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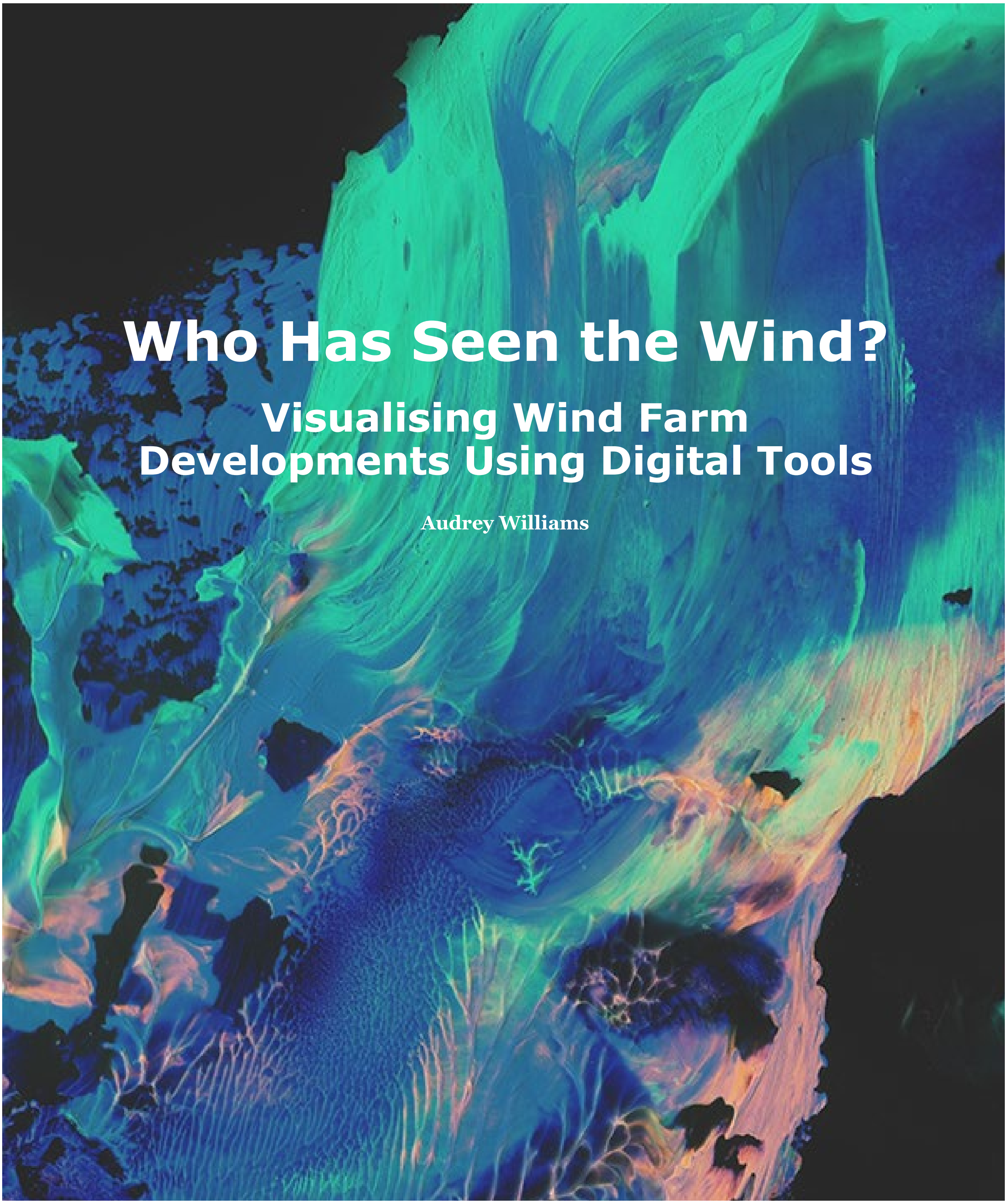

Who Has Seen the Wind?

Visualising Wind Farm Developments Using Digital Tools

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Abstract

Wind energy is an appropriate solution to reduce carbon emissions and climate change. The expansion of wind energy developments in Sweden in recent years has created substantial opposition which makes wind energy tougher to develop. The landscape and visual constraints associated with wind energy developments has become the critical reason for local opposition and protest. Planning information relating to the visual and landscape impacts of a proposed wind energy development are often brought forward through a landscape analysis. Digital tools are used in a landscape analysis to identify the proposed visual effects associated with a development. These tools provide visual aid of the proposed development through 2-dimentional and 3-dimentional images, identify constraint areas on a map as outlined in the respective development plans and identifies where visibility is likely to occur. This thesis uses a quantitative assessment by the example of a potential wind farm in Sundsvall Municipality in Sweden and theoretical research on landscape connotation. The motivation of this thesis is to outline the opportunities and limitations associated with the digital tools used to conduct a landscape analysis, promote a standardised approach to practice and implement suggestions to improve digital tools to allow for more public participation and to limit opposition towards wind farm developments. The results of this thesis suggest that the social issues and visual perceptions of turbines can be reduced through the inclusion of digital tools, but radical changes are needed within the planning process to recognise the benefits of digital tools and provide a standardised framework.

Key words: wind energy; landscape analysis; digital tools; visual effects; planning; public participation

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Chapter 1

1. Introduction

Fossil fuels have been a primary energy source for many years. However, concerns of climate change and rising temperatures has led to the search for more renewable energy systems. Many countries have looked to wind energy developments, being that wind energy is a free and cost-effective energy source, to reduce greenhouse gas emissions and meet their Sustainability Development Goals (SDGs). Energy goals across Europe have examined ways to provide cleaner, more renewable energy sources that do not depend on fossil fuels. The EU is aiming to have 32% renewable energy by the year 2030 (European Commission, n.d.). In 2003, Sweden introduced the Green Energy Certificate to increase the production of renewable energy as well as make renewable energy more cost effective and in 2017, the Swedish parliament vouched to increase its renewable energy production to a further 18 TWh (terawatt hour) by 2030 (Energy Agency, n.d.). On the upside, wind energy presents an opportunity for change because it is much cheaper to produce than oil or gas and is a clean renewable energy source.

Unfortunately, wind power has been viewed as either a source for renewable energy or a curse for destroying nature and landscapes and its visual impact is often scrutinised by the public (Rygg, 2012). NIMBYism (Not in My Back Yard) is a phenomenon whereby residents are unwilling to accept a development and consider it as inappropriate as it may impact their property value but are willing to accept the project elsewhere. NIMBYism can often be attributed from the lack of knowledge local residents have on the developments. While Sweden has an abundance of wind, onshore wind energy developments have been scrutinised due to their impacts on local landscape character and visual amenity as perceived by local stakeholders. In Sweden, wind energy developments have become tougher to develop over the years due to stricter legislation (areas identified for natural interest, reindeer herding, Sami land etc.) as well as several social implications where local opposition to the wind developments can be fierce (Ek & Persson, 2014). While wind energy provides an opportunity for politicians and wind entrepreneurs, it is often perceived by private individuals as a constraint (Bjärstig et al, 2022).

Planning information relating to the visual and landscape impacts of a proposed wind energy development are often brought forward through a landscape analysis. While the planning process typically involves many different parts, this thesis focuses on the landscape analysis. Landscape analysis is about understanding the landscape as the everyday place, which contains knowledge and cognitive values (Mels & Mels, 2014). Landscape analysis is important to study because man-made alternations and fragmentations can alter a landscape and people's attachment to the landscape (Angelstam, 1997). A landscape analysis can be divided into two parts to assess potential impacts: landscape and visual impacts. The Scottish National Heritage (SNH, 2018) guidance on landscape analysis describes the differences between landscape and visual impact. Landscape impact refers to the effect on the landscape receptors[1] including landscape character, fabric, and quality of the local and wider landscape. Whereas visual impact refers to the potential visual obstruction or intrusion the proposed development may have from specific visual receptors [2] or viewpoints, such as national parks, scenic routes, designated scenic viewpoints, parks, roads, or cultural/historical landmarks (SNH, 2018). Without a clear understanding of the landscape and its values, these landscapes would undergo intrusive changes that could not be undone.

Digital tools refer to any computer software program, application or resources that allow users to enhance and interpret digital processes to showcase an early indication of what a

1 Landscape receptors refer to elements of the landscape that may be directly or indirectly affected by a proposed development.
2 Visual receptors refer to viewers, either individuals or a group of individuals who may be directly or indirectly affected by a proposed development.

proposed development will look like before its built. Digital tools illustrate the planning guidance and policies to make communication to the stakeholders and municipal authorities more transparent and enhance public participation (Berry et al, 2010). Consultancy companies[3] use digital tools in a landscape analysis to identify the potential effects associated with the proposed development through providing a visual aid of the 3D effects of the developments, identify areas on a map that are of high value landscapes and identifies the key characteristics of the landscape. This helps to better inform stakeholders, especially NIMBY residents, of the proposed visual impacts to allow for more transparency between municipal authorities and residents. Wind farm projects are often refused due to the lack of planning information or access to digital tools to enable more transparency between stakeholders, municipalities, and developers (Grassi & Klein, 2016). There is a need to investigate further the possible benefits how digital tools contribute to wind farm planning in Sweden.

1.1 Aim

The aim of this research is to develop an understanding of how digital tools can be used to visualise wind farm developments and improve public participation in the wind planning process. To achieve this aim, this thesis will explore and analyse the various digital tools available to conduct a landscape analysis (landskapsanalys) to develop wind farms in Sweden. This thesis will use an example from Sundsvall Municipality to provide context to demonstrate how digital tools can be used in the planning process to visualise wind farm developments. More specifically, this research will examine the implications of digital tools through a quantitative study and determine how each tool contributes to informing public participation for wind farm developments. To do this, the methodology to inform a landscape analysis for wind farm developments in Sweden will be analysed and the role of

[3] Consultancy companies in Sweden work with landscape analysis to determine areas viable for wind energy developments and help steer decision-making for municipalities.

the various digital tools and how they aid in the process will be examined. With emphasis on the digital tools, this thesis provides a step towards identifying the current challenges of conducting a landscape analysis in Sweden and how these challenges can be addressed through a rigorous standardised approach.

The following research questions will be examined:

I. *How do digital tools contribute to the planning process for developing wind farms in Sweden?*
II. *How can digital tools increase and improve public participation in the wind farm planning process?*

1.2 Scope and Limitations

This thesis has been done in collaboration with AFRY consultancy company, which also worked with Sundsvall Municipality to examine areas in the municipality that could facilitate the development of a wind farm. This thesis takes the maps and data from Sundsvall to visualise graphical examples of how digital tools can be used in planning, but it is not within the scope to identify the Sundsvall example as a case study. The graphical examples are a crucial part of this thesis which analyses how digital tools helps understand the landscape analysis process.

While the social and political implications of wind farm developments are an important issue, they will not be discussed in detail nor be the central aim of this research paper. This thesis will also not discuss the visual impacts and site selection that is used when determining the landscape and visual impacts of a wind farm, as that is not within the scope of the thesis. This thesis will also only examine the landscape analysis process of onshore wind energy development projects in Sweden rather than offshore developments. Rather than determining the landscape and visual impact of a wind farm development, this thesis will focus on examining how digital tools are used to visualise wind farm developments.

1.3 Digital tools terminology

Common digital tools used to conduct a landscape analysis in Sweden are the applications of mapping and 2-dimensional and 3-dimentional computer programs which have wind farm applications built in (Grassi & Klein, 2016; Berry et al, 2010). These tools are further discussed in more detail throughout the paper to indicate the landscape or visual constraints associated with a wind farm development.

Geographical Information System (GIS) mapping

GIS is a computer-based technology that allows users to capture, analyse and manage geographical spatial data. GIS allows users to understand and interpret spatial patterns, relationships and trends which can be captured by linking data attributes on a map. The GIS mapping outlines the key landscape and visual constraints in a study area.

Zone of Visual Influence (ZVI)

A ZVI is a 2-dimensional colour banded visibility overlay to show where the proposed turbines are theoretically visible from over a base map. The ZVI indicates areas where visibility of the turbines is likely to occur, how much visibility is likely to occur and the extent to which visibility will occur within the study area. The ZVI outlines the visual constraints associated with a development.

Photomontages and Wireframes

Photomontages are still, 2-dimentional images taken from the site visit that are overlaid with real-life computer-generated images of the proposed wind farm development that help to inform the reader of what the development will look like. Photomontages consider anything in the landscape that will cause screening of the wind turbines including vegetation, buildings, landform, and any electrical infrastructure.

A wireframe is a still- 2-dimentional static image that is created in a digital software to inform what the proposed wind farm development will look like. A wireframe does not include any screening and instead is a superimposed depiction of the wind farm using bare-Earth data through the Digital Terrain Model (DTM). Wireframes are used in landscape analysis for viewers to compare the position and scale of the turbines against the natural landform. The photomontages and wireframes illustrate the visual constraints associated with a development.

Chapter 2

2. Theory and Literature Review

2.1 Landscape and Visual Perception

Acceptance of wind farms is largely influenced by public perception and peoples value of the aesthetic of the landscape (Grassi & Klein, 2016). Landscape perception provides a basis for digital tools and the values they provide to quantitatively evaluate the landscape analysis process. Public perception of wind energy developments has long been attributed with two fundamental issues, landscape perception and visual amenity. While there are many other concerns for wind energy developments such as noise and ecological constraints, local stakeholders often hold strong opinions on the landscape and visual constraints to wind farm developments. To understand the theory of landscape more deeply, one must first look to its meaning as why it is important to people and its role in the everyday life. Landscape perception is often twofold, it can be characterised by both physical and social properties. The study of landscape can often be attributed to its function for society, which holds similar connotation to an anthropocentric view. The paper by (Drdos, 1983) expresses that landscape evaluation is observed from the viewpoint of the user as an inhabitant but at the same time man is a component of landscape. While one often searches for the ideal landscape, its views and perceptions are often defined by man. The aesthetics one attributes to the landscape and the images and perceptions associated with place are remarkably anthropocentric in nature (Todd, 2010). Human connection to physical and cultural landscapes, the rights to indigenous people’s lands and the urban-rural divide are all important considerations to landscape studies (Bjärstig et al, 2022).

A person’s attachment to the environment can be linked to their upbringing, biological heritage, job, and physical surroundings (Tuan, 1990). The salience of landscape allows for various modes of thinking and feeling, it goes beyond our existential inhabitation to homeland and allows us to feel a locus of sentiment and attachment, as a wellspring of identity (Wylie, 2016). The landscape therefore is about identity, community, belonging, inclusiveness, and composition. People have constantly searched for the ideal environment and its perception is typically varied based on an individual's culture (Tuan, 1990). As Mitchell (2017) outlines, the question is not 'whose landscape' (as a means of the right to the landscape) but the 'landscape for whom'? This connotation holds strong similarities to Lefebvre's Right to the City in which he outlines that urban politics should be inclusive, sustainable and democratic (Purcell, 2002). The landscape therefore is not sought as a single entity or thought but comprised of several meanings and its meanings can change throughout time. Through each of these changes, the landscape of the previous formation obtains new meaning, of which becomes valued differently through each passing time (Palang et al, 2022). When the everyday landscape is changed, it can cause disruption, loss of attachment, and disassociation amongst people. The study of landscape and place attachment is an integral part of landscape planning as it testifies to the values and investments people have with the landscape (Wylie, 2016). Large infrastructure projects have the potential to threaten a community's wellbeing, therefore public perception of wind turbines and perception of landscape is integral to understand because it justifies whether these developments will be built (Grassi & Klein, 2016).

Landscapes can contain various attributes that differentiate its parts, this is referred to as the landscape character of an area. Landscape Character refers to the distinct set of patterns in a landscape that differentiates landscapes from each other (GLVIA, 2013). Nowadays, any developments that will alter the landscape need to undergo a landscape analysis to assess what the impacts to the landscape might be. A landscape analysis not only assesses the landscape character as an everyday place but also the visual quality and landscape sensitivity associated with that place. Visual quality refers to the visual perception and visual amenity of the attributes in the landscape as perceived by people (Guan, 2022). These aspects are important considerations because it informs planners of the attachment to specific landscape attributes perceived by people. Landscape sensitivity is when the landscape character is susceptible to change due to the high visual impact caused by the wind farm development (Guan, 2022). When a wind farm development introduces new man-made elements to a relatively unspoilt and natural landscape setting, this causes the landscape to undergo a degree of change, thereby affecting the landscape character and sensitivity. The landscape analysis is therefore considered central to the planning application and public consultation process because it informs the planners and public earlier in the process on the proposed developments and its potential impacts (Berry et al, 2010).

Trafikverket (Swedish Transport Administration) has created an Integrated Landscape Character Assessment (ILCA) for regional and national planning. The ILCA is used as a guidance document for planners working with projects that might have an impact on the landscape. The ILCA states that any projects that will affect the landscape need to understand the situation, the landscape, suggest measures for mitigation and understand whether those measures will alter or develop the landscape (Trafikverket, 2018). A landscape analysis is carried out in recognition of the Planning Conditions for Wind Energy Developments as well as the Participation Landscape Analysis for Wind Power report and Integrated Landscape Character Assessment (Mels & Mels, 2014; Trafikverket, 2018). Determining the mitigation measures early in the process can prevent any serious impacts before they happen and better the landscape for future generations to enjoy. Understanding the landscape as an everyday place, its history, character, relationships and why the landscape functions the way it does is an integral part of the ILCA (Trafikverket, 2018).

2.2 Social Challenges and Political Attitudes with Wind Farms

To reduce the social issues attributed with wind farm developments and the investment risk associated with the long planning process, digital tools have been developed to support planners and make decision making more transparent (Grassi & Klein, 2016). Several literature sources outline the social and political attitudes experienced by local stakeholders when it comes to wind farm developments. The most common and obvious phenomenon is Not in My Back Yard (NIMBYism). NIMBYism is a phenomenon whereby residents are unwilling to accept a development and consider it as inappropriate as it may impact their property value but are willing to accept the project elsewhere. Policy makers often attribute 'NIMBYism' to be the reason for the failure of wind farm planning applications driven by a wind farm development perceived negative visual impacts (Berry et al, 2010). It is often residents directly facing the turbine developments are more likely to support the NIMBY phenomenon (Guan, 2022). It is often opposition from NIMBYism residents that will halter a wind farm development from proceeding. As a result of the implications of this phenomenon, wind farm developments in Sweden have been pushed offshore to limit the landscape and visual impacts. While the public view to move turbines offshore or further from the public centres decreases, the pricing for moving the turbines offshore increases considerably (Hevia-Koch & Ladenburg, 2019). However, Ek & Persson (2014) discuss the implications with offshore windfarms and that those with second homes along the coast or go to the coast for recreational purposes tend to have negative perceptions for offshore wind developments. When it comes to wind farm planning, there are many social and political challenges, which can make the development process timely, pricey, and downright difficult.

2.3 Concerns with Wind Power Planning in Sweden

Grassi & Klein (2016) highlight that digital tools provide a realistic visual aid on the potential project impact and provide accessibility to inform the public on these impacts. There are many challenges with wind power planning, which leaves a lot of debate on its implications and inclusiveness. Wind power planning is often characterised for its top-down structure, which leaves a burden to the local communities to fight the consequences on its impacts on nature and landscapes (Rygg, 2022). These top-down views tend to determine the size, distance and landscape view in an objective way and are often misunderstood or misvalued by public perception (Mels & Mels, 2014). The challenges with a top-down structure of planning are that local citizens are often left out of the decision-making process and decision making is based on whether the municipality is in favour of wind power.

Wind farm planning in Sweden is based on a formal recognition of national and regional planning which outlines the siting and design of wind farm areas and shown as priority areas. These priority areas determine where wind power projects are to be developed. While there is no formal standardisation process, anything outside these areas is typically considered constraint areas but are determined on an individual basis by municipalities (Mels & Mels, 2014). In Sweden however, environmental acknowledgement is quite vague, because if a development is in an area of national interest for the purposes of nature conservation for instance, the legal rights pertaining to this designation provide very little guidance and leave the decision-makers with substantial discretion (Pettersson & Söderholm, 2011). Due to very little guidance in place, this leaves the prerequisites for wind power developments to be unpredictable and inconsistent. As a result of this, wind farm planning in Sweden is very much varied based on the decision making of the municipality. The paper by (Pettersson & Söderholm, 2011) outline two challenges in Sweden with regards to wind power planning, one being that some municipalities that favour wind power make wind farms easier to develop, however this may promote inefficient areas for wind farm development and may limit the role of the citizen and stakeholder participation. On the other hand, other municipalities where the planners and officials are more reluctant to wind power have stricter planning regulations in place, where wind farm planning face tougher restrictions and makes citizen participation more extensive (Pettersson & Söderholm, 2011). When it comes to Sweden's planning system, the process for developing wind farm can be unclear and unpredictable.

Another issue related to wind power planning is land use conflicts, in which private land is often sold to large developers. The developers could reduce the conflicts associated with land-use conflicts by listening to public opinion and creating an optimal design with a significant setback distance from the residences and with fewer turbines in the design to reduce the visual impact (Rygg, 2022). Several issues are presented by the literature when there is no clear management or cooperation between the landowners and corporate producers. Christophers (2021) demonstrates that when there is no transparent method or contract between the energy producers, landowners and corporations, corporate producers can sometimes buy the electricity for a contract of 15-20 years and falter the energy transition. Thereby, instead of the electricity being generated for the local communities and landowners, wind farm projects can be privatised where corporate producers can instead make an agreement with the energy producers on a fixed contract to supply energy for them instead. Therefore, there is a need for these large-scale projects to have a standarised process that is agreed upon at the national and regional level to avoid privatisation and conflict.

Many arguments brought forward by the articles outline that there is a need for more participatory and qualitative planning when it comes to wind farm developments. A streamlined approach to conducting landscape analysis and the types of digital tools used could facilitate cooperation and transparency between the relevant stakeholders involved. Effective communication in the planning process between stakeholders and planners can help to facilitate a more transparent environmental decision-making process. Denmark is a good example where wind turbine parks have been developed without controversy, since people have been living near wind turbines since the 1890's (Rygg, 2012). Perhaps if stakeholders are exposed to the information of the proposed development and its potential impacts for a longer period and have time to absorb the consequences of the development then conflict can be reduced. There is a knowledge gap between local stakeholders, planners and the professionals conducting the landscape analysis on what the real landscape and visual implications are associated with these developments and its ability to promote inclusion.

2.4 The Provision of Digital Tools and Public Participation

Digital tools are used as a visual aid in wind farm planning to promote democratic inclusion and public knowledge of a proposed project and its impacts before its built. As highlighted previously, digital tools provide a computerised graphic to interpret an actual scenario and showcase an early indication of how something will appear. This allows for stakeholders to visualise the project scope and the implications of the project before its built. For several years, public participation in the planning process has been discussed by theorists. The argument for public participation grew from the idea that decision making for planning projects was often top-down and there was a need for more objective judgement where the local public could voice their opinion on a particular development before it was built. In essence however, value-free knowledge in planning is often political and decision making is based on the information that is presented and produced to the planners and determined by those involved in the planning process (Lane, 2005).

The paper by Guan (2022) outlines that an objective visualisation approach is a logical and well-reasoned model in wind farm planning because it helps to standardise the evaluation results by quantifying the steps, data sources and approaches to indication election. Current landscape analysis practices are limited by subjective variables including people's perception of the landscape or visual preference or personal experience with wind power developments. However, a standardised approach that combines the subjective preference with an objective assessment assures that people's perceptions are considered, and the overall assessment is streamlined. An objective approach allows for the possibility to easily compare the results of the project before and after the development and assess the impact on landscape quality (Guan, 2022). An objective assessment therefore allows for an easier assessment on the landscape and visual effects by the professional conducting the landscape analysis rather than one that is flexible and subjective. The visualisation process in essence is based on the objective identification of the constraints identified at the national and regional development plans (Berry et al, 2010). Simply said, digital visualisations are developed based on the data used, and the process to measure the visualisations is determined based on how realistic the visualisations are. The more realistic the visualisation, the higher the achieved credibility (Grassi & Klein, 2016).

Digital tools in landscape planning are often sought as providing informative visuals to the public of the proposed project data. The paper by Berry et al (2010) highlights that that public access to the landscape analysis information is often restricted to consultation meetings later in the planning process and these meetings tend to be geographically restricted which discourages certain social groups from participating. The study of the paper interviewed 115 individuals of different backgrounds near a wind farm in South Wales, to assess how digital tools can facilitate better public participation in the planning process. The survey outlined that individuals prefer photomontages and 3-dimentional animations to mapping and ZVIs as they were easier to interpret. When asked if the respondents would participate in a virtual consultation strategy consisting of augmented reality, 72.2 percent of the respondents answered that they would participate and only 10.4 percent said they would not. The paper further examines how public participation can be improved with the inclusion of digital tools. The paper outlines that while increasing and improving public participation in wind farm planning may be difficult to define, improving diversity in the planning process can be achieved amongst the community members and how stakeholders can be well-informed on the project through the inclusion of access to digital tool visualisations. The conclusions of the study demonstrated that usability and interpretation of the visualisations remain an issue for the public, however, public participation in the landscape analysis can be improved by allowing for more access to digital tools (Berry et al, 2010).

Several literature sources outline the advantages that digital tools provide in terms of inclusion for landscape planning. Immersive methods such as digital walks or participatory mapping such as GIS help to generate a high degree of qualitative knowledge that can complement traditional forms of conducting a landscape analysis (Mels & Mels, 2014). In addition to 2D images, Gruehn & Roth (2014) demonstrate that 3D visuals provide a visual opportunity for the public to portray the turbines against the natural landforms and horizon lines. The assortment of visual tools provides an opportunity to inform the public about the various aspects of the proposed development and allows them to visualise the development in various ways. However, Hevia-Koch & Ladenburg (2019) address two main issues with regards to current practices; one being that still images are limited to only showing the current view and don't capture the visual impact arising from the turning movement of the blades. Another issue is that a lot of the time these tools don't show the visual impact arising from the night-time illuminations of the turbines, which can be another visual constraint that is not always considered in a landscape analysis (Hevia-Koch & Ladenburg,2019).

Several literature sources also highlight the need for more user-friendly and comprehensible visualisations. There is a need to develop a high-performance software tool that is easy to understand, cost effective and meaningful to limit the separation between landscape planning and landscape architecture and planning research and planning practice (Gruehn & Roth, 2014). The study by Grassi & Klein (2016) outlines that augmented reality and 3-dimentional visualisations provide planners and stakeholders with a more realistic interpretation and better perspective of the proposed turbines, which can be applied to any region for any wind farm layout, size and turbine model. The study further shows that the advantage of the 3-dimentioal augmented reality tool is that it combines the planning phase with augmented reality into a unique tool to allow users to have a real-time understanding of the proposed turbines in a virtual landscape (Grassi & Klein, 2016).

Since the 2020 COVID pandemic, virtual reality has been used more and more by municipalities across Europe to promote participation in energy development projects. Rather than hindering development, renewable energy development was expedited during the COVID pandemic. The pandemic promoted the search for more digital technology systems in renewable energy which allowed individuals to become more receptive (Huang et al, 2022). Since the pandemic, e-participation has become very successful (in Germany) because it makes it easier for diverse citizens to provide their direct input for the project and it motivates people to be more involved in the planning process (Bohn et al, 2021).

Summary of Theory Arguments

The arguments presented above have outlined that wind farm planning needs to be more standardised and inclusive. The arguments for and against value-free planning practices have demonstrated that both quantitative and qualitative variables are necessary in landscape analysis. Digital tools can provide visual aid in combining the visual sensitivity and visual exposure into a model which is then outputted in a way that is logical and measurable. As Guan (2022) suggests, given the subjectivity of people's perception of wind turbines, a quantified visual approach is necessary because it helps to standardise the evaluation steps, compare changes of landscape quality of the project as well as a horizontal comparison with other projects and outlines appropriate data sources. The paper by Berry et al (2010) also outlines that the diversity of public participation can be improved through the inclusion of access to digital tools.

Chapter 3

3. Methodology and Methods

3.1 Methodology

To achieve the research aim, empirical studies surrounding the topic were conducted and a quantitative methodology was used. While qualitative methods would have been useful to understanding people's perception of the wind farms and the landscapes in which they sit, quantitative methods are more useful in understanding how digital tools can visualise wind farms and what they will look like before they are built. A qualitative method was not within the scope of this thesis due to time constraints. This thesis used quantitative methods both through example studies of digital tools and through empirical literature review. As (Mentis et al, 2015) states, a quantitative or GIS approach allows one to visualise wind farm developments and analyse their constraints in a more strategic way.

3.2 Methods

To outline the methods for the landscape analysis process, the country of Sweden and the Swedish national data surrounding wind energy has been examined. For the regional level, the key constraints identified in the Sundsvall Development Plan will be examined.

3.2.1 Evaluation of how digital tools contribute to the wind farm planning process

To examine the first research question, the process to inform a landscape analysis was analysed because it pertains to how digital tools are used. The process is divided into 5 steps, which determine the process needed to collect the data and formulate the landscape analysis, as outlined in the Planning Conditions for Wind Energy Developments as well as the Participation Landscape Analysis for Wind Power Report and Integrated Landscape

Character Assessment (Mels & Mels, 2014; Trafikverket, 2018). While Step 4 (visualisation development) was the key focus for this thesis, the other steps were also outlined as they are important aspects in the wind power development process worth mentioning because they provide background to Step 4. The 5 steps are further outlined below. To demonstrate how the digital tools are used in the landscape analysis process, an example of a wind farm development area in Sundsvall was used. Followed by this assessment, the opportunities and limitations pertaining to each of the tools is shown in Table 1 below based on the literature review from Section 2 as well as what the images from the Sundsvall photomontage and wireframe examples show.

Step 1- Determine the project area and scope of the study area

Scoping is a procedure that involves identifying the key interests and any areas of likely significant effects (GLVIA, 2013). This step identifies any concerns early in the process that can be resolved before the project is submitted for planning.

<u>Collaboration with AFRY and Sundsvall Municipality</u>

This thesis was done in collaboration with AFRY consultancy company and Sundsvall Municipality. The data from Sundsvall Municipality and AFRY was used to illustrate an actual example for assessing digital tools and not as a case study for this thesis. The constraints mapping shown in this thesis were produced as part of a commercial project with Sundsvall Municipality, however the broader research scope and the additional example graphics were produced solely for the purpose of this thesis. AFRY’s contribution is limited to background information throughout this thesis.

Example area

Sundsvall Municipality was chosen as an example for this thesis as the author of this thesis has worked closely on a landscape analysis project for Sundsvall Municipality. This example area gives context to the thesis and suggests how the planning process for developing a wind farm in Sweden would occur. The study site in Sundsvall Municipality is approximately 2,757 square meters in area, as shown in Figure 1.

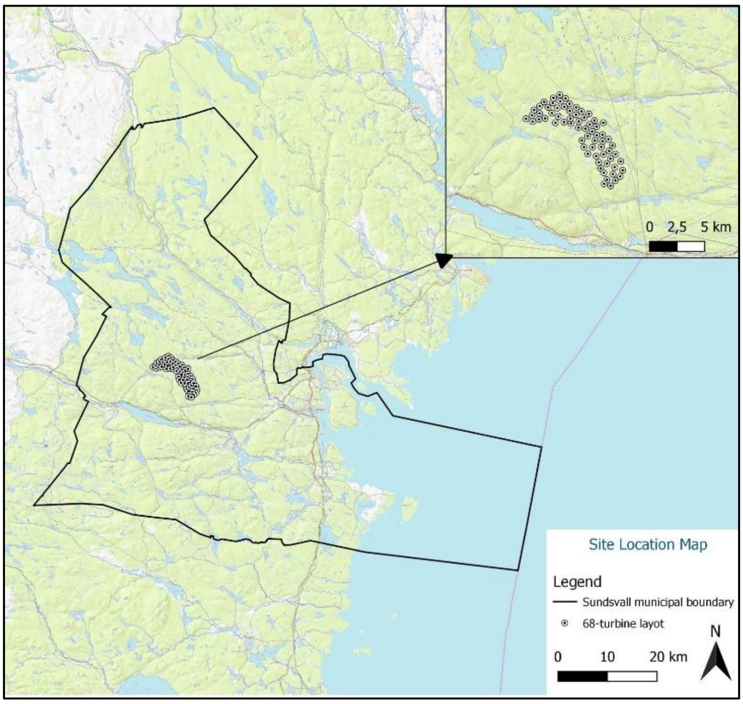

Figure 1: Site location map

Step 2- Landscape image/landscape character

This step involves the evaluation the landscape image and landscape character based on the national development plan, regional development plan and knowledge of the landscape/place. As stated previously by Grassi & Klein (2016), social acceptance of wind farms is largely influenced by public perception and peoples value of the aesthetic of the landscape. Landscape perception, therefore, provides a basis for digital tools and the values they provide to evaluate the landscape analysis process.

Step 3- Data collection

This step involves collecting the data, most of which is open sourced to use for the mapping and ensuring that the files are in the correct file format. For this thesis, most of the files used were open sourced and retrieved from Naturvårdsverket, Länsstyrelsen, Trafikverket and Riksantikvarieämbetet as well as setback distances from buildings, roads, electrical powerlines and railways, which are typically included in a landscape analysis in Sweden (Mels & Mels, 2014; Trafikverket, 2018). In working closely with AFRY, data was also used from the company database, which also had data collected from the Sundsvall Development Plan (SDP).

Step 4- Visualisation development

<u>GIS Constraints Mapping</u>

GIS is a computer-based technology that provides geographical spatial data and spatial patterns. Following the previous steps, the first step in the visualisation development phase was to map the constraints in the study area. The GIS constraints mapping outlines the landscape constraints in a given project area. For this step, web-based digital tools were used, including GIS and Wind Pro. All the mapping was done using QGIS version 3.22 with the functions of spatial analysis. ArcGIS can also be used for this step; however, this thesis was completed in QGIS, as QGIS is an open-source software.

A combination of vector and raster files were used in GIS to develop the constraints mapping needed in wind farm planning. The digital landscape model is typically retrieved from the project data as the 1-meter, or 5-meter grid data is used for accuracy of the spatial scale. The raster files include the Digital Elevation Model (DEM), Digital Terrain Model (DTM) and vegetation model. Vector files from the Sweden national plan and SDP for landscape and visual constraints were also used. In Sweden, the process for developing wind energy developments is stated below in *Section 3.2.2 Wind Power Constraints Mapping*

Themes and outlined in 9 themes/ and maps. These themes were used to identify the constraints that are outlined in both the national and regional development plans and where wind farm developments are considered inappropriate. Each theme comprises of several constraints shapefiles that are discussed in more detail in Section 3.2.2.

Once the GIS workspace is prepared with a SWEREF99 coordinate system and all the appropriate shapefiles were brought into GIS, the files were clipped to the Sundsvall Municipality boundary. Clipping the files makes the GIS program faster to run, if the files were for the entire county, the program would run very slowly. All the files were clipped together using a Python script and organised based on their respectable themes, as discussed below in Section 3.2.2. Some themes, as outlined below in Section 3.2.2. require certain setback distances from the turbines, as demonstrated in the national development plan. Therefore, a buffer was added to the respectable shapefiles through the function of *vector* > *geoprocessing tool* > *buffer*. Using the merge vector layers found in the toolbox window in GIS, the shapefiles were then merged based on their respectable category (nature, culture, recreation etc and as outlined below in Section 3.2.2.) and a new shapefile is created. The output merged shapefiles are then saved as geodata files based on their respectable themes and a symbology is given to each of the themes. The areas that show no constraints zones in the mapping are brought forward for further investigation, as these areas have the potential for wind farm developments and are far from constraint areas. If a wind farm is found to have the capacity in this area, then an indicative turbine layout is determined. An indicative turbine layout is developed based on wind energy guidance.

To provide a basis for this thesis, a turbine layout is needed to highlight the landscape analysis process and justify the other visualisations. For this example, 200-meter turbines with a rotor diameter of 150-meters were used to examine the visual constraints associated with the example in Sundsvall. Naturvårdsverket (2021) states that the total number of turbines is calculated based on the total area of the site, (2,757 square meters) divided by the rotor diameter of the turbines, with an added spacing of 5-times the rotor diameter distance between the turbines so the turbine blades don't impact each other. For the site example, approximately 68-turbines were calculated as the total number of turbines that are considered appropriate. The indicative turbine layout is important to identify because it is used in the ZVI and photomontage assessment.

ZVI

Once the constraint areas are mapped, an indicative turbine layout is determined. A ZVI is produced in either GIS, Wind Pro or Wind Farmer to determine the visibility of the turbines. In Sweden, most consultancies use the Wind Pro software to create ZVIs, although this can also be used in other software, most notably GIS or Wind Farmer. The ZVI for this thesis has been created using the software Wind Pro version 3.6. The ZVI is used to show the visual constraints associated with a proposed wind development.

The first step to produce the ZVI in Wind Pro is to set up the workspace, using the coordinate system of SWEREF99. Then the relevant shapefile of the proposed turbines as well as the DEM and DTM was brought into the software using the *insert grid data* function. Using the ZVI plugin that is preinstalled in the Wind Pro program, a ZVI can be created. In the ZVI plugin, the shapefile containing the 68-turbine information was used as the output layer. The DEM, DTM and vegetation model was selected in the land-cover data section and checked on as they will be included in the model. The turbine height was set to 200, the observer height set to 1,7 meters and the radius to calculate the ZVI was set to 50 meters. Once all the fields were set, the ZVI was run which resulted in an output ZVI feature as shown in Figure 3. The resulting ZVI layer was then appropriately banded and stylised into a ZVI layer which was overlaid onto an Ordinance Survey (topography 10 or topography 50) base-map.

For this example, the ZVI has considered screening by both topography and vegetation. Screening by buildings is also possible to produce in the ZVI however, due to changing data overtime, the building data is not the most accurate. The ZVI also helps to determine photo locations that are used in landscape analysis and areas where sensitive visual receptors will have some visibility of the proposed turbines. Areas identified as having full or partial visibility of the turbines are brought forward for viewpoint locations to inform the landscape analysis report. The selection of viewpoint locations is designed to give a representative range of views from various locations of the proposed development. The viewpoint locations are chosen after compiling a list of sensitive landscape and visual receptors from the constraints mapping that will have partial or full visibility asshown in the ZVI.

Following the ZVI stage, a site visit is done in the landscape analysis process to determine if the theoretical visibility identified in the ZVI is accurate or if turbines are less visible due to vegetation screening and building screening. The site visit is also used to photograph the chosen viewpoint locations for the photomontages. There is no clear standardisation for the photography in Sweden, but a minimum 50mm lens camera is recommended as well as capturing a 360-degree view from each photo location.

Photomontages and Wireframes

The final step in the digital visualisation process involves the creation of the photomontages and wireframes. The photomontages and wireframes are used to show the visual impacts associated with a proposed wind development. Photomontages and wireframes are created using the software Wind Pro (version 3.6) and supported with Photoshop. The photos taken from the site visit following from the ZVI stage, are used in this assessment to create the photomontages. The photos are first stitched together in Photoshop using the *file > automate > photo merge* function. Once the photos are merged, they are clipped from the 360-degree photos that were taken to a 150-degree view. This function is done using by dividing the width of the pixels and then cropping the image using the crop tool. Once the photos are cropped, they are brought into Wind Pro to produce the photomontages. Due to limited licensing availability, Wind Pro was not used to produce the photomontages and wireframe for this thesis. However, an example of a photomontage and wireframe are shown in Figures 4 and 5 below.

Step 5- Final assessment and evaluation of the landscape and visual impacts
This step includes the professional judgement of the significance of effects, where recommendations are given to mitigate the landscape and visual effects that arose from the proposed project.

3.2.2 Wind Power Constraints Mapping Themes

The themes presented below is based on data from Naturvårdsverket, Länsstyrelsen, Trafikverket and Riksantikvarieämbetet and identifies the landscape character, its history, sensitivity and why the landscape functions the way it does (Trafikverket, 2018). These themes are used in a landscape analysis for all of Sweden, but the maps presented below in Figure 2 for Sundsvall show how the tools are used in an actual example and to give this thesis some context.

Theme 1- Global Wind Atlas 200-meters - based on the available wind speed data as outlined in the Global Wind Atlas (2021) and measured in meters per second. Areas of higher wind speed (darker red shown in Figure 2 below) are considered appropriate for wind farm development sites.

Theme 2- Terrain/Height Model - The elevation model is used to show areas of higher elevation (shown in red or orange in Figure 2 below). Wind turbines are typically considered inappropriate in areas of higher elevation because views of the turbines would be more visible from further distances.

Theme 3- Cumulative Baseline (plus 1000-meter buffer)- other wind farms within the study area/municipality, as shown in Figure 2 below. Includes other wind farms that are built, under construction or have planning permission to be built.

Theme 4- Natural/National Interests - National interest Natura 2000, Natura 2000 and other areas identified with high nature values. Also includes areas for fish reproduction, eagle territories with confirmed breeding, wetland inventory (VMI class 1 and 2), reserve areas (according to the County Administrative Board), key biotopes, swamp forests (class 1 and 2), larger lakes and streams (with protection distances of 100 meters). The natural interests are shown in Figure 2 below.

Theme 5- Cultural Interests - Cultural heritage values, national interest in cultural conservation, agricultural landscapes worthy of conservation (according to the County Administrative Board, class 1 and 2), areas designated in the County Administrative Board's cultural environment program. The cultural interests are shown in Figure 2 below.

Theme 6 – National Interests and Reindeer Husbandry- National interests for outdoor recreation and coastal tourism as well as reindeer herding, outdoor recreation areas, areas of construction fishing, tour boat fairways, hiking trails, areas designated in the master plan urban and rural areas for recreation/local recreation, areas designated for tourism, airports and flight path data. A map outlining the national interests and reindeer husbandry is shown in Figure 2 below.

Theme 7– Buildings (plus 1000-meter protection distance)- Inhabited properties based on the land register and the population register, leisure properties and building areas from the master plan, as shown in Figure 2 below.

Theme 8- Infrastructure- (400-meter buffer applied to each and is calculated based on the total turbine height plus 25-meters)- Includes railways, major roads and electricity powerlines, as shown in Figure 2 below. Wind power is not possible in the immediate vicinity of other national interests for infrastructure such as roads, railways and power lines, but may be possible in connection with these.

Theme 9- Sundsvall Development Plan- Areas of recreational interests, greenways and local cultural or historical aspects as outlined in the Sundsvall Development Plan (Översiktsplan), as shown in Figure 2 below.

3.2.3 Evaluation of the digital tools to improve public participation

Digital tools allow an opportunity to visualise wind farm developments and create a form of participation, however, the literature provides an evaluation of how digital tools can be improved to promote democratic inclusion in planning. To assess how digital tools can increase and improve public participation, an evaluation of the arguments and theories presented in *Section 2 Theory* was done. A literature review on the topic was conducted through Google Scholar, Umea University literature databases and governmental websites. The paper by Bohn et al (2021) demonstrates that key themes can emerge from previous studies which have done qualitative surveys to understand how public participation can be improved through digital tools. Three objectives were identified to help outline the research in this thesis, based on the themes discussed by the literature. For example, Mels & Mels (2014) state the need to create a *qualitative method to increase diversity* though participatory mapping in GIS to therefore improve public participation. Berry et al (2010) discusses the benefits of *improved augmented reality* to increase public participation and Guan (2022) outlines that a *standardised approach* to quantify the analysis, steps, data sources and approaches can improve the visualisation and public participation process.

Therefore, the evaluation of the digital tools is done by assessing the key arguments presented from the literature in Section 2 which are then ‘coded’ into objectives:

Objective 1 – Qualitative method to increase diversity

Objective 2 – Improve augmented reality

Objective 3 - Standardisation

The objectives and outcomes are shown in Table 2 below. Outcomes or recommendations that the literature highlights as the need to address to improve public participation are listed under each objective. Together these three objectives help to answer the second research question by identifying how digital tools can improve public participation.

Chapter 4

4. Results

4.1 How do digital tools contribute to the planning process for developing wind farms in Sweden?

As outlined previously in *Section 2 Theory,* a landscape analysis consists of identifying the landscape and visual constraints, necessary for the planning process of developing wind farms. The landscape analysis is helped by digital tools, such as GIS mapping, ZVIs and photomontages and wireframes. This section will analyse how the digital tools contribute to the planning process, meaning, what the tools show and how they are used in wind farm planning.

<u>Constraints Mapping</u>

The GIS mapping is an important digital tool because it identifies the constraints associated with landscape perception, including sensitivity and aesthetic value and identifies landscape that people perceive to be important. The development process for wind farms consists of a combination of GIS processes to identify areas suitable for wind energy developments in which the outcome is then used in the 3-dimentional visualisations for augmented reality (Grassi & Klein, 2016). The constraints mapping is useful in the early stages of the landscape analysis because it identifies the key landscape and visual receptors in the study area and which areas to avoid. The constraint areas are a quantitative assessment based on landscape studies to identify the human connection to physical and cultural landscapes and aesthetic perception of the landscape (Bjärstig et al, 2022). The GIS constraints mapping helps to inform planners on areas where wind farms can and cannot be built.

An example of the GIS mapping based on the nine themes presented in Section 3.2.2 is shown in Figure 2 below. Figure 2 is divided into three sections as a, b, c, but together outline the 9 constraint maps from GIS mapping for the Sundsvall example area. Figure 2 shows an example of the constraint areas for the Sundsvall example site and identifies how GIS can be used to map the physical, social and cultural landscapes as outlined in Naturvårdsverket, Länsstyrelsen, Trafikverket and Riksantikvarieämbetet. For instance, any areas that are coloured are constraints and considered unacceptable for wind energy. In the landscape analysis process, areas where there are no constraints are taken ahead for further consideration to determine a turbine layout.

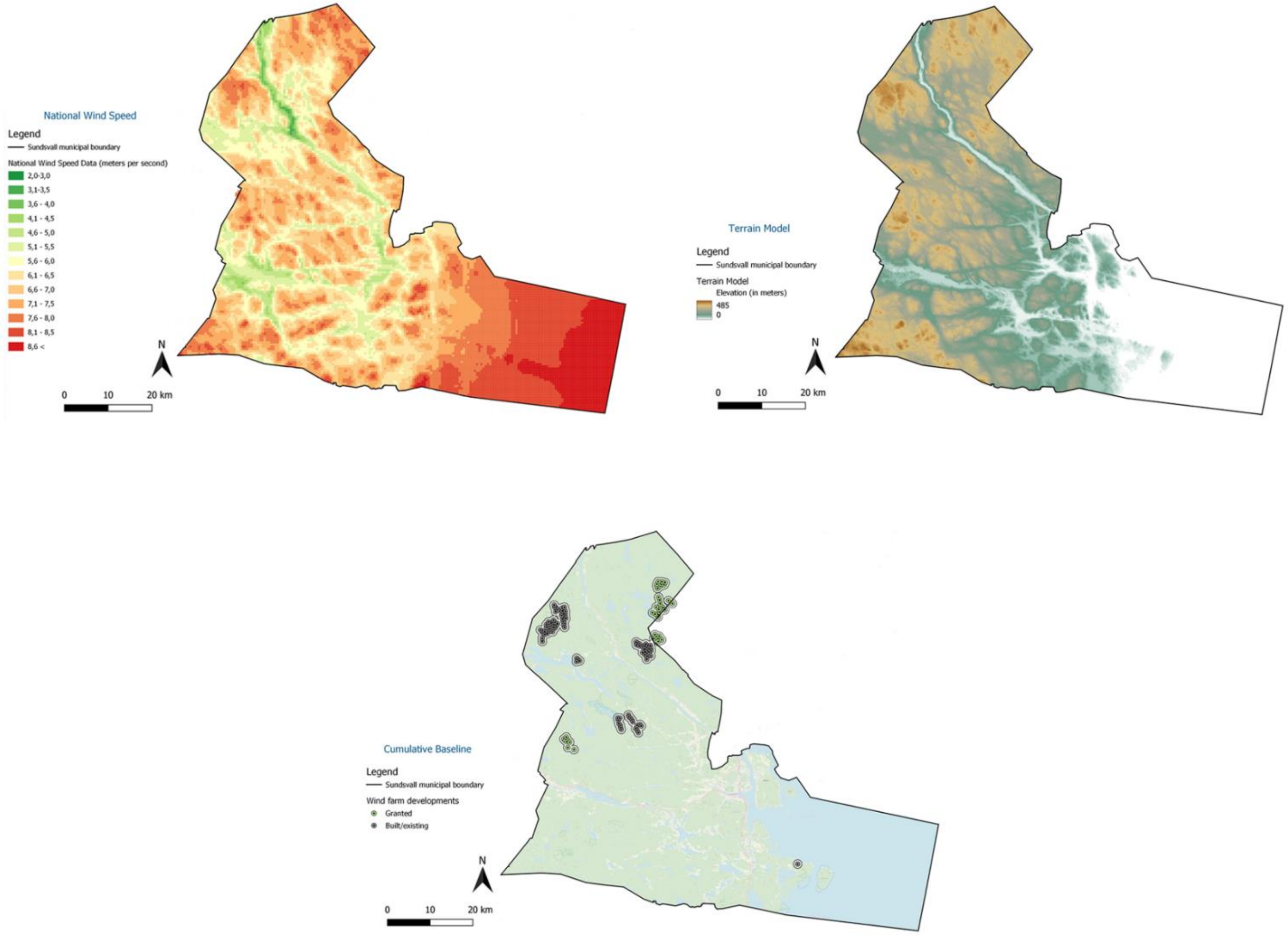

Figure 2(a): Themes 1, 2 and 3 showing the wind speed data (left), terrain data (right) and cumulative baseline (middle). The maps show the constrains in the Sundsvall site example, for instance areas of higher wind speed and lower elevation are considered suitable areas for wind projects. In a landscape analysis, proximity to other wind farms (cumulative) is important as projects should not be too close together to limit visual impacts.

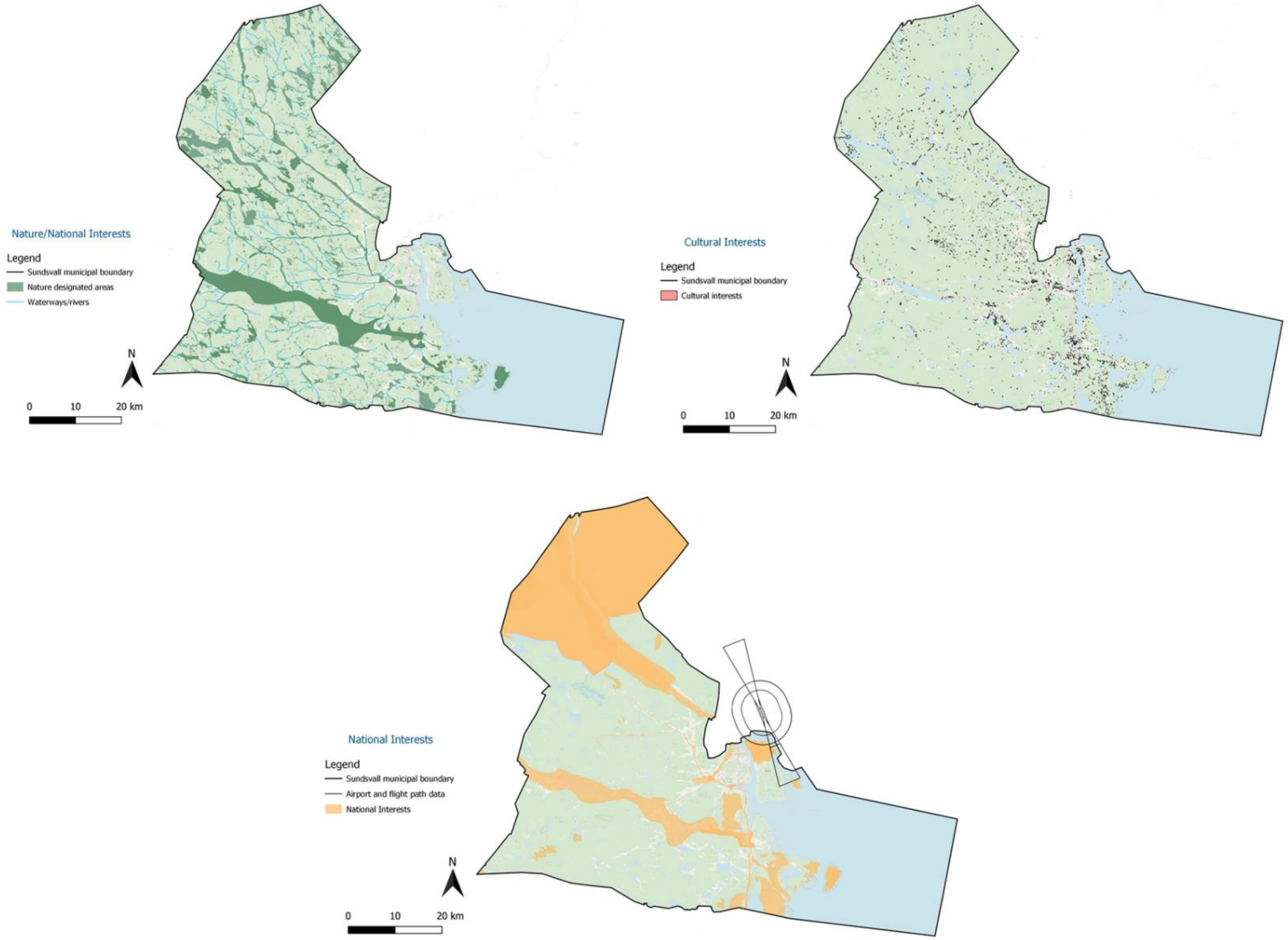

Figure 2(b): Themes 4, 5 and 6 showing the nature interests (left), cultural interests (right) and national interests (middle). The constraint maps show that turbines should not be built in any coloured areas (constraint areas) based on the data in the themes.

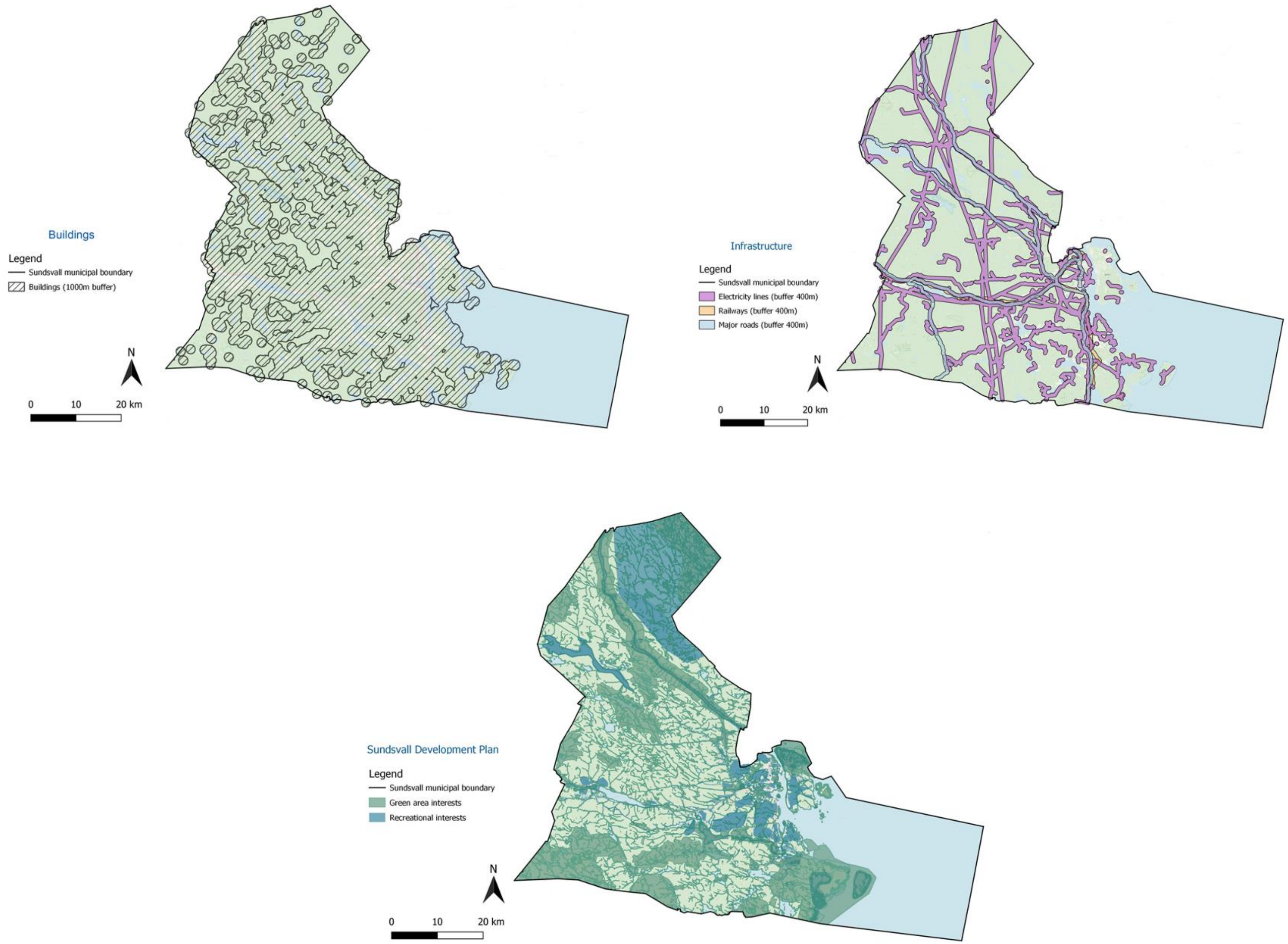

Figure 2(c): Themes 7, 8 and 9 showing the buildings (left), infrastructure (right) and Sundsvall Development Plan (middle). The constraint maps show that turbines should not be built in any coloured areas (constraint areas) based on the data in the themes.

ZVI

Following the constraints mapping and once an indicative turbine layout is determined, a ZVI is then produced. The ZVI shown in Figure 3 below is based on the Sundsvall example which shows the areas in which the wind farm development will be theoretically visible based on the Digital Terrain Model (DTM) which is overlaid on a base map. The ZVI indicates broad areas where the proposed turbine development is most likely to occur, how much of the wind energy development will likely be visible (indicated through colour band sections) and the extent of the pattern of visibility. Figure 3 shows an example of a ZVI for the indicative 68-turbine layout, where the darker blue areas indicate fewer turbines (1-14 turbines) are likely to be visible, while the orange areas (57-68) are where all the turbines are likely to be visible. The ZVI shows areas where the proposed turbines are likely visible based on the DTM, created by Williams A. and Hellquist T. (personal communication, April 20, 2023, AFRY), not to scale.

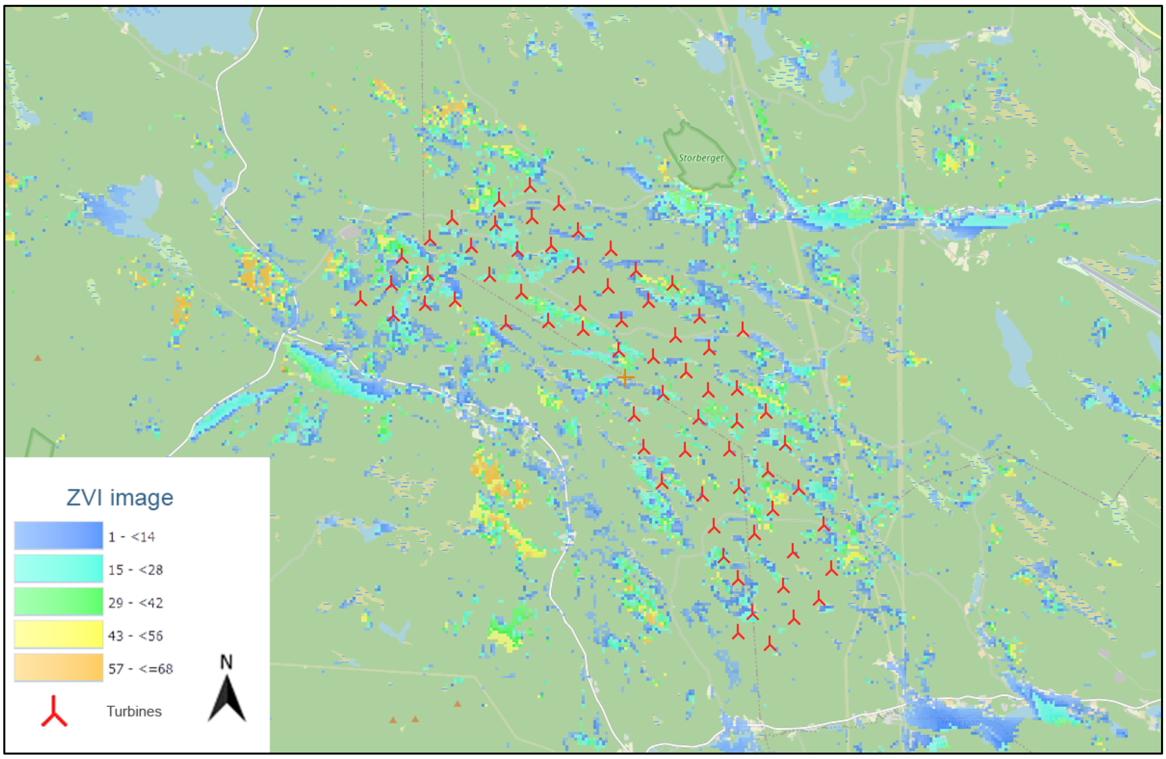

Figure 3: Showing an example of a ZVI used in the planning process for windfarm development. The ZVI is typically overlaid on the constraints maps to indicate if there will be visibility of the turbines from any sensitive receptors. The

number of suggested turbines visible at each location is shown by the colouring and the location of suggested turbine placements are shown with red marker.

The production of the ZVI is typically done in one of the first steps of the landscape analysis once the constraints are identified because it informs which areas of the study area will be visible from sensitive landscape and visual receptors and informs the photo locations. The ZVI is useful because it gives a visual aid early in the process to identify where the turbines will be visible from, based on DTM data. It shows where the turbines will be most visible from and where local opposition will likely be most prevalent. Based on the data shown in Figure 3, visibility of this turbine development is very limited to the local vicinity of the wind farm site. This data shows that areas of highest visibility (orange) are likely to occur north, west and south-west of the turbines. During the consultation phase of the landscape analysis, the ZVI is sometimes overlaid over the sensitive landscape and visual receptors to identify which receptors are likely to experience the highest rate of visibility. Although the ZVI is not the most comprehensible, it does provide a unique visual aid to identify which receptors are likely to be impacted by the visual constraints of the development. ZVIs can also be used to inform visibility of other developments such as solar farms, electrical powerlines, and buildings.

Photomontages and Wireframes

Photomontages are visualisations used to superimpose an image onto photograph or series of photographs. They are intended to provide graphical representations of how a proposed development will appear in the landscape at eye level. Photomontages are useful because they give the viewer a sense of how the turbines will appear in perspective view in the landscape. As Gruehn & Roth (2014) outline, photomontages and 3D visuals provide a visual opportunity for the public to portray the turbines against the natural landforms and horizon lines. While the wireframe does not show any screening, it does allow for viewers to compare the position and scale of the turbines against the natural horizon lines and landscape form.

The photomontages and wireframes shown in Figures 4 and 5 below provides an indication of how the wind turbines will appear in perspective view in the landscape in a photograph-like image. These visualisations are intended to provide a visual aid on how the proposed turbines will appear in a landscape setting if one were to take a photograph of that view. Figure 4 below is not from the Sundsvall example but gives an example of a photomontage. Photomontages and wireframes are done in the later stages of the project because they can be time consuming and costly to produce the data and intended as more high-quality visualisations once the final turbine layout is determined.

Figure 4: Photomontage example, retrieved from EMD International A/S (2015). The photomontage gives a presentation of the scale, size and visual obstruction of the turbines from this specific viewpoint location and how they would appear in the landscape taking into account screening by vegetation and electrical powerlines.

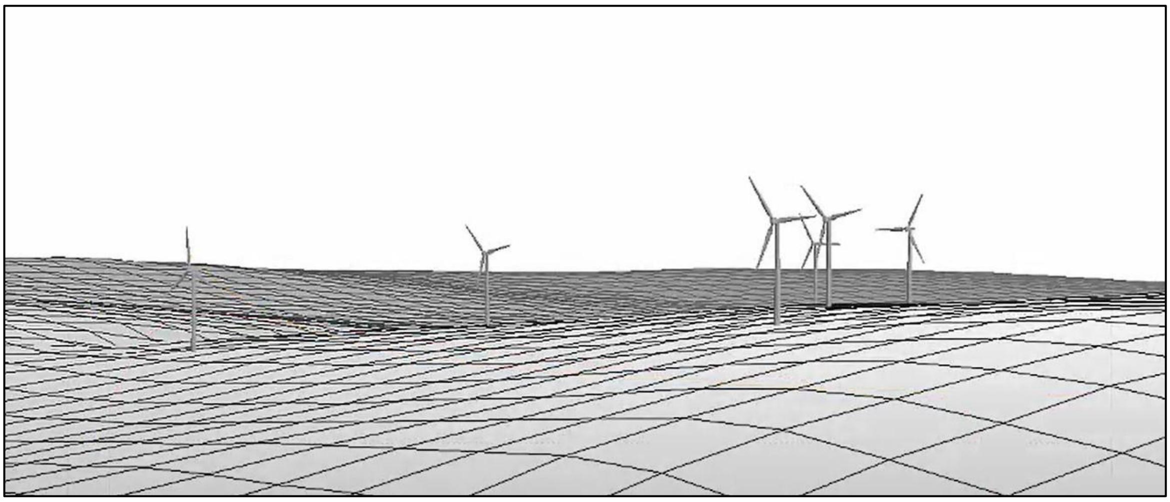

Figure 5: Wireframe example, retrieved from DNV- Energy Systems (2015). The wireframe gives a good visual representation on how the turbines will appear in the landscape based on their scale and size against the topography and natural landform patterns. The wireframe from this viewpoint shows the turbines appear to frame the natural curvature of the landscape and do not appear large or domineering.

The wireframe shown in Figure 5 above is also not from the Sundsvall example nor the same project shown in Figure 4 but is used to give an idea of what a wireframe looks like. The wireframe shows how the turbines will appear in the landscape and does not take into account screening by vegetation nor the built environment. Wireframes provide a good visualisation of how the turbines will appear as a worst-case scenario because there is no vegetation or built distractions between the viewer and the turbines.

<u>Opportunities and Limitations of the Tools</u>

The assortment of visual tools provides an opportunity to inform the public about the various aspects of the proposed development and allows them to visualise the development in various ways. While each of the digital tools may have some limitations as shown in Table 1 below, they are fundamental to the landscape analysis planning process in Sweden because they individually outline key aspects in the process that together are important. Going off this however, there are some possible alternatives worth mentioning, that are key considerations for the second research question that comes in the following section. The opportunities, limitations and possible alternatives for each of the digital tools discussed above are shown in Table 1 below. The opportunities and limitations are based on the literature review from Section 2 as well as an assessment of the Sundsvall, photomontage and wireframe examples.

Table 1: The opportunities and limitations of each of the digital tools. This assessment is a combination of what is stated by the literature in Section 2 and the results from the visual examples.

	GIS mapping	**Zone of Visual Influence (ZVI) image**	**Photomontage/ Wireframe image**
Opportunities	Identifies areas as acceptable or unacceptable for wind farm developments; QGIS is free to use and open sourced; identifies the key landscape and visual receptors; can be used early in the process for scoping.	Provides an early indication of the visibility likely to occur including how much visibility, the pattern of visibility and the areas of visibility (through multicolour bands); informs viewpoint locations.	Easy to interpret by majority of population (see Berry et al, 2010); considers screening by vegetation, topography and buildings and provides a photograph-like representation of what the proposed development will look like; wireframes allow the viewer to compare the position and scale of the turbines against the existing landscape (see Gruehn & Roth, 2014).
Limitations	Can be difficult to interpret the data (see Berry et al, 2010); some municipalities are more advanced in terms of identifying constraints which leaves a gap between municipalities in Sweden (see Mels & Mels 2014).	Can be difficult to interpret the data (see Berry et al, 2010); shows where a development will be visible but not how it will look and is only accurate based on the data which it is based.	No standard in Sweden for how they are produced (see Mels & Mels 2014); cannot convey the turning blade movement (see Hevia-Koch & Ladenburg, 2019); only as accurate as the data used to construct the data; difficult to align actual terrain with digital terrain data and replicate the real-eye image (see Berry et al, 2010).

Possible alternatives	Provide web-based and open-sourced GIS alternatives to enhance public consultation and standardisation.	Provide more comprehensible descriptions for how to interpret data.	Improve 3-dimentional augmented reality software to show the moving blades; photomontage for night-time illumination.

The possible alternatives discussed above in Table 1 are taken ahead for further consideration in Section 4.2.

4.2 How can digital tools increase and improve public participation in the wind farm planning process?

The digital tools outlined above, provide a stable foundation to inform the public on the visual impact of a proposed wind farm. The GIS mapping is useful for outlining constraint areas in the study area, the ZVI shows areas where the development is visible, and the photomontages and wireframe show how the turbines will appear in a photograph-like image. However, many literature sources outline that there is still a gap with regards to how public participation can be improved through digital tools. This assessment is therefore based on a literature review to summarise the critique from the literature in in *Section 2 Theory* and possible alternatives presented in Table 1 and presents suggestions on how to increase and improve public participation in wind farm planning through digital tools. As Berry et al (2010) states, increasing and improving public participation can entail increasing the diversity of those involved in the planning process, their access to information and how they are informed earlier so they can contribute to make well-informed decisions and improve the quality of participation. Three objectives are highlighted below in Table 2 to demonstrate how public participation can be increased and improved through the provision of digital tools in wind farm planning. These objectives are a ‘coded’ assessment based on the critique from the literature. The table then outlines three outcomes based on the literature under each objective to motivate for how the tools can be improved and what they can provide to facilitate better public participation.

Table 2: The provision of digital tools to improve public participation. The three objectives are outlined in bold, followed by an assessment of the outcomes as presented by the literature in Section 2.

Objective 1: Qualitative method to increase diversity	**Objective 2: Improved augmented reality**	**Objective 3: Standardisation**
Digital tools to provide more diversity from the public and expert opinion, standard evaluation free from landscape viewers (Guan, 2022)	Provide 3-dimensional moving images to capture the visual impact arising from the turning movement of the blades (Hevia-Koch & Ladenburg, 2019)	Provide formal standardisation in Sweden to inform digital tools used, how to use them and which data to show (Mels & Mels, 2014).
Provide more immersive path methods (walks) and participatory mapping (GIS) to initiate user knowledge earlier in the planning process (Mels & Mels, 2014)	Digital tools that provide night-time illuminations of the turbines (Hevia-Koch & Ladenburg, 2019)	Provide a software tool that is easy to understand, cost effective and meaningful to limit knowledge gap between planners, landscape architects and public (Gruehn & Roth, 2014).
Provide more transparency and accessibility of the public consultation meetings in terms of where they are and who is involved (Berry et al, 2010).	Augmented reality and 3-dimentional visualisations provide a more realistic interpretation and better perspective of the proposed turbines, which can be applied to any region for any wind farm size, layout and turbine model (Grassi & Klein, 2016)	Provide a standardised objective visualisation approach that is logical and well-reasoned to quantify the analysis, steps, data sources and approaches to indication election (Guan, 2022).

The arguments gathered from the literature discussed in Table 2 demonstrate the need for digital tools to be more standardised in Sweden with regards to which software to use, how they are used, which data needs to be implemented and how the data be examined. With standardisation comes the other two arguments, a more qualified approach to gather data from public knowledge as well as improving augmented reality. The three objectives will be brought forward for discussion and assess how the digital tools can be improved to allow for better public participation.

Chapter 5

5. Discussion

The results from the first research question pertaining to how digital tools contribute to the planning process is discussed above through Figures 2, 3, 4 and 5 and Table 1. The assortment of visual tools provides various opportunities to inform the landscape and visual constraints associated with a wind farm project. Sundsvall was chosen as an example to demonstrate how digital tools allow for one to visualise wind farms to give context to this thesis. The nine constraint themes, which are a national standard in Sweden, can be applied to any landscape analysis project nationwide. The ZVI provides a visual image to outline where the turbines will be visible, how much visibility will occur and the pattern of visibility. The photomontage and wireframe techniques provide a photograph-like visual to show the scale and size of the turbines and how they will appear in the landscape, considering screening effects. Together, the three main visualisations presented above provide a clear basis for how digital tools are used in wind farm planning and what details they offer to visualise wind farm developments. The results from the second research question pertaining to how digital tools can increase and improve public participation is summarised in Table 2 and based on a theoretical assessment. The literature outlines that digital tools can provide public participation, but give recommendations for how it can be improved, including providing more qualitative research to increase the diversity of participants involved in the planning process, improve augmented reality and create a standardised framework. This section will present some recommendations on how digital tools can be improved based on the objectives brought forward in Table 2 to better inform residents on a proposed wind farm project to minimise social opposition.

5.1 Objective 1: Qualitative Research to Increase Diversity

There are no one-size fits all when it comes to planning regulations and frameworks and it is important to capture people's perceptions of the landscape at a regional level. It is recommended that regional development plans incorporate wind farm planning policies and objectives based on a qualitative understanding of landscape value and landscape sensitivity, as characterised by those living in the regions (Rygg, 2012; Mels & Mels, 2014). By providing a transparent public consultation early in the wind farm development process, areas of landscape value and landscape sensitivity areas would be identified by the public. These constraint areas can then be mapped using GIS to outline areas where wind farm developments should be avoided based on people's values for the landscape. While a qualitative assessment is subjective in nature, it does determine the values and attitudes people have with regards to landscape change which can then be verified through quantitative methods. Therefore, a qualitative method could be beneficial in early-stage planning to understand the social perspectives and reduce challenges later (Guan, 2022; Mels & Mels, 2014).

There is a need to move away from the top-down structure when it comes to wind farm planning in Sweden and instead incorporate a more transparent, bottom-up approach that considers the needs of the public from the beginning. The question should not be "whose landscape?", but rather the "landscape for all". As Mitchell (2017) and Purcell (2002) mention above, everyone has a right to the landscape and should therefore be seen as a space for all.

This thesis suggests that more research would be beneficial in a qualitative aspect such as to interview local stakeholders to understand their perception of the wind turbine developments and develop a planning framework in line with their views before development of the wind farms begins. Although qualitative analysis was not within the scope of this thesis due to time constraints, future analysis could explore various regions in

Sweden to get an understanding for how digital tools can be utilised in their municipality to improve public participation.

5.2 Objective 2: Provisional Augmented Reality

Augmented reality allows for the 2-dimentional images to be turned into a 3-dimentioanl and portrays the dynamic impact of the wind turbines. Augmented reality was identified as one of the main topics that were discussed in Section 2 as the need to research more and devise solutions to improve current wind farm planning practices. Turbines contain rotating blades to generate electricity, however current digital tools mainly only account for the turbines as static features. There is a need to explore ways to show the visual impacts of the turbines as they will appear in real-life and consider the impact of the turning blades (Hevia-Koch & Ladenburg, 2019; Gruehn & Roth, 2014).

An example of how this can be achieved is through the software program Adobe After Effects, which creates a video montage. It combines a video of the current view of a site, taken at a site visit, overlaid with a photomontage depiction created in Wind Pro to show how the turbine movements will appear in the landscape to create a motion graphic. Videos could be taken on site with a camera on a tripod or through drone imagery. Video montages can also be created in the software programs Wind Pro or Unreal Engine, however, the outputs may vary slightly. This example of the Adobe After Effects software aligns with the points mentioned in Section 2 because this tool creates a video of the turning movements of the blades. Additionally, such a tool can be valuable both during public consultation to inform local stakeholders of the visual impacts to arise as well as shown during site visits to local residents in line with the arguments presented by Gruehn & Roth (2014). However, it is worth mentioning that computer generated models using 3-dimentional or game-engine technology are still in development and some municipalities have not fully accepted their use. An example of this software and how it works is shown in Figures 6 and 7 below. These image renderings were created by EDM International and show the camera position and video taken during site visit (Figure 6) and the rendered image with the turbines of the proposed view (Figure 7).

Figure 6: Video montage example, existing view, EMD International (2022)

Figure 7: Video montage example, proposed view, EMD International (2022)

Although the photo shown in Figure 7 above appears as a still image, the actual image is from a video montage to capture the moving effects of the turbine blades. This video montage could be introduced as part of a wind farm planning assessment to address the visual impacts of the turbine blades moving as they would do so in reality. This videomontage provides a more realistic interpretation and better perspective of the turbines compared to the 2-dimentional image and can be applied to any region or wind farm project (Grassi & Klein, 2016). Figure 8 below shows another example of a photomontage rendering created in the software Unreal Engine for a project in Katajamäki, Finland (Nordström, 2023). Unreal Engine is a gaming software that consultancy companies in Sweden sometimes use to produce still-photomontages. However, one challenge with this tool is that it is difficult to align the actual terrain data with the digital terrain data to produce the video montage, therefore the output may not be very accurate, which is unfortunately a drawback with digital tools that needs to be explored.

Figure 8: Photomontage example, Unreal Engine Software, Nördstrom, M. (2023)

Another key topic that was addressed in this thesis is the night-time illumination visual effects that turbines create. Turbines with a height of 150 meters or more are required to have red or white lights for air traffic safety (Transport Styrelsen, 2020). These lights are located on the turbine nacelle (top of the turbine) and blink on and off to inform aircrafts of their position. In flatter landscapes where there are many wind turbines, the blinking red lights can be seen as a major issue. Residents often perceive this as a disruption to the natural landscape. Night-time illumination is currently not involved in wind farm planning, unless requested for by planning authorities. However, night-time illuminations and their proposed impacts can be digitised and created through photo-like images, as shown in Figure 9 below, created in Photoshop. These additional images can help stakeholders to visualise the wind farm developments and better understand how the visual impact will look during night-time. As outlined by Hevia-Koch & Ladenburg (2019) in both Section 2 and Table 2, by allowing for such tools to be incorporated into wind farm planning, public participation can be improved because people will be more aware of all the visual impacts associated with the proposed developments including both the daytime and night-time visual effects.

Figure 9: Night-time photomontage, created by Audrey W. The image shows the nighttime effect of the red lights of the turbines and how these red lights can be a visual obstruction to local residents.

The video montage presented above could also be used to demonstrate the night-time illumination effect of the turbines along with movement of the turbine blades. With the inclusion of advanced digital tools to be aided in current wind farm planning practices, stakeholders would gain a better understanding of the visual constraints associated with the proposed projects. While there are cost constraints associated with these tools, if such tools were standardised and implemented, wind farm planning would become more transparent, consistent and would relieve pressure from the municipalities to make all the decisions. It is important to note that this thesis shows examples of some of the digital tools used to conduct a landscape analysis in Sweden but doesn't exclude the possibility of other digital tools used by consultancies or municipalities. There is a need to recognise the benefits of these tools and how they can be implemented in future planning projects.

5.3 Objective 3: Standardisation to Meet the Energy Ethics Conflict

To address the energy ethics conflict and improve wind energy development guidelines, standardisation is crucial. For wind energy development guidelines in Sweden, there is an unclear standardisation when it comes to planning. Limited transparency between the national and regional planning levels have led to limited knowledge regarding landscape sensitivity and landscape value, the type of photography methods to utilise and which software to use when conducting landscape analysis as well as which data needs to be included in the assessment (Grassi & Klein, 2016; Berry et al, 2019). In Sweden there is no guidance to suggest to not place the turbines in an area of interest but is considered acceptable if they are visible from these areas. Additionally, there is no clear-cut solution in Sweden for determining areas of national interests and which area takes precedent over the other. The limited standardisation has led to unclear decision-making processes and policy standards. The risk with limited standardisation in the visualisation process is that it makes it difficult for municipal authorities to evaluate the results, especially if consultancy companies produce their data in different ways. This can lead to discrepancies in the data being used or the accuracy of the output of the visual aids which can also be misleading. As mentioned previously in Table 2 under the objective of standardisation, a standardised approach would not only allow for streamlining across all professions to create their data based on the same approach but would allow planning decisions regarding wind farm developments a lot easier (Gruehn & Roth, 2014; Mels & Mels, 2014; Guan, 2022).

In Ireland and the UK, there is a better balance between regional and national planning standards as well as planning guidance for wind farm planning. For example, there is a clear guidance practice in Ireland, including the Guidelines for Landscape and Visual Impact Assessment (GLVIA 2013), Visual Impact Assessment Best Practices (Scottish National Heritage 2018), Photography and Photomontages for landscape and visual impact assessment (Landscape Institute Advice Note, 2011) as well as the regional development plan guidance in which the project site is located, just to name a few. In 2015, the

Department of Arts, Heritage and Gaeltacht published a National Landscape Strategy for Ireland as a compliance document to ensure the regional-level planning met the national Landscape Character Assessment and Developing Landscape Policies. Since then, any planning projects that may impact the landscape character, must undergo the same assessment and procedural methods. When there is a standardisation, it allows planners to compare different projects and their impacts in an easier way because these projects follow the same methodologies to arrive at their conclusions.

When it comes to planning, procedural justice in wind farm planning remains a significant issue. If there was better information balance, trust in government and more transparency between local stakeholders, residents would likely not have as strong opposition to wind farm planning. While this thesis has highlighted the issues when it comes to wind farm planning and landscape ethics, it is important to recognise that wind farm planning remains a social problem and there is a need to address this issue from a planning perspective. To minimise social conflict, there is a need for more standardisation in landscape planning to allow for a more democratic alliance between the public and planning authorities. The power relations between corporations supplying the energy and the local residents also remains an issue. These corporations often don't supply the energy to the residents but rather for their own benefits and therefore the locals don't think they need to be involved in the decision making. However, such issues could not be addressed through digital tools although is important to point out with regards to wind farm planning. The three objectives presented in Section 5 are responses to the outcomes and objectives discussed in Table 2. While increasing and improving public participation may be challenging to define, three objectives pertaining to this tropic have been highlighted in the literature overview as to how digital tools can increase diversity and promote inclusion and ensure well-informed participants.

Chapter 6

6. Conclusion

When it comes to meeting future sustainability development goals, developing wind energy is an efficient way to reducing carbon emissions and reducing climate change. Digital tools, such as GIS, ZVI and photomontages and wireframes, have been shown to provide a good basis for visualising wind farms and help public participation. The Sundsvall example has demonstrated how digital tools can be used to highlight constraints mapping and visibility analysis in the form of a ZVI. The photomontage and wireframes create a realistic visual of a wind farm development. This thesis establishes an assessment of the ways in which wind farms can be visualised, based on a quantitative and theoretical review. However, wind energy development has shown to be a complex dilemma when it comes to planning. The Swedish legislation regarding wind power has been outlined as inconsistent and there is a clear gap when it comes to balancing local participation with municipal regulation. Balancing wind energy development with social challenges and people's perception of wind turbines can be supported with digital tools.

One of the greatest challenges with digital tools is accessibility and standardisation. Wind farm projects are often rejected by NIMBYism residents due to inaccessible planning information or digital tools to visualise the developments. The social issue of land use conflict and people's perception of turbines can be reduced by allowing for more transparency and accessibility between planning authorities and stakeholders and creating an objective standardised approach to visualise wind farm developments that considers social, political, and environmental perceptions. An objective approach will allow for a standardisation process whereby results are quantified based on the evaluation of steps, the data collected, and approaches taken. This will not only allow for more transparency between planners and stakeholders but will also create a system that allows the possibility to compare the impacts between projects thereby reducing social and political tension at all levels.

Digital tools are only an aid, inclusion and democratic participation derives from political will. This thesis has demonstrated that digital tools can help to visualise wind farms but to improve public participation, radical changes is needed within the planning process to recognise the benefits of digital tools and provide an appropriate standardisation process to balance local participation with municipal regulation.

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