counting is probably not significant in the result. Yet in the *Extensive bird protection* scenario, double-counting clearly has occurred. The southern part of the main island receives low scores because bird values affect via two criteria: distance to bird protection areas and regional land use plan draft wind energy mark. Figure 25e shows how the area looks like with both of the criteria in the *Extensive bird protection* scenario, Figure 25g how it looks like without regional land use plan marks or modified bird criterion and Figure 15d, the original score map without modified birds and with regional land use plan. These maps reveal that double-counting may cause significantly lower rankings for the main island in the south.

8.3 Methodological considerations

8.3.1 Objective function generation

Objective functions in this study are assumed to be linear, which means that preference value changes linearly with distance, windiness or price. Linear scale transformation is used in many SMCDM studies (e.g. Ferretti 2011, Janke 2010, Tegou et al. 2010) as it is intuitive, simple to implement and mathematically justifiable. Linear scale transformation avoids pitfalls of point assignation systems, which include unnecessary thresholds that lead to inaccuracy in results. However, preferences might not change linearly in real life, and this introduces error that is integral to the standardization procedure that was used in this study.

There are methods of commensurate criterion map generation that do not assume such linearity. Fuzzy set methods can include decision-makers into the definition of objective functions. It can be expressed with linguistic variables whether the preference value increases or decreases as the distance increases between certain points. These threshold points have to be determined justifiably. In its simple form, fuzzy set methods applied on objective function generation are not much different from linear scale transformation with threshold values (e.g. Aydin et al. 2010, Hansen 2005, Jiang & Eastman 2000), which was used in this study. Rashed and Weeks (2003) have a different approach to fuzzy set standardization with 0.5 value point and S-curve instead of linear function approach. They use AHP for weight generation and additive function for aggregation similarly to this study.

Malczewski (2000) recommends using value function analysis instead of linear transformation. In value function analysis decision-maker or expert assigns preference values between one and zero for selected raw values based on which the value function will be derived. This method certainly could provide more accurate results than linear transformation but it introduces new issues such as who should be consulted for the value function generation. It is also much more time-consuming to acquire value functions than linear transformation functions. It certainly would be interesting to study differences between value function and linear criteria in wind energy siting context.

8.3.2 Decision analysis interviews

In order to select a suitable method for conducting pairwise comparisons, several tests were made with two interviewees. At first it was tested if pairwise comparison could be done using forms without a formal interview but that posed several problems. Firstly, the consistency measure of 0.2 was difficult to achieve if the experts did not have a chance to review their answers. Secondly, informants interpreted the directions differently and filled the comparison table with numbers that were not useful for the analysis. Thirdly, interpretation of the criteria themselves required further clarifications. The experts needed answers for their questions in order to fill the form correctly. For these reasons, structured analysis interviews were selected for the method of acquiring pairwise comparisons as recommended by Marttunen et al (2008) even though they were time-consuming.

Another issue rose from the scale in which the original test interviews were made. At first the question asked was “How much more criteria x increases risk for wind energy production in Finland than criteria y” but that proved to be too general. The reviewed question was limiting the area of interest to the actual study area. The test interviewees commented that the changes affected significantly on how they answered to the pairwise comparison form and helped them to consider criteria in a more specified manner.

Maps were used in the interviews for orienting the informants to the study area but they also pose a risk. Sometimes maps have unexpected power on people, and visualization of a map, for instance colors and surface area of a feature, may influence the interviewee's perception of the risk that the phenomenon poses. In addition, during the test interviews it became evident that recent events and issues on the interviewee's mind affect the results substantially. Moreover, human misunderstandings and differing interpretations cannot be completely excluded. They were minimized by selecting interview instead of questionnaire, by giving an orienting presentation and showing maps as well as by supervising the pairwise comparison process.

8.3.3 Values and definition of criterion weights

Weights were evaluated based on nine interviews. In order to acquire more reliable results, more interviews should be made. However, in this case there is only a very limited amount of people that have local knowledge on the study area and which were working with wind energy. Five of the decision-makers were from statutory land use planning or municipality sector and four from wind energy development sector. Because the results were not standardized according to the interest group, planners have slightly more emphasis on the decision outcome.

Expertise of the interest groups was centered on different themes. Developers were most assured in estimating the economical theme whereas planners evaluated environmental values with high confidence. They also weighted their area of expertise as an attribute higher than the other group, although both groups assigned the highest weight to the environmental theme.

In the societal practices theme, planners emphasized more distance to population centers and houses whereas developers emphasized phased regional land use plan wind power mark and distance to restricted areas. Possibly that is because planners are more familiar with the human aspect due to participation processes of planning, in which they are closely involved. Developers on the other hand expect easier acceptance from the authorities if the project area has been marked as a suitable wind power area either in the phase regional land use plan or wind power study conducted by the Regional Council. It is possible that developers rely too much on that, after all, it is the municipality construction authority that eventually decides on the construction license and municipality council that approves the land use plan.

Restricted zones appear threatening to wind power developers as The Defence Forces' statements may bring any project to halt. It is well known by the developers on Kemiönsaari that on the neighboring municipality, Parainen, military statement has brought the development of 8-turbine project in Stortervolandet to halt with their statement (Defence Command 2012), which suggests that there might be a similar risk also in Kemiönsaari. When the first projects on Kemiönsaari receive the statement after VTT's radar study during the winter 2012–2013, there will be more indication on the risk level. If this study would be conducted after receiving these statements, military weight might be different and the interviewees may have more uniform opinion on its level of risk.

When the criterion weights from this study are compared to weights in some other studies, and weights from different studies are compared with each other, it is difficult to pinpoint similarities. Windiness usually receives high weights (e.g. Paakkari 2011, Tegou et al. 2010). Distance to roads has received relatively low values in this thesis perhaps due to differing definition of roads or density of road network. Altogether, differences in legislation and scale of study are so different, that it is difficult to compare weights of different studies and draw any conclusions on differences and similarities of appreciation. In addition, differing methods are used for weight acquisition, decision-maker groups in all studies are quite restricted, and some assign weights themselves or assume all criteria to have the same weight. Therefore weights of different studies are not comparable.

When comparing sensitivity analysis maps, it seems that more radical changes to rank maps are caused by changing input data than altering weights. Therefore in this case when selecting least risky project areas, it is perhaps more important to consider the data used for the study than precise weights especially when it comes to highly weighted criteria. In that sense, the Finnish studies that assign points to criteria are sufficient if the lack of weights is compensated by a carefully considered range of point values for each criterion. The results may well be precise enough even without AHP if weights are determined directly by a group of experts.

SMCDA can also be initiated from the other end of the process: existing decisions. This method is called preference disaggregation analysis (PDA), and it starts from actual decisions that have been made and proceeds to the definition of weights (Doumpos & Zouponidis 2002). It does not require interviewing decision-makers but it is necessary to have a representative set of existing decisions. It is basically a regression analysis, and the weights derived from it can be used within the study area to define other low-risk locations. This approach has been used by for instance Mann et al. (2012) for explaining and projecting wind energy development in Iowa. Due to the lack of existing decisions on the study area, this methodology cannot be applied in this study. Regardless of the solid statistical basis, PDA is not able to simulate decision making or involve contemporary decision-makers into the process, so it is questionable whether it actually is beneficial to use it as a decision-aid method. PDA also copies past decisions regardless of whether those have proved successful or problematic. Nevertheless, it would be very interesting to see a national scale study of Finland utilizing PDA.

It would be fascinating to observe how the result would vary with SMCDA methods other than AHP. Comparison of AHP results to the more complex and reliable ANP results would provide another set of weights as well as indication of the actual level of redundancy between criteria. A carefully considered fuzzy methodology approach might also introduce further understanding on this particular decision problem.

8.3.4 Uncertainty of criterion weights

Criterion weights were averaged for each thematic group and all the decision-makers together. Averaging introduces error as it levels out differences in the decision-makers opinions, and consistency measure cannot be calculated because the averaged weight is not directly based on pairwise comparison. Uncertainty is integral to averaging and should not be ignored. In order to scrutinize it, the range of values is depicted for both relative weights and absolute weights in appendix II. Charts describing relative weight variance should be used for comparing criterion weights within first-level attributes and absolute weight tables for comparing weights across different first-level attributes. All the decision-makers agree only on one thing: windiness is more important than relative elevation, foundation price, distance to roads or distance to grid. This is visible only in the relative weights (Figure 29) and masked in the absolute weights by the multiplication with the first-level weight. There the only agreed difference is between roads and windiness.

When it comes to the planner group, they agreed on a few more relations: proximity of landscape protection areas causes more risk than proximity of shoreline but all developers did not agree to this. In addition, environmental aspects were considered at least as important as economical aspect by the planners. Developers judge them approximately of similar significance. This could be expected as planners have more background knowledge on environmental aspects than on the economical ones. In fact, during the interviews it occurred that some planners would be more willing to see wind energy on economically risky areas than in environmentally risky places because they thought that the economical side can be made to work everywhere in the study area.

As there was strong agreement on the relative significance of environmental and economical aspects among the planners, multiplying second level weights with the first level weights revealed further relations between criteria. Windiness was considered more important than shoreline. Due to the low first level weight of economical aspects, it is also safe to say that for the group of planners, proximity of bird, nature, and landscape protection areas is more significant cause of risk than distance to roads. In addition, Regional Council's wind power mark is judged more important than distance to roads. It is also more important seek high-wind locations and to keep distance to landscape protection areas than to restricted zones. The developer group did not agree with any of these statements.

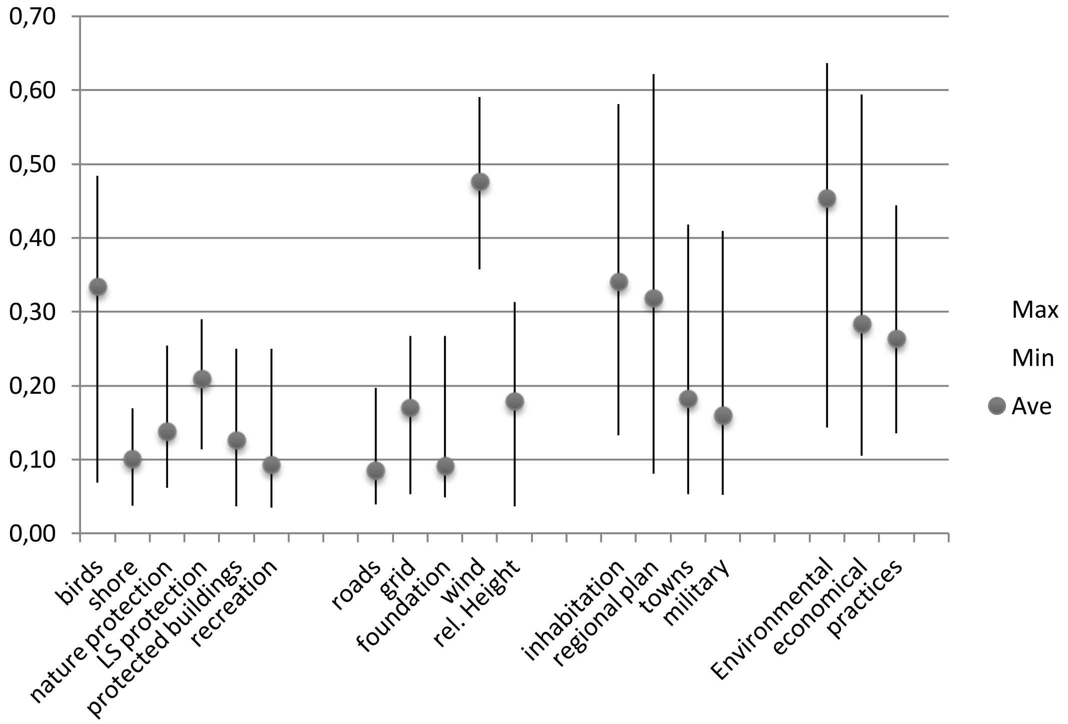

Figure 29. Variance of second level attribute weights obtained with pairwise comparison in the analysis interviews.

The developer group was unanimous about more relations of relative weights than the planners. This might not be because developers were more united than planners but because there were only four developers whereas five planners were interviewed. Anyhow, it should be noted that the decision-maker groups were too small for drawing any comprehensive conclusions. This discussion is valid only regarding those decision-makers that were interviewed.

Weight variance within the economical attribute is strikingly small for the developer group. Therefore it can be derived that it is rather clear to the selected developers how economical risk depending on location is formed. Relative elevation has more variance perhaps as it is more abstract than the other economical criteria and it is not quite as familiar to the decision-makers. However, the variances of economical criteria are significantly narrower than those of societal ones, which have strikingly large variance for both of the interest groups. It indicates that there is so much uncertainty involved in this criterion that it is the weakest one of all first level criteria. In addition, the developers do not agree on the significance of the first level criteria, which is transmitted to the variance of absolute weights.

Uncertainty by averaging can be avoided in several ways. Firstly, bringing decision-makers together and having them agree on unanimous set of weights eliminates variance altogether. This introduces a new source of error caused by human character: some people are more prone on giving in while others dominate discussion. Strong characters and opinions would dominate the group meeting. The second approach is to find more decision-makers for interviews. Of course, then there would be even wider variance in the results but the average would be more reliable due to larger sample size. Thirdly, probability or fuzzy techniques integrate uncertainty into the analysis. The fourth way is to avoid hierarchical attribute structure because in most cases multiplication diminishes the differences in the second level of attributes although this would contradict the decomposability rule of attribute quality definition.

8.3.5 Timing of applying constraints

Alternatives were defined after decision variables because the interviewed experts were asked questions regarding the whole study area. Another possibility would have been to exclude unsuitable alternatives first and define criteria within the set of feasible alternatives. This would provide a narrower range of standardized criterion values and reveal more differences in the acceptable area. In addition, it would eliminate the error that may occur when a significant set of values from one end of the range is excluded afterwards in some layers while in the others exclusion occurs across the whole range of values. This causes a situation where the standardized criterion would get values of for instance 0.0–0.5 within the acceptable area, whereas the other ones would receive values between 0.0 and 1.0. Narrow range undermines the weight assigned to the criterion and the criterion seems more insignificant in the analysis than it is perceived by the informants. However, considering the task of the informants, it was decided to exclude unsuitable areas only after the aggregation process. It certainly is easier for the decision-makers to orient themselves to discuss the whole study area than a fragmented collection of sites that are left after applying the constraints. This way they could also think of just one factor at a time and avoid confusion between constraints and evaluation criteria, which were often based on the same data sets.

8.3.6 Weighted linear combination

WLC was selected as the aggregation method for this analysis for several reasons. Firstly, it is simple to implement in GIS environment. Secondly, it does not exclude areas with one zero criterion score. Exclusion has already been done using constraints. Thirdly, low score in one attribute may be compensated by high score in another one. Often in wind energy development there are no places that are free all risks. If the minimum standards are met, then it is the remaining factors that determine the attractiveness of an area. All factors of course affect on it but if the area is located close to for instance nature reserve or church the area is not automatically excluded. Yet the major drawback of WLC is that it does not tolerate dependency between attributes as discussed in the section 8.2.5.

8.4 Reliability of results

8.4.1 Sensitive and robust results

Robustness of a result can be determined by comparing the ranking of alternatives in different scenario outcomes. If the ranking does not change, the result is robust, but if there are changes, it is sensitive to changes in weights or input data. As mentioned in section 6.7, this study does not include a thorough sensitivity analysis but instead introduces selected scenarios, which exemplify alternative situations. Apart from the scenarios, also planners' and developers' analyses can be considered as sensitivity scenarios.

All the scenario rank maps as well as developers' and planners' rank maps receive rather similar values central areas of the main island ranking high and exterior areas low. Påvalsby is the only area which is almost completely within the least risky 10 % in all the rank maps. Another fairly robust area is Nordanå-Lövböle, which receives in all but two rank maps the highest ranking. In the *Extensive bird protection* and *Unplanned* scenario it is ranked to the highest 10–30 %. Edges of this area are ranked slightly lower in many scenarios. It is not a surprise that these two areas receive high values, after all, they were selected by the regional council as wind energy areas as well. Both of them also have plans of wind energy development.

There are five areas in the 10–30 % class in the outcome rank map (Figure 21). They include all the areas that received a wind power point mark from the regional council, and a small area in Björkboda. Wind energy has been planned for only one of them, Gräsböle. Ranking of these areas is not quite as robust as the 0–10 % class as the class is in some scenario maps one category higher or lower. There is also internal variance within these areas as some places within the same area are ranked high while others are ranked low.

Misskärr wind energy project is ranked mainly to classes 30–50 % and 10–30 %. It is more attractive for planners than developers. The area is in most scenarios ranked to the 10–30 % category or to the neighboring classes in different scenarios. Nevertheless, in the *Extensive bird protection* scenario it receives rankings of 70–90 % and 90–100 %. As the variance of results is so large, it cannot be said that the result regarding Misskärr is robust even though there is significant double-counting in the *Extensive bird protection* scenario. The situation is similar in the area west from Misskärr, which also have been suggested for wind power construction (Burman & Forsell 2012). A major risk for both of the areas is bird protection, namely an important bird area that in located in an inlet between these two areas (see Koskimies 2012).

There are two more areas, Stusnäs and Kasnäs, on which wind power production has been planned. Both of the areas are rather small and would not accommodate more than just a few turbines. Stusnäs is mostly ranked to 50–100 %, although in some scenarios there is a small area of 30–50 % in the east. Ranks are lower in the west close to the shoreline and neighboring nature protection area. In all the ranks maps, Kasnäs is ranked between 50 and 100 %. Low values in this context do not mean that these areas would not be good places for wind energy development, but that they are considered risky areas based on the existing spatial data.

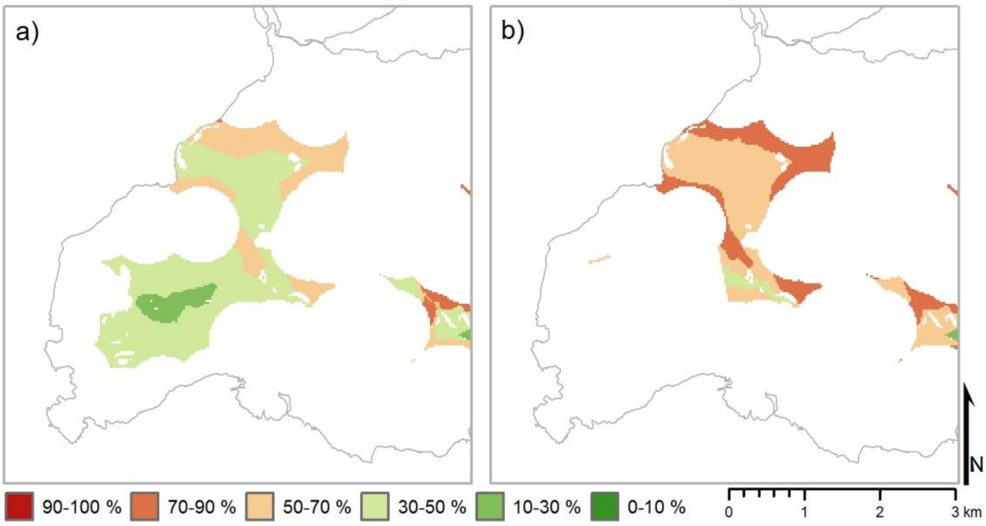

Figure 30. a)Tolvnäs ranking with *Högsåra* scenario. For comparison, the rank map of the same area is provided in figure b)

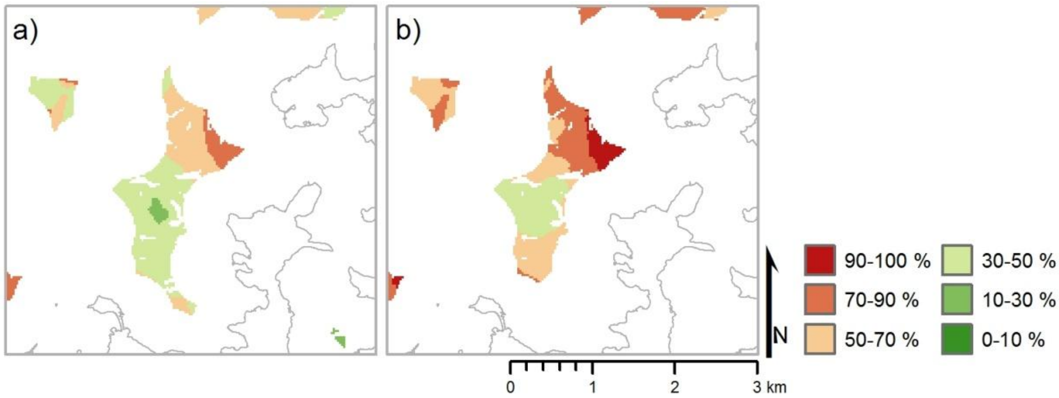

Figure 31. Southeastern area a) *Högsåra* scenario ranking, b) Result rank map.

There are rather many on-going wind energy plans in Kemiönsaari for such a small area, and undoubtedly not all projects will be realized. If 30 % was considered as a limit for recommending an area for further studies, apart from some of the existing planned areas, also Pungböle, Helgeboda, Östanå-Labböle and Björkboda areas would be worthy of further studies. Björkboda area is 175 ha large and more than 2 km long, and could accommodate about 5 turbines. Together with the neighboring small areas they could form a park that has 6-8 turbines. However, this is located west from Påvalsby, which has been planned for wind energy production and it might cause some loss of production to Påvalsby due to park effect. In addition, there are significant bird values, which have been studied for the regional statutory land use planning. If the recommendation was 10 %, then only western areas of Östanå-Labböle would be recommended. However, as there is already Misskärr park being planned to the main wind direction, that area would face significant park effect, which reduces its attractiveness. In addition, the *Högsåra* scenario revealed two other areas that might be recommended for small parks: One in Tolvnäs and another one in the southeastern corner of the main island (Figures 30 and 31). Tolvnäs is about 200 ha, and could accommodate four 3 MW turbines. The southeastern area is about 3 km long and covering 135 ha. The southern part of it has received high values in the *Högsåra* scenario. This might be a feasible place for a small park of 3 turbines.

8.4.2 Consistency of criterion ranking in AHP

Now that results from different scenarios have been compared, an aspect affecting their reliability should be discussed. Those scenarios in which attributes have been removed, weights have been recalculated linearly, and not derived using AHP. If attributes were deleted from the value tree and new weights calculated, they would be different from the weights used here. AHP weights would not be correct either, because the weights of the first level attributes are dependent on the second level attributes it contains. Without conducting a new round of pairwise comparisons, the weights would not be reliable. Therefore for the sensitivity analysis it is assumed that when the lowest ranking attributes are deleted, the proportions will not change in the rest of them.

Another reason why the existing pairwise comparison tables cannot be used when criteria are removed or introduced is the rank reversal problem discussed by for instance Doumpos & Zouponidis (2002). When a criterion is introduced or excluded from the analysis, order of the original remaining criteria may change. The linear methodology for weight acquisition used for the scenarios maintains existing relations between remaining criteria. It is also worthwhile to mention that AHP as a methodology may not be the best way to derive weights due to rank reversal problem. Saaty and Sagir (2009) propose ANP to solve this issue.

8.4.3 Comparison of results and regional wind energy plans

In order to compare regional land use plan marks influence to the analysis results, phased regional land use plan impact was excluded from the result in the *Unplanned* scenario (Figure 25, p.93). Some differences between Regional Council's wind power marks and the *Unplanned* scenario rank map are caused by differential input data. Firstly, the shape of areas is different because different data sets were used in order to create housing buffer. In addition, the wind power study did not consider safety buffers for 110 kV lines, and one of them cuts through Degerdal. All the areas with the mark are described in the rank map as feasible alternatives. Högsåra is excluded from feasible alternatives for several reasons such as distance to grid, White-tailed Eagles and landscape impacts. Then again, Högsåra park is only 6 MW, which is much less than the 12–25 MW assumption of this study, and its turbines are roughly half of the size of example turbines.

Differing recommendation by the *Unplanned* scenario and regional land use plan draft can be explained to most extent just by one thing: consideration of the Regional Council's bird study. Once the bird study is applied into the *Unplanned* scenario, ranking changes completely (Figure 32). Helgeboda and Degerdal are ranked almost entirely as 0–10 %, and Pungböle as 10–30 %. Misskärr is moved from the least risky 10–30 % changes to the 70–90 % class. Nordanå-Lövböle, Påvalsby, and Östanå-Labböle rank lower, especially those edges close to Björkboda. If the weight of these new bird areas was not quite as high as in the Figure 31, the areas ranked 0–30 % would quite possibly resemble closely to the regional land use plan marks. One more thing that affects the differing results is the area size definition. Small areas are not considered in the regional council study or plan draft.

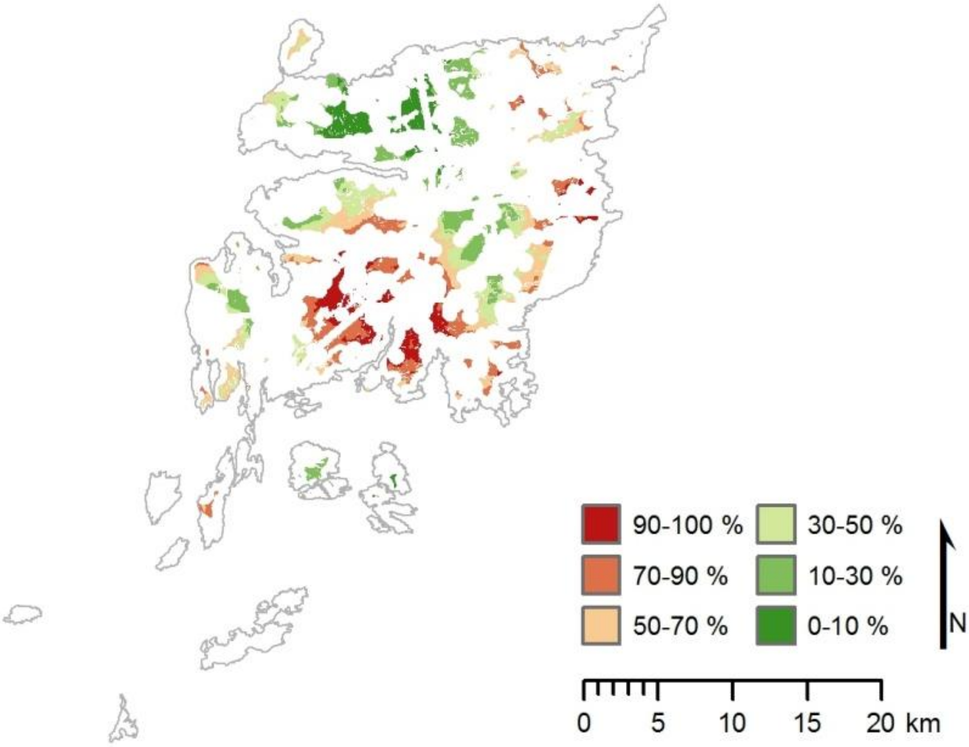

Figure 32. *Unplanned* scenario rank map with the impact of regional council bird study.

8.5. Functionality in decision-making

Information on the low-risk locations for wind energy production is necessary for both municipalities and project developers. This method does not replace on-site studies but it provides indication where to find the least risky places for wind energy production. More importantly, this method can be utilized by municipalities and wind energy developers for searching and evaluating production sites. Commercial wind energy producers usually prioritize places with the highest wind potential but there are more aspects to be considered. Wind measurements and other expensive studies can be initiated only after conducting preliminary studies, to which this method can be included.

This study includes only wind energy developer and planner views but the methodology can be used to include also other groups of interest. For instance, opinions of environmental organizations or authorities could be acquired and used similarly. Moreover, this method could be used for enabling participation of municipality residents to the decision-making process. For instance, it is possible to conduct questionnaires where different criteria are ranked or given points according to preference of the residents. This kind of study would provide a preference map of the residents instead of a risk map. In addition, multicriteria decision making can be used for opening communication between groups that have conflicting interest. More on communication-oriented MCDA methodology can be read from a report by Marttunen et al. (2008).

In Kemiönsaari, these results may be used to provide indication on where to orient further studies regarding wind energy development. However, the sample of experts is limited, and in order to increase the reliability of this research, more experts should be included through decision analysis interviews. Moreover, framework of the criteria should be revised with decision-makers.

In the summer 2012, there were five on-going statutory land use planning processes of different sized wind parks in Kemiönsaari. Since the statutory land use planning has been initiated, these projects have already proceeded so far that results of this study are not applicable to them anymore. Significant investments have already been made on these projects, and environmental studies related to them have provided more detailed information. Perhaps this study may have minor value in hindsight but detailed case-specific studies are more reliable than this general spatial analysis.

For wind energy developers, perhaps the most practical way to use this method is to conduct the analysis within an interesting municipality or other defined area of interest. SMDCA can be applied anywhere but the selection of evaluation criteria and constraints should always be place specific. In this study they are based on Finnish legislation and practices of wind energy business, and in other countries those might be substantially different. In other parts of Finland there are other aspects that should be considered, for instance reindeer herding and wilderness areas in the north. In the continental Finland it may be necessary to exclude some areas due to low wind conditions.

Weights used in this study are not recommended to be applied directly in other municipalities as the experts were asked place-specific questions. If this method is used elsewhere, it is important to conduct new interviews with experts that have sufficient knowledge on the area of interest.

It is essential to remember that weights, as well as the set of criteria and their definition are also time-specific. Legislation, practices, environmental and economical conditions are always changing, and so is the perceived importance of different criteria. For instance, the risk by military may be changing as the radar technology and legislation changes, and new noise guidelines may change the minimum distance that is commonly used. If the Finnish legislation would change regarding protection areas or tariff was removed, this analysis would not be reliable anymore. When the economical profitability is not supported by tariff, developers may set more emphasis on the economical side. If this study was done in that situation, probably the difference between group appreciations would be much larger as the developers were more focused on the economical risk. According to Butler and Neuhoff

(2008), projects are less probable to fail in the licensing phase in countries with feed-in tariff than another type of subsidiary system. In Finland, the preceding investment subsidy for wind energy production was removed abruptly in the beginning of 2012 (Finnish Energy Industries 2012b) so it the tariff was removed, there would be nothing to compensate it unless the emission trade system raised non-renewable electricity prices sufficiently. To conclude, if this study was repeated within the study area after a few years from now, the results could be very different.

9 Conclusions and future research ideas

The goal of this thesis was to find low-risk locations for wind energy development and rank them according to their level of risk posed by a variety of different criteria. This was done by the means of spatial multicriteria decision analysis (SMCDA), more specifically using a spatial variation of analytic hierarchy process (AHP). The study aimed at estimating data suitability, attribute quality, risk level of potential wind power areas and the result reliability.

The first study aim scrutinized suitability of existing data for this SMCDA study. Resolution of the model is only as high as the lowest spatial accuracy data set used in the analysis. All the other data sets met the resolution requirement of 25 m apart from wind data and quaternary deposits map. In addition, the Regional Council's wind power study had input data of 250 m grid resolution, which reflected to the results. Low resolution of windiness was compensated by relative elevation, and remaining inaccuracies were acknowledged and tolerated in order to maintain completeness of the set of attributes. Crude generalizing assumptions had to be made for some data sets without sufficient attribute data but most data sets did not require compromises for data quality.

Another aspect of the first study aim was to estimate the necessity of data sets for the analysis. This was done first by estimating qualitatively the level of necessity for each data set, and secondly by excluding low-scoring criteria in the sensitivity analysis. When selecting input data, data sets describing features that had been described elsewhere with more accuracy or more practically were excluded. In the sensitivity analysis it was shown that if criteria with low weight are excluded, ranking of alternatives does not change significantly, and therefore data in low-weight criteria may not be necessary. However, if a similar study was conducted on a different area or different scale, these data sets might prove more important. For instance, soil would perhaps play a more important role if this analysis was conducted within just one wind park area. The most important data sets within the study area were the Topographical database and White-tailed Eagle nest data followed by for instance windiness and different protection area data sets.

The second study aim regarded attribute quality. Attribute quality was determined qualitatively based on Malczewski's (1999) set of quality criteria, and some issues were found. Firstly, available spatial data and criteria layers derived from them could not describe thoroughly objectives, which means that there are comprehensivity issues. For instance, distance to bird protection areas does not completely indicate the risk for projects caused by bird values. However, for the purpose of this study, which is to conduct a preliminary study in order to direct further studies, these attributes have the benefit of simplicity and generality, understandability and data achievability.

The quality criteria of operationality, measurability, completeness, decomposability and minimality were fulfilled well by the attributes. The decision-makers understood the attributes and their consequences, and therefore the set of attributes fulfilled the quality criterion of operationality. All the alternatives were measurable meaning that they could be assigned a justifiable number practically and it could be translated into a figure describing decision-maker appreciation. Completeness required a compromise with minimality and was limited by contemporary knowledge, data availability and confidentiality. All the attributes that would increase the model reliability with a reasonable amount of effort were taken into consideration. The hierarchical structure was disaggregated into three first level attributes that ease comprehension, which means that the set of criteria was decomposable as well. Furthermore, no attribute could be eliminated without weakening the model reliability, so the set of criteria is minimal.

The final criterion of redundancy was subject to much discussion. Spatial correlations were revealed among certain criteria. However, this spatial dependency did not extend to the reasons behind attribute selection. Therefore removing or combining correlating criteria would have risked the model completeness. The set of attributes was certainly not flawless but anyhow provided a justified result that could be used for providing recommendations to decision-makers as long as quality issues as well as their reasons and implications are recognized.

The third study aim discussed those areas least risky for wind parks, and two areas clearly emerged: Nordanå-Lövböle and Påvalsby. Those are large and well away from the most critical places such as bird or landscape protection areas. In addition, they have sufficient road and electric infrastructure readily available as well as reasonably high wind speeds. Other smaller low risk areas included Helgeboda, Degerdal, Pungböle, Björkboda, and Östanå-Labböle, although these areas were more risky then the two large ones.

The fourth study aim considered the reliability of results. As there was not much variance on Nordanå-Lövböle and Påvalsby in the sensitivity analysis ranking, recommendation regarding them is rather reliable. The recommendation regarding other low-risk area is not quite as reliable due to higher variance in alternative ranking. It should be noted that the level of risk as well as reliability were estimated only within the study area, and therefore the results presented in this study may change if the shape or size of the study area was altered.

In similar future studies, use of certain methodologies would present interesting new aspects. It would be interesting to study the phenomenon of wind energy locating in varying scales and areas in order to observe how the set of attributes and their weights change spatially and across scales. In the national scale, preference disaggregation analysis might reveal unexpected patterns and significance of different criteria in the past.

During the study, it became evident that there may be interdependency between criteria, and that AHP results in errors if interdependencies are not detected and treated. Yet AHP does not provide means of detecting interdependencies, and correlation analysis does not introduce reliable estimations of interdependency when spatial criteria are at stake. Therefore a more complex version of AHP, analytic network process (ANP), would improve reliability of the analysis. ANP accommodates interdependencies but it is also more time consuming than AHP.

This thesis has concentrated in methodology and data even though SMCDA could offer much more for wind power discussion in Finland. Often wind power evokes opposition and strong feelings in citizens, experts and authorities. Nevertheless, in order to achieve sustainable energy production goals, wind power plants must rise somewhere. MCDA could be used as an intermediary tool for problem solving, helping opposing sides understand each others' views and even establish routes for communication as well as spread accurate information on the situation at hand. Use of MCDA as an intermediary tool would be a fascinating human geographical research subject. SMCDA can also be used for bringing masses of citizens into the realm of decision-making if the weight assignation process was simplified, and instead of risk levels, values of citizens would be enquired. In that case, SMCDA would take the role of a true public participatory GIS method. SMCDA can be used in many ways for many purposes, and it has the potential to serve not only scientific community but also the public, organizations, private interests and authorities.

Acknowledgements

This study was conducted using many different data sets, for which I would like to thank all the data producers. Thanks to GTK, ELY-center, SYKE, FMI, BNA, BirdLife and all the other data producers for allowing their data to be used in this study. Lounaispaikka also deserves thanks as it displays many of the data sets used here in a user-friendly internet map service and because its staff provided me with personal assistance for searching quarters that were responsible of different data sets. In addition, I would like to thank all the data producers that kindly provide their data through different download services: as a geographer and citizen I appreciate free and readily available data and information.

I have relied on advice and help from many different experts during the work. Aleksis Klap from the Regional Council of Southwest Finland provided me with several data sets as well as a great deal of valuable advice and inspiration. Help from him and his colleagues in the Regional Council was much needed and appreciated. Thanks to Jouko Högmander and Toni Laaksonen from Metsähallitus for their insightful advices and encouraging discussions as well as trusting me with the eagle nest data. I am grateful also to biologist Lauri Erävuori from Sito, who took the time to answer my questions regarding potential impacts of wind power parks; to Mikko Niininen from WinWinD who provided me with specific information on turbines and wind power production; and to Kari Tuominen from Peikko, who gave me valuable advice regarding turbine foundations. I have borrowed also many other people's expertise for this study, and I greatly appreciate their willingness to provide information and support when it was needed.

I would like to give my thanks to those four people that provided me with their advice on methodology and contributed otherwise to the quality of this thesis. Firstly, my instructor in efe, Ansgar Hahn, was never too busy for my questions regarding wind energy development. His enthusiasm and trust pushed me forward when the work did not seem to proceed. I thank also efe for our fruitful co-operation and a scholarship that was admitted for this thesis. Secondly, my instructor Jukka Käyhkö helped me to organize my thoughts on paper and did a great deal of quality control. Much needed support regarding methodology came from an unexpected direction: thanks to my former teacher Juha Hiedanpää and my fellow student Ilpo Tammi for their valuable insights. In addition, a big thanks to all the fellow students in UTU-LCC who helped me with many practical GIS issues.

Most importantly: I cannot thank enough those anonymous experts that took the time and effort to participate to the analysis interviews. They are the key element of this study and

provided its justification when they expressed their knowhow in the form of numbers during the pairwise comparison process. In addition, all the interviewees had important and interesting comments many of which became matters of discussion.

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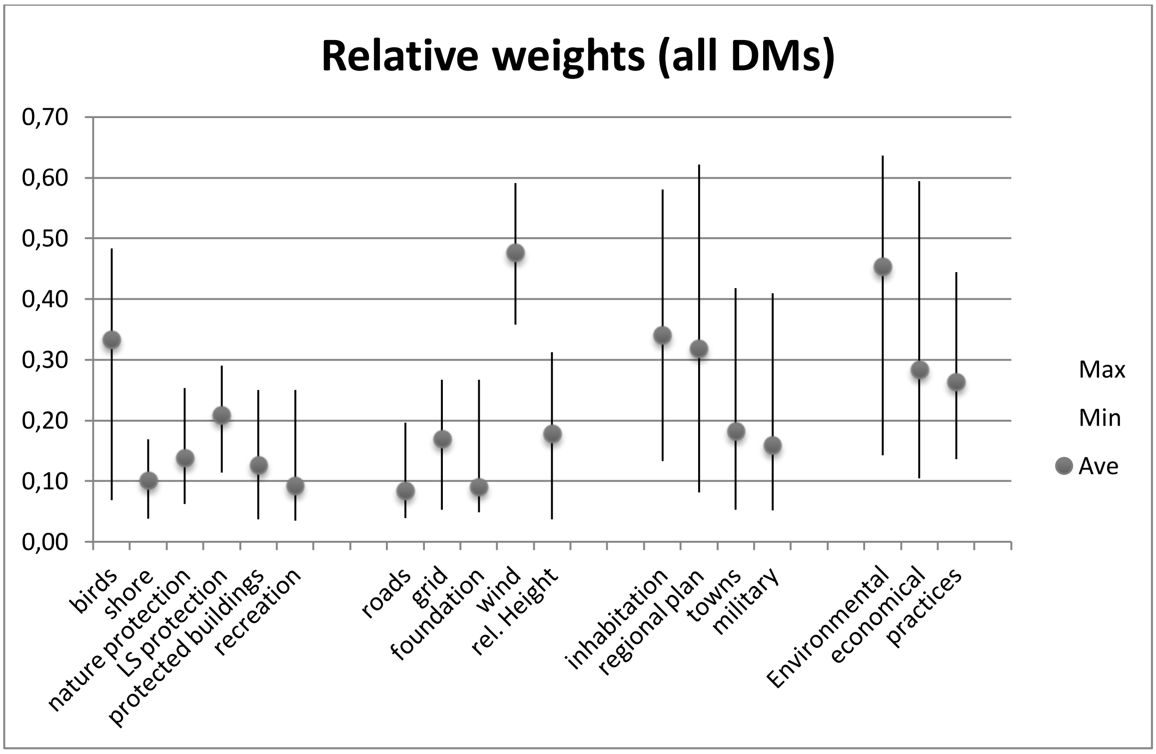
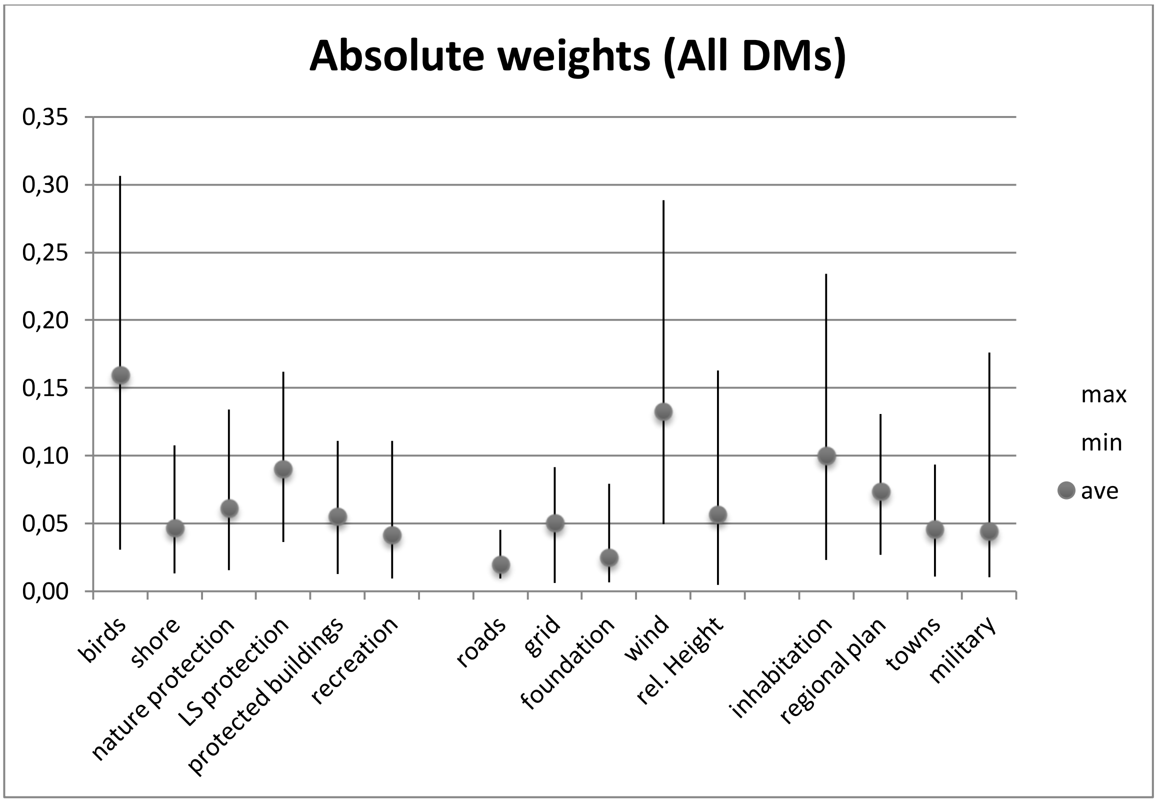
Appendices

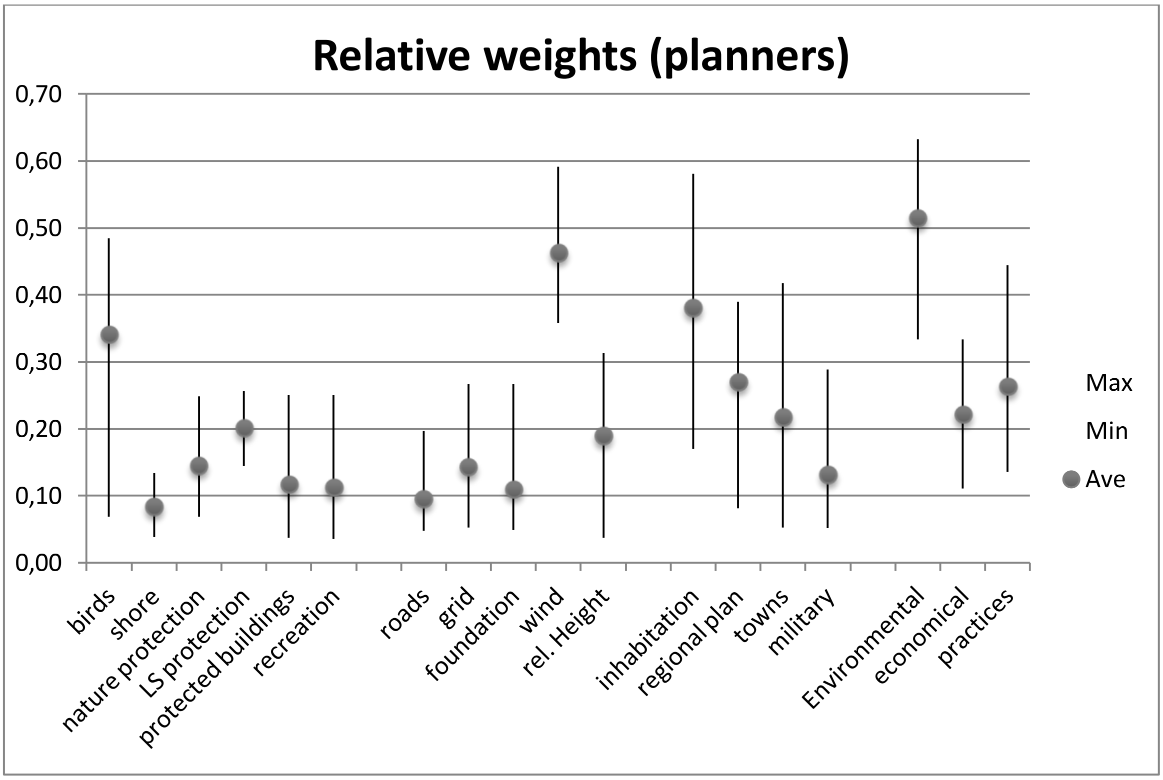
Appendix I: Criterion weights

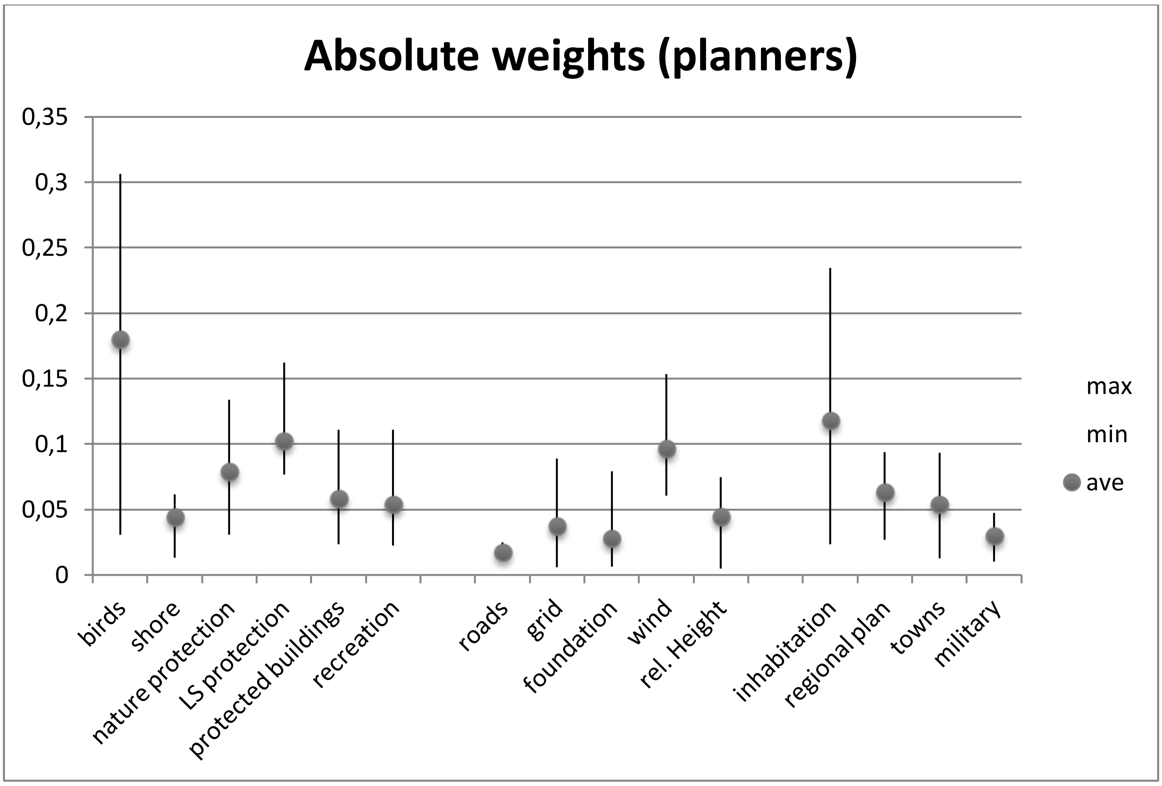
criterion	planners (5)		developers (4)		all (9)	
	rel.	abs.	rel.	abs.	rel.	abs.
economical	0.221		0.361		0.283	
windiness	0.463	0.102	0.494	0.178	0.476	0.135
relative elevation	0.190	0.042	0.165	0.059	0.179	0.051
distance to grid	0.143	0.032	0.203	0.073	0.170	0.048
distance to roads	0.095	0.021	0.071	0.026	0.084	0.024
foundation cost	0.109	0.024	0.067	0.024	0.091	0.026
environmental	0.515		0.376		0.453	
distance to nature reserves	0.145	0.075	0.130	0.049	0.138	0.063
distance to bird protection areas	0.341	0.176	0.325	0.122	0.334	0.151
distance to landscape protection areas	0.201	0.104	0.218	0.082	0.209	0.095
distance to protected buildings	0.117	0.060	0.138	0.052	0.126	0.057
distance to recreation areas	0.112	0.058	0.068	0.026	0.093	0.042
distance to shoreline	0.084	0.043	0.122	0.046	0.101	0.046
societal	0.263		0.264		0.263	
distance to houses	0.381	0.100	0.290	0.077	0.340	0.090
distance to population centers	0.217	0.057	0.137	0.036	0.182	0.048
wind power mark in the regional land use plan	0.270	0.071	0.379	0.100	0.318	0.084
distance to restricted areas by Defence Forces	0.131	0.034	0.195	0.051	0.159	0.042

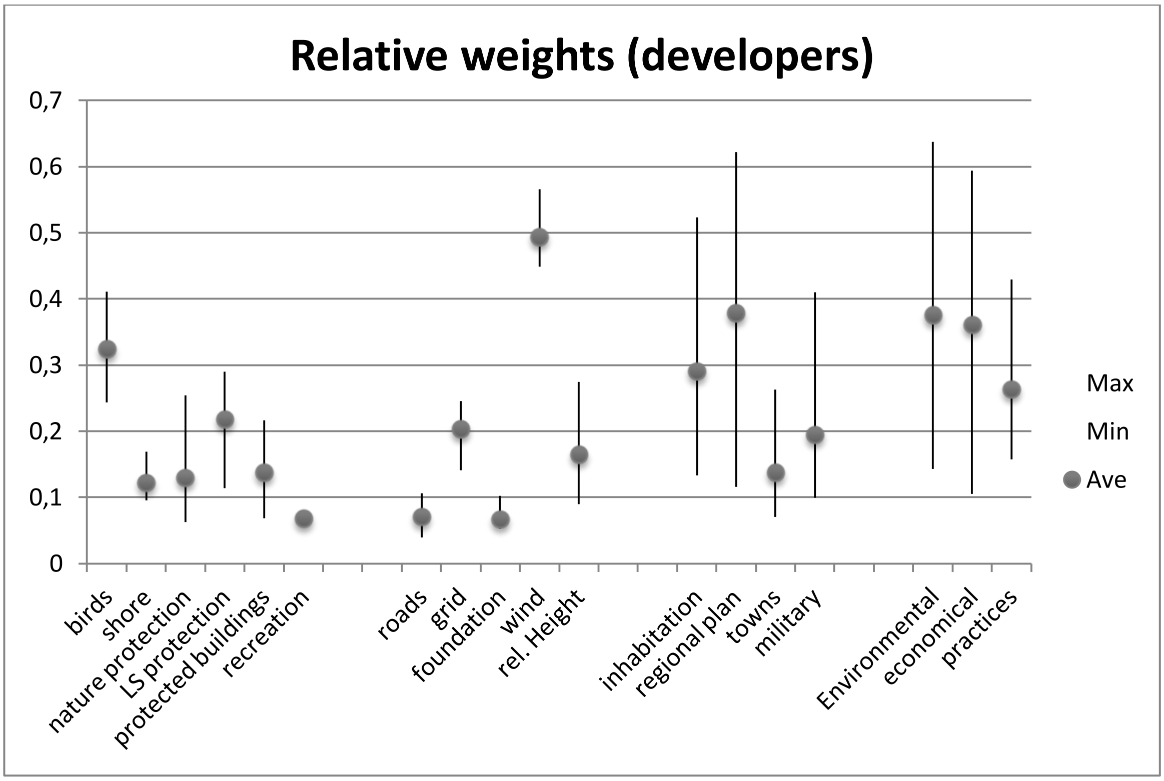
Appendix II: Variance of weights

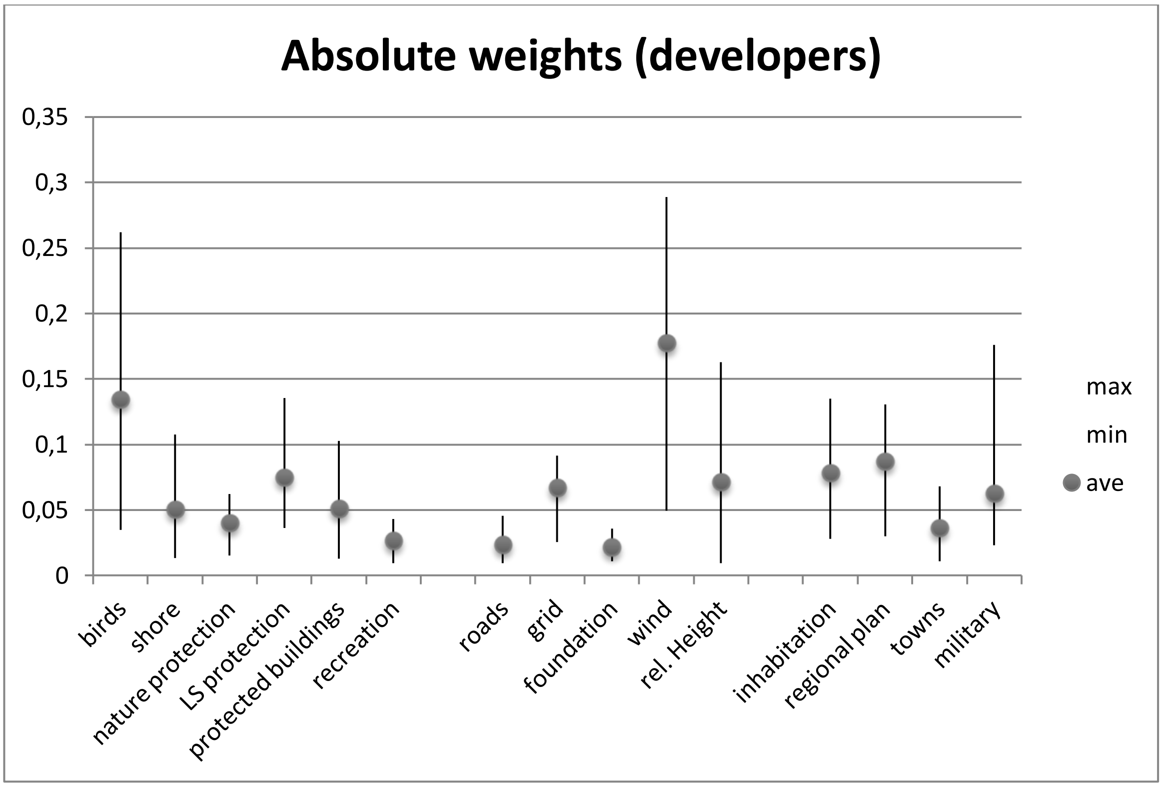





Relative weights (planners)
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
birds
shore
nature protection
LS protection
protected buildings
recreation
roads
grid
foundation
wind
rel. Height
inhabitation
regional plan
towns
military
Environmental
economical
practices
Max
Min
Ave


Absolute weights (planners)
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
birds
shore
nature protection
LS protection
protected buildings
recreation
roads
grid
foundation
wind
rel. Height
inhabitation
regional plan
towns
military
max
min
ave

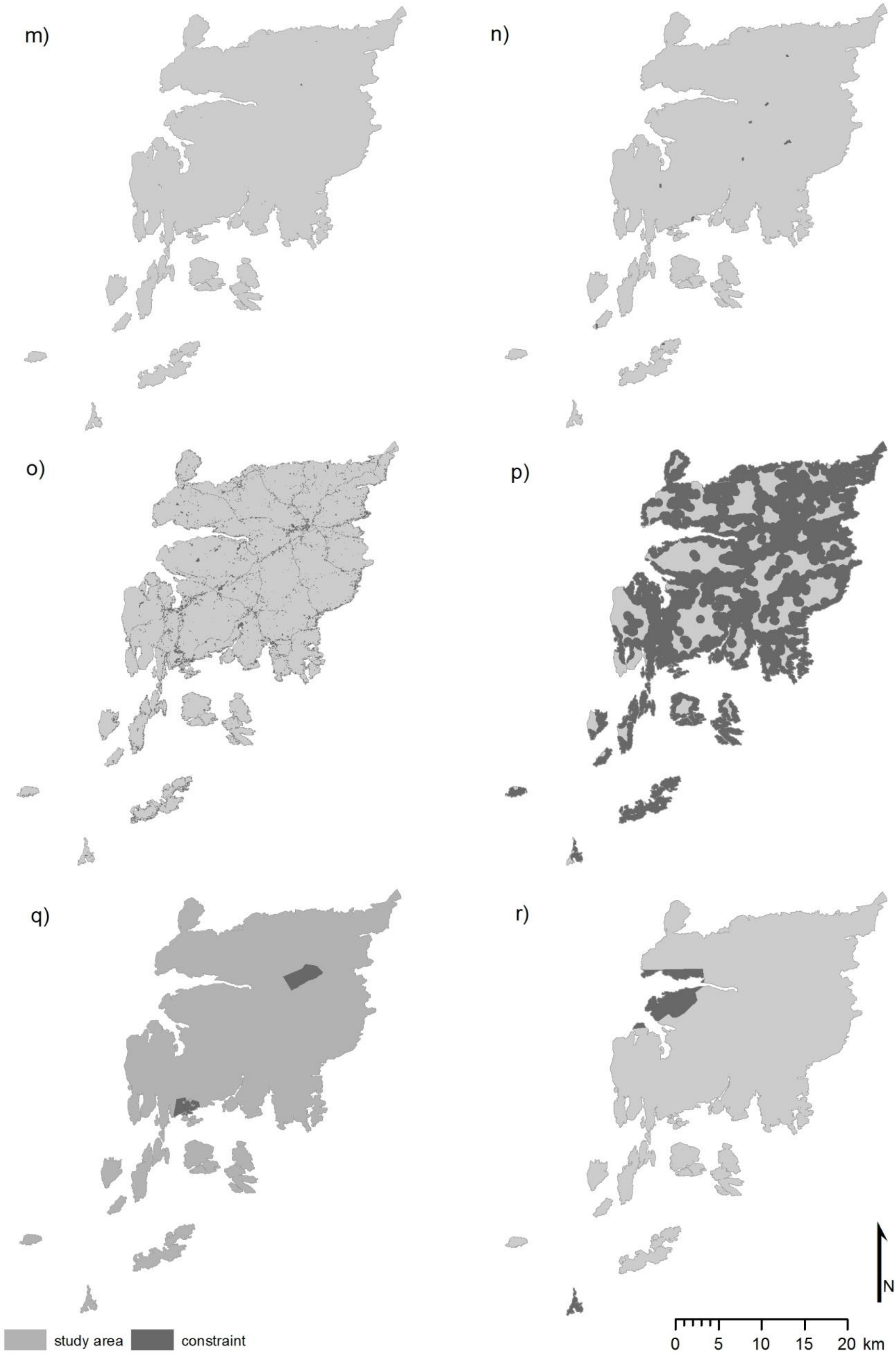

Relative weights (developers)
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
birds
shore
nature protection
LS protection
protected buildings
recreation
roads
grid
foundation
wind
rel. Height
inhabitation
regional plan
towns
military
Environmental
economical
practices
Max
Min
Ave


Absolute weights (developers)
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
birds
shore
nature protection
LS protection
protected buildings
recreation
roads
grid
foundation
wind
rel. Height
inhabitation
regional plan
towns
military
max
min
ave

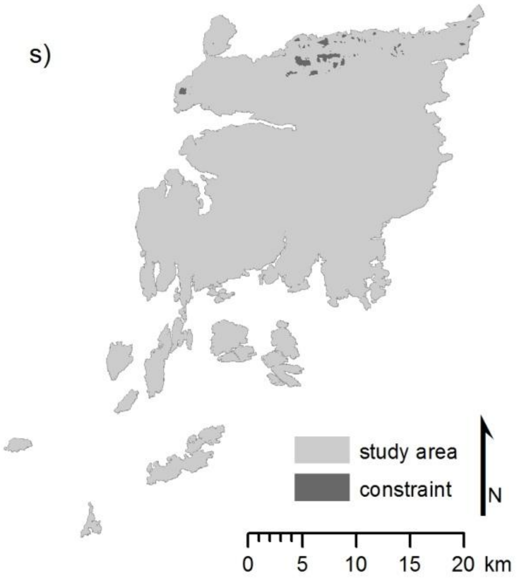
Appendix III: Constraint maps

Constraints. a) Grid, b) state roads, c) steepness, d) lakes, e) Natura 2000 areas and f) protection areas.

Constraints continue. g) Protection program areas, h) protection in the regional land use plan, i) FINIBA, j) significant landscape conservation areas, k) traditional landscapes and l) cultural environments.



Constraints continue. m) Archaeological sites from the National Board of Antiquities, n) archaeological sites from the regional land use plan proposal, o) unsuitable land use from CLC2006, p) inhabitation buffer, q) towns and r) restricted areas of the Defence Forces



Constraints continue. s) Flight surface restriction.

Appendix IV: List of abbreviations

DEM – Digital elevation model

EIA – Environmental impact assessment

ELY – Centre for Economic Development, Transport and the Environment

FMI – Finnish Meteorological Institute

GIS – Geographical information system

GTK – Geological Survey of Finland

LUBA - Land Use and Building Act

MAUT – Multiattribute utility theory

MCDA – Multicriteria decision analysis/assessment/aid

NBA – National Board of Antiquities

NIMBY – Not in my back yard

NLS – The National Land Survey of Finland

PDA – Preference disaggregation analysis

SMCDA – Spatial multicriteria decision analysis

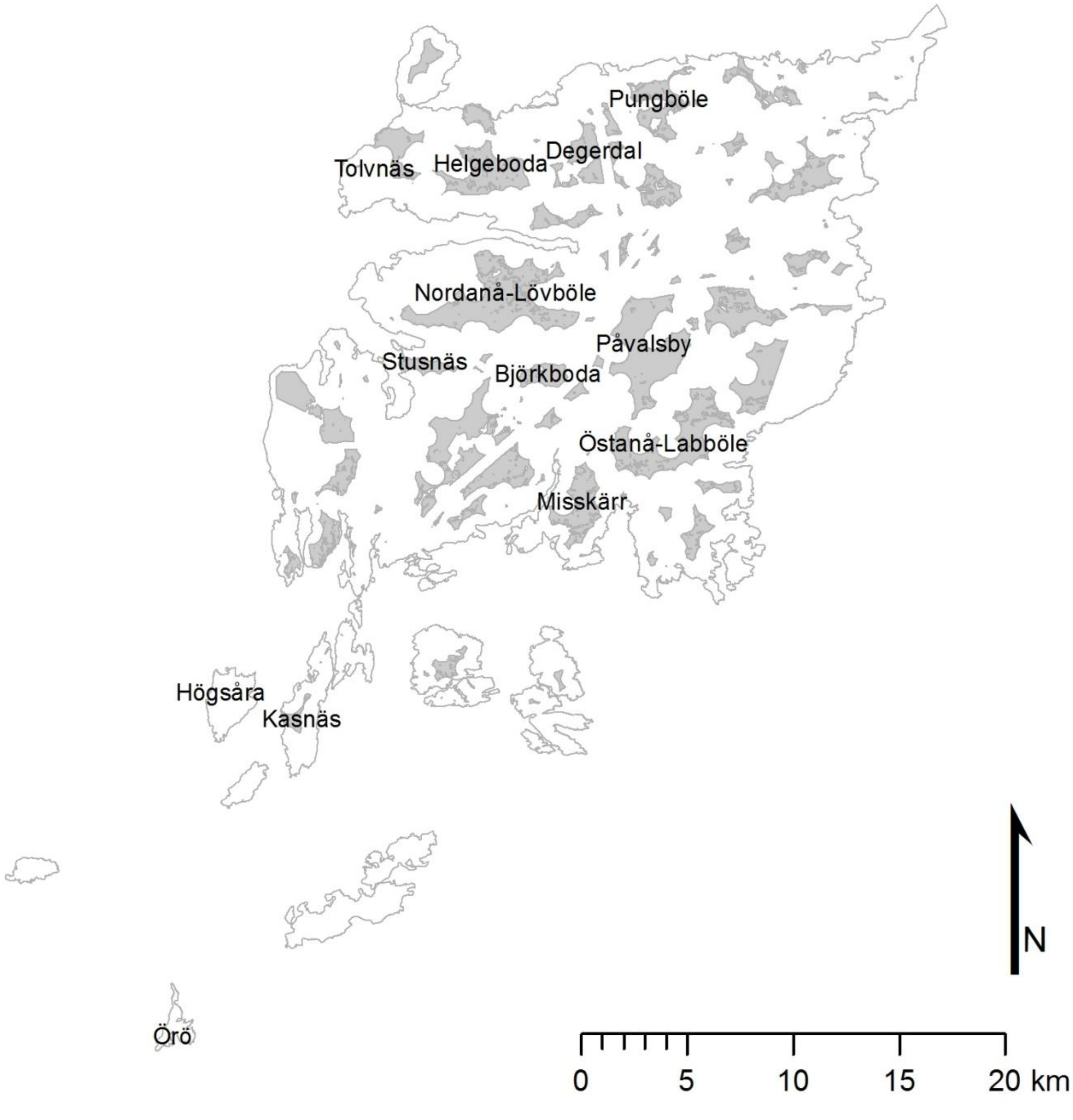
SCI – Site of Community Interest

SPA – Special Protection Area

SYKE – Finnish Environment Institute

WLC – Weighted linear combination

Appendix V: Place names



Appendix VI: Correlation of criteria

Criterion	Birds	Shore	Nature	Landscape	Recreation	Buildings	WP areas	Inhabitation	Towns	Military	Roads	Grid	Foundation	Wind	Height
Birds	1,00	0,05	0,17	-0,07	0,04	-0,30	0,17	0,02	0,20	-0,24	0,00	-0,03	0,06	-0,28	-0,02
Shore	0,05	1,00	0,17	0,14	0,52	-0,22	0,14	0,09	-0,47	-0,07	0,06	0,55	-0,22	-0,48	-0,09
Nature	0,17	0,17	1,00	0,01	0,22	-0,24	0,07	-0,13	-0,05	-0,05	0,18	0,19	-0,10	-0,33	-0,03
Landscape	-0,07	0,14	0,01	1,00	0,06	-0,14	0,18	0,19	-0,04	-0,18	-0,11	0,04	-0,03	-0,16	-0,01
Recreation	0,04	0,52	0,22	0,06	1,00	-0,04	0,12	0,11	-0,17	-0,27	0,03	0,36	-0,15	-0,37	-0,06
Buildings	-0,30	-0,22	-0,24	-0,14	-0,04	1,00	-0,03	0,06	0,18	0,13	-0,29	-0,18	0,14	0,51	0,05
WP areas	0,17	0,14	0,07	0,18	0,12	-0,03	1,00	0,40	0,04	-0,16	-0,07	0,00	0,05	-0,12	-0,02
Inhabitation	0,02	0,09	-0,13	0,19	0,11	0,06	0,40	1,00	0,01	-0,18	-0,10	-0,05	0,10	0,00	0,00
Towns	0,20	-0,47	-0,05	-0,04	-0,17	0,18	0,04	0,01	1,00	-0,14	-0,01	-0,75	0,16	0,35	0,05
Military	-0,24	-0,07	-0,05	-0,18	-0,27	0,13	-0,16	-0,18	-0,14	1,00	-0,23	0,14	-0,02	-0,07	0,02
Roads	0,00	0,06	0,18	-0,11	0,03	-0,29	-0,07	-0,10	-0,01	-0,23	1,00	0,12	-0,12	-0,28	-0,06
Grid	-0,03	0,55	0,19	0,04	0,36	-0,18	0,00	-0,05	-0,75	0,14	0,12	1,00	-0,24	-0,61	-0,07
Foundation	0,06	-0,22	-0,10	-0,03	-0,15	0,14	0,05	0,10	0,16	-0,02	-0,12	-0,24	1,00	0,28	0,35
Wind	-0,28	-0,48	-0,33	-0,16	-0,37	0,51	-0,12	0,00	0,35	-0,07	-0,28	-0,61	0,28	1,00	0,17
Height	-0,02	-0,09	-0,03	-0,01	-0,06	0,05	-0,02	0,00	0,05	0,02	-0,06	-0,07	0,35	0,17	1,00