























## Spatial Multi-Criteria Decision Analysis (SMCDA) toolbox for Consensus-based Siting of Powerlines and Wind-power plants (ConSite)

Frank Hanssen  
Roel May  
Jiska Van Dijk  
Bård G. Stokke  
Matteo De Stefano



-  ConSite Powerlines
-   1. Study area
  -   2. Calculate Social criteria maps
  -   3. Calculate Technological criteria maps
  -   4. Calculate Ecological criteria maps
  -   5. Calculate routing maps



-  ConSite Wind Power
-   1. Study area
  -   2. Calculate Social criteria maps
  -   3. Calculate Technological criteria maps
  -   4. Calculate Ecological criteria maps
  -   5. Calculate siting maps

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Tone Ibenholt

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NØKKELOD

GIS, arealplanlegging, romlige beslutningsverktøy, beslutningsstøtte, beslutningsteori, AHP, fuzzy logic teori, konfliktkartlegging, medvirkning, dialog, konfliktreduksjon, konsekvensutredning, fornybar energi, lokalisering av vindkraft, trasevalg for kraftledninger, optimalisering, multikriterieanalyse, sensitivetsanalyse, vurdering av risiko og kompromiss, layout design, økosystemtjenester

## Abstract

Hanssen, F., May, R., Van Dijk, J., Stokke, B.G., De Stefano, M. 2018. Spatial Multi-Criteria Decision Analysis (SMCDA) toolbox for Consensus-based Siting of Powerlines and Wind-power plants (Con-Site). NINA Report 1455. Norwegian Institute for Nature Research.

The expansion of wind energy development causes both societal and environmental concerns worldwide. Traditional land use planning approaches however limit addressing such concerns adequately. The scale and complexity of emerging renewable energy construction projects enforce the development of improved plan- and decision support tools that ensure democratic and cost-effective processes securing qualified decision making. The multiplicity of criteria and actors involved in decision-making processes requires holistic approaches that enable capturing the variety stakeholder views from technological, economic, societal and environmental perspectives.

As a response to this societal need, the Norwegian Institute for Nature Research (NINA) has developed a Spatial Multi-Criteria Decision Analysis tool (SMCDA) for siting of onshore wind-power plants and associated infrastructure such as powerlines and roads. The tool ConSite (Consensus Based Siting) aims to ensure socially acceptable, environmentally friendly and cost-effective siting, routing and design of wind-power plants and powerlines. ConSite helps to identify and justify decisions taken with respect to both transparency and verification. ConSite is based on current developments in stakeholder dialogue theory, GIS-based Spatial Multi-Criteria Decision Analysis (SMCDA) and decision theory.

The ConSite framework is structured into the operational steps of a classical SMCDA and combines stakeholder dialogue with multi-criteria assessment. The objective of the toolbox is to identify areas with the lowest possible conflict level and the highest possible production level. Dialogue with affected stakeholders and documentation of relevant expertise is used to provide information about, and to consider the relative importance of (weighting of) the different stakeholder interests. This helps to identify potential land use conflicts in a “conflict-map”. The “conflict-map” is used together with wind resource maps to identify which areas are most optimal for wind power development. This way ConSite helps to structure the decision problem, balance conflicting interests and identify relevant decision strategies based on a holistic evaluation of risk and trade-off between different alternatives. ConSite can be used to evaluate different scenarios by visualizing the spatial consequences of different decision strategies

This report exemplifies the practical usage of the ConSite toolbox. ConSite has previously been successfully implemented in spatial planning of wind-power development in Lithuania, and validated through a power line routing case study in Sør-Trøndelag County (Bevanger et al., 2014 & Hanssen et al., 2014). Further development to integrate the ecosystem services concept into an adaptive landscape planning context, helps making the complexity of social-ecological systems more comprehensible for involved stakeholders. This enables the application of ConSite across sectoral interests (e.g. renewable energy, road infrastructure, urban development and fish farming). ConSite can thus help decision makers to secure socially acceptable, environmentally friendly and cost-effective siting and optimal design of renewable construction projects. The current version of the ConSite SMCDA toolbox framework is developed for a desktop GIS platform. To increase the access to and user-friendliness of ConSite, NINA has the ambition to move the ConSite SMCDA framework to an online GIS- platform. This development will be based on an evaluation of user needs, a detailed requirement specification and system prototyping.

Frank Hanssen, NINA, Box 5685 Sluppen, N-7485 Trondheim, [frank.hanssen@nina.no](mailto:frank.hanssen@nina.no)  
Roel May, NINA, Box 5685 Sluppen, N-7485 Trondheim, [roel.may@nina.no](mailto:roel.may@nina.no)  
Jiska Van Dijk, NINA, Box 5685 Sluppen, N-7485 Trondheim, [jiska.van.dijk@nina.no](mailto:jiska.van.dijk@nina.no)  
Bård G. Stokke, NINA, Box 5685 Sluppen, N-7485 Trondheim, [bard.g.stokke@nina.no](mailto:bard.g.stokke@nina.no)  
Matteo De Stefano, NINA, Box 5685 Sluppen, N-7485 Trondheim, [matteo.destefano@nina.no](mailto:matteo.destefano@nina.no)

## Sammendrag

Hanssen, F., May, R., Van Dijk, J., Stokke, B.G., De Stefano, M. 2018. Spatial Multi-Criteria Decision Analysis (SMCDA) toolbox for Consensus-based Siting of Powerlines and Wind-power plants (Con-Site). NINA Report 1455. Norwegian Institute for Nature Research.

Den omfattende utbyggingen av vindkraft forårsaker både samfunnsmessige og miljømessige bekymringer verden over. Tradisjonell arealplan-metodikk har en begrenset evne til å adressere alle disse behovene på en tilstrekkelig måte. Omfanget av og kompleksiteten i nye energiprojekter vil tvinge frem utviklingen av forbedrede plan- og beslutningsstøtteverktøy for å sikre mer demokratiske, kostnadseffektive og kvalifiserte beslutningsprosesser. Mengden av kriterier og aktører som er involvert i plan- og beslutningsprosesser krever en helhetlig tilnærming for å kunne fange opp alle berørte interesser innenfor teknologiske, økonomiske, samfunnsmessige og miljømessige perspektiver.

Som en respons på dette samfunnsbehovet har NINA gjennom CEDREN<sup>1</sup> utviklet et romlig multi-kriteriebasert verktøy for konsensusbasert lokalisering av landbasert vindkraftverk og kraftledninger. Verktøyet har fått navnet ConSite (kortform for Consensus Based Siting) og bidrar til samfunnsmessig akseptabel, miljøvennlig og kostnadseffektiv plassering og utforming av vindkraftverk. ConSite kan bistå med å identifisere og begrunne vedtatte beslutninger både med hensyn til transparens og etterprøvnbarhet. Verktøyet er basert på gjeldende kunnskap innenfor dialogteori, GIS-baserte beslutnings-systemer og beslutningsteori.

ConSite-rammeverket er strukturert som et klassisk romlig multi-kriteriebasert beslutningsverktøy og kombinerer dialog med multi-kriteriaanalyse. Målet med verktøyet er å identifisere områder som har lavest mulig konfliktnivå og høyest mulig produksjonsnivå. Dialog med berørte parter og dokumentasjon av relevant fagkunnskap benyttes til å fremskaffe informasjon om, og å vurdere den relative betydningen av (vektingen av) de ulike arealinteressene. Dette bidrar til å identifisere potensielle arealkonflikter i et eget «konfliktkart». Konfliktkartet brukes sammen med vind-ressurskart til å identifisere hvilke områder som egner seg best til utbygging av vindkraft. ConSite er på denne måten behjelpelig med å strukturere beslutningsproblem, balansere motstridende interesser og identifisere relevante beslutningsstrategier basert på en helhetlig vurdering av risiko og avveining mellom ulike alternativ. ConSite kan brukes til å vurdere ulike scenarier med tanke på romlige konsekvenser av ulike beslutningsstrategier.

Denne rapporten inneholder eksempler der ConSite har vært benyttet. Dette for å illustrere den praktiske bruken av verktøyet. ConSite er tatt i bruk til planlegging av vindkraftutbygging i Litauen og validert gjennom en case-studie med trasévalg for kraftledninger i Sør-Trøndelag (Bevanger et al., 2014 & Hanssen et al., 2014). Videre utvikling for å integrere økosystemtjenester i landskapsplanlegging er under planlegging. Dette vil bidra til å gjøre kompleksiteten av sosio-økologiske systemer mer forståelig for berørte interessenter i en plansak. Dette vil også bidra til å gjøre ConSite mer anvendelig på tvers av ulike sektorer (f.eks. energiprojekter, veibygging, byutvikling og fiskeoppdrett). ConSite kan på denne måten hjelpe beslutningstakere med å sikre en samfunnsmessig akseptabel, miljøvennlig og kostnadseffektiv lokalisering og utforming av fornybar-energiprojekter. Den nåværende versjonen av ConSite er utviklet på en desktop GIS-plattform. For å gjøre verktøyet mer tilgjengelig og brukervennlig har NINA som ambisjon å migrere ConSite over til en online GIS-plattform. Dette utviklingsarbeidet vil bli basert på en vurdering av brukernes behov, kravspesifisering og system-prototyping.

Frank Hanssen, NINA, Box 5685 Sluppen, N-7485 Trondheim, [frank.hanssen@nina.no](mailto:frank.hanssen@nina.no)  
Roel May, NINA, Box 5685 Sluppen, N-7485 Trondheim, [roel.may@nina.no](mailto:roel.may@nina.no)  
Jiska Van Dijk, NINA, Box 5685 Sluppen, N-7485 Trondheim, [jiska.van.dijk@nina.no](mailto:jiska.van.dijk@nina.no)  
Bård G. Stokke, NINA, Box 5685 Sluppen, N-7485 Trondheim, [bard.g.stokke@nina.no](mailto:bard.g.stokke@nina.no)  
Matteo De Stefano, NINA, Box 5685 Sluppen, N-7485 Trondheim, [matteo.destefano@nina.no](mailto:matteo.destefano@nina.no)

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<sup>1</sup> [www.cedren.no](http://www.cedren.no)

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## Foreword

The main aim of this report is to describe the structure of the ConSite SMCDA framework and how we plan to further develop and migrate this framework from a desktop to an online platform in order to support better collaboration and information exchange between stakeholders, developers, land-use planners and decision makers in future planning and decision-making processes. The principal functionality of ConSite, and how it works, is demonstrated in the ConSite animation film at Youtube<sup>2</sup>.

The ConSite SMCDA toolbox framework is an outcome of the R&D-projects “OPTImal design and routing of POver-Lines (2009-2013)<sup>3</sup>” and “*Consensus-based siting (2014-2016)*<sup>4</sup>” funded through the Centre for Environmental Design of Renewable Energy (CEDREN)<sup>5</sup>.

ConSite will be a major component in several new R&D activities in the years to come as described in Chapter 1. As a part of these projects and future collaboration with stakeholders, NGO`s, management authorities, industrial companies and research communities we hope to leverage the ConSite approach for improved decision making, not only within the energy sector, but also in other sectors like for example transport, fish-farming, land-use planning and nature management.

The ConSite SMCDA framework is based on state-of-the art knowledge (Dialogue process methodology, Value functions, Multi-Criteria Analysis function, Sensitivity analysis, Criteria aggregation, Siting/Routing and Optimisation) and thoroughly described in Chapter 2. Chapter 3 gives a brief description of the current ConSite Desktop SMCDA platform and how we plan to migrate towards a ConSite Online SMCDA platform. Chapter 4 describes how we plan to integrate public goods and ecosystem services in order to develop ConSite as an adaptive landscape planning toolbox.

Frank Hanssen  
Trondheim, January 22<sup>nd</sup> 2018

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<sup>2</sup> [https://www.youtube.com/watch?time\\_continue=11&v=nqBNZRIDHiE](https://www.youtube.com/watch?time_continue=11&v=nqBNZRIDHiE)

<sup>3</sup> <http://www.cedren.no/Prosjekter/OPTIPOL>

<sup>4</sup> <http://www.nina.no/consite>

<sup>5</sup> <http://www.cedren.no/>

# 1 Introduction

In information technology, migration is the process of moving from one operating platform to another with the purpose of the new platform performing better than the original one. This may involve hardware and software upgrades, as well as making sure that relevant key concepts from the previous platform are refined in such a way that the new platforms potential is fully exploited, uncertainties minimized, and that the migrated application becomes fully operational.

OPTIPOL LCP (Bevanger et al. 2014 & Hanssen et al. 2014) which were renamed ConSite (ConSite Wind and ConSite Powerlines)<sup>6</sup> (Hanssen et.al 2018) were developed as standalone desktop toolboxes in ESRI ArcGIS Advanced version 10.2/10.3. This platform was selected for its powerful raster processing capabilities. ConSite utilizes certified ESRI geoprocessing tools and algorithms. The ConSite toolboxes have been developed in ESRI's Modelbuilder, which is a visual programming language that strings together sequences of geoprocessing tools. This approach gives an effective and transparent solution for documenting, using and reusing, maintaining and refining GIS workflows. The standalone toolboxes are easy to implement in planning and decision-making processes without relying on the competence of system managers or developers. Usage and modification requires only basic to medium user knowledge in ArcGIS 10x.

In the past years there has been a growing interest in the ConSite Spatial Multi-Criteria Decision Analysis (SMCDA) approach from NGOs, consultancy companies, energy companies, research institutions and authorities across Norway and other countries. OPTIPOL LCP was successfully validated in Sør-Trøndelag County, and ConSite Wind was recently successfully validated in the EEA-grant project "Sustainable Wind Farm Development in Lithuania- DAVEP-VLIT (2015-2016)"<sup>7</sup>. ConSite, locally called the Wind Power Conflict Zoning Tool (WPCZT) in Lithuania, was from 2017 implemented by the Lithuanian Ministry of environment as a wind power decision support tool for regional land use planning authorities in Lithuania.

Beyond the CEDREN project period of 2014-2016, ConSite will play a major role in new R&D activities including the RCN project "Siting of Fish Farms in Central Norway (2017-2018)", the RCN-project "WindLand: Spatial assessment of environment-economy trade-offs to reduce wind power conflicts" and the BiodivERsA IMAGINE research project "Management of Green and Blue corridors Multi-functionality, Ecosystem integrity & Ecosystem Services (2017-2020)"<sup>8</sup>.

Further use and implementation of ConSite is to a certain extent however restricted by the current desktop platform. It is currently not possible to facilitate simultaneous access to the ConSite tools and databases at desktop level. Also, restricted by commercial licensing, only users with valid ArcGIS-licenses can use ConSite.

The main aim of this report is to describe the ConSite SMCDA framework, and to boost further use and implementation of ConSite by leveraging the ConSite framework from a desktop towards an online geoprocessing platform in order to support better collaboration and information exchange between stakeholders in future planning and decision-making processes. We also propose the inclusion of especially the public good type ecosystem service concept into the ConSite SMCDA framework so as to facilitate consistent and transparent valuation and weighting by the different stakeholders. This will minimize choice uncertainties and maximize concise decision-making.

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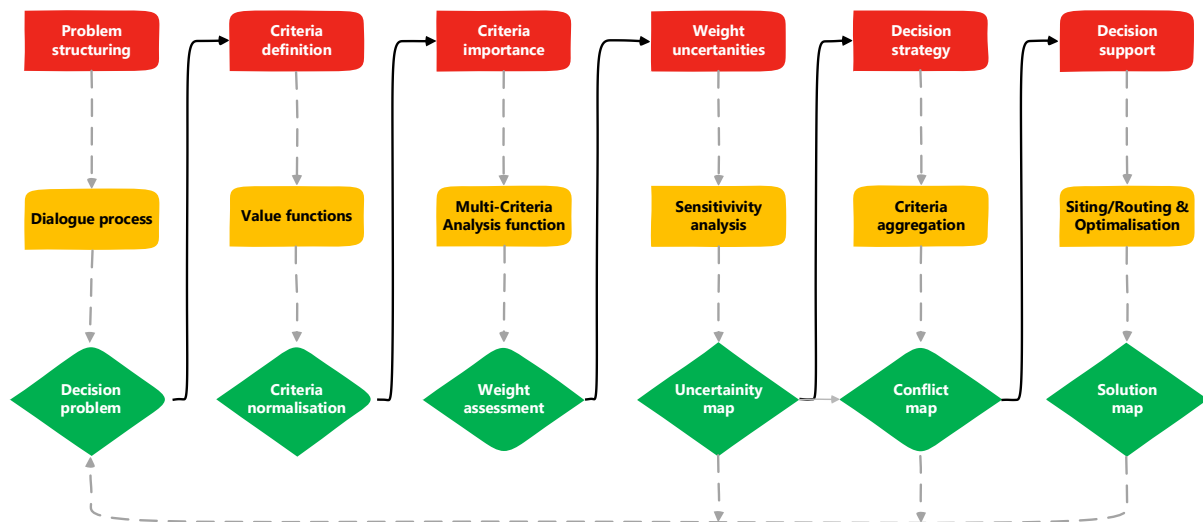
<sup>6</sup> <http://www.nina.no/consite>

<sup>7</sup> <http://www.nina.no/Forskning/Prosjekter/DAVEPVLIT>

<sup>8</sup> <https://www.era-learn.eu/network-information/networks/biodiversa3/biodiversa3-joint-call-2015/integrative-management-of-green-infrastructures-multifunctionality-ecosystem-integrity-and-ecosystem-services-from-assessment-to-regulation-in-socio-ecological-systems>

## 2 The ConSite SMCDA methodological framework

ConSite is based on current developments in stakeholder dialogue theory (Ferretti et. al. 2016, Owen 2015, Dente 2014, Reed et.al. 2009, Hansson et al. 1990, Holling 1978), GIS- based Spatial Multi-Criteria Analysis (Mateo 2015, Goepel 2013, Liu 2013, Comber 2009, Jiang et al. 2000, Malczewski 1999, Yager 1988, Zadeh 1996, Zadeh 1965) and decision theory (Bottero et al. 2015, Comino and Ferretti 2015, Ferretti 2011, Geneletti and Abdullah 2009, Keisler and Sundell 1997, Keeney 1994). The ConSite Wind principal framework is illustrated in Figure 1 and briefly explained below.



### Consensus based siting - Spatial Multi-Criteria Decision Analysis

Figure 1: The ConSite SMCDA framework. Red boxes represent the user interface, yellow boxes represent the process steps (see section 2.1 to 2.6) and the green boxes represent the outputs of each process step.

### 2.1 Dialogue processes

The first step in the ConSite workflow is to structure the decision problem. ConSite utilizes the principles and approaches of the Adaptive Environmental Assessment and Management (AEAM) methodology into a participatory scoping dialogue process (Bevanger et al. 2014, Hanssen et al. 2014, Thomassen et al. 2013, Thomassen et al. 2012, Hansson et.al. 1990, Holling 1978). This includes a representative group of stakeholders affected by a construction project, and is a step-by-step process that enables problem structuring, decision problem formulation and identification of relevant drivers, thematic content, criteria, criteria values and weights (see section 2.3).

The ConSite dialogue approach has both advantages and drawbacks. In general, it helps to gather information about and insights into inherent concerns and priorities among stakeholders. This helps to establish a consensus-based and transparent knowledge platform, which is crucial for obtaining stakeholder acceptance and high-quality decision-making (Owen 2015). On the other hand, stakeholder involvement is challenging, costly and time consuming. The group dialogue may be characterized by differences in mandates, conformity pressure, dominating personalities and ambiguous responsibilities, which in some, if not most, cases may stall the decision making process (Ferretti et al. 2016, Owen 2015, Felipe-Lucia et al. 2015).

To optimize the dialogue process it is very important to balance the competing interests, and from that, decide who may be involved and how they can contribute. This can be accomplished by undertaking stakeholder analysis methodology which helps to decide who should participate and how (Dente 2014). Reed et al. (2009) outlined a typology of stakeholder analysis methods for natural resource management (Figure 2). Reed et al. (2009) also identified the required resources, level of stakeholder participation, and strengths and weaknesses of each of the methods identified in the typology (Table 1). These findings are important guidelines for future dialog processes within the ConSite framework.

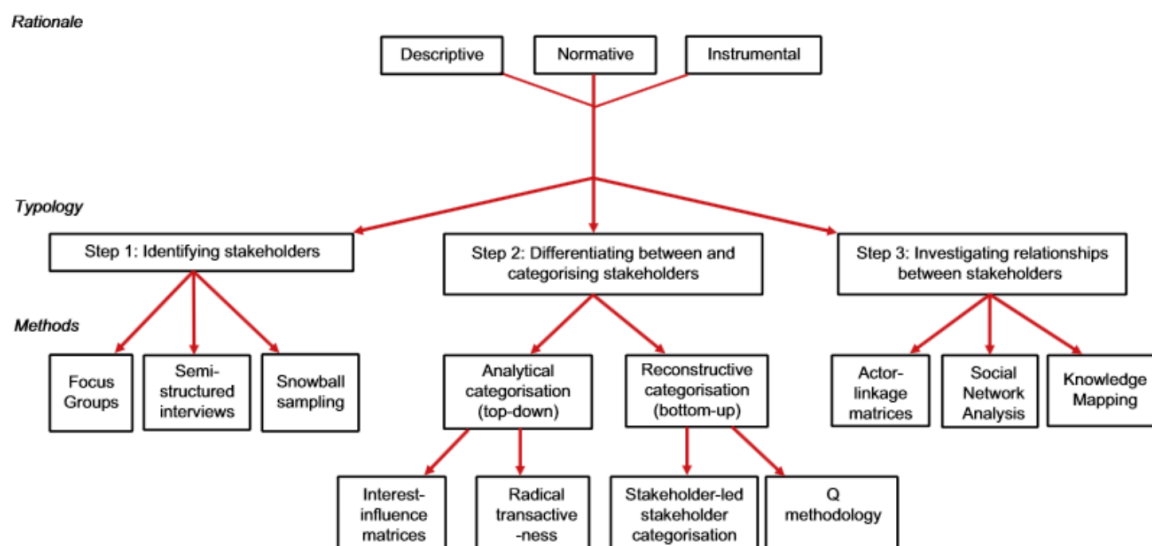


Figure 2: A typology of stakeholder analysis methods for natural resource management (Reed et al. 2009)

Method	Description	Resources	Strengths	Weaknesses
Focus groups	A small group brainstorm stakeholders, their interests, influence and other attributes, and categorise them	High quality facilitation; room hire; food and drink; facilitation materials e.g. flip-chart paper and post-its	Rapid and hence cost-effective; adaptable; possible to reach group consensus over stakeholder categories; particularly useful for generating data on complex issues that require discussion to develop understanding.	Less structured than some alternatives so requires effective facilitation for good results
Semi-structured interviews	Interviews with a cross-section of stakeholders to check/ supplement focus group data	Interview time; transport between interviews; voice recorder	Useful for in-depth insights to stakeholder relationships and to triangulate data collected in focus groups	Time-consuming and hence costly; difficult to reach consensus over stakeholder categories
Snow-ball sampling	Individuals from initial stakeholder categories are interviewed, identifying new stakeholder categories and contacts	As above: successive respondents in each stakeholder category are identified during interviews	Easy to secure interviews without data protection issues; fewer interviews declined	Sample may be biased by the social networks of the first individual in the snow-ball sample
Interest-Influence matrices	Stakeholders are placed on a matrix according to their relative interest and influence	Can be done within focus group setting (see above), or individually by stakeholder during interviews (see above) or by researcher / practitioner	Possible to prioritise stakeholders for inclusion; makes power dynamics explicit	Prioritisation may marginalise certain groups; assumes stakeholder categories based on interest-influence are relevant
Stakeholder-led stakeholder categorisation	Stakeholders themselves categorise stakeholders into categories which they have created	Same as semi-structured interviews	Stakeholder categories are based on perceptions of stakeholders	Different stakeholders may be placed in the same categories by different respondents, making categories meaningless
Q methodology	Stakeholders sort statements drawn from a discourse according to how much they agree with them, analysis allows social discourses to be identified	Materials for statement sorting; interview time; transport between interviews	Different social discourses surrounding an issue can be identified and individuals can be categorised according to their 'fit' within these discourses	Does not identify all possible discourses, only the ones exhibited by the interviewed stakeholders
Actor-linkage matrices	Stakeholders are tabulated in a two-dimensional matrix and their relationships described using codes	Can be done within focus group setting (see above), or individually by stakeholders during interviews (see above) or by researcher/ practitioner	Relatively easy, requiring few resources	Can become confusing and difficult to use if many linkages are described
Social Network Analysis	Used to identify the network of stakeholders and measuring relational ties between	Interviewer, questionnaire, training in the approach and analyses, time, software	Gain insight into the boundary of stakeholder network; the structure of the network;	Time-consuming; questionnaire is a bit tedious for respondents; need specialist in the method.

Table 1: Resources required, level of stakeholder participation, strength and weaknesses of each of the methods identified in the typology (Reed et al. 2009)

## 2.2 Value functions

A decision-making process is often complex and multifaceted. Involved criteria are often multiple and incommensurable because they have different objectives measured along qualitative, quantitative, discrete or continuous scales.

To make the different criteria comparable along a common scale they have to be normalized using a value function that helps to translate a measure of achievement (e.g. stakeholder acceptance) on the criteria concerned into a value score from 0 to 1. ConSite utilize different value functions (linear, binary, sigmoid and parabolic) in order to normalize all criteria relative to the stakeholder’s degree-of-acceptance.

The ConSite normalization procedure is based on Fuzzy logic theory (Zadeh et al. 1996, Zadeh 1965) which helps to transform the criteria values into a continuous scale from 0 (low acceptance) to 1 (high acceptance). This is illustrated with an example from the Lithuanian implementation of ConSite (see Figures 3, 4 and 5) using a “Distance from road” criterion with respect to bats. Roads often have lines of trees or shrub growing along them that attract insects, and consequently bats. Based on expert judgements bats would prefer siting of wind farms away from roads. The “Least acceptable distance” from roads was set to 200 meters and the “Preferred distance from roads” was set to 400 meters. In this example, the criteria normalization was made with a sigmoid value function on a Euclidian distance raster with the following formula:

$$\frac{1}{1 + \exp\left(\frac{\ln\left(\frac{2-\alpha}{\alpha}\right)}{(X_{min} - X_{mean})} * (pixel - X_{mean})\right)}$$

A threshold value of  $\alpha = 0.1$  is set to express the uncertainty interval related to how we define Low (0.05) and High (0.95) acceptance.  $X_{mean}$  is the inflection point at  $Y = 0.5$  where the curvature of the graph changes.

The Conflict degree map for the “Distance from road” criteria is given by  $1 - \text{degree-of acceptance}$ :

$$1 - \left(\frac{1}{1 + \exp\left(\frac{\ln\left(\frac{2-\alpha}{\alpha}\right)}{(X_{min} - X_{mean})} * (Cell - X_{mean})\right)}\right)$$

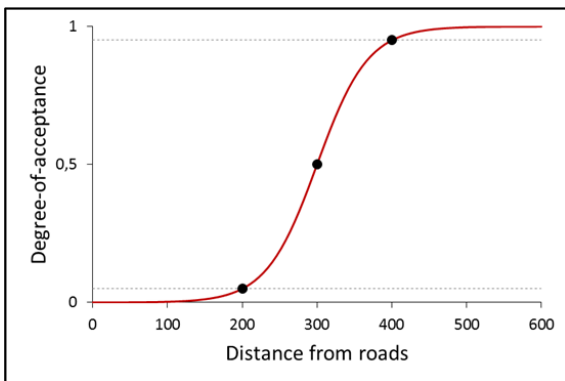


Figure 3: Conflict-degree (sigmoid function)

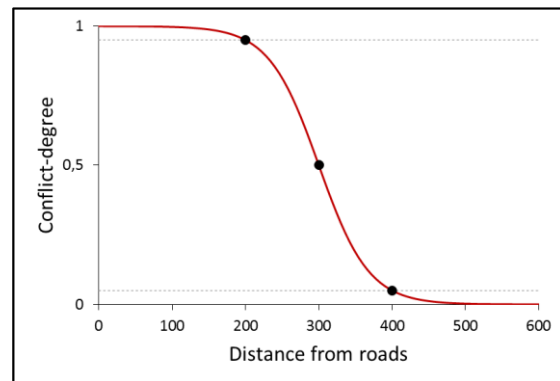


Figure 4: Degree-of-acceptance (sigmoid function)



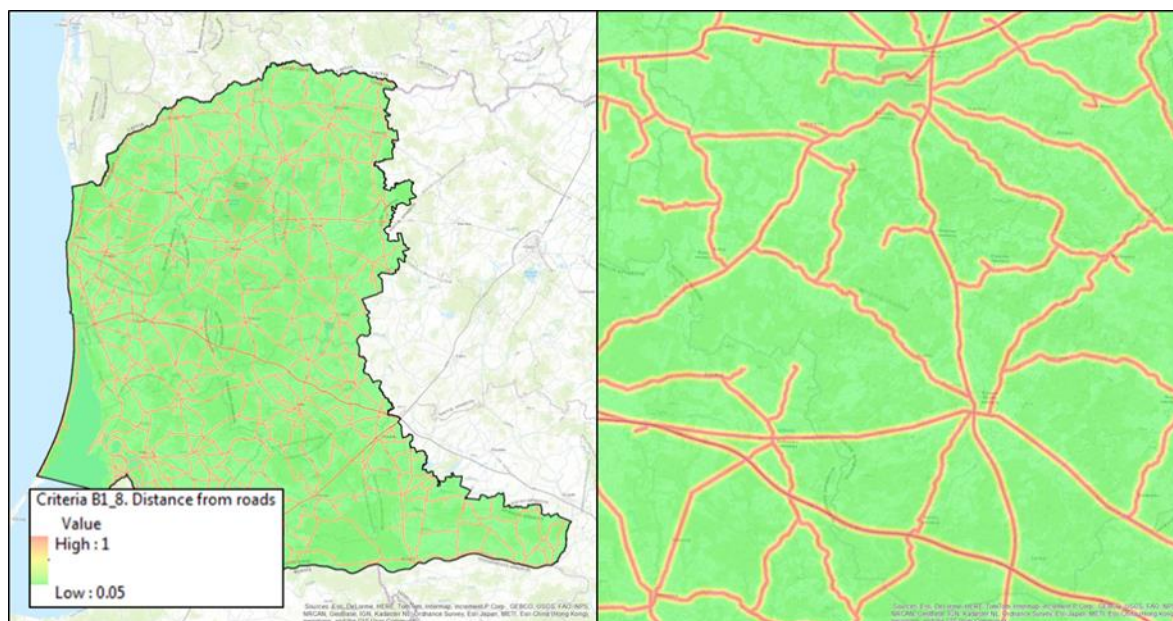


Figure 5: Conflict degree map for «Distance from roads» based on a sigmoid value function

### 2.3 Multi-Criteria Analysis function

After the normalization procedure ConSite utilizes the Analytical Hierarchical Processes (AHP) decision-making procedure (Saaty 1980) to mathematically structure the findings from the dialogue processes (see section 2.1) in order to determine the relative importance (weights) of the individual criteria. Throughout the years after Saaty, AHP has been further developed and is currently one of the most used Multi-Criteria Analysis (MCA) based decision-making procedures in renewable construction projects worldwide. This is related to its practical usefulness as a support tool for decision justification both in terms of transparency and verification (Mateo 2015).

Mateo (2015) illustrates the use of AHP with an example where an optimal site for a wind farm is sought. Four locations ( $A_1$ ,  $A_2$ ,  $A_3$  and  $A_4$ ) are evaluated according to the five criteria  $C_1$  (Topography),  $C_2$  (Operation/maintenance costs),  $C_3$  (Land use),  $C_4$  (Infrastructure) and  $C_5$  (Investment costs). The goal (top level), criteria (intermediate level) and decision alternatives from combination of criteria (bottom level) could be structured as illustrated in Figure 6.

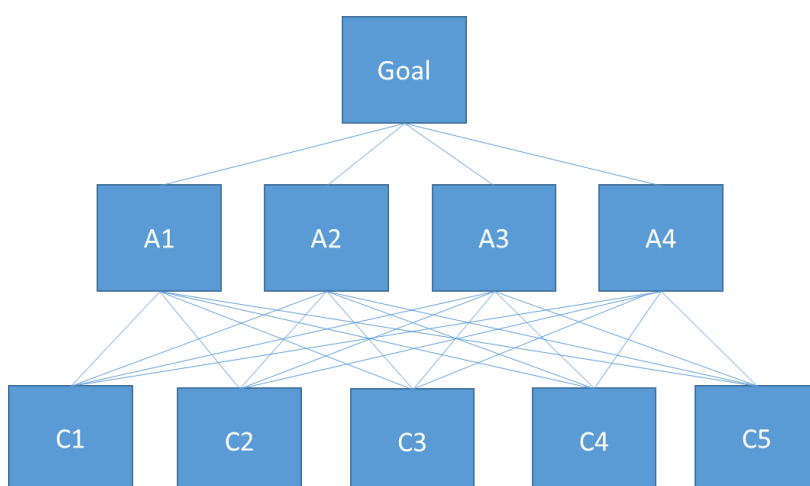


Figure 6: Hierarchical structure of goal, criteria and decision alternatives

Once the relations between the goal, the criteria and the decision alternatives have been determined, the criteria will be compared pairwise. A pairwise comparison matrix has to be structured using stakeholder expressed judgements. Saaty (1980) suggested transforming the expressed judgements into a numerical scale from 1-9 (see Table 2).

Assigned value	Interpretation
1	<b>C<sub>1</sub></b> and <b>C<sub>2</sub></b> are of equal importance
3	<b>C<sub>1</sub></b> is weakly more important than <b>C<sub>2</sub></b>
5	Experience and judgements indicate that <b>C<sub>1</sub></b> is strongly more important than <b>C<sub>2</sub></b>
7	<b>C<sub>1</sub></b> is very strongly or demonstrably more important than <b>C<sub>2</sub></b>
9	<b>C<sub>1</sub></b> is absolutely more important than <b>C<sub>2</sub></b>
2,4,6,8	Intermediate values, e.g. a value of 8 means that <b>C<sub>1</sub></b> is midway between strongly and absolutely more important than <b>C<sub>2</sub></b>

Table 2. Pairwise comparison scale

Stakeholder judgements of the individual criteria's importance are compared for each site. The pairwise comparison matrices below show the scores for the different decision alternatives (combinations of criteria):

C1	C2	C3	C4	C5
$\begin{bmatrix} 1 & 6 & 3 & 4 \\ \frac{1}{6} & 1 & \frac{1}{6} & \frac{1}{2} \\ \frac{1}{3} & 6 & 1 & 3 \\ \frac{1}{4} & 2 & \frac{1}{3} & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 2 & 4 & 6 \\ \frac{1}{2} & 1 & 2 & 3 \\ \frac{1}{4} & \frac{1}{2} & 1 & 2 \\ \frac{1}{6} & \frac{1}{3} & \frac{1}{2} & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{6} \\ 3 & 1 & \frac{1}{6} & \frac{1}{2} \\ 5 & 6 & 1 & 3 \\ 6 & 2 & \frac{1}{3} & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{6} & \frac{1}{5} \\ 3 & 1 & \frac{1}{3} & \frac{1}{2} \\ 6 & 3 & 1 & \frac{1}{2} \\ 5 & 2 & 2 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{2} \\ 3 & 1 & \frac{1}{3} & 3 \\ 5 & 3 & 1 & 4 \\ 2 & \frac{1}{3} & \frac{1}{2} & 1 \end{bmatrix}$

For each site (A1, A2, A3, A4) the score values then have to be normalized by:

$$Matrix_{norm} = \frac{1}{n} \sum_{i=1}^n \frac{criteria\ entries}{sum\ of\ criteria\ entries}$$

The sum of each column in the normalized matrices equals 1, and the derived weights are given by the average of each criteria column within the normalized matrices:

$$Weights = \sum_{i=1}^n \frac{[w_1 + w_2 + \dots + w_n]}{n}$$

C1	C2	C3	C4	C5
$\begin{bmatrix} 0.527 \\ 0.064 \\ 0.291 \\ 0.117 \end{bmatrix}$	$\begin{bmatrix} 0.519 \\ 0.260 \\ 0.140 \\ 0.081 \end{bmatrix}$	$\begin{bmatrix} 0.064 \\ 0.128 \\ 0.552 \\ 0.256 \end{bmatrix}$	$\begin{bmatrix} 0.064 \\ 0.170 \\ 0.347 \\ 0.419 \end{bmatrix}$	$\begin{bmatrix} 0.083 \\ 0.257 \\ 0.532 \\ 0.128 \end{bmatrix}$

The stakeholder judgements (structured in the pairwise comparison matrix above) need to be checked for consistency. A small Consistency Index (CI) indicates a small deviation from perfect consistency (0) and means that the comparisons probably are consistent enough to give useful estimates of the weights. The consistency is calculated by the following procedure:

1. Calculate the maximum eigen-value  $\lambda_{max}$ :

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{ith\ entry\ in\ estimated\ weights}{jth\ entry\ in\ estimated\ weights}$$

2. The Consistency Index (CI) of the pairwise comparisons is calculated from:

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

3. To know if the Consistency Index (CI) is acceptable it has to be compared with expected Random Consistency Index (RI) values for an appropriate number of n (see Table 3). The RI- values in Table 3 is derived from reference tables with known values for matrices of order 1 to 9 obtained by approximating random indices using a sample size of 500 (Saaty 1980, Saaty 2000). If  $\frac{CI}{RI} < 0.10$  the degree of consistency is good. If  $\frac{CI}{RI} > 0.10$  serious inconsistency may occur. Under such condition, AHP may not give meaningful results.

N	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 3. RI for different values of n

From the current example, the eigen-value  $\lambda_{\max}$  and consistency ratio (CI/RI) are listed in Table 4 below:

	C1	C2	C3	C4	C5
$\lambda_{\max}$	4.12	4.01	4.21	4.14	4.11
$\frac{CI}{RI}$	0.046 (0.044)	0.004 (0.004)	0.079 (0.078)	0.051 (0.052)	0.040 (0.041)

Table 4: The eigen-value  $\lambda_{\max}$  and consistency ratio (CI/RI), with a set RI of 0.90.

The overall score for each alternative is given by:

$$\text{Overall score for A1} = \frac{\sum_i(\text{local priority of A1 with respect to C1})}{x(\text{local priority of C}_i \text{ with respect to goal})}$$

Alternatives	Score
A1	0.343
A2	0.341
A3	0.176
A4	0.141

Table 5: The overall score for each alternative in the current example

As shown in Table 5 A1 and A2 are the highest ranked alternatives and should be prioritized over alternatives A3 and A4.

AHP is a decision-making method that works especially well on qualitative data and when decision-makers have to rely on expert judgements. The method has been criticized for its inability to cope with uncertainties and imprecisions related to some particular environments (Matteo 2015). Another downside of AHP is that it is difficult to subjectively scale a concrete quantitative number for pairwise comparisons without losing some degree of accuracy (Matteo 2015). Despite this, the way AHP handles multiple qualitative and quantitative criteria data has favored its use as a decision-making method. AHP has been widely used in a number of different domains related to energy production and transmission lines (Al-Shabeeb et al 2016, Eroglu and Aydin 2015, Liu et al 2012, Lee et al. 2009).



ConSite has currently implemented an AHP excel template developed by Goepel 2013 (available from <http://bpmsg.com/academic/ahp.php>). The methodology behind this template is described in detail at <http://bpmsg.com/ahp-introduction/>.

## 2.4 Sensitivity analysis

Currently ConSite uses quality flags (polygon features) to outline no-data or poor data quality areas. Simple sensitivity analyses (scenario visualization) can be performed by analyzing the effects of over- or underestimating the importance (weights) of the different criteria or perspectives (including areas that have no-data or poor data quality).

In the future, we aim to develop algorithms that measure the uncertainty of variability among stakeholder preferences and the uncertainty of applied decision strategies. Feizizadeh (2015) has successfully utilized Monte Carlo Simulation (MCS) and variance-based Global Sensitivity Analysis (GSA) to compute the inherent uncertainty and perform sensitivity analysis for minimizing the chance of error in decision-making for Green Infrastructures based on Fuzzy-modified AHP (FAHP).

## 2.5 Criteria aggregation

There is a great diversity of methods on how to aggregate and analyze spatial multi-criteria data in order to support decision-making. For spatial decision support tools like ConSite various considerations have to be taken into account on how to include risk and tradeoff assessments during criteria aggregation.

Tradeoff assessments are based on the traditional paradigm of competing demands of economic-technological, socio-cultural and environmental considerations (Klinsky 2010). This paradigm has been frequently criticized for treating each domain independently and for promoting tradeoffs among them (Gibson 2005, Pope 2006), although the ecosystem services bundles approach, and its analytical methods, are a new step forward (Raudsepp-Hearne et al. 2010). Nevertheless, considerations of landscape functions and their associated services (from all three domains) have become a central concept in policy and decision-making. Pinto-Correia et al. (2006) and de Groot et al. (2010) claim however that holistic evaluation of competing objectives is lacking in most policy support tools.

de Groot et al. (2010) has identified a number of issues associated with optimal strategies for different objectives such as ecosystem services under tradeoff analysis and in decision-making:

- Proper accounting for all the costs and benefits (from all domains) of any changes in ecosystem services and for the values of all stakeholders (both temporally and spatially). To ensure an understandable and transparent way forward and as attempt to capture the public issues at stake while enterprises and landowners also express their considerations, NINA aims to include public good type ecosystem services in the ConSite SMCDA framework as described in Chapter 4.
- Analytical and participatory methods have to be combined in order to support effective participatory policy and decision-making dialogues.
- Spatial modelling has to be linked to participatory tradeoff assessment methods in order to optimize multi-functional land use.
- Tools for visualizing alternative landscapes have to be made accessible for decision-making.

To facilitate decision-making de Groot et al. (2010) suggest the use of GIS to visualize the impact of land use changes on ecosystem services and to assess tradeoffs at different scales. GIS and Multi-Criteria Decision Analysis (MCDA) are suggested as robust approaches with the explicit involvement of stakeholders in the tradeoff analysis (Henkens et al. 2007). Paracchini et al.

(2008) argue that a combination of non-compensatory (e.g. Boolean AND & OR) and compensatory MCA linear additive models (e.g. Weighted Linear Combination (WLC) and Ordered Weighted Average (OWA)) is best suited for assessments of policy options. They propose a framework for assessing competing demands associated with whether multiple land use functions are sustainable or not based on linear additive models. The tradeoff evaluation space is represented using a spider diagram (see Figure 7 below):

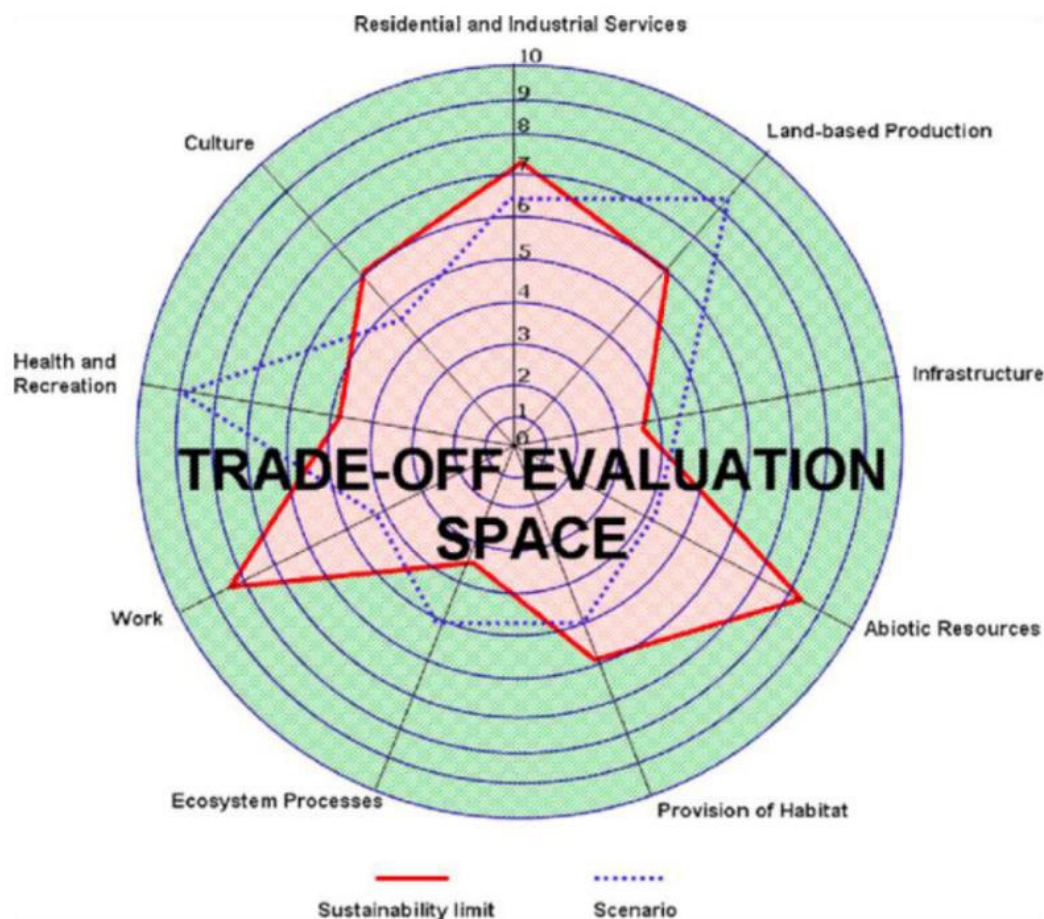


Figure 7: The tradeoff evaluation space from Paracchini et.al. (2008)

Greene et al. (2011) reviewed the capacity of GIS-based MCDA to support spatial analysis in decision-making<sup>8</sup>. They conclude that complex landscape decisions demand spatial information and tools in order to help humans to understand the inherent tradeoffs between different decisions. Greene et al. (2011) proposed a family of MCDA as a suit of techniques that aid decision makers in formally structuring multi-faceted decisions and evaluating the different decision alternatives.

ConSite has in addition to Analytical Hierarchy Processing (weighting method with ranking and tradeoff) implemented compensatory aggregation methods like Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA) (Drobne & Liseč 2009) for criteria aggregation, risk assessment and tradeoff analysis within the domain of economic-technological, socio-cultural and environmental considerations. A next step will be to include a methodological approach to capture the different tradeoffs within the ecosystem services domain.

### 2.5.1 Weighted Linear Combination (WLC)

Weighted Linear Combination (WLC) is a compensatory multi-criteria evaluation aggregation method that seeks to overcome the lack of sensitivity in traditional Boolean overlay techniques.

Aggregating suitability areas using Boolean operators AND (both of the factors have to be true) and OR (one of the factors have to be true) implies minimum risk and maximum risk decision alternatives (see Figure 8).

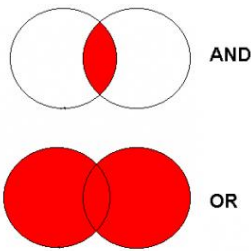


Figure 8: Boolean AND & OR

Weighted Linear Combination, also called Weighted Mean, is a refinement of Boolean combination and ensures accommodation of the uncertainties of combining different criteria maps.

WLC is given by (Comber 2009):

$$S_i = \sum_{j=1}^n W_j * X_{i,j} \text{ where } \sum_{j=1}^n W_j = 1$$

$S_i$  is the suitability score for site  $i$ ,  $W_j$  is the weight of criterion  $j$ ,  $X_{ij}$  is the criteria values of Site  $i$  under Criterion  $j$ , and  $n$  is the total number of criteria.

In opposition to Boolean suitability aggregation, WLC allows tradeoffs between criteria by weighting the normalized criteria according to their relative importance. A low value in one criteria with a high weight may be equivalent to a higher value in another criteria with a lower weight. This capability of compensating a low score for one criteria with a high score for another criteria is known as *tradeoff* or *substitutability* (Comber 2009). There are a number of problems associated with multi-criteria evaluation analyses using Boolean and WLC approaches (Jiang & Eastman 2000). First, Boolean analysis produce binary decision alternatives (by using AND & OR) whereas WLC provides tradeoff decision alternatives relative to the criteria weights and values. Second, the criteria normalization procedure may be problematic especially when the rationale is a simple linear transformation. Therefore, both methods lack proper capabilities to evaluate the decision risk, because potential decision risk by using Boolean and WLC approaches can only be estimated by modelling the error associated with the input data and their weights (Comber 2009). The main objection to WLC is how it relates to decision-making. A high WLC score indicates high suitability, but does not support a decision to allocate areas to choose and areas to exclude. The WLC weights express the uncertainties (and the decision risk), but are combined through an averaging process (Comber 2009). The Boolean AND-operator is a risk-averse aggregation operator while the OR-operator signifies a risk-taking aggregation operator. WLC is exactly in-between these two extremes and provides solutions that have full substitutability (when the weights are employed fully) and average risk. Therefore, WLC is more often used in decision-making processes than the Boolean approaches (Jiang & Eastman 2000).

## 2.5.2 Ordered Weighted Average (OWA)

Ordered Weighted Averaging (OWA) was suggested by Yager (1988) as a way to overcome the systematic problems related to risk and tradeoff in multi criteria evaluation. OWA is therefore a method for managing decision risk. OWA treats the normalized layers as fuzzy measures allowing for more flexible multi-criteria evaluation operations and control of the degree of ANDness, ORness and tradeoff in decision-making<sup>20</sup>. OWA use two sets of weights; the criteria weights (as in WLC) and the order weights. The order weights are given by ranking the criteria values after the application of the criteria weights. The criteria weights ( $W_j$ ) are applied uniformly to the  $j^{\text{th}}$

criteria map reflecting each layer's relative importance. The order weights ( $\mathbf{V}$ ) are applied to the  $i^{th}$  locations attribute in decreasing order on a cell-by-cell basis. The OWA operator associates a set of order weights  $\mathbf{V} = v_1, v_2, \dots, v_n$  with the  $i^{th}$  location such that  $v_j \in [0, 1]$  for  $j = 1, 2, \dots, n$  and  $\sum_{j=1}^n v_j = 1$ .

$$OWA_i = \sum_{j=1}^n \left[ \frac{u_j v_j}{\sum_{j=1}^n u_j v_j} \right] z_{ij}$$

Where  $z_{i1} \geq z_{i2} \geq \dots \geq z_{in}$  derives from reordering the criteria values and  $u_j$  is the reordered  $j^{th}$  criteria weight  $v_j$ .

The order weights control the degree of tradeoff between ANDness and ORness. They are complementary to each other and together they summarize to 1. Absolute ANDness (where ANDness equals to 1) is the most risk-aversion position, whereas absolute ORness (where ORness equals to 1) is the most risk-taking position. The second parameter TRADEOFF represents the degree to which different criteria are allowed to tradeoff with each other. These operators are defined as follows (Jiang & Eastman 2000, Comber et al. 2010):

$$ANDness = (1/j - 1) \sum (j - i) W_{order\ i}$$

$$ORness = 1 - ANDness$$

$$TRADEOFF = 1 - \sqrt{\frac{j \sum (W_{order\ i} - \frac{1}{j})^2}{j-1}}$$

Where  $j$  is the total number of criteria maps,  $i$  is the order of criteria and  $W_{order\ i}$  is the weight for the criteria of the  $i^{th}$  order.

OWA provides an alternative to WLC where the level of TRADEOFF is full and not adjustable. ANDness and ORness is governed by the amount of skewness in the order weights, and TRADEOFF is controlled by the degree of dispersion in the order weights. In this way OWA allows control for both ANDness, ORness and TRADEOFF. This is illustrated in Figure 9 below:

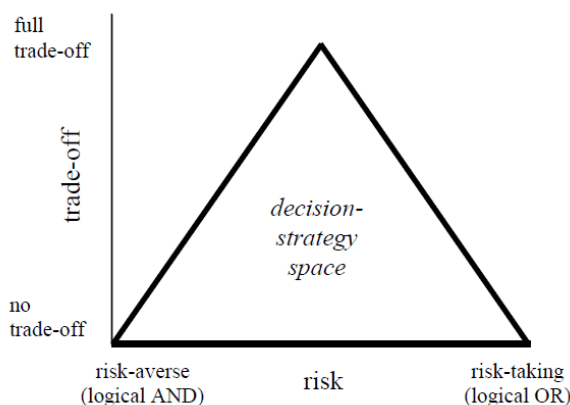


Figure 9: The Decision strategy space in OWA (Jiang & Eastman 2000)

In short, the OWA- procedure includes the following steps (Comber 2009):

1. Each criterion is weighted for its relative importance.
2. An intermediate layer is derived from each criterion map and the weighted values at each location (pixel) are evaluated and ranked from lowest to highest values.
3. The order weights are then applied in the following way: the first order weight is applied to the lowest value, the second order weight is applied to the next lowest value, and so on

The example in Table 6 illustrates six sets of order weights and the tradeoffs they permit:

Order weights	Implications
<b>1-0-0-0</b>	Low risk with no TRADEOFF
<b>0-0-0-1</b>	High risk with no TRADEOFF
<b>0-0.5-0.5-0</b>	Average risk with no TRADEOFF
<b>0.5-0.3-0.15-0.05</b>	Low risk with some TRADEOFF
<b>0.05-0.15-0.3-0.5</b>	High risk with some TRADEOFF
<b>0.25-0.25-0.25-0.25</b>	Intermediate risk with full TRADEOFF. There is no impact of order weights. Result identical to WLC.

Table 6: The overall score for each alternative in the current example

OWA has been used in many different GIS-applications (Comber 2009), and provides considerable refinement of the Boolean and WLC approaches. In this review of aggregation techniques, we have only described the global OWA approach as this is the one implemented approach in ConSite. Global OWA approaches are based on the assumption that the range of criterion values are spatially homogeneous. Global OWA approaches are therefore not sensitive to range as compared to local OWA approaches, which is based on the “range sensitivity principle” suggesting that criterion weights highly depend on the spatially variable range of criterion values (Malczewski & Liu, 2014). Local OWA approaches implement neighborhood, local range and local criteria weights in order to tackle spatial heterogeneity and local context (Liu 2013).

## 2.6 Siting/routing and optimisation

### 2.6.1 The ConSite Powerline module

The ConSite Powerline module normalizes criteria maps and aggregates conflict maps (as previously described in Chapter 2.1, 2.2, 2.3, 2.4 and 2.5) and utilizes standard Least Cost Path algorithms from ESRI ArcGIS 10.4 to calculate optimal powerline routing and impact assessment corridor(s) between two transformer stations in a pre-construction powerline routing project. ConSite Powerlines only support AHP and Weighted Linear Combination (WLC) for criteria aggregation. The ConSite Powerlines toolbox (formerly OPTIPOL LCP) has been successfully validated on an existing power line route (Bevanger et al. 2014 & Hanssen et al. 2014). Figure 10 displays the user interface of the ConSite Powerlines conflict map calculation tool. Figure 11 displays the output conflict map.

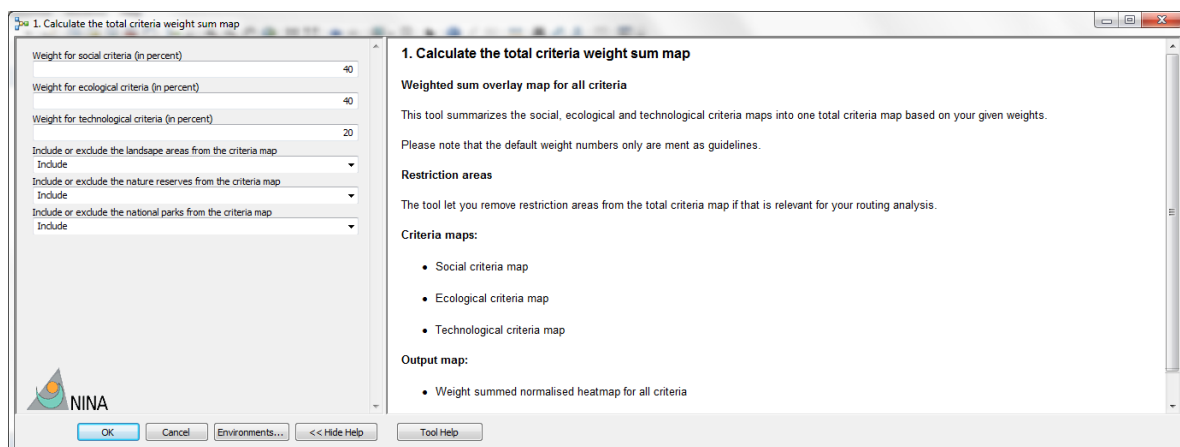


Figure 10: The ConSite Powerlines conflict map calculation tool



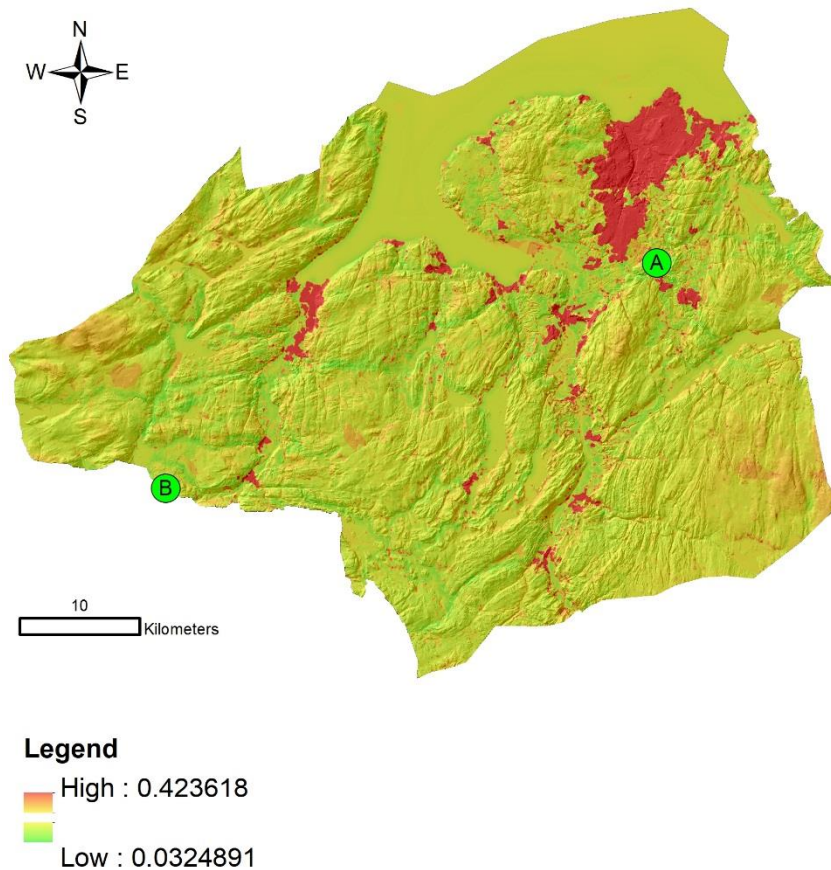


Figure 11 displays the ConSite Powerlines conflict map based on WLC.

The ConSite Powerline tool for calculation of the cost surface and the corresponding optimal powerline routing and impact assessment corridor is illustrated in Figure 12. Figure 13 display the output cost surface, the modelled optimal corridor and the modelled power line path in comparison with the existing black power line.

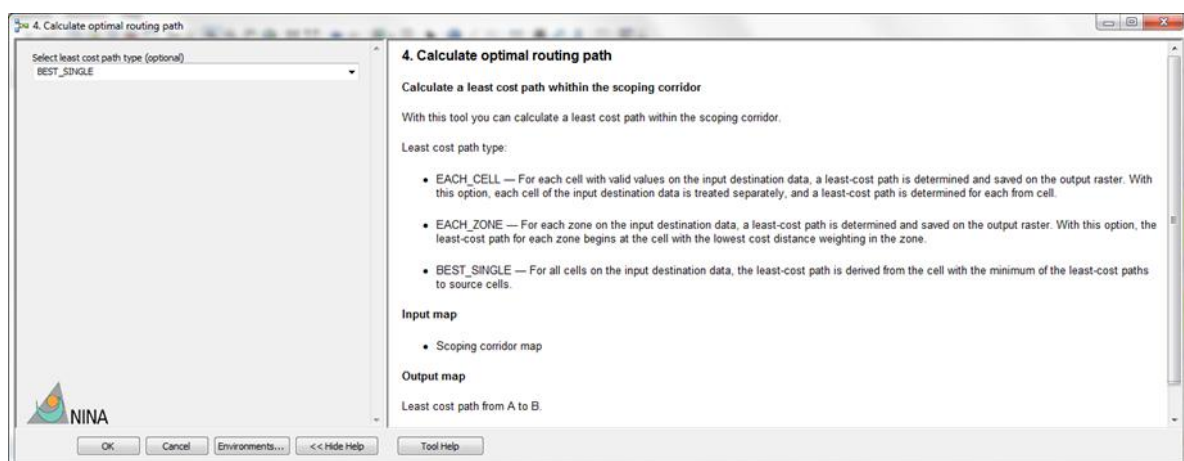


Figure 12: The ConSite Powerline tool for optimal routing

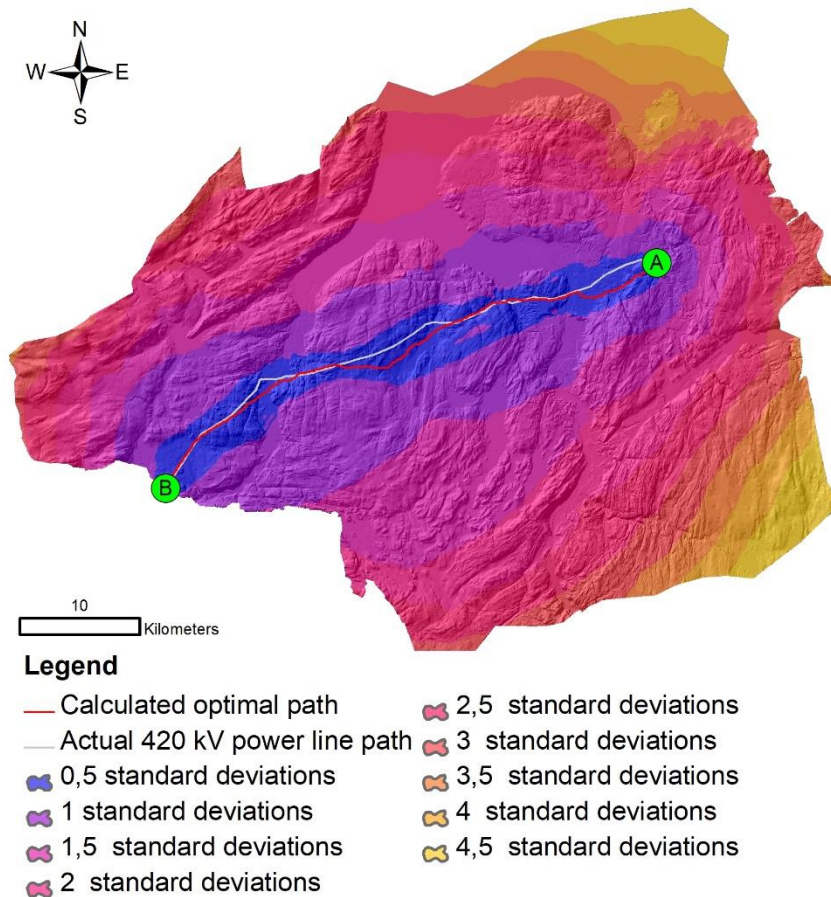


Figure 13: Optimal corridor (blue) and power line path (red line) based on equal weighting of ecological, social and technological criteria. The example is from a successful validation of the ConSite Powerline tool against an existing power line path (white line) in the Municipalities of Trondheim, Klæbu and Orkdal in Trøndelag (Central Norway).

As said in Chapter 2.4 ConSite supports simple sensitivity analyses (scenario visualization) by analyzing the spatial effects of over- or underestimating the importance (weights) of different criteria or perspectives (Figure 14).

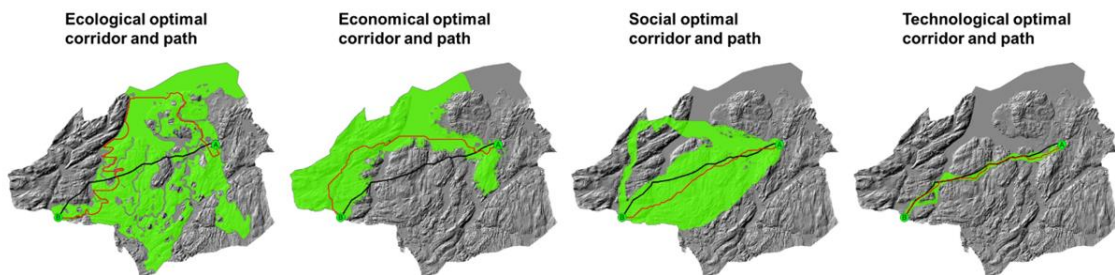


Figure 14: Shows the consequences of overemphasizing the importance of one interest towards other interests. The four maps show the modelled optimal corridors (in green) and paths (red) based on a biased emphasize of ecology, economy, society and technology. The existing power line is outlined in black.

## 2.6.2 The ConSite Wind module

The ConSite Wind module helps to identify high interest areas for wind-power development from available wind data (annual wind speed<sup>9</sup> or wind-data with higher temporal and spatial resolution), compute conflict maps, conflict zone maps (with inherent conflict statistics) and utilize specially developed algorithms to optimize siting and layout design of a wind power plant (based on a preferred conflict level, required wind conditions, required wind farm size and power output). ConSite Wind was recently also successfully validated in the EEA-grant project “Sustainable Wind Farm Development in Lithuania (DAVEP-VLIT, 2015-2016)”<sup>10</sup>.

ConSite Wind supports both WLC and OWA for criteria aggregation, risk assessment and tradeoff analysis. The toolbox can be used for both ecological, social and technological criteria. Economic criteria have not yet been implemented in ConSite, but this can be done as long as these criteria have a spatial aspect like for example property values and compensatory allowances related to wind-development projects. Applied criterion definitions and values can be derived from legal requirements, best practices, expert judgements or layman definitions. Such definitions/criterion values have to be defined in the Dialog seminars (Chapter 2.1) or from peer-reviewed literature. Figure 15 illustrate the ConSite Wind tool for conflict map aggregation related to distance from overhead powerlines.

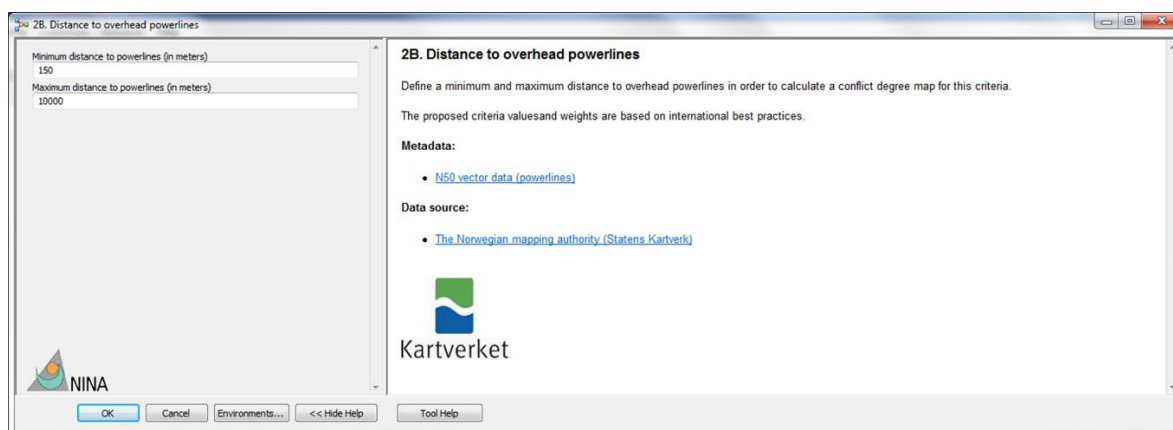
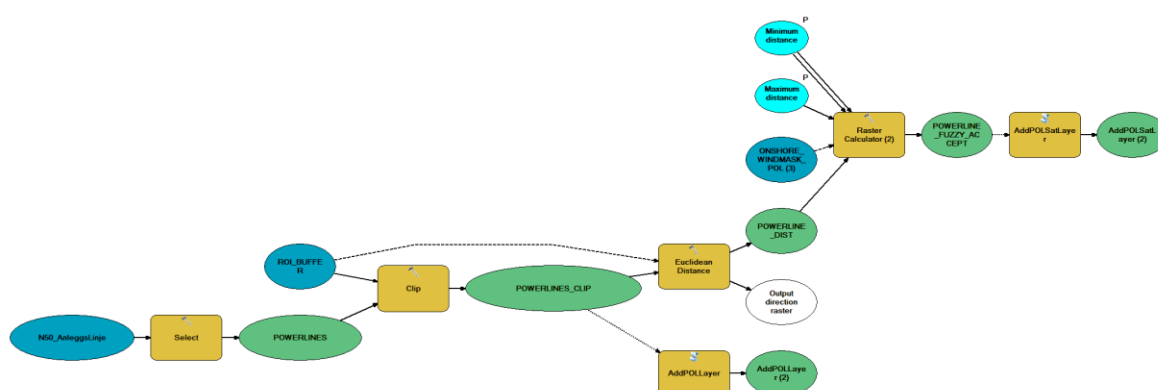


Figure 15: ConSite Wind tool for conflict map aggregation related to distance from overhead powerlines. Example from a local case study in the Municipality of Åfjord at the coast of Trøndelag (Central Norway).

The workflow (Figure 16) executed by this tool is comprised by the selection of power-lines (from a national power-line vector dataset), Euclidian distance calculation and normalization based on the given minimum distance and maximum distance to powerlines in meters.



<sup>9</sup> <http://www.vindteknikk.no/tjenester/analyser/vindkraft/pre-konstruksjon/vindkartlegging>

<sup>10</sup> <http://www.nina.no/Forskning/Prosjekter/DAVEPVLIT>



Figure 16: Workflow for calculation of a conflict map related to distance from overhead powerlines

The normalization procedure of the conflict map (Figure 17) is done on the Euclidian distance raster map (distance from powerlines) with the following ArcGIS Raster calculation expression (described in Chapter 2.2):

$$1 - (1 / (1 + \text{Exp}(\text{Ln}((2 - 0.1)/0.1)/((\% \text{Maximum distance to powerlines (in meters)}\% - \% \text{Minimum distance to powerlines (in meters)}\%))) * (\% \text{POWERLINE\_DIST}\% - \% \text{Minimum distance to powerlines (in meters)}\%)))$$

A threshold value of  $\alpha = 0.1$  is set to express the uncertainty interval related to how ConSite define Low (0.05) and High (0.95) acceptance.  $X_{\text{mean}}$  is the inflection point at  $Y = 0.5$  where the curvature of the graph changes.

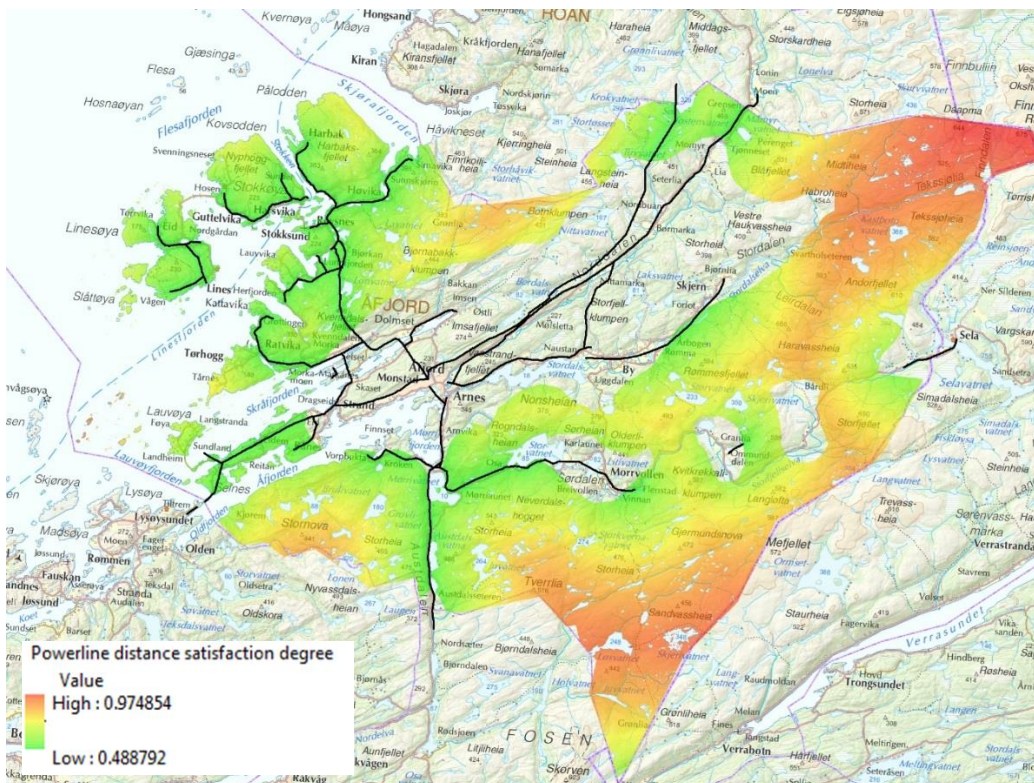


Figure 17: Conflict map related to distance from overhead powerlines (represented by black lines). In this example, the conflict level arises in distance from powerlines. Non-colored areas within the Municipality border represent areas with annual mean wind speed below 4 m/s.

Figure 18 illustrates the Conflict map aggregation tool. Here the decision maker can choose between a set of predefined risk and high tradeoff decision strategies for the conflict map aggregation (Figure 19).

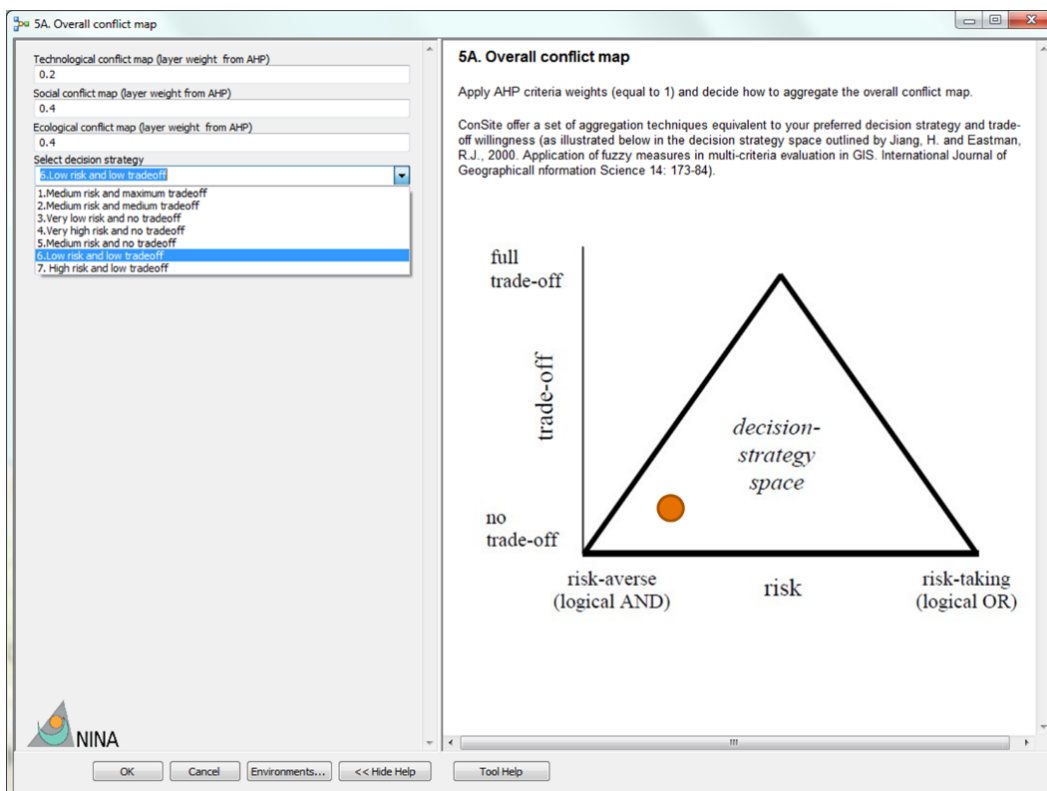


Figure 18: Conflict map aggregation using AHP, OWA and a low risk and high tradeoff decision strategy

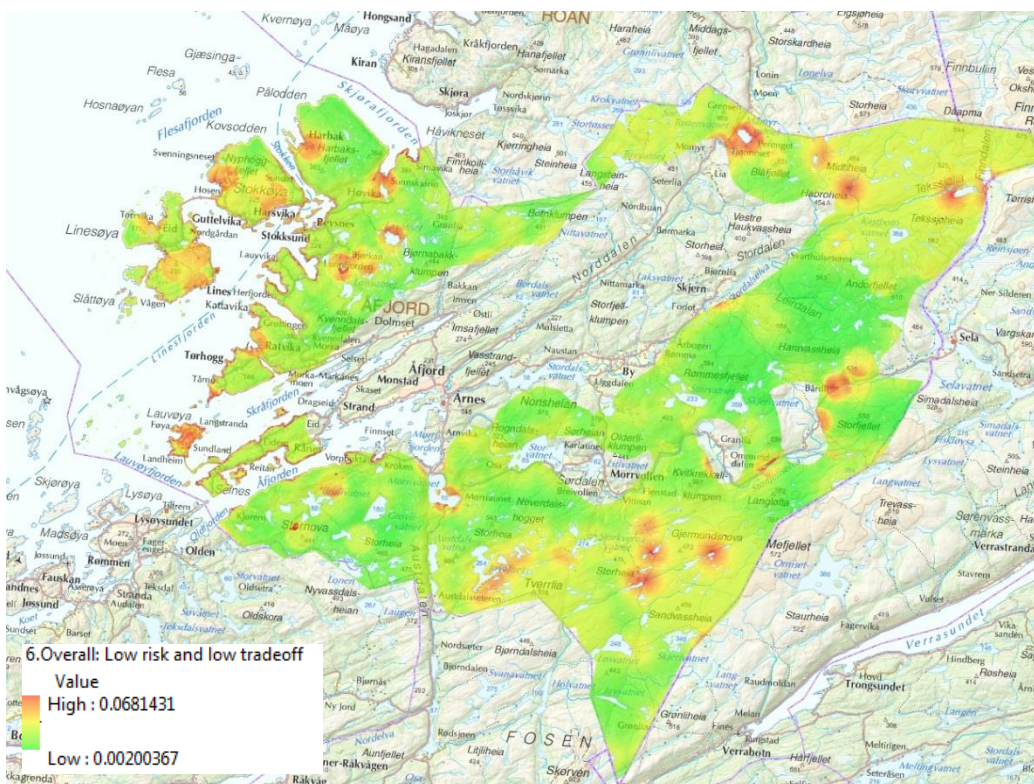


Figure 19: Conflict map aggregation based on AHP, OWA and a low risk and high tradeoff decision strategy

ConSite provide functionality to classify the continuous conflict map into conflict zones (figure 20 and 21). In the same user interface the user can decide to exclude restriction areas (e.g. protected nature areas, military installations, etc.) from further analysis if that is relevant.



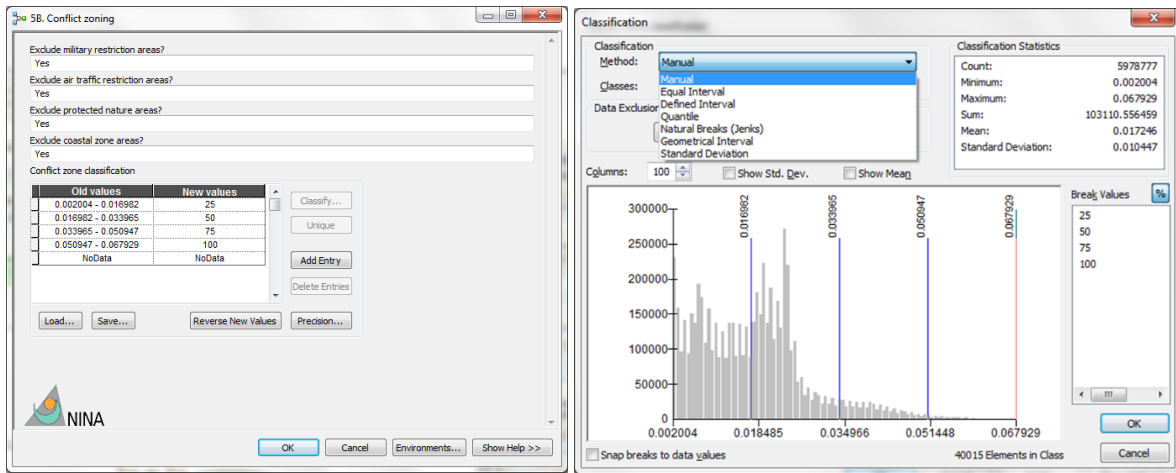


Figure 20: The ConSite Wind Conflict Zoning tool

The conflict zone maps is especially relevant for further dialog and scoping of impact assessment areas and siting of wind-power plants. Low conflict zones with sufficient wind resources (e.g.  $\geq 4$  m/s annual mean wind speed) and patch area size (given by the required amount of wind turbines, and given turbine latitudinal and longitudinal separation distances) may represent very suitable areas for siting of wind-power plants.

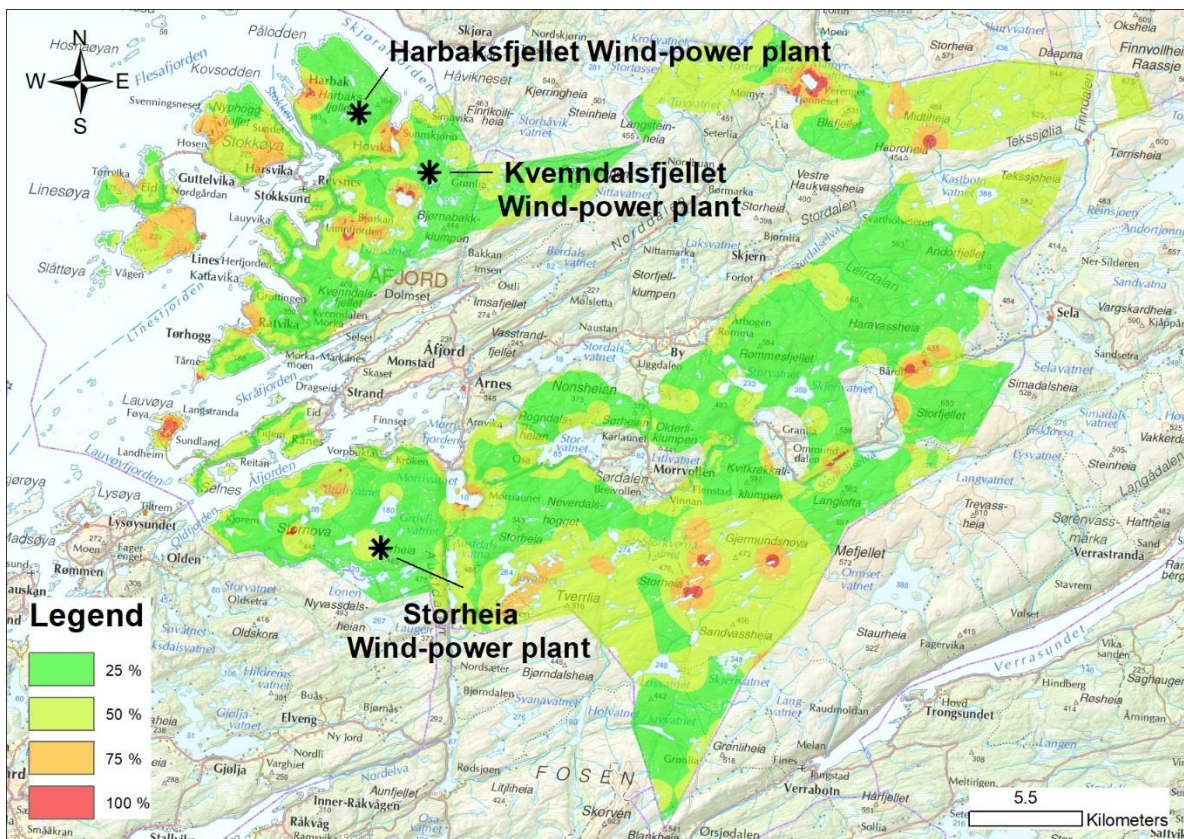


Figure 21: Conflict levels in the Åfjord municipality case study area (based on a Low risk and Low trade-off decision strategy), in areas with sufficient wind resources, derived from socio-economic, technological and ecological criteria maps. The Harbaksfjell wind-power plant (outlined in red) has a low conflict level, and hence a high suitability, based on the applied criteria in this example. Consented wind-power plants are indicated with a black asterix.

The ratio of power produced by a turbine ( $P_T$ ) from the total wind resource ( $P_W$ ) is given by the Power Coefficient ( $C_p$ ) as described in Equation 1:

$$C_p = \frac{P_T}{P_W} \quad (1)$$

The Betz Limit (Betz 1966) is the maximal possible  $C_p = 16/27 = 0.59$ , meaning that 59% is the maximum theoretical efficacy a conventional wind turbine can do in extracting power from the wind.  $C_p$  is turbine-specific and often ranges between 0.25 and 0.45. It is also highly dependent of the wind speed and the spatial and temporal distribution of the wind resources. ConSite uses by default a  $C_p = 0.4$ . This value can be changed by the user in the tool graphical user interface.

The turbine output power ( $P_m$ ) is given by Equation 2 (RWE npower n.d., Manyonge et al. 2012) and the turbine Annual Energy Output (AEO) is given by equation 3):

$$P_m = \frac{1}{2} * \rho * A * v^3 * C_p \quad (2)$$

$P_m$  is given in Watt,  $\rho$  is the air density (given in  $\text{kg/m}^3$ ),  $A$  is the rotor swept area given by  $\pi r^2$  (radius given in meters),  $v^3$  is the wind velocity cube (wind velocity given in m/sec),  $C_p$  is the power coefficient and  $C_F$  is the capacity factor describing the fraction of the year that the turbine generator is operating at peak power.

$$\text{The turbine AEO (in MWh) is given by } \frac{P_m}{1000000} * C_F \quad (3)$$

Where the turbine capacity factor ( $C_F$ ) is dependent on the characteristics of the turbine itself and the site characteristics. A good site has typically a  $C_F = 0.3^{11}$ , this means that the turbine produces at maximum installed (energy) effect only in 2628 hours out of 8760 hours throughout a year.

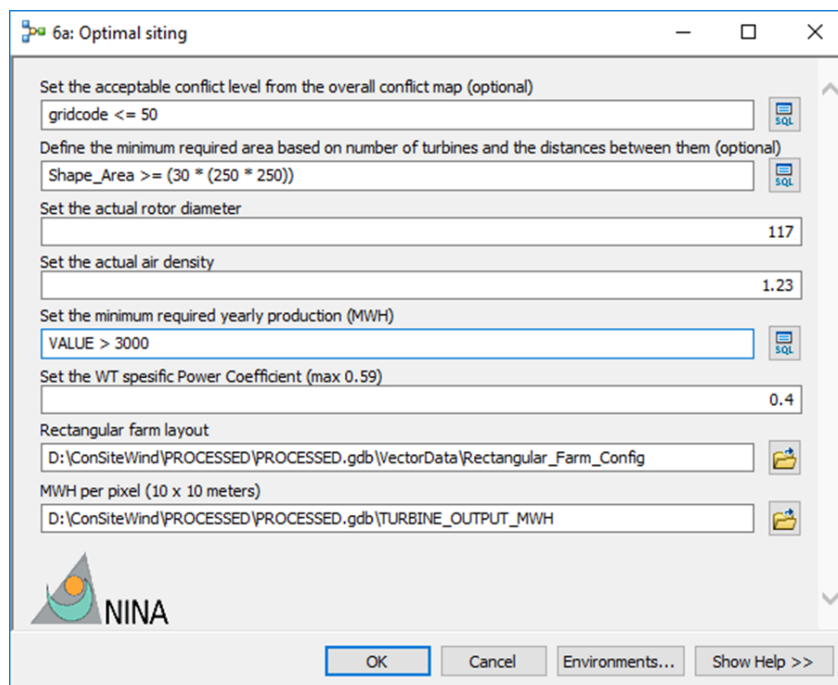


Figure 22: The ConSite Wind module for estimating annual potential turbine power output. The tool select areas that has a conflict level  $\leq 50$  %, patch area size  $\geq 1.875 \text{ km}^2$  ( $30 \text{ turbines} \times 0.0625 \text{ km}^2$ ) and a potential turbine power output per pixel  $> 3000 \text{ MWh}/100 \text{ m}^2$  per year.

<sup>11</sup> <http://www.vindportalen.no/Vindportalen/Vindkraft/Vindfysikk/Vindenergi/Regneeksempler2>



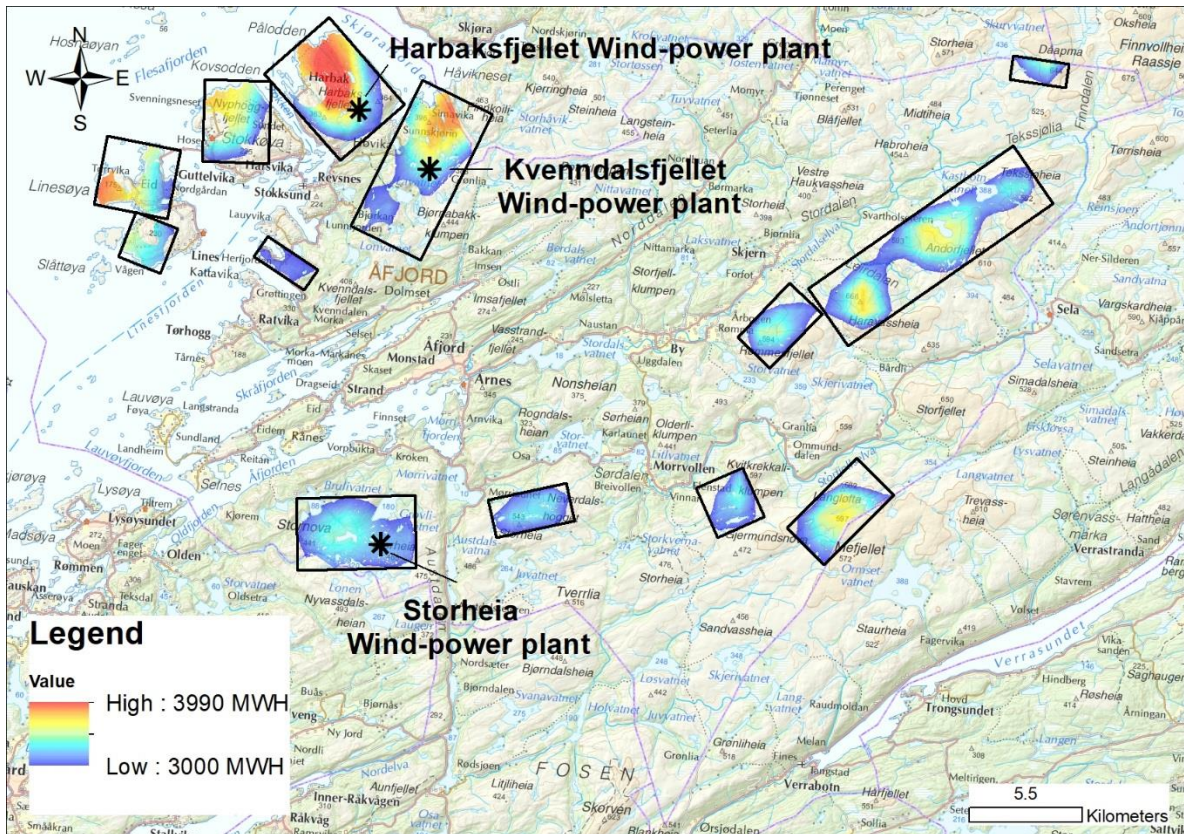


Figure 23: The most suitable areas for wind-power production according to the ConSite tool suite within the Åfjord municipality on the Fosen peninsula, central Norway. Consented wind-power plants are indicated with a black asterisk.

the user to select the most productive site, and evaluate potential wind turbine locations in relation to the prevailing wind direction and the preferred turbine-distances along and perpendicular to the wind direction.

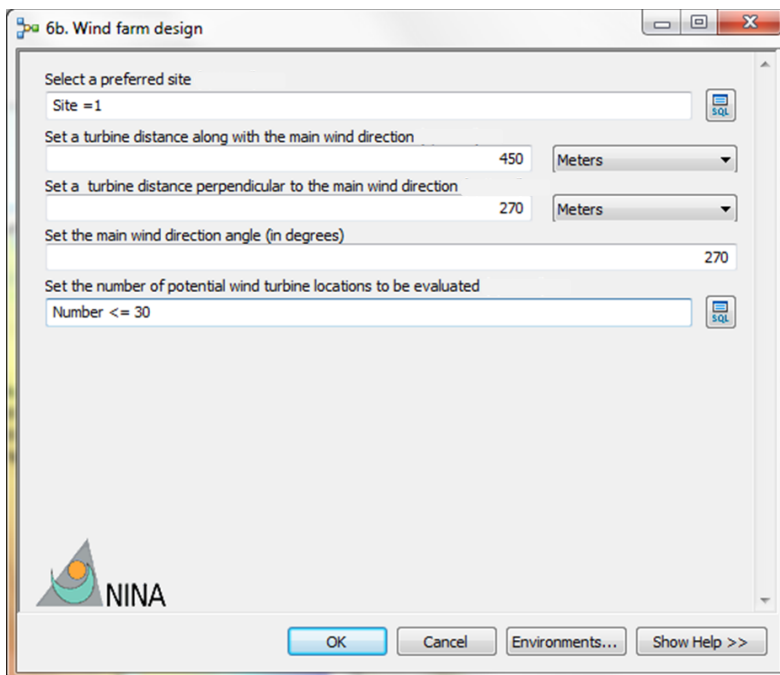


Figure 24: The ConSite Wind design module



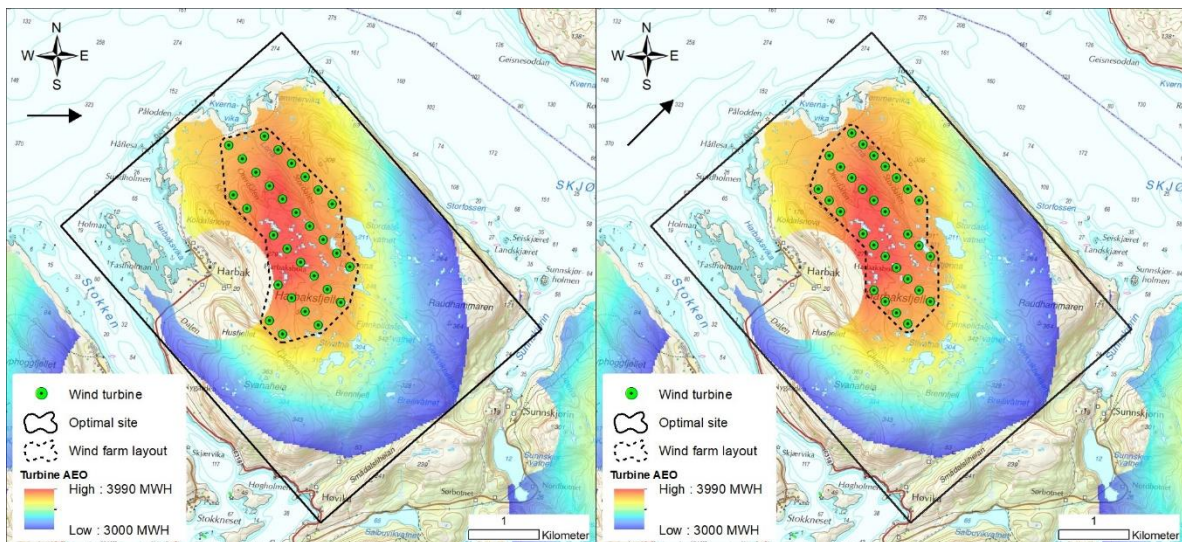


Figure 25: Wind-power plant layout map based on a turbine array of 30 wind turbines, a turbine distance 450 meters along and 270 meters perpendicular to the prevailing wind direction (western wind in the left map and southwestern wind in the right map).

For further dialog and process scoping ConSite Wind also provides functionality for zonal conflict statistics (Figure 26). This can especially be valuable to identify and prevent conflicts at local level in order to achieve consensus about the best wind farm configuration.

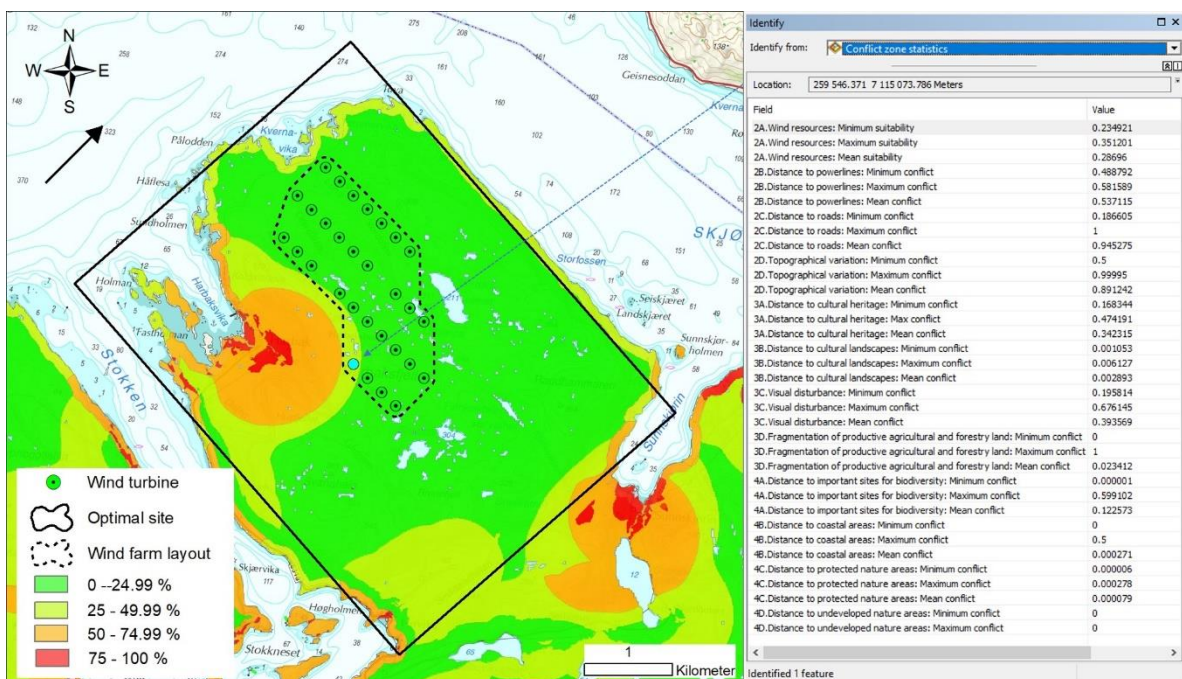


Figure 26: Zonal conflict index value statistics (minimum-mean-maximum) for a selected wind-turbine location

Wind farm configuration is a complex process. In current international wind energy projects there is a particular concern about the extent of bird (and bat) collisions. Possible mitigation approaches to reduce collision risk can be categorized as bird-based or turbine-based (May *et al* 2015).

Bird-based mitigation approaches directly alter the bird behavior and include technical wind turbine additions such as flashing lights, loud noises and changes to habitats in order to increase the attractiveness of areas outside wind power plants or to decrease the attractiveness of the wind turbine area.

The turbine-based mitigation approaches include measures like wind farm design, turbine micro-siting, repowering and operational measures. Such turbine-based measures have small or only indirect effects on bird behavior, but may effectively reduce bird mortality.

A turbine-based wind farm design will normally, depending of the local context, have to balance technical factors (e.g. wind conditions, topographical constraints, turbine design, turbine numbers and turbine micro-siting) with economic factors (e.g. cost-efficiency), societal factors (e.g. noise, visual impacts and shadow flickering) and environmental factors (e.g. migration corridors and bird collision risk). Several engineering tools on the market today address these technological, economical and societal factors (e.g. WaSP, WindSim, ECN WakeFarmer and GH Wind-Farmer), while none of them provides functionality for forecasting risk-enhancing topography related to movement corridors and bird collision risk.

In addition to ConSite Wind, NINA has developed a GIS-based tool for bird-friendly micro-siting of wind-turbines (INTACT Micro-siting GIS) as a part of the Norwegian R&D project "*Innovative Mitigation Tools for Avian Conflicts with wind Turbines (INTACT)*". The INTACT Micro-siting GIS tool provides functionality for high-resolution spatial modelling of migratory corridors and updraft landscapes. This tool utilizes state-of-the-art algorithms in geomorphometric, orographic and thermal updraft modelling highly relevant for fine-scale micro-siting of wind turbines.

The high spatial resolution makes the INTACT Micro-siting GIS tool relatively unique compared to similar thermal updraft modelling which is mainly based on weather forecast models with spatial resolutions ranging from 12.5 x 12.5 km to 32 x 32 km. Thermal updrafts are caused by vertical air fluxes produced by diurnal solar heating and the spectral reflectance characteristics of the land cover. Estimating thermal updrafts is very complex due to the chaotic nature of turbulence governing the atmosphere (Reddy *et al.* 2016). Bohrer *et al.* (2012) estimated thermal updraft velocity from the North American Regional Reanalysis (NARR) model-observation hybrid dataset (32 x 32 km). Shannon *et al.* (2003) and Harel *et al.* (2016b) refer to the estimation of thermals based on weather forecast models such as e.g. the European Centre for Medium Range Weather Forecast model (12.5 x 12.5 km). Shamoun-Baranes *et al.* (2016), Shepard *et al.* (2016), and Treep *et al.* (2016) applied high-resolution digital elevation models in their updraft modelling.

The INTACT micro-siting GIS estimates thermal updraft velocity from the Landsat 8 thermal band 10 (holding a spatial resolution of 100 x 100 m) using the standard atmospheric scaling coefficient called the *Free connectivity scaling velocity* or the *Deardorff Velocity* (Bohrer *et al.* 2012). The *Deardorff Velocity* is estimated from the surface sensible heat flux, the land surface temperature and the potential temperature. The surface sensible heat flux describes how the thermal energy is transferred from the ground surface to the atmosphere through conduction and convection (Hu *et al.* 1999). The land surface temperature was calculated in ESRI ArcGIS using Python algorithms for automated mapping of land surface temperature from Landsat 8 (Walawender *et al.* 2012). The potential temperature describes the temperature of an unsaturated part of dry air when brought adiabatically and reversibly from its initial state towards a standard pressure expressed by Stull (1988). Orographic updraft velocity is the function of horizontal wind forced upwards by elevated topography and is estimated according to Brandes and Ombalski (2004), and Bohrer *et al.* (2012). The INTACT micro-siting GIS estimates the orographic updraft velocity at 10 x 10 meters spatial resolution based on the Norwegian DTM10 terrain model (10 x 10 meters spatial resolution) and proxy climate variables from the Norwegian Meteorological Survey. Terrain slope and aspect were derived from DEM10 using the ESRI ArcGIS Slope and Aspect tools.

The updraft models of the INTACT Micrositing GIS tool have been successfully validated with high-frequency GPS tracking data for white-tailed eagle at the island of Hitra in Norway (Hanssen et al., paper in review 2018) and for black kites in the Tarifa area in Gibraltar, Spain (Santos et al., 2017).

Both ConSite Wind and the INTACT GIS Micro-siting tool can be further developed as add-ons to existing engineering tools for wind farm configuration, optimisation, mitigation of boundary and landscape constraints, energy yield calculation, siting of wind-power plants and micro-siting of wind-turbines as illustrated in figure 27 below.

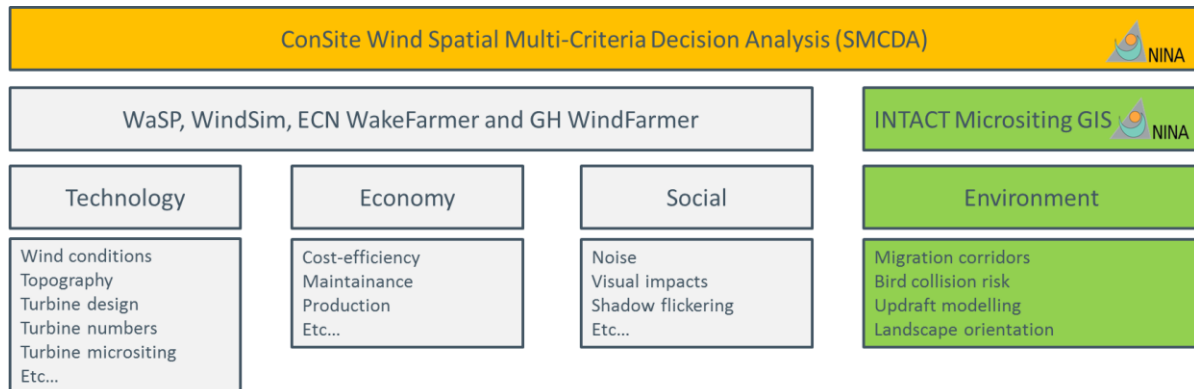


Figure 27: How ConSite Wind and the INTACT GIS Micro-siting tool may relate to existing engineering tools



### 3 The ConSite SMCDA platform

#### 3.1 The ConSite SMCDA desktop platform

The current desktop platform is outlined in Figure 28 below. This offline platform has powerful raster processing capabilities, but is not accessible for simultaneous use by several users. The toolbox and its additional file-geodatabases can be shared through Nina’s ftp-server for users with a valid ESRI ArcGIS-license.

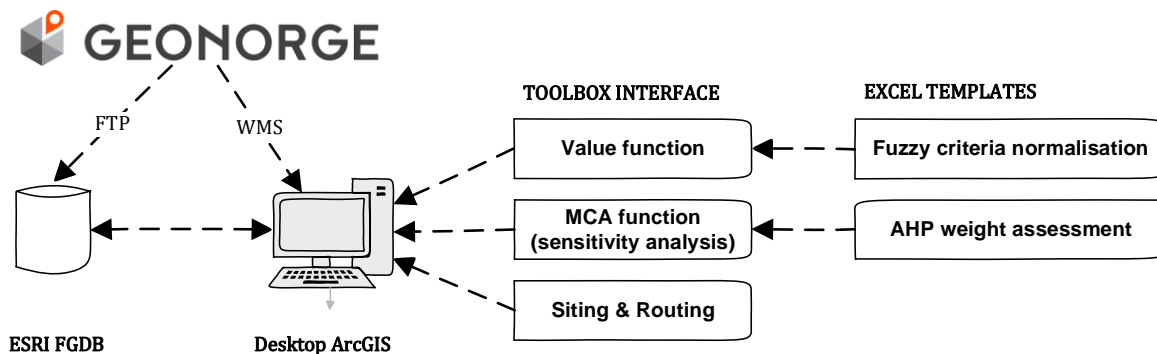


Figure 28: Current ConSite SMCDA desktop platform

When implementing ConSite in the planning phase of a wind-power or power line construction project the actual toolbox first has to be configured with relevant criteria and corresponding spatial data. For Norway ConSite utilizes spatial data from GEONORGE<sup>12</sup> managed in a local ESRI File Geodatabase.

The two toolboxes (ConSite Wind and ConSite Powerlines) are designed for use in ESRI ArcGIS Advanced version 10.x with the Spatial Analyst extension. The toolbox is developed in Model-builder, which is a visual programming language for building workflows that string together sequences of standardized geoprocessing tools. Modelbuilder is very effective for executing GIS workflows and provides advanced methods for extending standard ArcGIS functionality by creating and sharing models as tools. Each tool can be operated as a singular workflow or through a graphical user interface (GUI). These workflows (and their accompanying processing logs) also represent useful documentation of the geoprocessing steps. Python scripts organize the output maps in thematic group-layers.

The toolboxes contain toolsets (Figure 29) with tools (or workflows) for selection of the study area, normalization of criteria maps (social, technological and ecological), conflict map aggregation, wind farm siting/configuration (ConSite Wind) and power line routing (ConSite Powerlines).

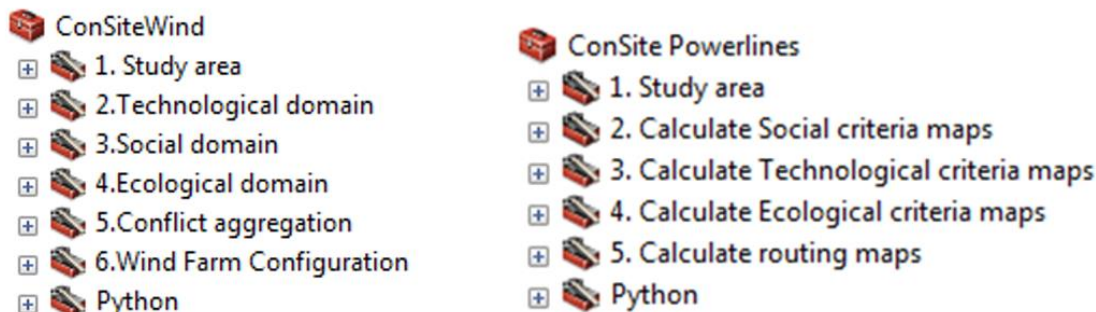


Figure 29: The ConSite Wind and ConSite Powerlines desktop toolboxes

<sup>12</sup> [www.geonorge.no](http://www.geonorge.no)

## 3.2 Migrating towards an online ConSite platform

With the advent of robust online geoprocessing functionality<sup>13</sup> (Hofer 2015) and standardized online spatial data web-services<sup>14</sup> it is the ambition of NINA to migrate the ConSite SMCDA framework towards an online platform. This development has to be based on a requirement analysis approach, a detailed requirement specification and system prototyping.

The main user groups for ConSite are industrial developers, land-use planners and decision makers. Stakeholders will be directly involved in the dialog process and have access to the ConSite SMCDA through a public web-interface where they can do their own simulations, communicate, and give feedback and comments directly to the developers, land-use planners and decision makers. The online ConSite SMCDA system should therefore have a very simple and intuitive web-interface designed especially for non-experts. To increase the communication interface we also consider implementing gaming approaches (Van Der Hulst et al. 2014).

We would like to develop the online ConSite SMCDA platform as a Service Oriented Architecture (SOA) that is able to handle distributed data and processes using OGC web-services such as Web Map Services (WMS)<sup>15</sup>, Web Feature Services (WFS)<sup>16</sup>, Web Coverage Services (WCS)<sup>17</sup> and Catalogue Services for Web (CSW)<sup>18</sup>. At the national level this will increase ConSites integration with the Norwegian Spatial Data Infrastructure collaboration GeoNorge<sup>19</sup>, and thereby, the majority of planning authorities and decision makers in Norway. At the international level, this strategy will increase potential collaboration opportunities for NINA and further inclusion of ConSite into new contexts. Due to budget constraints and the need to secure project continuity, and future adoption uncertainties, we aim to develop the ConSite SMCDA online platform using Open Source technology. This will secure access to future developments at reduced costs, and may provide international collaboration opportunities in future projects.

The ConSite MCDCA online platform will be case-specific. The business idea is that NINA in the future will offer ConSite as a facilitated decision-support service towards larger infrastructure construction projects. These projects will have their separate project domains within ConSite MCDCA online platform hosted at the NINA website.

Figure 30 outline the conceptual design of the ConSite SMCDA web-application. This proposal must of course be adapted to stakeholder requirements in a realization of the web-application. The web-application will be based on current developments in online spatial multi-criteria decision support systems (e.g. the integrated GeoSpatial Urban Energy Information and Support System- iGUESS<sup>20</sup>). The web-mapping client will provide the user interface with the four modules of, respectively, Value functions (section 2.2), Multi-Criteria Analysis aggregation (section 2.3 and 2.4), Sensitivity analysis (section 2.5) and Siting, routing & optimisation (section 2.6). The web-application will have a technical backend framework based on e.g. Python-Django. The ConSite SMCDA web-application will read and write spatial data (and their corresponding metadata) from the spatial data storage. Spatial data from GeoNorge (or other external data providers) will be fed into the spatial data storage (both file-based and a geospatial database such as for example PostGIS) using FTP or web-services such as WFS/WCS. The geospatial database will be managed by a DataBase Management System (e.g. PostgreSQL). A metadata catalogue will handle metadata between the spatial data storage and GeoNorge using Catalogue Services for the WEB (CSW) using a Metadata Publishing Platform such as for example PyCSW.

<sup>13</sup> <http://www.esri.com/news/arcnews/summer09articles/process-models.html>

<sup>14</sup> <http://www.opengeospatial.org/standards>

<sup>15</sup> <http://www.opengeospatial.org/standards/wms>

<sup>16</sup> <http://www.opengeospatial.org/standards/wfs>

<sup>17</sup> <http://www.opengeospatial.org/standards/wcs>

<sup>18</sup> <http://www.opengeospatial.org/standards/cat>

<sup>19</sup> [www.geonorge.no](http://www.geonorge.no)

<sup>20</sup> <http://iguess.tudor.lu/>

The Mapping-server (e.g. the web-mapping platform MapServer) will help to publish online maps using web-services such as WMS, WFS and WCS for use in the Web Mapping-client (e.g. OpenLayers3). The Processing-server will provide Web Processing Services and processing capabilities (e.g. based on GRASS or PyWPS) to the web-application and to GeoNorge.

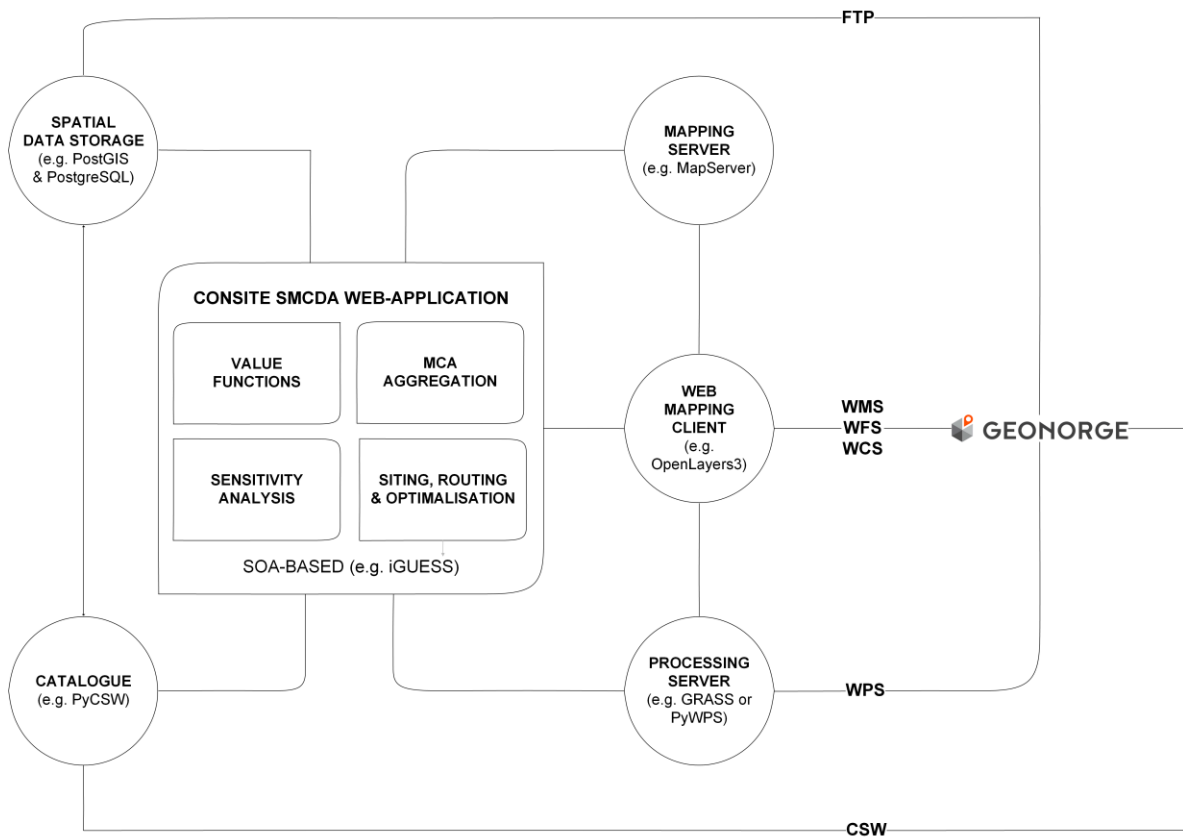


Figure 30: Conceptual design of the ConSite SMCDA web-application

Project outcomes (from the OPTIPOL, ConSite and DAVEP-VLIT- projects), validation results and the growing interest and awareness among stakeholders clearly demonstrates that there is a market for spatial multi-criteria based decision-support solutions like ConSite in future pre-construction infrastructure projects. With funding from the BiodivERsA project IMAGINE (started in 2017) we plan to include the ecosystem services approach into the ConSite SMCDA framework as described in chapter 4. This will enable ConSite with adaptive landscape planning capabilities based on the ecosystem services concept and the inclusion of ecosystem services bundles and trade-offs in future renewable energy construction projects. In addition, we also plan to include climate change scenarios for the same purposes.

Migrating ConSite towards an online platform will require close collaboration with potential stakeholders in order to secure relevance and proof-of-concept. It will also require substantial funding and a business model that can secure continuity and long-term management of ConSite. Future actions will be addressed in the next years:

1. Identify synergies from the ongoing research projects (the EU BiodivERsA project «Management of Green Infrastructures Multifunctionality, Ecosystem integrity and Ecosystem Services: From assessment to regulation in socio-ecological systems (IMAGINE 2017-2020)<sup>21</sup>»

<sup>21</sup> <https://www.era-learn.eu/network-information/networks/biodiversa3/biodiversa3-joint-call-2015/integrative-management-of-green-infrastructures-multifunctionality-ecosystem-integrity-and-ecosystem-services-from-assessment-to-regulation-in-socio-ecological-systems>

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and the Norwegian research projects «Spatial assessment of environment-economy trade-offs to reduce wind power conflicts (WindLand 2017-2020)»<sup>22</sup> and «Bird-friendly design of power lines (BirdPOL 2018-2021)».

2. Maintain/enlarge the network of partners in order to develop more formal strategic partnerships with NGOs, industrial companies and the governmental sector
3. Identify potential funding sources for a migration project

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<sup>22</sup> [http://www.forskningsradet.no/prognnett-energix/Nyheter/Nye\\_prosjekter\\_for\\_miljovennlig\\_energi\\_far\\_en\\_halv\\_milliard\\_kroner\\_fra\\_ENERGIX/1254022827057](http://www.forskningsradet.no/prognnett-energix/Nyheter/Nye_prosjekter_for_miljovennlig_energi_far_en_halv_milliard_kroner_fra_ENERGIX/1254022827057)

## 4 ConSite Adaptive Landscape Planning

### 4.1 Introduction

Most of our landscapes are the long-term socio-ecological products of human interactions with their natural environment. Anthropogenic activities and changes in the use of landscapes have affected, and will continue to affect, ecosystems at varying intensities across space and time. Through anthropogenic use, existing interrelationships among species, biophysical structures, ecosystem functioning and landscape configurations are shaped. This in turn affects the manifold direct and indirect benefits humans derive from nature, conceptually framed as ecosystem services (Haines-Young & Potschin 2010). Landscape-scale policy decisions on the optimal allocation and management of the different land use options are still strongly pattern- and sector-oriented and lack the inclusion of the services concept (de Groot et al. 2010). In land-use planning relatively short term economic development often overrides natural values present in landscapes. Current decision-making processes for infrastructural projects often lacks the inclusion or underestimate the different values of ecosystem services and thereby implicitly also the weighting of environmental criteria and choices related to this weighting process. Although the ecosystem service approach has shown that coinciding cultural and natural values do not necessarily pose a trade-off between the environment and socio-economic development, it does require policies and management practices for balancing conflicting land use based on reconciled user-relevant knowledge (McNie 2007; de Groot et al. 2010).

In today's multiple-use landscapes, decision makers have to take account of the explicit demands from a wide range of stakeholders and interest groups; necessitating embracing the landscape functions and services concept in policy making. The participatory GIS-based multiple criteria decision analysis toolbox ConSite allows the holistic assessment of optimal siting of infrastructure and human activities from technological, socio-economic and environmental perspectives, set within social-ecological landscapes. Because the ecosystem service concept is based on the benefits people obtain from ecosystems (MA 2005), and embraces the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services (TEEB 2010), it is desirable to link the ecosystem services concept with ConSite. Decision-making processes concerning ecosystems and their services can however be particularly challenging because not only different disciplines, philosophical views, and schools of thought assess the value of ecosystems differently, direct stakeholders and interest groups assess the values differently. In addition environmental values often change over time and space. The potential advantage of the ecosystem service concept, however, is that it enables us to highlight the importance of environmental goods and services for governments, communities and corporations and to identify those who bear the costs versus those who benefit when certain ecosystem services are affected by the decision. Because ConSite is about optimal siting and routing of natural and manmade features in the landscape, a logical next step is to develop an innovative decision support module within ConSite based on the ecosystem service approach for optimal adaptive landscape planning. By adaptive landscape planning we mean a structured, iterative and evolving process of robust decision making regarding planning issues in the face of certainties and uncertainties (Lempert et al. 2007; Rist et al. 2013). The challenge in using this adaptive landscape planning approach is to find the correct balance between gaining knowledge to improve, in our case, landscape planning in the future and achieving the best short-term outcome based on current knowledge (see also Allan & Stankey 2009).

In this chapter, we highlight the opportunities and challenges for inclusion of the ecosystem service approach into ConSite, following our aim to develop an innovative decision support module for optimal adaptive landscape planning. A proposition for circumventing the potential shortcomings of the application of the ecosystem service concept in the case of ConSite where private and public interests are the main drivers determining the least cost siting or pathway, the public good-type ecosystem service concept is introduced. We argue that the public good-type ecosys-

tem service approach may results in a better recognition and acknowledgement of the environmental goods and services at stake and with that leading to a more accurate assessment of preferences. This in turn enables us to work towards an inclusive assessment of shared values in landscape planning issues. An inclusive assessment of shared values is necessary to reduce conflict levels and enables us to find mitigation options.

## 4.2 Ecosystem services versus environmental public goods and services

The ecosystem service concept links the cascade of biophysical structures and processes, through their functions and service provision, to how humans benefit from and value these services (see Figure 31, the original cascade figure from Haines-Young & Potschin 2010). The *Common International Classification of Ecosystem Services (CICES)* categorizes ecosystem services into provisioning, regulating and maintenance, and cultural services. While the first two categories are related to more or less the direct benefits, the latter cultural services render more indirect and less tangible benefits. Although ecosystem services provides a valuable concept, as it highlights different kinds of services ranging from provisioning to regulating and maintenance to cultural services, the concept has been criticized for mixing ecological processes for achieving certain services through other services or within services themselves (Wallace 2007, Fisher & Turner 2008). Clearly, there exist trade-offs between ecosystem service provision; where services influence their respective level of provision, e.g. through exclusion. For instance, forest has a provision service when it comes to timber production, but has also a provision service for berry and mushroom picking. Thus, services are bundled within specific ecosystems. What CICES has shown, is the complexity of the different interactions and feedback loops existing among services as it takes ecosystems as starting point. Also, by linking biophysical structure to ecosystem function and service provision, the cascade model in figure 31 is inherently ecosystem-specific. By placing the benefits humans derive from ecosystems at a central place, and how humans value the ‘services’ and ‘goods’ these benefits provide, greatly affect the flows of the cascade model and ultimately the feedback loop to ecosystem integrity (Figure 31). Value setting is dependent on the social-cultural setting within societies influencing among other things access to resources and the level of demand for specific environmental goods and services. Prioritization and trade-off issues thereby depend on power structures, dominance and social acknowledgement and thus social settings within which choices are made. However, the cascade model currently does not highlight the differential opportunities and values across stakeholders within societies. Therefore, when opting for inclusion of the ecosystem services concept as a tool for ConSite adaptive landscape planning social-cultural structures should be taken into account within the social-ecological setting of the ecosystem services cascade model.

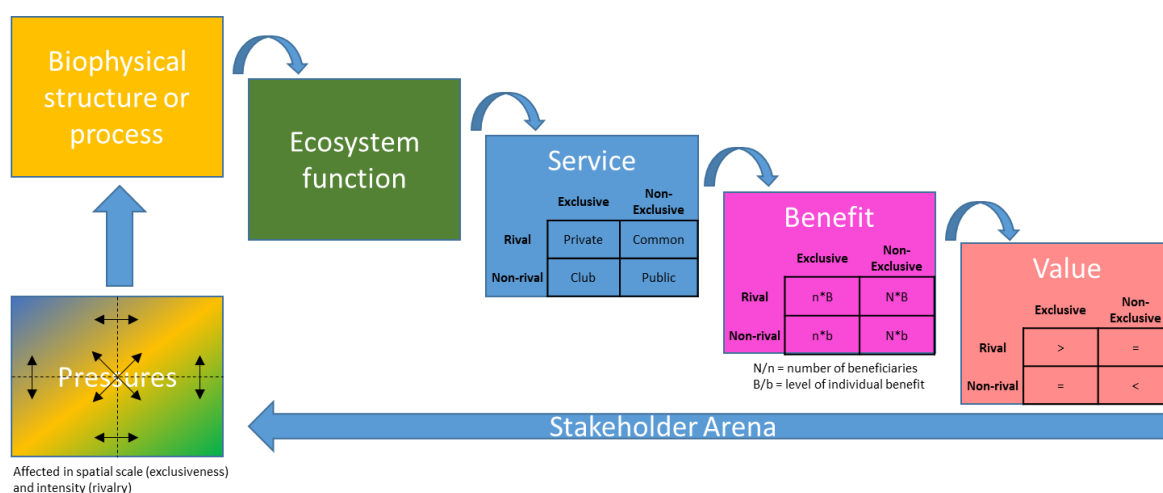


Figure 31: Public goods theoretic ecosystem services cascade model, adapted from Haines-Young & Potschin (2010).



The origin of the ecosystem services concept can be found in environmental economy where 'goods', 'services' and 'benefits' all have an economic origin. Whilst there is much overlap between the concepts of ecosystem services and public goods, they stem however from different theoretical backgrounds (environmental science and (neoclassical) economics respectively), leading to some confusion in how the terms should be linked in policy and practice (Dwyer et al. 2015). The UK National Ecosystem Assessment (NEA)<sup>23</sup> argued that services (e.g. trees) are the final outputs and goods (e.g. timber) are the things that are valued in terms of the benefits they generate. The complexity around valuation arises when one values goods alongside other forest services such as the capacity of carbon storage or reduction capacity against erosion. In this context, the difficulty of value pluralism arises when there are several values which all may be equally correct and fundamental in themselves but which may be in conflict with each other or between user groups. From the moment humans changed their daily practice from being nomadic hunters and gatherers, to being sedentary farmers within agriculture settlements, the concept of privatization and property rights was established. This rendered certain services and goods exclusive to private properties in distinction to services and goods available to all. As a result of human evolutionary and cultural processes (Kopnina 2013), together with different forms of cooperation and group structures (Wilson 1975, Ostrom 2009), societies have developed through exchange of goods and payment in cash, into market-based economies. The private strive for status, security and prosperity has driven the demand for valued and/or scarce goods.

Nowadays, many democracies differentiate between the public and private spheres and associated goods as laid down in laws, regulations, policy and public/governmental budgets. Balancing private-public demands as well as choices on public expenditure on public goods and services are common and (de-)prioritizations and trade-offs are numerous. Samuelson (1954) developed in his paper *The Pure Theory of Public Expenditure* the theory of public goods, in which he placed the concepts of rivalrous, non-rivalrous, excludable and non-excludable goods in a private market context. Within the setting of the ecosystem services concept, this differentiation may help considerably as the level of access to and need for sharing a common good affects the way how ecosystem services are valued and used. According to Brown et al. (2007), no one will pay for ambient air in a private market as long as ambient air is not scarce. In addition, a scenic view with several access points (i.e. a non-rival and non-exclusive 'public good') can for a recreationist who 'consumes' the enjoyment of the view easily change into a rival good when the scenic view is very popular and crowded or may become an exclusive 'club good' in the case when wind turbines are placed which are blocking the scenic view (Figure 31). Brown et al. (2007) argue that a landowner with the capability to protect the quality of the river through a property will have little incentive to do so if those efforts are enjoyed freely by those benefitting from the goods and services downstream. Similarly, the benefits derived from the goods and services from ecosystems, can be expected to vary according to the number of beneficiaries and the level of benefit that is to be shared. While private goods may render large individual benefits to few people, public goods are to be shared by many, rendering relatively small individual benefits (Figure 31), which together benefit society at large. This effect can in turn be expected to reflect in the perceived values of private versus public goods. The consequent use and demand of valued goods and services will ultimately feedback to the ecosystem through pressures that may be differentiated spatially due to the distribution of accessibility to specific ecosystem services. Due to interdependencies within ecosystems service bundles, private goods may negatively affect public goods in adjacent areas, and vice versa. On public lands, non-exclusive goods and services are typically regulated or provided by the government and financed with tax revenues; cf. environmental public goods and services.

ConSite is centered around the intertwined institutional and governance settings (i.e. private energy companies, government authorities, landowners, non-governmental interest groups and the public at large) and argumentation uncertainty where weighting the different environmental, technological and socio-economic criteria needs to be as robust as possible. We argue therefore that

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<sup>23</sup> <http://uknea.unep-wcmc.org>

including the ecosystem service concept would be helped with the extension of the public goods and services approach. Solely mapping and assessing ecosystem services in cases for human infrastructure development may be challenging due to differences in the spatial distribution of societal demands and natural supply for the specific services, which in turn may affect different services in the same area or elsewhere. In addition, landscape interventions are often guided, if not always guided, by economic principles, institutional restrictions and power play of the business sector weaved into the public domain (e.g. private versus public issues, positions of political parties). Ecosystem services are not necessarily shared equally among stakeholders due to excludability and rivalry. Elucidating the linkages, synergies and trade-offs between goods and services with regard to private benefits of landscape interventions and the loss of public goods to society at large may support sustainable landscape planning decisions. By incorporating the public goods approach into the ecosystem service concept, the complexity of social-ecological systems may become more comprehensible for the diversity of stakeholders and interest groups. This may assist in better weighting of the different options necessary to reach consensus in landscape planning tools such as ConSite. Including the public good type approach enables also the differentiation between individual and collective interests, as well as the relative importance and relationships existing between interests and associated valuation of specific goods and services. ConSite may through such a holistic approach better address *'the overlap between what people collectively want and what is biologically and ecologically possible'* (Bormann et al. 1994).

### 4.3 Integration of public goods and ecosystem services into ConSite

For further integration of the public-good type ecosystem services approach, a first step will be to elaborate the ConSite framework in Figure 1 with the specific spatial status quo of the public and private goods and services (i.e. rival, non-rival, excludable, non-excludable). With help of the adjusted cascade model (Figure 31) an indication can be given on the changes in this status quo as a result of siting decisions. For instance the environmental public good 'berry picking' may be non-rival but excludable in an area with little access, but may change into non-excludable when the area becomes accessible due to infrastructure development necessary for building and operating a wind-power plant. It will enable us to analyze goods and services in the way they are recognized, desired or required differently by diverse groups in society. The following steps are deemed necessary to integrate public goods and ecosystem services into the ConSite framework step-by-step:

1. Criteria definition: Map ecosystem services through spatially explicit biophysical structure and process indicators. With help of tailoring the Estimap tool for mapping ecosystem services in a given area (Zulian et al. 2014) ecosystem service provision can be downscaled to a local setting.
2. Criteria importance / Weight uncertainties: Create an n-n influence matrix of ecosystem services; the diagonal equals the intrinsic value of each ecosystem service (stakeholder-based weight including uncertainty therein); the other cells represent the relative influence (-1 – 1) of each ecosystem service upon the focal ecosystem service (science-based) as  $MAP_{wgt} = [MAP * W_{i,i} + (\sum MAP * W_{i,j..n} / (n-1))] / 2$ . Stakeholder dialogue processes and the Q method (Brendin et al. 2015) can contribute to assess value plurality for creating a better understanding of the selection, valuation and weighting of criteria and to obtain consensus on the different criteria at stake.
3. Criteria integration: Assess the level of rivalry (0 – 1) through relative human density (by multiplying 1 – density with  $MAP_{wgt}$ ), and exclusiveness (0 – 1) through public (=0) / private (=1) property and relative distance to roads (multiplying 1 – average factor by  $MAP_{wgt}$ ) for each ecosystem service within the study region. Thereafter summarize the ecosystem services to obtain the overall provision of public goods and services. Similarly, the spatial distribution of private goods and services can be obtained by subtracting  $MAP_{wgt}$  with the previously derived public goods and services map.



## 5 References

- Allan C., Stankey G.H. 2009. *Adaptive Environmental Management - A Practitioner's Guide*. Springer, Netherlands.
- Al-Shabeeb, A.R., Al-Adamat, R., & Mashagbah, A. 2016. AHP with GIS for a Preliminary Site Selection of Wind Turbines in the North West of Jordan. DOI: 10.4236/ijg.2016.710090.
- Bevanger, Kjetil Modolv; Bartzke, Gundula; Brøseth, Henrik; Dahl, Espen Lie; Gjershaug, Jan Ove; Hanssen, Frank Ole; Jacobsen, Karl-Otto; Kleven, Oddmund; Kvaløy, Pål; May, Roelof Frans; Nygård, Torgeir; Refsnæs, Steinar; Stokke, Sigbjørn; Thomassen, Jørn; Meås, Roger. Optimal design and routing of power lines; ecological technical and economic perspectives (OPTIPOL). Final Report, findings 2009 – 2014. 2014. (ISBN 978-82-426-2622-6) 92 s. NINA rapport (1012) NINA. Trondheim: Norsk institutt for naturforskning.
- Betz, A. (1966) *Introduction to the Theory of Flow Machines*. (D. G. Randall, Trans.) Oxford: Pergamon Press.
- Bohrer, G., Brandes, D., Mandel, J. T., Bildstein, K. L., Miller, T. A., Lanzone, M., Katzner, T., Maisonneuve, C. & Tremblay, J. A. 2012. Estimating updraft velocity components over large spatial scales: contrasting migration strategies of golden eagles and turkey vultures. *Ecol Lett*, 15: 96-103.
- Bormann B.T., Brookes M.H., Ford E.D., Kiester A.R., Oliver C.D., Weigand J.F. 1994. A Framework for Sustainable Ecosystem Management. Gen. Tech. Rep. No. 331. USDA, PNW, Forest Service.
- Bottero M., Ferretti V., Figueira J., Greco S., Roy B. 2015. An extension of Electre III for dealing with a multiple criteria environmental problem with interaction effects between criteria. *European Journal of Operational Research*, Vol. 245, issue 3, pp. 837-950.
- Brandes, D. & Ombalski, D. W. 2004. Modeling raptor migration pathways using a fluid-flow analogy. *Journal of Raptor Research*, 38: 195-207.
- Bredin, Y. K., Lindhjem, H., van Dijk, J., & Linnell, J.D.C. 2015. Mapping value plurality towards ecosystem services in the case of Norwegian wildlife management: A Q analysis. *Ecological Economics* 118:198-206.
- Brown, T. C., Bergstrom, J.C., & Loomis, J.B. 2007. Defining, Valuing, and Providing Ecosystem Goods and Service. *Natural Resources Journal* 47:329-376.
- Chapin III, F.S., Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., Clark, W. C., Olsson, P., Smith, D.M.S., Walker, B. & Young, O.R. 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution* 25: 241-249.
- Comber, A. 2009. Review of tools for risk assessment and tradeoff analysis. Appendix 8, Defra ref: WC0794.
- Comber, A.J., Carver, S., Fritz, S., McMorran, R., Washtell, J. and Fischer, P. 2010. Different methods, different wilds: Evaluating alternative mappings of wildness using Fuzzy MCE and Dempster Schafer MCE. *Computers, Environment and Urban Systems*, 34:142-152.
- Comino E., Ferretti V. 2015. Land suitability analysis for wetland location: a spatial multicriteria approach, Proceedings of the 27th European Conference on Operational Research (EURO), 12–15 July 2015, Glasgow (UK).
- Costanza, R. d'Arge, de Groot, R., Farber, S., Grasso, M., Hannon, B. et al. 1997. The Value of the World's Ecosystem Services and Natural Capital. *Nature* 387: 253–260.
- Daily, G.C. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington. 392pp.
- de Groot R.S., Alkemade R., Braat L., Hein L., Willemsen L. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7:260-272.
- Dente, B. 2014. Understanding policy decisions, Springer Briefs In Applied Sciences and Technology.

- Drobne, S. & Lisec, A. 2009. Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging. *Informatica* 33: 459-474.
- Dwyer, J., Short, C., Berriet-Sollic, M., Gael-Lataste, F., Pham, H-V., Affleck, M., Courtney, P. & Déprès, C. 2015. Public Goods and Ecosystem Services from Agriculture and Forestry – a conceptual approach. Initial report on review of theories and concepts. WP1.1. PEGASUS.
- Eroglu, H. & Aydin, M. Turkish. 2015. *Journal of Electrical Engineering and Computer Sciences* 23(5):1418-1430. DOI: 10.3906/elk-1211-59.
- Feizizadeh, B., Omrani, K. & Aghdam, F.B. 2015. Fuzzy Analytical Hierarchical Process and Spatially Explicit Uncertainty Analysis. *Journal for Geographic Information Science* 1-2015.
- Felipe-Lucia, M. R., et al. 2015. "Ecosystem Services Flows: Why Stakeholders' Power Relationships Matter." *PLoS One* 10(7).
- Ferretti V. 2011. A Multicriteria- Spatial Decision Support System (MC-SDSS) development for siting a landfill in the Province of Torino (Italy), *Journal of Multi-Criteria Decision Analysis*, Vol. 18, pp. 231-252, (prize-winning paper for the Wiley Practice prize at the International Conference on Multiple Criteria Decision Making, June 2011, Jyväskylä, Finland).
- Ferretti & Montibeller. 2016. Key challenges and meta-choices in designing and applying multi-criteria spatial decision support systems. *Decision Support Systems*.
- Fisher, B. & Turner, R.K. 2008. Ecosystem services: classification for valuation. *Biological Conservation* 141, 1167–1169.
- Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. & Rockström, J. 2010. Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society* 15:20.
- Geneletti, D. and Alias Abdullah (Eds). 2009. *Spatial decision support for urban and environmental planning. A collection of case studies*. Arah Publications, Kuala Lumpur.
- Gibson, R. B. and Hassan, S. 2005. *Sustainability assessment: Criteria and processes*. London Earthscan.
- Goepel, Klaus D. 2013. Implementing the analytic hierarchy process as a standard method for multi-criteria decision making in corporate enterprises – a new AHP excel template with multiple inputs. *Proceedings of the international symposium on the analytic hierarchy process*, Kuala Lumpur, Malaysia.
- Greene, R., Devillers, R., Luther, J.E., and Eddy, B.G. 2011. GIS- based Multiple-Criteria Decision Analysis. *Geography Compass* 5/6:412-432.
- Haines-Young, R.H. and Potschin, M. 2010. The links between biodiversity, ecosystem services and human well-being In: Raffaelli, D. and Frid, C. (eds) *Ecosystem Ecology: A New Synthesis*. BES Ecological Reviews Series, CUP. Cambridge: Cambridge University Press, 110–139.
- Harel, R., Horvitz, N. & Nathan, R. 2016b. Adult vultures outperform juveniles in challenging thermal soaring conditions. *Sci Rep*, 6: 27865.
- Hanssen, F., May, R., Dijk, J. & Rød, J.K. Spatial multi-criteria decision analysis tool suite for consensus-based siting of renewable energy structures (paper in review, 2018)
- Hanssen, F., May, R. & Nygård, T. How can high-resolution modelling of updraft landscapes help to reduce the collision risk for soaring raptors in spatial planning and layout design of future wind-power plants? (paper in review, 2018)
- Hanssen, F., May, R., Thomassen, J., and Bevanger, K. 2014. A Least Cost Path (LCP) Toolbox for Optimal Routing of High Voltage Power Lines for a Sustainable Future. Pages 181-186 in J. Doucet, editor. *Environmental Concerns in Rights-of-Way Management 10th International Symposium*. Utility Arborist Association, Phoenix, Arizona, USA.
- Hansson, R., Prestrud, P. & Øritsland, N.A. 1990. Assessment system for the environment and industrial activities at Svalbard. - Norwegian Polar Research Institute, Report 68. 267 pp.

- Henkens, R. Tassone, V., Grafakos, S., De Groot, R.S., and Luttik, J. 2007. A participatory decision support tool to assess costs and benefits of tourism development scenario. Application of the Adaptive model to Greater Giyani, South Africa. Alterra-Report 1583, ISSN 1566-7197, p.80.
- Hofer, B. 2015. Uses of online geoprocessing technology in analyses and case studies: a systematic analysis of literature, *International Journal of Digital Earth*, 8:11, 901-917, DOI: 10.1080/17538947.2014.962632.
- Holling, C.S. 1978. *Adaptive environmental assessment and management*. - John Wiley & Sons: Chichester, New York, Brisbane, Toronto.
- Hu, Z. L., Islam, S. & Jiang, L. 1999. Approaches for aggregating heterogeneous surface parameters and fluxes for mesoscale and climate models. *Boundary-Layer Meteorology*, 93: 13-336.
- Jiang, H. and Eastman, R.J. 2000. Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science* 14: 173-84.
- Keeney, R.L. 1994 Creativity in decision making with value-focused thinking. *Sloan Management Review*, 35, 33–33.
- Keisler, J.M., Sundell, R.C. 1997. Combining Multi-Attribute Utility and Geographic Information for Boundary Decisions: An Application to Park Planning. *Journal of Geographic Information and Decision Analysis* 1(2): 101-118.
- Klinsky, S. 2010. Geographic Information Systems and Ecological Footprints as Tools for Sustainability. *The Professional Geographer*, 62(1): 84-102.
- Kopnina, H. 2013. Environmental Problems and the Grand Old Theory of 'Human Nature'. *Journal of Ecological Anthropology* 16: 61-68.
- Lempert, R.J. et al. 2007. Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches. *Risk Anal*, 27: 1009-26.
- Liu, S., Zhang, J., Liu, W. & Qian, Y. 2012. A Comprehensive Decision-Making Method for Wind Power Integration Projects Based on Improved Fuzzy AHP. *Energy Procedia*, Volume 14, 2012, Pages 937–942. <http://dx.doi.org/10.1016/j.egypro.2011.12.1036>.
- Liu, Xinyang. 2013. GIS-Based Local-Ordered Weighted Averaging: A Case Study in London, Ontario. University of Western Ontario- Electronic Thesis and Dissertation Repository. Paper 1227.
- Malczewski, J. 1999. *GIS and MCA Decision analysis*. John Wiley & Sons.
- Malczewski, J. & Liu, X., 2014. Local ordered weighted averaging in GIS-based multicriteria analysis. *Annals of GIS Vol. 20* , Iss. 2,
- Manyonge, A. W., R. M. Ochieng, F. N. Onyango & J. M. Shichikha (2012) Mathematical Modelling of Wind Turbine in a Wind Energy Conversion System: Power Coefficient Analysis. *Applied Mathematical Sciences*, 6, 4527-4536.
- May, R., Reitan, O., Bevanger, K., Lorentsen, S. & Nygård, T. (2015). Mitigating windturbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options. *Renewable and Sustainable Energy Reviews* 42, pp.170–181. DOI: 10.1016/j.rser.2014.10.00 2.
- Mateo, J.R.S.C. 2015. *Multi-Criteria Analysis in the Renewable Energy Industry*. Green Energy and Technology, Springer-Verlag London.
- McNie E.C. 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environmental Science & Policy* 10:17-38.
- Millennium Ecosystem Assessment (MA). 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington. 155pp.
- Ostrom, E. 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325: 419-422.
- Owen, D. 2015, Collaborative Decision Making. *Journal on Decision Analysis*. Volume 12 Issue 1, March 2015, Pages 29-45. DOI 10.1287/deca.2014.0307.

- Paracchini, M.L., Pacini, C., Calvo, S., and Vogt, J. 2008. Weighting and aggregation of indicators for sustainability impact assessments in the IP SENSOR context. In: Helming, K., Tab-bush, P., Perez Soba, M. (eds), *Sustainability Impact Assessment of Land Use Changes*. Springer-Verlag, pp.349-372.
- Pinto-Correia, T., Gustavsson, R., Pirnat, J. 2006. Bridging the gap between centrally defined policies and local decisions- towards more sensitive and creative rural landscape management. *Landsc. Ecol.* 21, 333-346.
- Pope, J. 2006. What's so special about sustainability assessment? *Journal of Environmental Assessment Policy and Management* 8(3).
- Randall, A. 1987. *Resource economics: an economic approach to natural resource and environmental policy* (Second ed.). New York: John Wiley and Sons.
- Raudsepp-Hearne C., Peterson G.D., Bennett E.M. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107:5242-5247.
- Reddy, G., Celani, A., Sejnowski, T. J. & Vergassola, M. 2016. Learning to soar in turbulent environments. *Proc Natl Acad Sci U S A*, 113: E4877-84.
- Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L.C. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management* 90:1933–1949.
- Rist, L. et al. 2013. A New Paradigm for Adaptive Management. *Ecol Soc*, 18.
- Saaty, T.L. 1980. *The analytic hierarchy process: planning, priority setting, resources allocation*. McGraw-Hill.
- Saaty, T.L. 2000. *Fundamentals of Decision Making and Priority Theory*. 2.nd edition. Pittsburgh PA: RWS Publications.
- Samuelson P. A. 1954. The Pure Theory of Public Expenditure, *Review of Economics and Statistics*, 36 (4): 387–89.
- Santos, C.D., Hanssen, F., Muñoz, A.R., Onrubia, A., Wikelski, M., May, R. & Silva, J.P. 2017. Match between soaring modes of black kites and the fine-scale distribution of updrafts. *Scientific Reports* 7: 6421. doi:10.1038/s41598-017-05319-8
- Schlüter, M. et al. 2013. How to use models to improve analysis and governance of social-ecological systems - the reference frame MORE (Working Paper, April, 05 2013). Available at SSRN: <http://ssrn.com/abstract=2037723>.
- Shamoun-Baranes, J., Bouten, W., van Loon, E. E., Meijer, C. & Camphuysen, C. J. 2016. Flap or soar? How a flight generalist responds to its aerial environment. *Philos Trans R Soc Lond B Biol Sci*, 371: 20150395.
- Shannon, H. D., Young, G. S., Yates, M. A., Fuller, M. R. & Seegar, W. S. 2003. Measurements of thermal updraft intensity over complex terrain using American white pelicans and a simple boundary-layer forecast model. *Boundary-Layer Meteorology*, 104: 167-199.
- Shepard, E. L., Williamson, C. & Windsor, S. P. 2016. Fine-scale flight strategies of gulls in urban airflows indicate risk and reward in city living. *Philos Trans R Soc Lond B Biol Sci*, 371: 20150394.
- Stull, R. B. (1988) *An Introduction to Boundary Layer Meteorology*, 1st edition, Dordrecht, the Netherlands: Kluwer Academic Publishers.
- The Economics of Ecosystems and Biodiversity (TEEB)*. 2010. Ecological and Economic Foundation. Chapter 1, p.19, Earthscan, Cambridge (2010)
- Thomassen, J., Hanssen, F., May, R. & Bevanger, K. 2012. Optipol Least Cost Path dialogue. Report from a dialogue workshop concerning themes, sub-themes and criteria in the Optipol-LCP version 1.0. - NINA Report 856: 48 pp.

- Thomassen, J., Hanssen, F., May, R. & Bevanger, K. 2013. OPTIPOL Least Cost Path dialogue 2. Report from the second dialogue workshop concerning criteria and criteria values in the OPTIPOL-LCP version 1.0. – NINA Report 907. 43 pp.
- Treep, J., Bohrer, G., Shamoun-Baranes, J., Duriez, O., Prata de Moraes Frasson, R. & Bouten, W. 2016. Using High-Resolution GPS Tracking Data of Bird Flight for Meteorological Observations. *Bulletin of the American Meteorological Society*, 97: 951-961.
- Van Der Hulst, A., Muller, T., Buiel, E., Van Gelooven, D. & Ruijsendaal, M. 2014. Serious gaming for complex decision making: Training approaches. Article in *International Journal of Technology Enhanced Learning* 6(3):249. DOI: 10.1504/IJTEL.2014.068364.
- Walawender, J. P., Hajto, M. J. & Iwaniuk, P. 2012. A new ArcGIS toolset for automated mapping of land surface temperature with the use of LANDSAT satellite data. In *International Geoscience and Remote Sensing Symposium (IGARSS)*. (ed. IEEE), pp. 4371-4374. Munich, Germany: Institute of Electrical and Electronics Engineers (IEEE).
- Wallace K.J. 2007. Classification of ecosystem services: Problems and solutions. *Biological Conservation* 139:235-246.
- Wilson E.O. 1975. *Sociobiology*. Harvard University Press, Cambridge Massachusetts.
- Yager, R.R., 1988. On ordered weighted averaging aggregation operators in multi-criteria decision making. *IEEE Transactions on Systems, Man and Cybernetics*, 18, 183-190.
- Zadeh, L.A. 1965. Fuzzy sets. - *Information and Control* 8: 338-353.
- Zadeh, L.A., Klir, G.J., & Yuan, B. (eds) 1996. *Fuzzy Sets, Fuzzy Logic, Fuzzy Systems. Selected papers by Lofti A. Zadeh.* - World Scientific Press.
- Zulian, G., Polce, C. and Maes J. 2014. ESTIMAP: A GIS-based model to map ecosystem services in the European Union. *Annali Di Botanica*. (Roma), 2014, 4: 1–7. Journal homepage: <http://annalidibotanica.uniroma1.it>







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## Norwegian Institute for Nature Research

NINA head office

Postal address: P.O. Box 5685 Sluppen, NO-7485 Trondheim, NORWAY

Visiting address: Høgskoleringen 9, 7034 Trondheim

Phone: +47 73 80 14 00

E-mail: [firmapost@nina.no](mailto:firmapost@nina.no)

Organization Number: 9500 37 687

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