Opportunities for Small-Scale Wind Turbines in the municipality Utrechtse Heuvelrug

Transdisciplinary Case Study (GEO4-2302)

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Management Summary

For the energy transition to be successful, cost-effective and socially feasible, municipalities must carefully weigh the pros and cons of different renewable energy sources. In this context, Small Wind Turbines (SWTs) are sometimes seen as an elegant alternative, due to their limited impact on the living environment. This report investigates the potential of SWTs in the municipality of the Utrechtse Heuvelrug (UH). The analytical framework integrates the technical, economic, social and environmental aspects of small-scale wind energy at the municipal level.

Based on detailed KNMI-data, a wind atlas is made to select one area (of 2.5 by 2.5 km) with (relatively) optimal (4.5 m/s) and one area with acceptable (4.18 m/s) wind speeds. For these areas, performance (both output and capacity factors) of eight different SWTs (with a height of 20 m) is estimated, using 10 years of hourly data. With capacity factors of 20% or higher, three models are technically feasible in specific areas, and would produce between 20 and 70 MWh per year. While these results are certainly indicative, it should be noted that location-specific turbulence (which has a significant (positive or negative) impact on SWTs) is unknown.

The Net Present Values (NPV), Levelized Costs of Electricity (LCOE) and Pay-Back Periods (PBP) are calculated based on the average annual output of each turbine. Under optimal wind conditions, NPV is positive for two turbines, assuming an electricity price of €0.18/kWh, SDE+ subsidy is included, and VAT is excluded. Slightly less optimal wind speeds result in negative NPVs. The business case of for SWTs will in most cases depend on (additional) subsidies, also due to PBPs exceeding 10 years.

While these figures stand in the way of a widespread uptake in UH, SWTs might be interesting for individual stakeholders (e.g. in combination with other decentral renewable energy, such as solar energy). Currently, opaque and complicative legislative procedure are a main barrier. On the other hand, environmental awareness and a desire for energy independence appear to be a counterweight against limited economic feasibility. Effective governance strategies and best-practice ownership models should ensure socially sustainable uptake of SWTs in these limited cases. Since SWT have a more benign impact on the environment, one may assume that social opposition may be limited. Even so, case studies demonstrate that precautionary involvement of residents, even in the case of SWTs, is advised. Some of the turbines examined will exceed permitted noise levels during night-time and should thus not be installed near residential areas. Provided appropriate distances are kept from bird- and bat habitats, ecological impacts should be limited.

Considering all criteria, a total area of about 20 km^2 is suitable for SWTs. If one fourth of this area is fully occupied by 600 SWT, the annual yield would theoretically meet the renewable energy-target in the municipality's climate roadmap (14 GWh). However, 3 conventional wind turbines of 100 meters would generate the same amount of energy. Weighing techno-economic potential against governance-effort required, this report thus concludes that SWTs are unlikely to be a logical energy source to pursue as a significant contribution to future energy supply of UH.

Management Samenvatting

Om een succesvolle, kosteneffectieve en maatschappelijk haalbare energietransitie te realiseren zullen gemeenten de voor- en nadelen van verschillende duurzame energiebronnen zorgvuldig moeten afwegen. In deze context worden Kleinschalige windmolens (SWT's) soms gezien als een elegante deeloplossing, vanwege de geringe impact of het landschap. Dit adviesrapport onderzoekt de haalbaarheid van SWT's in de gemeente Utrechtse Heuvelrug (UH). Hierbij worden de technische, economische, sociale en ecologische aspecten van SWT's geanalyseerd.

Op basis van KNMI-data is een windkaart gemaakt, om gebieden (van 2,5 bij 2,5 km) met (relatief) optimale (4.5 m/s) en acceptabele (4.18 m/s) windsnelheid te selecteren. Voor deze gebieden worden de prestaties van acht SWT's (met een hoogte van maximaal 20m) ingeschat o.b.v. 10 jaar aan data (per uur). 3 SWT's halen een capaciteitsfactor van 20% of hoger en zijn daarmee technisch geschikt voor de gemeente, en leveren tussen de 20 en 70 MWh per jaar. Hierbij dient wel te worden vermeld dat locatie-specifieke turbulentie (die een significante impact (zowel positief als negatief) heeft op de prestatie van SWT's) niet kon worden meegenomen.

De Net Present Value (NPV), Levelized Cost of Electricity en Pay-Back Period (PBP) zijn berekend o.b.v. de gemiddelde jaarlijks energieopbrengst van elke windmolen. Onder optimale omstandigheden is de NPV van slechts twee SWT's positief, bij een elektriciteitsprijs van €0.18/kWh, inclusief SDE+ subsidie, en exclusief BTW. Bij acceptabele windsnelheden is de NPV van deze windmolens ook negatief. In de meeste gevallen zullen dus aanvullende subsidies (zoals POP3) nodig zijn om de business case rond te krijgen, ook vanwege PBP's van meer dan 10 jaar.

Deze uitkomst staat de structurele installatie van kleine windmolens in de weg, maar ze zouden wel interessant kunnen zijn voor individuele stakeholders (bijvoorbeeld i.c.m. zonnepanelen). Moeilijk te doorgronden regelgeving en procedures zijn daarbij echter een belemmering. Aan de andere kant compenseren milieubewustzijn en de wens naar energieonafhankelijkheid de beperkte economisch haalbaarheid. In deze gevallen kunnen effectieve beleidsstrategieën en best-practice eigenaarsmodellen de sociale haalbaarheid bevorderen. Vanwege de geringe impact op de omgeving wordt minder weerstand verwacht. Uit verschillende casestudies blijkt echter dat dit niet zou moeten leiden tot verminderde mogelijkheden voor burgerinspraak.

Enkele SWT's overschrijden de geluidsnormen gedurende de nacht, en dienen op voldoende afstand van woningen te worden geplaatst. De verwachte impact op vogels en vleermuizen is beperkt, mits SWT's ver genoeg van leefgebieden worden geplaatst. Als deze aspecten worden meegenomen blijkt een gebied van zo'n 20 km2 geschikt voor SWT's. Het volledige theoretische potentieel van één vierde van dit gebied zou met 600 molens de duurzame energiedoelstelling van 14 GWh in de *Routekaart Energieneutraal Grondgebied 2035* behalen. Eenzelfde opbrengst zou echter worden behaald met zo'n 3 conventionele windturbines van 100 m. Een afweging tussen het techno-economische potentieel en de vereiste beleidsinspanning leidt daarmee tot de conclusie dat kleinschalige windmolens geen logische energiebron zijn om op in te zetten als toekomstig onderdeel van de energievoorziening van de gemeente.

Contents

1. Introduction

1.1 Background

I. The Energy Transition of the Municipality of the Utrechtse Heuvelrug

The Netherlands is committed to climate change mitigation as guided by the Paris Agreement, which aims to limit global warming to a maximum of two degrees Celsius. In alignment with the European Union's (EU) binding reduction target of 40%, the Netherlands aims to cut greenhouse gas (GHG) emissions by 49% by 2030, compared to 1990 (klimaatwet, 2019). This will require a rapid decarbonization of the energy system. The recently adopted National Climate Accord ("het *Klimaatakkoord"*) envisions an energy mix with 70% renewables by 2030. Decentral governments in the Netherlands (municipalities, provinces and water boards) will play a crucial role in making and implementing policies to achieve this target by reducing the carbon footprint of electricity and the built environment (Klimaat Akkoord, 2019).

The municipality of the Utrechtse Heuvelrug (UH) is currently collaborating with 15 other municipalities, 4 water boards and the province of Utrecht to develop a Regional Energy Strategy, alongside the 29 other "energy regions" in the Netherlands (Gemeente Utrechtse Heuvelrug, 2019). Moreover, the municipality aims to become carbon neutral by 2035. This ambition is outlined in the municipality's "Routekaart Klimaatneutraal Grondgebied 2035" ("Roadmap Climate Neutral Territory"), which was published in 2015 (Gemeente Utrechtse Heuvelrug, 2019). The roadmap is largely based on the views of inhabitants, and explores possible pathways and defines targets, such as a 25% reduction of the municipality's GHG emissions by means of increasing renewable energy capacity. The report suggests that there is a positive mindset regarding solar photovoltaics and that further expansion will be stimulated, a sentiment reflected by figure 1. The roadmap remains ambiguous about renewable energy (RE) like wind energy.

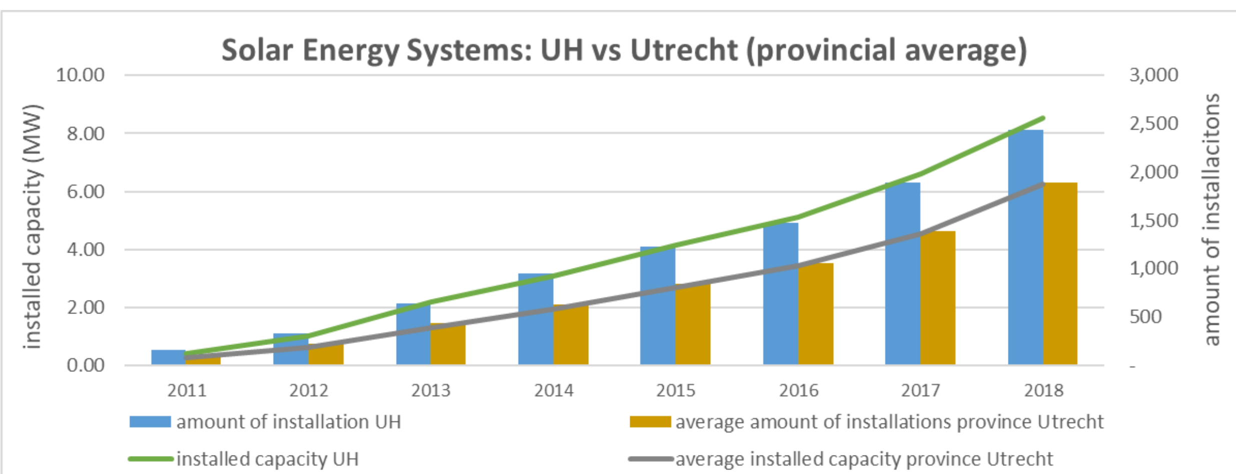

Figure 1 Decentralized Renewable Energy Systems in the Utrechtse Heuvelrug. Note that the number of households in UH corresponds to the average amount households in municipalities in Utrecht.

Notwithstanding the successful expansion of solar PV as revealed in figure 1, the intermittent and unpredictable nature of solar energy will cause technical challenges if this trend continues. The expansion of grid capacity and (inter-seasonal) storage required for the energy transition will exacerbated if the municipality only opts for solar PV. Instead, a diversified portfolio of RE systems would enable the reduction of intermittency, hence increasing reliability and reducing costs (Badwawi et al, 2015).

II. The Potential Contribution of Small Wind Turbines

The general geography of the Netherlands allows for the feasible integration on wind energy in its currently carbon intensive energy mix. In addition, the advanced development of wind energy technologies offers a plethora of application for different scales of supply and demand. Offshore wind energy will account for 41% (49 TWh) of the RE capacity in 2030, while an expansion to 35 TWh is envisioned for all onshore renewables (Klimaat Akkoord, 2019). Since municipal governments deal with cross-cutting development themes (e.g. economic, social, and environmental), and the roll-out of wind energy is financially and technologically demanding, wind project development is coming to the forefront of decision making in municipalities. Especially the installation of conventional onshore wind turbines poses a substantial governance challenge, due to its landscape- and socio-economic impact. While the onshore deployment of large scale wind turbines is advantageous for harnessing a large power capacity, reaching more efficient energy production and having a strong potential for carbon abatement, economic cost (e.g. construction, maintenance, payback period), aesthetic nuisance and noise pollution are important concerns for municipalities like UH (Lloyd, 2014).

The municipality's precaution with respect to environmental conservation, economic boundaries and technical availability, as well as the involvement of its inhabitants in local politics, may render large-scale turbines less suitable. As an alternative, the municipality of UH is exploring the potential for small scale wind turbines (SWTs) to contribute to its ambitions of expanding RE consumption from local sources to about 14 GWh.[1] (Gemeente Utrechtse Heuvelrug, 2015). From a social perspective the surrounding area of residents, consumers, and businesses may be less affected by SWTs and its impact on the economy and the environment. From an environmental perspective there is inevitable biodiversity and land use change resulting from any wind power development that then links back to impacts on the socioeconomic construct. For example, the potential for a new power grid distribution may influence the economic paradigm (e.g. taxes, subsidies, land value) where the financial flow impacts the governing institution, central authority and thereby the standard of living.

[1] This is a back-of-the-envelope calculation based on the reduction target of 63 Kton CO2 from electricity, and carbon intensity of 0.505 kgCO2/kwh in the Netherlands (EEA, 2018) (Gemeente Utrechtse Heuvelrug, 2018)

III. Knowledge gap

The main knowledge gap that will be addressed by this report is the unawareness of the appropriate technologies and strategies for the expansion of wind energy at the municipal level. The installation of wind farms tends to be contested and the municipality of UH is wondering is SWTs are a feasible alternative to meet its RE targets. Moreover, UH wants to foster public dialogue to ensure better information sharing and to avoid opposition from residents. There have not yet been investigations carried out to understand the different aspects (e.g. economic, social, environmental) involved in installing SWTs. Furthermore, there has been no study on the technological potential of small-scale windmills in a geographic area such as UH.

This report aims to fill this knowledge gap by analysing the multiple aspects that ensure the beneficial outcome from deploying SWTs. The technical and economic potential of various SWT models is analysed in the context of various geographical barriers (national park areas, low average wind speeds, densely populated areas). A better understanding of governance aspects regarding SWTs is sought through various windmill deployment cases studies, analysing the potential social participation and the links to the local legislative authority.

1.2 Research Questions

Taking into account the sustainable energy ambitions of the municipality of UH and the spatial, economic and environmental impacts of the energy transition, the following main research question is formulated:

> *What is the potential of small-scale wind turbines (SWTs) to contribute to renewable electricity generation in the municipality Utrechtse Heuvelrug (UH)?*

The potential for renewable energy generation is defined as the maximum feasible electricity production in kWh (kilowatt hour) or MWh (megawatt hour) per year considering technological, economic, social, spatial and ecological boundaries. These boundaries should be considered relative to alternative energy transition possibilities on a local geographical scale. This research will however focus on the technical and economic aspects of SWTs in UH, feasible governance strategies and environmental impacts. Hence, the main research question is approached from a multidisciplinary perspective, integrating the following set of sub-questions listed below.

A. <u>Technical Potential of Small-scale Wind Turbines in Utrechtse Heuvelrug</u>

   1. *What is the potential electricity yield of SWTs?*
   2. *What amount of surface area is available and suitable for SWTs?*

B. <u>Economic Potential of Small-scale Wind Turbines in Utrechtse Heuvelrug</u>

   3. *Are SWTs economically feasible?*

C. <u>Social feasibility of implementing Small Scale Wind Turbines in Utrechtse Heuvelrug</u>

   4. *What governance strategies exist for managing SWT projects?*
   5. *What are the best-practice ownership models for SWTs?*

D. <u>Environmental Impact of implementing Small Scale Wind Turbines in Utrechtse Heuvelrug</u>

   6. *What are the potential impacts of SWTs on bird and bat mortality and how could these be reduced?*
   7. *How might land use and property value change as a result of implementing SWTs?*
   8. *Are SWTs causing noise pollution?*

2. Theoretical Background

2.1. Wind as a Sustainable Energy Resource

2.1.1 Wind Energy Resource

Wind is the flow of air and is variable because of geographical and physical features. For example, friction with the ground and disturbances by trees, large buildings, mountains and hills may cause turbulence. In addition to wind speeds and air density, turbulence may reduce power output by up to 4% (Lubitz, 2014). Wind speed varies in heights, where higher heights without obstructions increase wind speeds and thus impacts the functioning of all wind turbines. At low heights, obstructions also cause variations in direction (Twidel & Weir, 2017).

The power available in airflow that can be converted into useful energy varies strongly over time and distance, and depends on changes in wind speed, wind direction and air density, which in turn depends on temperature, pressure and humidity (Shi & Erdem, 2017). As speeds may vary over distances even as short as one km, and throughout the year, an assessment of wind speed requires site measurements for a minimum of 12-month observation period. However, natural variation and climate change may still lead to a per annum uncertainty factor of at least 20%, so multi-annual data are be preferable. Although average wind speeds are a key indicator for site-selection, the power in the wind is proportional to the wind speed cubed[2], which means that above-average speeds contribute disproportionately more power. Hence the probability distribution of wind speeds is important to estimate the wind power potential of wind for a specific location, in the absence of frequent measurements over an extended period of time (Twidel & Weir, 2017).

2.1.2 Wind Turbine Performance

The efficiency with which a wind turbine captures the power in the wind is called the power coefficient, which is simply the ratio of a turbine's output power to wind power. The power coefficient has a theoretical limit of about 59% (the Betz-limit), because the airflow through the wind turbine must be maintained. Since the space surrounding the turbine is not a vacuum, some energy is required. The power coefficient of a wind turbine depends on the rotational speed of the tips of the rotor caused by the wind speed (the tip-speed ratio) and the ratio of lift and drag forces that work on the turbine, and thus changes with wind speed (Andrews & Jelley, 2013).

Fixed-speed wind turbines are designed to achieve maximum efficiency at one particular wind speed and to produce an electric current with the same frequency as the grid. This allows for a

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[2] The kinetic energy per second of the volume of air flowing through a certain area is given by: P=½ Aρu^3, a relationship which will be further analyzed in the methods section of this report.

simpler, and cheaper, electronic interface to ensure the current is grid compatible. On the other hand, the fixed rotation speed means that the tip-speed ratio cannot be held at the optimal level, reducing the power coefficient below and beyond the rated wind speed (see figure 2). Variable-speed turbines are able to optimize efficiency for varying wind speeds, but this requires a more advanced interface to adjust the frequency. (Hansen, 2017)

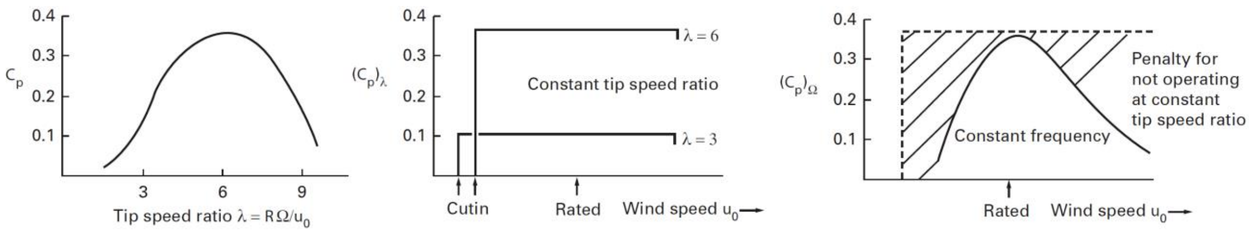

Figure 2 Speed-tip ratio influences power coefficient (Cp) (l). If held constant, Cp can be kept stable for a range of different wind speeds (m), but this means frequency will vary (r).

Although the Betz-limit provides a good benchmark for the actual conversion efficiency of a turbine, it does not take into account several physical and mechanical characteristics that limit the maximum power extraction. For instance, the Betz-limit does not consider the angular momentum that actually drives the turbine (Twidel & Weir, 2017; Andrews & Jelley, 2013). The aggregate influence of wind speed on the power output of a turbine, i.e. including the mechanical and electrical conversion efficiency, is expressed by the power (performance) curve (pp-curve). The pp-curve graphs turbine power output to wind speed and are an expression of operational efficiency. Pp-curves are a characteristic feature of specific wind turbines but share three general characteristics that describe the relation of wind speed and power output: cut-in speed, rated wind speed and cut-out speed (figure 3). The cut-in speed is the minimum wind velocity at which the rotors start to rotate and produce useful energy. At the rated wind speed the maximum power output of the generator is reached. At the cut-out speed, the turbine's rotation is stalled to prevent damage to the turbine's components and structure, and prevent unsafe situations (Hansen, 2017).

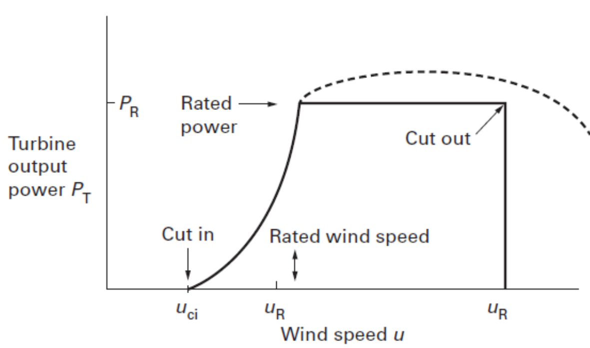

Figure 3: PP curve illustrating wind speed and power output relation

2.2. Small Scale Wind Turbines

Generally, wind turbines with a maximum hub height of about 20 meters and a maximum power output is below 20-50 kW are considered “small” (although some sources still refer to an output of 100 kilowatt as ‘small’) (Figure 4). This definition corresponds to the *Provinciale Ruimtelijke Verordening Provincie Utrecht* (2017) which allows wind turbines of up to 20 meters hub height to be built on current building plots. Small wind turbines, can be subdivided in several classes, such as micro (0-1,5 kW), small (1,5-15 kW) and small commercial (larger than 15 kW) turbines, roof- and pole mounted turbines, and vertical- (VAWT) and horizontal axis turbines (HAWT). Despite the suitable size of SWTs, their installation in urban and sub-urban areas is generally not considered feasible. Turbulence, which has a substantial impact on the performance of SWTs and negatively impacts their lifetime, is higher in urban areas. At best, this increases the divergence between predicted and observed energy production up to 40%. At higher wind speeds, turbulence negatively impacts energy production. (Anup, Whale and Urmee, 2019) While VAWTs may be suitable in these environments, these designs are less mature than HAWTs. HAWTs, whose rotor must turn when the wind direction changes, are best installed in open, rural areas. At average windspeeds of at least 4-4.5 m/s to achieve economic feasibility, these wind turbines should be break-event (Grieser, Sunak, Madlener, 2015).

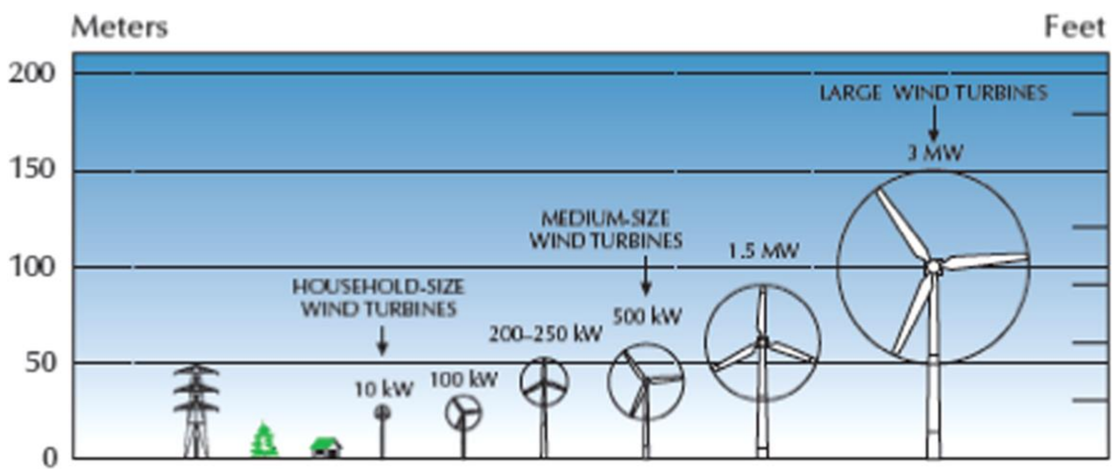

Figure 4 Sizes and power output of wind turbines (Edvard, 2011)

2.3. Governance Mechanisms

Facilitating SWTs in UH can be part of a government policy of decentralised energy production. Renewable energy strategies are often operationalised through Local Energy Initiatives (LEI’s) which provide the organising framework (Hoppe et al, 2015). Transition mechanisms to advance renewable energy on a greater scale by engaging stakeholders and managing social opposition at a local level should also be considered. In many cases the aim is to promote a grassroots energy transition. With regards to the preliminary stage of the SWT technology, Strategic Niche

Management (SNM) could be the foundation of legislative changes through which the municipality and respective organisations may promote wind energy. SNM can be understood as "the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies as a means of experimentation" (Hoppe et al., 2015: p. 1902). This could relate specifically to UH's national parks, forests and buildings and where the installation of SWTs could be reconsidered. Whilst efforts must be made to conserve integrity and maintain the natural conditions of UH, SWTs built on shared public spaces as part of a government strategy may attract more support than promoting implementation of private land. Additionally, smart energy governance "provides flexible support funding schemes that empower community-based concepts and emplaced strategies" (Susser et al., 2017: p. 340) and will be key to an effective governance strategy for promoting energy through SWT's.

Stakeholder engagement is an important renewable energy strategy (Reed et al., 2009) and a provincial stakeholder analysis may help to connect those involved and reduce potential conflicts as well as shortfalls in a municipal wind project. The expected stakeholders in UH are the municipality, farmers and farmer organisations, landowners, businesses and energy companies, residents, citizen's cooperatives, and land management organisations (e.g. forestry department, office for national parks). Primarily stakeholder analysis aims to "identify those actors who are likely to be affected by renewable energy deployment and to describe their interrelationships and interactions" (Li et al., 2013: p. 721). Figure 5 demonstrates the significance of various stakeholders from the perspective of a "Most influence" to 'Least Influenced' matrix and helps to determine appropriate governance actions. Many stakeholders would likely fall within the cross-over category due to the bottom-up nature of SWT implementation. Best-practice ownership and governance models will help uncover the most effective way to engage stakeholders in a dynamic relationship that limits conflict, bottlenecks and inefficiencies.

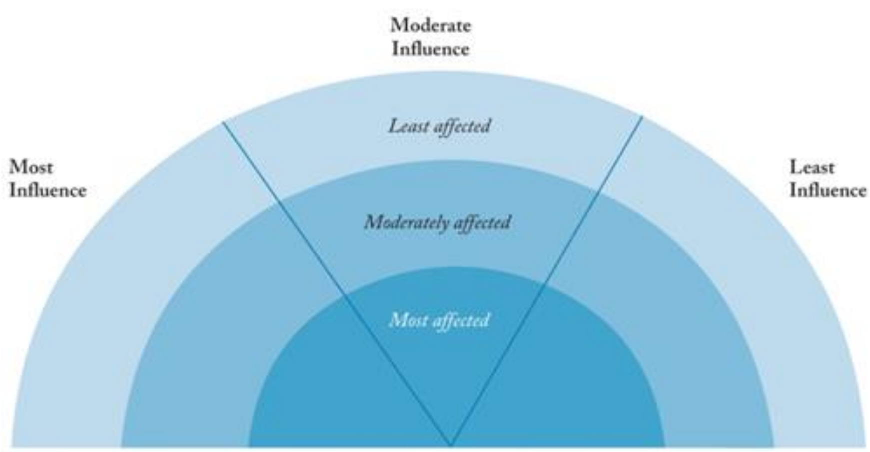

Figure 5 Rainbow diagram for classifying stakeholders according to the degree they can influence or be influenced by a problem or action (Chevalier & Buckles, 2008, p. 169).

Figure 6 represents a general stakeholder analysis relevant to community energy management, which can form a basis for community management of SWTs. The figure is relevant specifically for a self-sustaining energy community: in a conventional scenario, some elements may be more complicated than community managed turbines or wind farms. Additionally, as turbines become an element of wider community or landscapes rather than being contained *within* a community, other social and civic considerations will likely become apparent (e.g. planning aspects or public opposition).

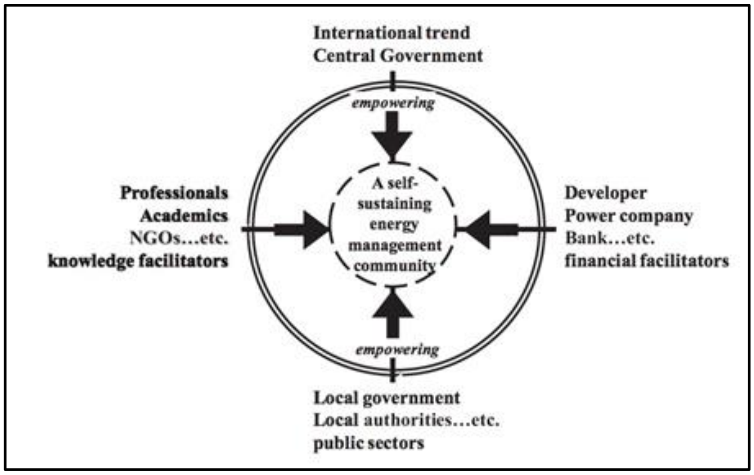

Figure 6 A collective action model of public private partnerships for empowering a self-sustaining energy community (Li et al, 2013: p. 721).

In addition to adequate facilitation through national and regional governance, the degree of social acceptance is another key component of social feasibility. Confirming the social acceptance remains a barrier to realizing several renewable energy projects (Wustenhagen et al., 2007). Early studies of social acceptance pointed to "issues such as the lack of support among key stakeholders, reluctance among policy makers to dedicate themselves to consistent and effective policies, and the lack of understanding of the roots of public attitudes towards wind power schemes, in particular the underrating of the crucial significance of landscape issues in the attitude towards wind power schemes" (Wustenhagen et al., 2007: p. 2684). As such, these concerns will form an important basis for understanding, assessing and measuring social acceptance of wind turbines which translates to an aspect of social feasibility.

2.4. Environmental Impact of Wind Energy

According to the Netherlands Commission for Environmental Assessment (NCEA), a wind farm with less than 20 turbines does not require an Environmental Impact Assessment (MER). Although SWT-projects will most likely not exceed this amount, a prudent transition strategy should still consider environmental impact. After all, severe impacts of the turbine's surroundings would defeat the purpose of clean energy and will erode public acceptance.

In general, wind energy has less environmental impact than convention electricity generation based on the entire production value chain. Nonetheless, specific issues related to wind energy are wildlife habitat impacts, noise produced by the rotor blades, aesthetic disruption, potential land use change and property value change, and bird and bat mortality (Saidur et al., 2011).

Wildlife-impacts can be categorized into direct and indirect impacts. The direct impact is the mortality from collisions with a turbine, while the indirect impacts are avoidance, habitat disruption and people displacement. However, the impacts are not as severe in comparison to other sources of energy. According to an American Wind Wildlife Institute paper (AWWI, 2019) investigating the interactions between wind energy and wildlife habitats in North America, there are 3.1 or fewer bird fatalities per MW per year with a median value of 1.8 fatalities reported. This is not a large number, compared to the bird kills caused by hunting and household pets, which amount to more than 1,000 bird fatalities per year (Rebecca, 2009). On the other hand, the bat fatality rate is found to vary among regions. The median bat fatality value in 2018 reached 6.2 per MW in the Midwest America, whereas in the Pacific Northwest it was 0.7 per MW (AWWI, 2019). Given these research findings, factors that lead to such variation has not yet been determined, and research reports targeting the impact of SWTs are lacking.

Land issues are another major concern of applying wind energy. These issues include land use shift caused by the occupation of wind farms, and property value change caused by turbine construction (Nadaï & Van Der Horst, 2010). According to an estimation, if Britain applies wind energy on all available lands with a conservative interval of five diameters, 320 wind farms will be needed with an occupation 900 and 2000 square kilometres, whereas only less than 200 square kilometres of them can be used for other activities including farming (Howard et al., 2009). For property value change, a famous theory proposed by Peter Reardon stated that land value could decline 30% to 60% due to nearby wind farms (Reardon, 2013). However, this theory has long been criticized, due to no clear indication on how he chose the samples, and on the factors involved (Renew Economy, 2013). Overall, it has been concluded that some attributes can have a major effect on the property values. They are the proximity to residences, proximity to high-density population, and uncertainty factors such as public concerns, which has potential impact on the amount of time required to sell a property (URBIS, 2016).

Noise issue is also note-worthy. Wind turbines generate sound via mechanical operation and aerodynamic vibration. The sound level, exceeding a certain value which is usually subjective, becomes noise. The noise transmission is dependent on (1) sound properties such as intensity, frequency, noise source patterns, etc., (2) background sound level, (3) transmission medium properties, and (4) resilience of the receptor. There have been numerous studies and research on the noise abatement, and a big proportion of them focus on improving the source properties. As technologies improve, wind turbines have generally become much quieter than before (Rogers et al., 2006).

3. Process

3.1. Analytical Framework

The analytical framework integrates the problem statement and the main research question to reach conclusive results and answers. To investigate whether there is a potential for renewable electricity generation provided by SWTs in the municipality of UH, the problem is divided into 8 sub-questions (Section 2.2). The research overlaps multiple disciplines, so the questions are divided into the four following domains: (1) technical requirements; (2) economic feasibility; (3) social governance and (4) environmental impact study.

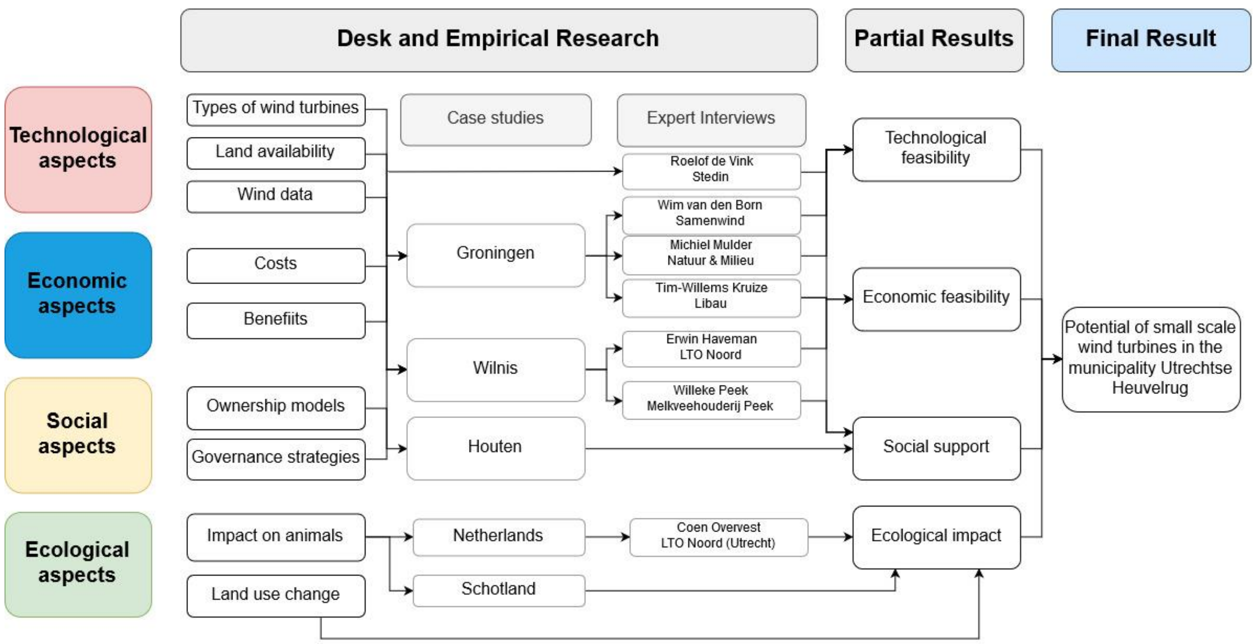

Figure 7 Analytical framework and guidance for answering the research questions

The framework (figure 7) covers all the necessary elements needed to address the problem and answer the main research question, as well as considering the logical analytical approach. Whether SWTs exist as a viable opportunity for UH will depend first on the technical requirements, principally wind conditions across the municipality and then the type of turbines available. Secondly, it is essential for turbines to be economically feasible in the current context based on investment and operational costs and power generation compared to current grid costs. Once these conditions have been satisfied, or deemed to be feasible, elements of social governance and stakeholder interactions must be analysed as well as methods to limit negative environmental impacts. As such, these two sections encompass the third and fourth sub-categories, bringing to completion the research requirements.

Each question will be answered through a literature study, that includes academic papers and policy documents, and looking at selected case studies that can provide insight from each of the project's experience. The case studies provide a better understanding of the technique and strategy to generate electricity with SWTs. The case studies form the empirical part of the research for this report. To fulfil the knowledge gaps that may remain (i.e. post the literature analysis and case studies) interviews are carried out with experts and contribute to overall data collection. Through this analysis a deliverable will be generated for each section that provides the partial-results and which will answer in clear terms for SWTs: the technical components and feasibility; the economic feasibility; the best-practice social governance strategies and ownership models; and a full environmental impact study with recommendations. This way an overall synthesis on the feasibility and therefore potential for renewable energy generation of SWTs is concluded. Lastly, any significant but removable barriers to the successful implementation of SWT projects will be highlighted by tailor-made recommendations.

Defining criteria and related sub-questions

The technical potential relates to the wind energy potential or electricity generation of SWTs measured in MWh per year per hectare (SQ. 1). The quantitative value is retrieved from the power curve (Equation 1). The technical potential further depends on the available geographical surface area where the turbines can be built (SQ.2). This is measured in hectares and related to the potential electrical yield. Combining the two criteria, it is possible to get a final measure of aggregated technical potential energy yield over a period expressed in MWh per year.

The economic potential relates to the economic feasibility of building SWTs and is based on the related concepts of the Levelized Cost of Energy (LCOE), Net Present Value (NPV) and Payback Period (SQ. 3). A project is economically feasible when the LCOE of the project is lower than the sales price or the price the investor would otherwise have paid. If this is the case the NPV of the project will then be larger than zero, implying that a profit can be made. The payback period depicts the amount of years in which the investment will be earned back. Erwin Haverman working at LTO Noord, a member-based association of agricultural entrepreneurs, suggests that for farmers to consider the investment, the payback period should be less than 10 years.

The social feasibility is considered through qualitative based criteria (for analytical framework see Appendix 1). The two main components considered are governance strategies (principally project management), and ownership models for SWTs. The criteria for project management strategy is based upon the roles and responsibilities of authoritative parties and key participants (i.e. individuals or groups that hold certain leverage in decision making for municipality projects). The roles and responsibilities involve tasks related to legislative review, seeking financial support, media and communication updates, and educatory actions. The criteria for ownership models are based on a distinct literature review of best practice bottom-up ownership models in the field of renewable energy. The bottom-up approach is chosen because in this case study for UH, there is assumed to be a limited capacity of power generation connection to the central grid; therefore, electricity usage from SWTs should mainly comprise self- or neighbourhood-consumption.

Governance strategy must also address the degree of social support for SWTs in UH. The social acceptance rate is based on the strength and proportion of peoples' stance on the deployment and aftermath of a wind farm, measured through a variety of factors. The assessment of social acceptance considers both technical and spatial variations in rates of acceptance that come about as a result of windmill type (height, materials, aesthetics etc), location (land-use type, proximity to residence etc) and ownership model. Results from the case study evaluation will provide a qualitative and quantitative indication of levels of opposition that may occur in the case for implementing SWTs in UH but will not be used as empirical evidence.

Environmental impact was analysed from three aspects, which are bird and bat mortality, land use and property value change, and noise. Given that we failed to find the legislative standard of bird and bat fatalities caused by wind turbines for the Netherlands, an approach to determine whether the bird and bat mortality is acceptable or not is to compare the estimated value to the value of existing permitted wind farm. If the estimated value is significantly lower, then it is acceptable, and vice versa. The estimated value was obtained from case studies. To study the impact on land-use and property value change, land-use and property value data were compared before and after the construction of wind turbines, and if there is no significant variation, we can conclude that there is no significant impact. Noise issue was evaluated by comparing noise parameters of SWTs provided by manufacturers to the legislative standards.

By analysing literature on renewable energy governance and incorporating the above framework, conclusions can be drawn on the strategies that exist for the municipality to implement SWT and choose the best-practice ownership models. Assuming the technical and economic conditions are met for SWTs in UH, then the deliverable for the social governance section will promote a further step beyond project implementation that may entail possible legislative changes.

Integration of natural- and social sciences

The essence of this research can be captured in two non-scientific research questions: First, *what SWTs do we want?* Second, *where do we want to place the selected SWTs?* These questions form the basis for integrating both the natural and social sciences and contribute to the transdisciplinary nature of the research project. To identify which SWTs are most suited for the case in UH, there is a need to include the technological performance, economic performance, social support and environmental impact. Then, to decide where SWTs should be placed geographically, we review the technological criteria of available and suitable land, social support and ecological vulnerability of the land. This multidisciplinary thematic integration is visually depicted in the analytical framework (figure 7).

3.2. Proposed End Products

Every sub-chapter of the results-section will consider the performance of all considered SWTs in each specific context (i.e. economics, social etc). Since most aspects have a spatial dimension, the suitability of SWTs will based on the established criteria will be displayed using map (except for the economic and social sub-chapter) (figure 8). The conclusion will integrate the results of the four sub-chapter in one table to create a holistic overview of the performance of the several SWTs with respect to all aspects considers (table 1). In addition, a map will depict the areas that are technologically, socially, and ecologically feasible.

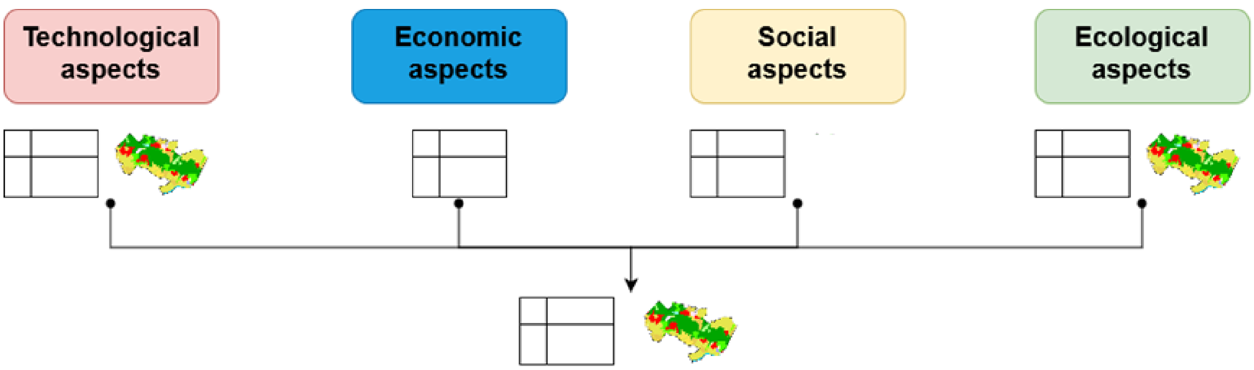

Figure 8 visualization of final results

	criteria	grading		
Technological aspects	Annual Yield (MWh)	High (>30)	Medium (10 - 30)	Low (<10)
	Wind speeds (m/s)	<4.5	3.5-4.5	< 3.5
Economic aspects	Payback Period (years)	< 10	10 to 20	>20
	LCOE (Euro)	< €0,20	€0,20 to €0,30	> €0,30
Social Aspects	Support Base	General opinion positive		General opinion negative
Environmental Aspects	Expected Bird & bat mortality	acceptable[3]		Not acceptable[4]
	Expected Land use & property value change	acceptable [5]		Not acceptable[6]
	Legislative standard	Sufficient[7]		insufficient[8]

Table 1 Criteria per four aspect sub-category

[3] significantly lower than the criterion
[4] not significantly lower than the criterion
[5] no expected decline after commissioning
[6] expected decline after commissioning
[7] lower than the standard (47 dB during the day and 41 dB at night)
[8] Higher than the standard (47 dB during the day and 41 dB at night)

4.Methods

The main research question is approached from a multidisciplinary perspective and is further broken down into several sub questions, delineated amongst four aspects: technological, economic, social, and ecological. For each of the four aspects criteria are formulated to distinctively answers the sub questions, rather than in a descriptive approach (Table 1). A more comprehensive description of each aspect is found in chapters 4.1 to 4.5.

4.1. Technical Potential

A complete feasibility study for wind energy includes preliminary area identification, area wind resource evaluation and micro-siting (i.e. determining the optimal location for wind turbines within the selected area). Since our feasibility study is exploratory and encompasses the entire municipality, the analysis is limited to the first two steps, and extended with an estimation on the total installed capacity potential in UH.

4.1.1 Potential Site Selection

Preliminary area identification is based on wind atlases, which depicts the variation in wind speeds across an area. Wind atlases combine data from satellites, ground measurements and meteorological models (Stepek & Wijnand, 2018; Erdem & Shi, 2011). Wind atlases for individual municipalities in the Netherlands are not available, and published maps with wind patterns at the hub height for designated SWTs are scarce. Hence, this report uses data from the Dutch Off-Shore Wind Atlas (DOWA) to construct wind atlases for UH at a height of 20 meters (the approximate average hub height of most SWTs).

The DOWA was created by KNMI (Royal Netherlands Meteorological Institute), ECN (Energy Research Center Netherlands) and Whiffle to "[help] the offshore wind energy sector to better understand the wind resource on the North Sea". However, it provides onshore wind data as well. The DOWA is based on a global reanalysis by the European Center for Medium-range Weather Forecasts (ECMWF), which involves fitting state-of-the-art atmospheric models to historical weather measurements. The model is further "downscaled" using KNMIs HARMONIE-model, and provides hourly windspeed data between 2008 and 2018, for 17 different heights (10m to 600m) across grid squares of 2,5 km by 2,5 km. The presumed accuracy and realistic detail of the DOWA is the major justification for using this dataset. For instance, the model includes roughness factors based on the land use in each grid square. (Duncan et al., 2019) (van Ulft, 2019).

The hourly data retrieved from the DOWA is averaged between 2014 and 2018 for four separate quarters, in order to capture seasonal changes, and projected on a basic map of the municipality with Panoply. Panoply further interpolates the data per grid square to provide a better visualization of gradual spatial differences. Based on the wind atlas, feasible locations for small wind turbines can be selected, based on a rough estimate of energy production required to break-even.

4.1.2 Wind Resource Evaluation

Despite the improved accuracy of wind atlases during recent decades, field measurements are still required to validate the preliminary site selection based on a wind atlas (Erdem & Shi, 2011). Nonetheless, the potential site assessment performed in this report is based on the DOWA. It is important to note that due to time and resource constraints, as well as the exploratory purpose of this report, the actual identification of available sites will be decided by the client and its stakeholders. Hence, this report primarily uses site assessment as a benchmarking approach, in order to show the potential for SWTs in UH. The potential electricity yield is both calculated for the optimal location within the municipality and for a location representative of the area with an economically feasible wind speed. This also means that our approach does not account for local variations in roughness, and hence for local turbulence.

While average wind speeds provide sufficient information to select the location with the highest wind speeds, energy yield assessments critically depend on the frequency of different wind speeds, since wind power depends on the cube of the wind speed, through the Equation 1 with ρ, density; A surface of the rotor disk, and v wind speed).

Equation 1

$$P_w = \frac{1}{2}\rho A v^3$$

Normally, preliminary wind energy assessments rely on the modelling of a probability distribution of wind speeds (the so-called Weibull or Rayleigh-distributions) in order to account for the cubed wind speed. However, the granularity of the DOWA (hourly data over a 10-year period), allows us to accurately approximate annual energy available in the wind in kWh: Assuming year-to-year differences are small, hourly wind power can simply be summed[9], and then averaged over 10 years.

Similarly, yearly turbine output could be calculated by multiplying power coefficients of different turbines with wind power (excluding wind speeds below the cut-in speed and above the cut-out speed). Unfortunately, the coefficient for different wind speeds can only be determined in a controlled setting of a wind tunnel, or through extensive field testing, and is generally not provided by manufacturers. Instead, most manufacturers provide a *power curve* in the form of a

[9] Since DOWA provides hourly data between 00:00 - 1 jan 2008 and 23:00 - 31 december 2018, summation over one year directly yields Watt hour (1 Watt power delivered over 1h) per year (which for practical purposes is converted to MWh).

range of outputs for different wind speeds. Under the assumption that the air density at the manufacturer's testing site is similar to the average air density of UH we can use power curves to estimate the annual yields of different turbines. Since wind power is directly proportional to air density, it is less sensitive to small violations of this assumption. Annual power output is then calculated using equation 2, where *E* is energy (*MWh*)*, P* power output (*MW*) at different wind speeds (*u*). *P(u),* the power curve between cut-in and rated speed, is the least-squares-fit of a polynomial of degree four on the power curve data.

Finally, the load factor, or capacity factor will be calculated, which is the ratio of total energy produced in a year, to the energy that would have been produced if the turbine would have operated at rated power for 100% of the time. Here we again use all data and use the yearly average energy that would be produced.

Equation 2 annual power output

$$E_{turbine/year} = \sum_{t=[00:00\ 01-01]}^{[23:00\ 31-12]} \begin{cases} P_{output/hour} = 0, & u_t < u_{cutin} \\ P_{output/hour} = P(u_t), & u_{cutin} \leq u_t < u_{rated} \\ P_{output/hour} = P_{rated}, & u_{rated} \leq u_t \leq u_{cutout} \\ P_{output/hour} = 0, & u_t > u_{cutin} \end{cases}$$

Grid Requirements

To provide some context on challenges and opportunities regarding the integration of SWTs in the grid, we will hold an expert interview with the grid operator (Stedin).

4.1.3 Land Availability and total wind resource availability

There should be enough space between multiple turbines, as rotor disks will otherwise obstruct the airflow on other turbines, causing *wake loses*. As a rule of thumb, 5-9 rotor diameters in the prevailing wind direction, and between 3-5 diameters in the direction perpendicular to the prevailing wind direction should be maintained (Shi &Erdem, 2017). The final step of the methodology will use 8 rotor diameters in both directions to determine the total resource availability in UH, excluding surface areas that do not fit within social and environmental constraints.

4.2. Economic Potential

To determine the economic feasibility of a project several measures are available. The most widely used is the NPV. For energy generating projects, often the LCOE is used. The LCOE defines the costs of power generation in cents*(kWh)$^{-1}$. For wind power projects Ragheb (2017) defines the LCOE for the United States market. Here the LCOE is adjusted for the Dutch market. In short, the LCOE shows the cost of the project over time, divided by the generation potential of the energy source:

Equation 3 Levelized Cost of Energy (LCOE) for wind on land in The Netherlands

$$LCOE_{SWT} = \frac{\sum_{t=0}^{N} \frac{I_t + O\&M_t + R_t + T - SDE_t}{(1+i)^t}}{\sum_{t=0}^{N} \frac{G_t}{(1+i)^t}}$$

Where,

$LCOE_{wind}$ = Electricity cost [cents*(kWh)$^{-1}$]

I_0 = Investment costs

$O\&M_t$= Operation and maintenance in year t [€]

SDE_t = Subsidy (Subsidie Duurzame Energie) [€]

R_t = Royalties or land rents [€]

G_t = Electrical generation in year t [kWh]

t = Year number

i = Discount rate

N = lifetime of the wind turbine

T_t = taxes [€]

More specifically, the investment (I_t) can be defined as the Capital Expenditure, which Blanco (2009) divides into (1) the cost of the turbine itself, (2) the cost of the grid connection, (3) the cost of civil work (e.g. infrastructure, roads), and (4) other capital costs such as permits and consultancy, advising costs. Operation and maintenance costs include provisions for maintenance (e.g. labor, spare parts) as well as insurance premiums and other management costs (Blanco, 2009). SDE reflects the subsidy available for renewable energy projects in the Netherlands. Tax levy is the tax owed and royalties and land rents are expenses to be paid if the turbine is built on rented land. represents the discount factor. In the denominator the generation potential can be defined as the Load Factor (%/100) * Rated Power (kW) * Hours in a Period (8760/year) (James and Bahaj, 2017) (see Equation 3).

The profitability of the project will then depend on the price at which the electricity can be sold, or, when the produced electricity is directly used by the owner, that is the price that would have otherwise been paid. The NPV (cash flow*(discount factor)$^{-1}$) can be calculated by slightly tweaking the LCOE formula:

Equation 4 NPV for wind on land in The Netherlands

$$NPV_{SWT} = \sum_{t=0}^{N} \frac{G_t * r_t - I_t - O\&M_t - T_t - R_t + SDE_t}{(1+i)^t}$$

With:

r_t = revenue of energy in year t (cents*(kWh)$^{-1}$)

Finally, the payback period will be calculated. This is the period in which the investment will have yielded the same (discounted) revenue as the initial investment. More technically this is the moment in time when the NPV of the project is zero.

4.3. Social Feasibility

Desk research will be the main method of research for social feasibility due to the limited capacity for primary data collection in UH. Adding to the theoretical background, a synthesis of literature will be analysed through the criteria laid out in Chapter 3. In addition, empirical evidence from the economic feasibility and the three case studies will be used to advise governance strategies and to determine the best-practice ownership models. It will not be possible to understand levels of social acceptance specific to UH, but the study will recommend data collection methods that could generate this evidence.

4.4. Environmental Impact & Land Availability

4.4.1 Desk Research

Due to time limit and lack of equipment for a thorough field investigation, desk research was the major approach in this study, to investigate the environmental impact by SWTs, which includes the issues of bird and bat mortality, land use and property value change, and noise pollution.

Bird and bat mortality were investigated through case studies. However, there were still obstacles. First, the information regarding the distribution and location of local bird and bat communities was not available, which meant that quantitative simulation could not be implemented in this project. Second, most scientific literature and institutional reports provided information regarding the general impact of wind turbines, such as the number of bird and bat fatalities per MW electricity generated per year, or fatalities related to large-scale wind turbines, but very few studies targeted on SWTs. In this case, we reviewed institutional reports to acquire the general pattern of such impact and looked specifically into two case studies in Scotland (Minderman et al., 2012) and the Netherlands (Brenninkmeijer & Klop, 2017). Minderman et al. (2012) focused on the impact of SWTs on bird and bat mortality, and provides detailed elaboration on the procedure of field investigation, while Brenninkmeijer and Klop (2017), though investigated the impact of large-scale wind turbines, studied general patterns of the impact of wind turbines on birds in the Netherlands. Through these case studies, we extracted conclusions that could serve as references to the situation in UH, and proposed advice that would possibly abate the ecological impact.

The desk research studying the impact of SWTs on land use and property value change was conducted by reviewing institutional reports. In countries such as the USA, the UK, and Australia, these reports were issued by governments on a regular basis, discussing the land use and property value change caused by the construction of SWTs. By reviewing these reports, we can extrapolate the trend of the land use change and property value change and see if there have been significant variations before and after the construction of wind farms. Since wind turbine construction and operation is not the only factor causing the land use and property value change, and the difficulty to separate the impact from other factors, we would investigate multiple places, in order to offset the uncertainties. A prospect of the land use and property value change after applying SWTs in UH would be based on these results.

The risk of noise pollution was studied by comparing the parameters of available types of SWTs and the legislative standards of noise caused by wind turbines. The parameters could be found in reports issued by European Commission under the *Intelligent Energy* program.

4.4.2 Interview

Since social acceptance acts as a major factor affecting the property value, we conducted an interview with Coen Overvest, the secretary of LTO Noord, to investigate the opinions of farmers on the impact of applying and the siting of SWTs on the land use and property value of their lands.

5. Results

5.1. Technical Potential

5.1.1 Potential Site Selection & Assessment

The wind maps (figure 9 and 10) demonstrate that, while windspeeds are relatively low in UH, the area around Kasteel Sterkenburg is one of the optimal locations, and will be further analyzed and compared to Leersum, the reference location, which experiences mildly advantageous winds. Windspeeds are relatively stable throughout the year, as is shown in Figure 11. While peak windspeeds may fluctuate, mean speeds and frequency distributions are consistently slightly below 5 m/s and mostly between 1 and 6 m/s, respectively. Figure 12 further illustrates this.

Figure 12 and 13 show that while very high wind speeds occur on some days the general average is relatively low. Specifically, Sterkenburg experienced an average wind speed of 4.5 m/s between 2008 and 2018 (In Leersum this was 4.18 m/s). The wind direction in both locations is very comparable, and show most, most strong winds come from the south-west (and south-south-west, and west-south west), in total 35%, the lion’s part of strong wind (figure 14). This means that locations with no buildings or trees on the south west are preferred for the placement of SWTs.

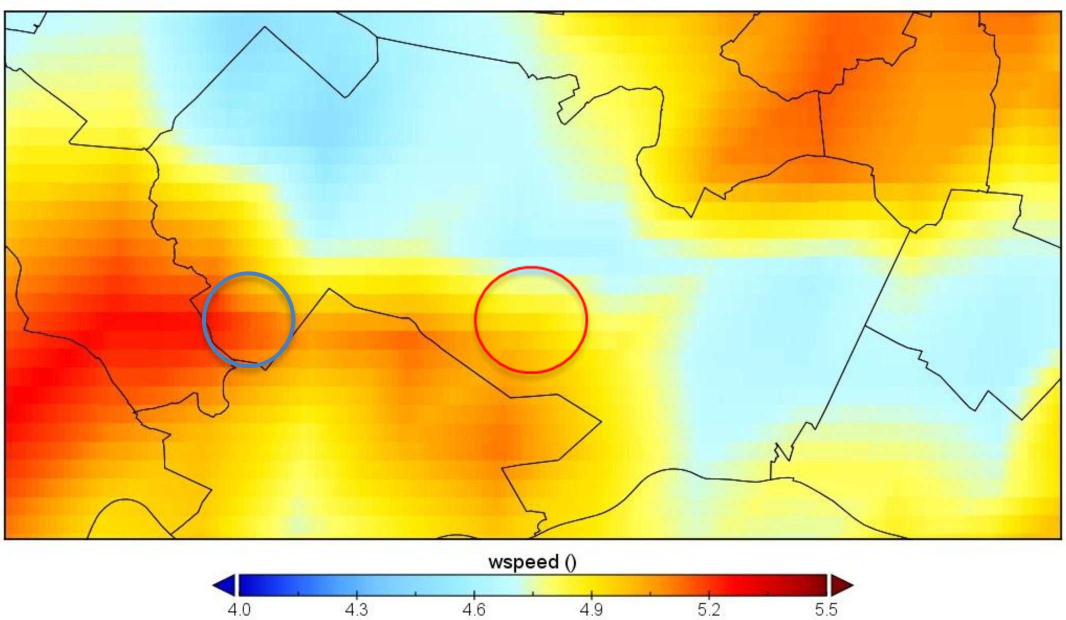

Figure 9 Wind speed distribution of UH at 20 meters above the surface in Q1 (average 2014-2018), Sterkenburg is indicated by the blue circle, Leersum is indicated by the red circle.

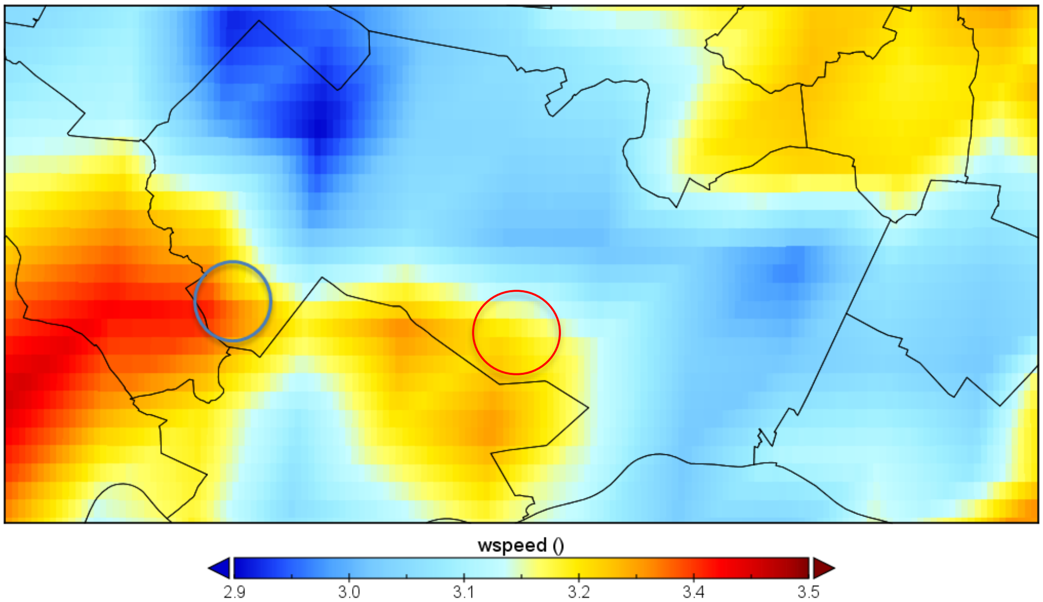

Figure 10 Wind speed distribution of UH at 20 meters above the surface in Q3 (average 2014-2018), Sterkenburg is indicated by the blue circle, Leersum is indicated by the red circle.

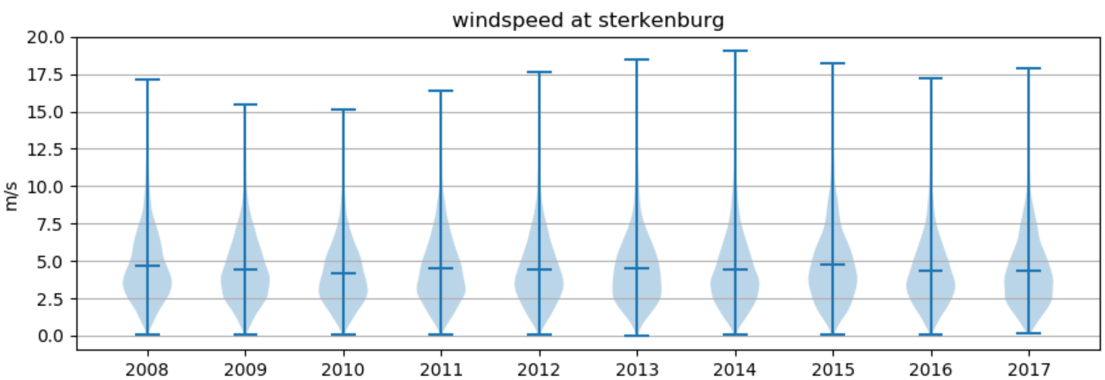

Figure 11 yearly average wind speeds: averages outliers and distributions

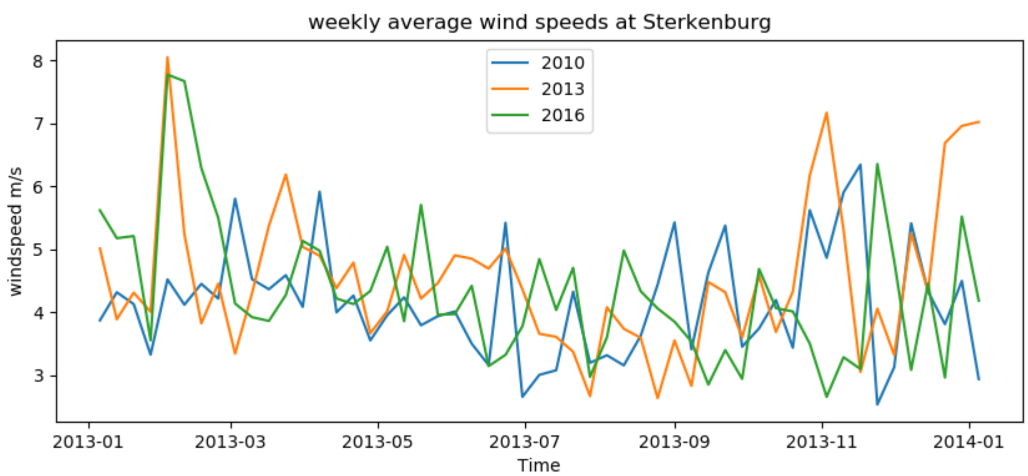

Figure 12 weekly average wind speeds at Sterkenburg

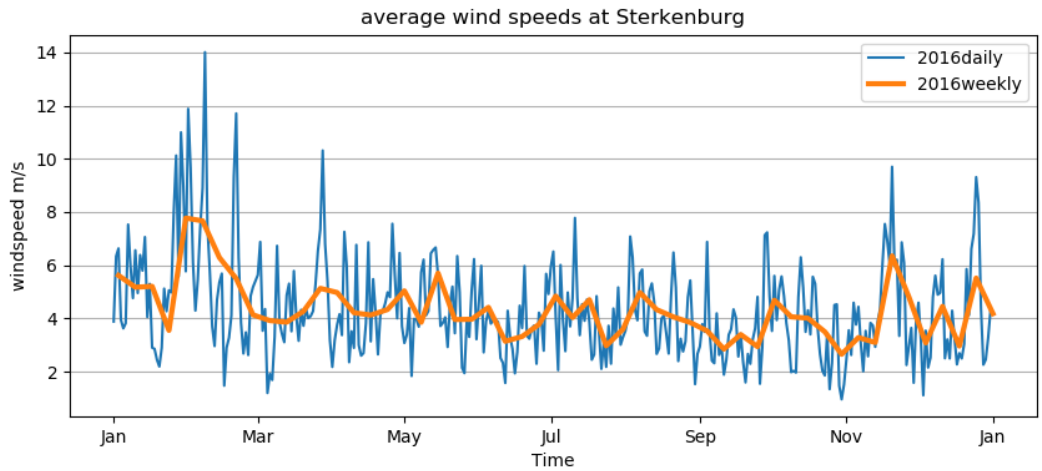

Figure 13 Average wind speed at Sterkenburg

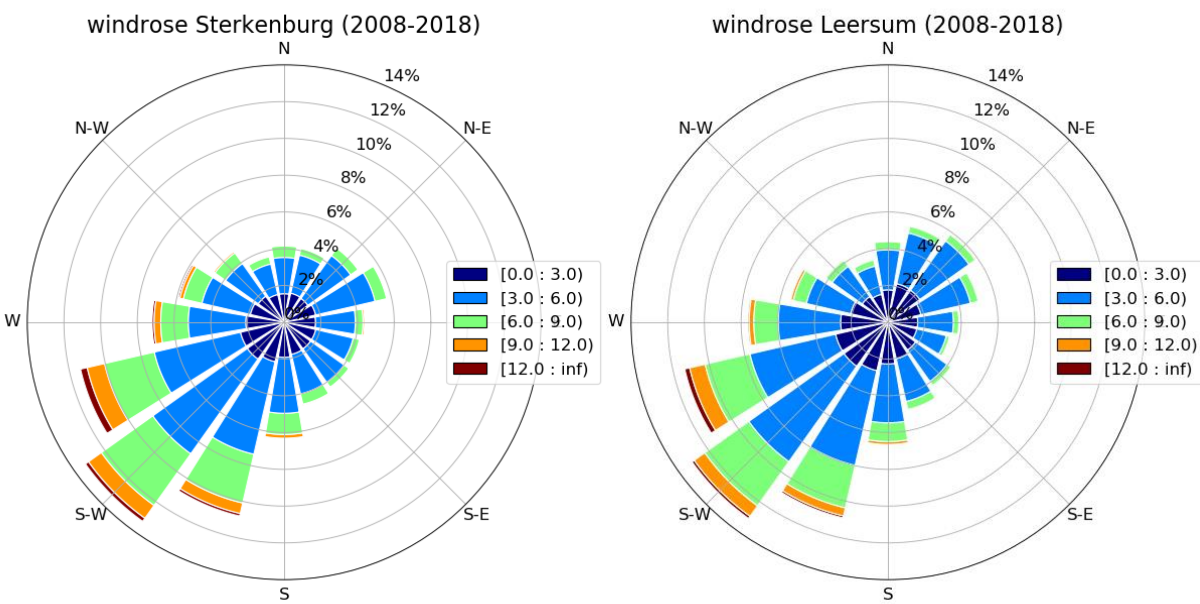

Figure 14 . The wind roses of Sterkenburg and Leersum from 2008 to 2018

5.1.2 Available Small Wind Turbine Models

The yields of several small wind turbines will be examined (see figure 15). Three of these (A, B and C) are included for illustrative purposes: Turbine A to demonstrate the feasibility of micro-scale wind turbines, turbine B to show the functioning of HAWTs, and turbine C to examine a purpose-built turbine for land-locked low-wind areas. Turbine C is however only available in Switzerland and a price estimate could not be obtained. The following three turbines, (D) E.A.Z. Wind, (E) Solid Wind and (F) the WES 80 have the largest likelihood to be feasible and available for the Utrechtse Heuvelrug, as they are within the norms of the "verordeningen ruimtelijke vormgeving" with a hub height of 15-20 meters. The Skystream 3.7 (G) is a smaller windmill and the Innoventum Dalifant (H) is only available in Sweden.

A. Energy Ball V100 (Home Energy, 2019)

The energy ball is the smallest wind turbine considered. It is (in this report) the only one purposefully made to be mounted atop a roof and costs around €3,000. An additional €1,500 - €2,000 must be counted for installation the installation of the Energy Ball. The Energy Ball has a rated power output of 0.5 kW and an estimated yearly power generation of 500 kWh. Rooftop mounted wind turbines, however, often suffer from poor performance due to the inconsistent and low-energy winds in (sub)urban areas (James and Bahaj, 2017). Considering the shortcomings of the technology, this paper considers the energy ball only for holistic knowledge purposes. Technical and economic data for this model come from the report "Resultaten testveld kleine windturbines Schoondijke" (Ingreenious, 2014).

B. Turby (Turby, 2019)

The Turby is the only VAWT that is considered in this report. Generally, VAWTs have a lower performance ratio than HAWT and are not suitable for commercial exploitation, but rather function well in off-grid (extreme) situations. Even based on the manufacturer's calculations, energy produced by the Turby is 18 times more expensive than regular energy. The Turby can be rooftop- or pole mounted with the turbine having a diameter of 2 meters and a height of 2.9 meters. It is rated at 2.5 kW and will generate 3,000 kWh/year under optimal conditions. With a price of about €16,000 it is relatively expensive for its power output. Technical and economic data for this model come from the report "Resultaten testveld kleine wind turbines Schoondijke" (Ingreenious, 2014).

C. Aventa LoWind (Aventa AG, 2018)

The Aventa LoWind is considered best in its category when it comes to low-wind performance (Appendix 4). The turbine has been designed for average wind speeds of up to 4.5 m/s. The LoWind also has a hub-height of 18m and has a rotor diameter of 12,9m. Rated at 6,5 kW it should generate 16.000 kWh/year with an average wind speed of 3,5 m/s, 20.000 at 4,0 m/s, and 24.000 at 4,5 m/s. A price estimate from the manufacturer is unavailable, so the LoWind is solely included to assess the technical performance in the landlocked area of the UH.

D. E.A.Z. Wind 12 (EAZ Wind, 2019)

The relatively young (2014) Dutch company, E.A.Z designed a wooden, pole-mounted wind turbine to be aesthetically pleasing, to merge with its environmental surroundings, to provide enough energy for a single farm and to be built with locally sourced materials. This wind turbine sparked the interest of the municipality Utrechtse Heuvelrug in small-scale wind turbines and is this report's benchmark for social acceptance. With support from local residents E.A.Z. Wind has built over 400 of these turbines in Groningen (province) and the first has been built outside of Groningen only last month near Vinkeveen in the province of Utrecht. The turbine has a hub height of 15 meters and a rotor diameter of 12 meters. The E.A.Z turbine is rated at 15 kW and is expected to generate 33,000 kWh at an average wind speed of 5 m/s. Since the power curve could not be obtained, a power curve has been estimated based on the cut-in, cut-out and rated wind speed. Since EAZ is a fixed-speed turbine the power output is assumed to decrease after the rated power output. The estimated initial costs for the E.A.Z turbine including permits and installation amount to approximately €56,000.

<table>
<tr><td>A] Energy Ball
</td><td>D] E.A.Z. Wind
</td><td>G] SkyStream 3.7
</td></tr>
<tr><td>B] Turby
</td><td>E] Solid Wind
</td><td rowspan="2">H] InnoVentum Dalifant
</td></tr>
<tr><td>C] Aventa LoWind
</td><td>F] WES 80
</td></tr>
</table>

Figure 15 Selection of Small Wind Turbines

E. Solid Wind 25kWh (Windmolens op Maat, 2019)

The Solid Wind turbines is included in this report because its capacity fall in between the InnoVentum and WES 80. However, after emailing and calling the manufacturer they were not willing to provide us with a price estimate and power curve, therefore we were unable to include this model in the analysis. For a detailed analysis of this model we would like to refer to the upcoming report of LTO Noord (Case study Wilnis, Appendix 5).

F. WES 80 (Wind Energy Solutions, 2019)

The WES 80 is the most powerful and the most expensive SWT considered (€178,000). With an 80-kW power output and rotor diameter of 18 meters it is disputable whether or not the WES 80 fits as a small-scale turbine or is categorized as a mid-sized turbine (Appendix 4). However, the turbine does provide the option of an 18-meter hub-height setup, which is within the legal boundaries set by the Utrecht province. To receive a price-quote for this setup we agreed to mention that the manufacturer does not recommend this low hub-height setup in the relatively low wind speed area of the UH because it does not allow for the full potential of the SWT. Also, for an analysis of the larger version we would again like to refer to the upcoming report of LTO Noord (Case study Wilnis, Appendix 5).

G. AdviTek SkyStream 3.7 (AdviTek, 2017)

This turbine is the smallest 'classic' three-bladed turbine to date. It has a blade diameter of 3.72 meters and a swept area of 10.87 m^2. The AdviTek Skystream is designed to be pole-mounted and is small enough to fit on a rooftop. This specific turbine is included because it has the lowest LCOE of all turbines tested at Zeeuwse Schoondijke (Ingreenious, 2014). The manufacturer rates the turbine at 1.8 kW whereby with an average wind speed of 4.5 m/s it should reach a power generation of 2,400 kWh/year. The combined costs for the turbine and installation are just above €10,000. Technical and economic data for this model come from the report "Resultaten testveld kleine wind turbines Schoondijke" (Ingreenious, 2014).

H. InnoVentum Dalifant (InnoVentum, 2019)

The tallest wind turbine considered in this report measures 19.8 meters (i.e. hub height). It is advertised by the manufacturer as "the most beautiful wind turbine in Sweden". The Innoventum Dalifant has a wooden base and fiberglass upper part, making it the opposite style structure of the E.A.Z. Wind turbine when considering the wood architectural construct. Marketed at about €88,000 for a complete installation, the InnoVentum is the second most expensive SWT technology considered in this report. The Innoventum Dalifant has a rotor diameter of 13 meters and is rated at 11 kW. Designed for average wind speeds of 6 m/s it is expected to generate 38,000 kWh/year.

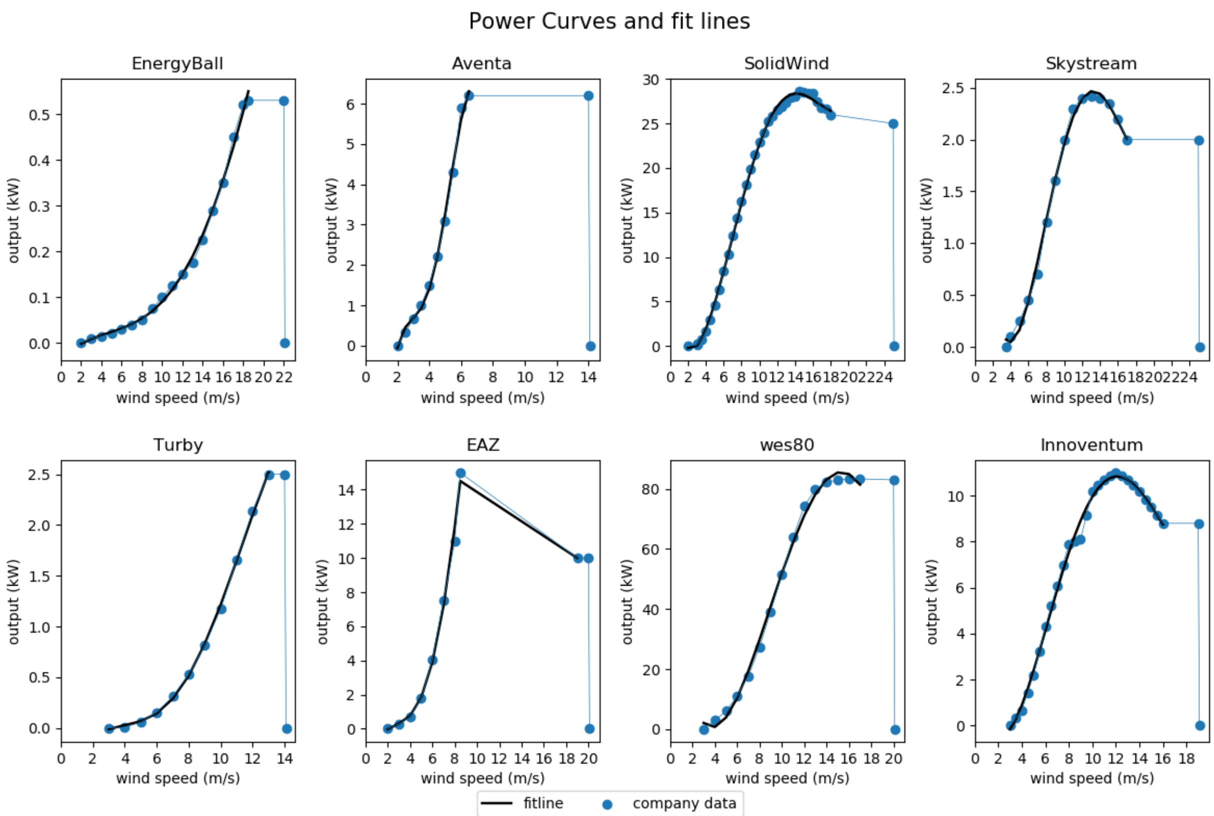

Figure 16 power curves of each wind turbine as provided by the manufacturer, and the polynomial which was fitted in order to do calculations

	Rated power (kw)	Rated wind speed (m/s)	Yield (MWh/year)		capacity factor	
			Sterkenburg	Leersum	Sterkenburg	(Leersum)
EnergyBall	0.55	17	0.20	0.18	0.05	0.04
Turby	1.90	14	1.26	1.02	0.08	0.06
Aventa	6.50	6	22.08	19.57	0.39	0.34
EAZ	15.0	8.5	24.40	20.40	0.18	0.15
SolidWind	25.0	11	42.50	35.83	0.19	0.16
wes80	80.0	13	68.19	55.57	0.10	0.08
Skystream	2.10	11	2.67	2.18	0.17	0.14
Innoventum	11.0	12	19.82	16.77	0.21	0.17

Table 2 An overview of technical performance of SWTs

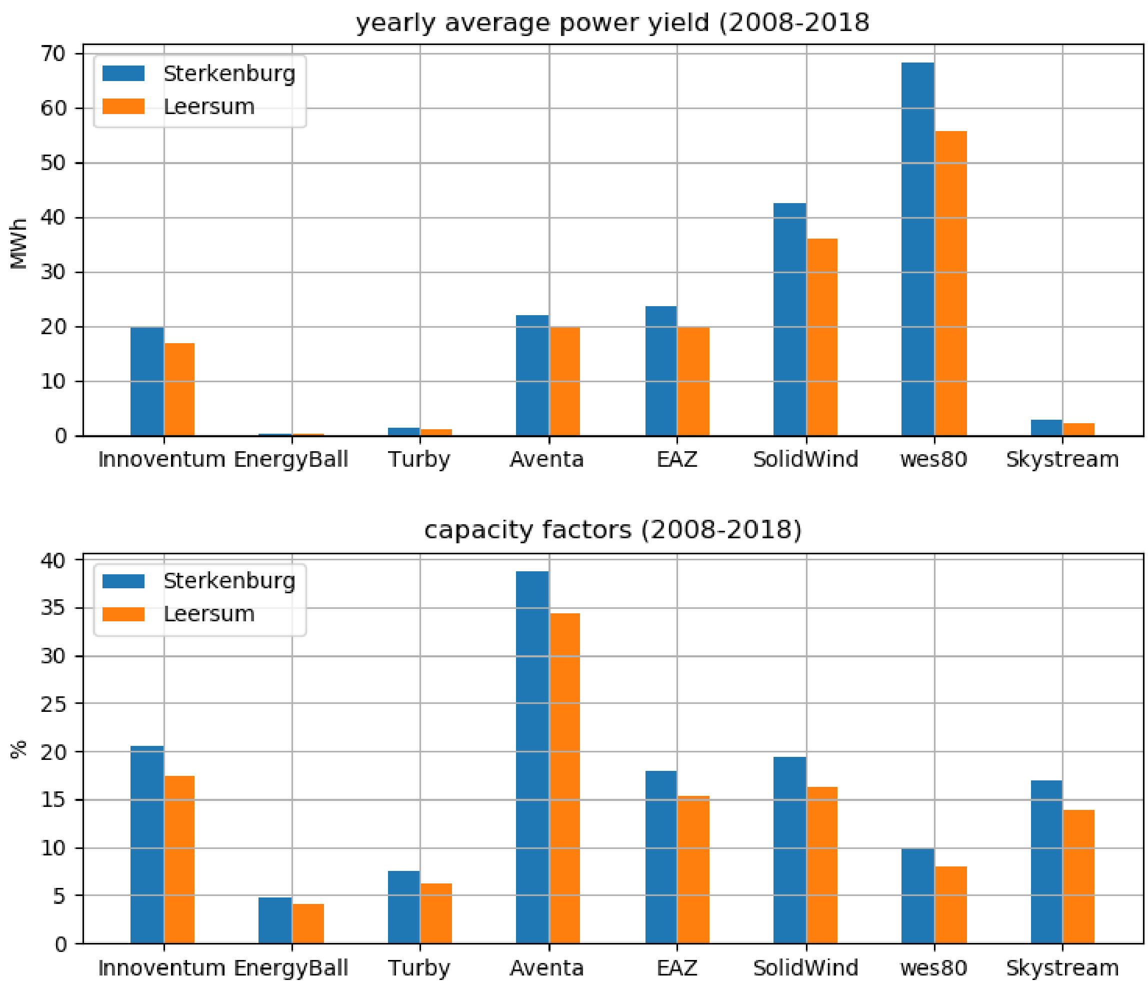

Figure 17 The yearly average power yield of eight selected SWTs (upper) and their capacity factors in Sterkenburg and Leersum (lower).

Figure 13 displays the average yield at the optimal and the reference location, and the capacity factor. Whilst some wind turbines achieve a substantial yield, their capacity is not very appropriate for the wind speeds that occur at UH. This leads to very low capacity factors, which means the turbines are not used to their full potential.

To put these results in perspective, table 3 displays the results for a representative, conventional 2MW wind turbine with a hub height of 100 meter. The capacity factor for both locations is meaning this type of wind turbine, which would supply the equivalent of about 100 to 300 SWTs, feasible in UH. This is due to the greater height (where the average windspeed in UH is 7 m/s), as well as the greater rotor diameter.

	Sterkenburg (MWh/y)	**Leersum (MWh/y)**	**Rated power (kW)**	**capacity factor (St. burg)**
Vestas V90	6718.1	6506.3	2000	0.38

Table 3 similar analysis applied to the Vestas V90 (hub height 95-105m)

5.2. Economic Potential

This chapter elaborates on the costs (e.g. capital expenditures, tax levies, and royalties) and benefits (e.g. subsidies, tax cuts, and sold/used energy) as discussed in the method section (4.2). An example calculation will show how the costs are summed to compute the LCOE, NPV and payback period. Hereafter, an overview will be provided of the economic measures for all considered SWTs (i.e. where the data allows it). Full economic data for the E.A.Z. Wind, WES 80, SkyStream and InnoVentum Dalifant can be found in appendix 4. The Energy Ball and Turby have such high costs that full details will not provide additional insights. As for the Aventa LoWind no (economic) data was obtainable.

5.2.1 Costs

The largest cost for SWTs is the upfront investment cost for acquiring the turbine. Although these costs can be divided into several categories as done by Blanco (2009) most manufacturers offer 'full-service packages' in which they take charge of logistics from building the foundation and connecting the turbine to the grid to applying for the available subsidies. E.A.Z. Wind, for example, offers such a package for roughly €56,000 and InnoVentum estimates full installation costs at €88,000 for a standard placement. Operation and maintenance costs are relatively low for SWTs and average approximately €200/year.

Standard prices quoted by SWT manufactures exclude the Value Added Tax (VAT or 'BTW' in Dutch), which makes sense for businesses such as farms, because the business can deduct the VAT as it will not increase the company's net expenses. For other ownership structures however (e.g. private, energy cooperatives) the VAT is an added value of 21% in addition of the gross sales price. Depending on the place and circumstances, when one builds a structure in the Netherlands, one might be subject to a building levy, which, in the case of Willeke Peek (Appendix 6.2), amounted to an unexpected €1500 additional amount to all other costs.

Lastly, there are the costs for royalties and land rents. These costs mainly apply to energy cooperatives that do not own land on which SWTs can be built. Farmers and private customers who built SWTs on their own land are not be subject to royalties and land rent costs.

5.2.2 Benefits

The first and most significant benefit of installing a SWT is the generated power that can be either sold or used by the owner. Depending on the ownership structure, subsidy schemes and current (private) electricity use of the owner can vary from ± 5 cents/kWh to 23 cents/kWh (Consumentenbond, 2019). Where 5 cents/kWh is roughly the (volatile) market price of energy and 23 cents/kWh the maximum price that a private customer pays.

There are currently four types of subsidy schemes available for SWTs: SDE+, POP3, net metering and the 'postcoderoosregeling'. All three have different pricing schemes and not all of them are available for every ownership structure. The SDE+ scheme is the most general of the four and covers the difference between the current base-line price of grey electricity and the price of the generated green electricity (with a preset limit) (RVO, 2019). The height of this subsidy varies per case but amounts to approximately €750/year or 3 cents/kWh in the case of Willeke Peek (section 5.5.2).

The POP3 subsidy scheme is part of the rural development program of the EU in collaboration with national and regional governments (Provincie Utrecht, 2019). Although it was awarded in 2019 it is not yet decided whether it will return in 2020. The POP3 subsidy is only available to commercial farms and amounts to 40% of the total investment costs in sustainable energy production (i.e. SWTs).

Net metering is only available for non-commercial grid connections and allows the end user to sell back electricity for the same price that he/she has bought the electricity for (Rijksoverheid, 2019). Therewith not having to pay for taxes and transportation costs. Due to the Dutch electricity taxation scheme that decreases with use, the height of the net metering subsidy scheme depends on the current price the owner of a SWT pays for electricity.

The 'postcoderoosregeling' is set-up specifically for energy cooperatives and releases them from the tax burden when the electricity is used within the zipcode region of electricity production (Ministerie van Economische Zaken, 2014). This amounts to a guaranteed price of €0.1193/kWh in 2019 (E.A.Z. Wind and SamenWind, 2019, section 5.5.1).

5.2.3 Calculation Assumptions

For each of the turbines several scenarios have been analysed, using different available subsidies, applicable taxes (i.e. VAT), and the price of electricity. For all calculations a discount factor (r) of 4% has been used based on the information provided by the TriodosBank Helpdesk (TriodosBank, 2019). All prices considered for the results in tables 4 and 5 are without VAT. LCOE includes the SDE+ subsidy (€0.03/kWh) and excludes the land rents. The NPV is calculated for a lifespan of 20 years and a price of €0.18/kWh (price for electricity when using between 10,000 and 50,000 kWh/year). According to most manufacturers, the average lifespan of a wind turbine is about 20 year, so this estimate is applied here. Operation and maintenance costs are assumed to be €200/year for the E.A.Z. Wind, WES 80 and InnoVentum Dalifant (E.A.Z. Wind and SamenWind, 2019, section 5.5.1), €100/year for the SkyStream and Turby, and negligible for the Energy Ball.

The results in table 3 show that most SWTs are not cost-effective, only E.A.Z and WES 80 have a positive net present value. However, at slightly less windy condition at Leersum, NPV is negative also for these turbines (table 5).

Type of SWT	**Price** (excl. VAT)	**LCOE** (w/ SDE+)	**NPV** (20 years, €0.18/kWh)	**Payback period** (years)
EnergyBall	€4,324. -	1.56	€-3753. -	103
Turby	€21,350. -	1.22	€-17754. -	80.7
Aventa	-	-	-	-
EAZ Wind 12	€56,000. -	0.15	€10,919. -	11.4
SolidWind	-	-	-	
WES 80	€178,000. -	0.17	€13894.-	12.6
Skystream	€10,742.	0.34	€-5,840. -	29.8
Innoventum	€88,000. -	0.3	€-34,152. -	22.2

Table 4 An overview of the economic performance of SWTs at Sterkenburg

Type of SWT	**Price** (excl. VAT)	**LCOE** (w/ SDE+)	**NPV** (20 years, €0.18/kWh)	**Payback period** (years)
E.A.Z. Wind 12	€56,000. -	€0.15	€ -480.-	13.7
WES 80	€178,000. -	€0.18	€-22,111.62	15.5

Table 5 An overview of economic performance of SWTs at Leersum

5.3. Technical and Economic Aspects of Grid Integration

The integration of increasing intermittent RE sources in the central grid poses a challenge for the Distribution System Operator (DSO). Anticipatory capacity increase ahead of actual project implementation in a certain area is currently prohibited, so DSOs must follow the private and public investments in RE systems. The investment and time required for the expansion of the high-capacity grid and accommodate these systems has currently left little room in on the grid for additional systems in many places in the Netherlands, including UH. An interview with Stedin's Area Director ("Gebiedsregiseur") of the UH revealed that since SWTs are small and dispersed over an area, they can be connected to the low-voltage grid. Hence, the grid capacity expansion is less costly and time-consuming than for conventional wind-turbines. Standard instead of tailormade units can be installed and if neighbouring windmills are installed at the same time, total costs could be limited further. The exact cost estimate will have to be based on area specific analysis by Stedin, and depends on site-specific demand, supply and capacity.

5.4. Social Feasibility

A synthesis of theoretical and research-based literature concludes that social feasibility must include a three-pronged approach that considers: governance and management strategies; best-practice ownership models; and indicators of social acceptance. Due the limited implementation of SWTs, it is difficult to formulate a specific recommendation for the social feasibility of SWTs. However, the following three cases, backed up by academic literature will clarify what elements should be generally included in a successful wind energy governance strategy.

5.4.1 Literature Study

There is a large amount of literature that investigates the importance and success of community involvement at a local level for renewable energy transitions. Participation may comprise membership to wider energy cooperatives or local ownership and/or management of renewable energy technologies. Three main incentives for community ownership of energy production include "local income and regeneration", greater chances of "local approval and planning permission" and "local control" (Walker, 2008: p. 4402). Meanwhile "wind farms have achieved a clear commercial viability which helps to enable community ownership" (Walker, 2008: p. 4402); whether by reducing individual energy costs or providing collective income through the sale of electricity back to the grid. What it is not clear in the literature is precisely how large a farm needs to be, or if the 'commercial viability' can be applied to SWT's in the development stage. The difficulty is that regardless of opportunities for community ownership, wind energy has historically retained a level of social opposition that makes it exclusive in comparison to other renewable energy types (Wüstenhagen et al., 2007).

Energy cooperatives are an important component of a wider energy transition and "community-led approaches become innovative in the sense that they aid in the process of people changing their everyday practices together…", whilst also strengthening "citizens in their (joint, collective) capacity to change societal structures " (Hoppe et al., 2015: p. 1903). An unintended benefit of successful SWT implementation in UH may inspire a wider environmental 'revolution' in clean energy and sustainable consumption at a community level that pushes the municipality in realising more ambitious climate emission targets. In this case, local government as a facilitator of Local Energy Initiatives, does not operate as the main driver of the renewable energy transition but exists primarily to provide citizens with confidence (Hoppe et al, 2015) whilst the "existence of regulations and policies can act as stimuli to those with environmental concerns but who may not be sure how to act upon them" (Chmutina et al, 2014: p. 128). Therefore, if the municipality of UH harbours greater ambitions of clean energy and environmental policy, beyond the implementation of SWTs, then promoting community-owned or managed models may be an innovative means to do so. Literature analysing case studies in the UK suggests that environmental concern and awareness ranks as significant as legislation and compliance in achieving renewable energy targets at a local level. Whilst residents of UH may take exception to the concept of (large) wind turbines in their neighbourhood, the general appreciation for a green and natural environment in the municipality may translate into a combined and organised effort for wider environmental improvement. Furthermore studies from Scotland concluded that while community ownership is not the outstanding factor in public acceptance, "the promotion of a more locally embedded approach to wind energy projects (whether through community ownership or energy cooperatives) can help reduce the incidence of damaging and controversies that currently afflict wind power development" (Warren & McFadyen, 2010: p. 211). That said, whilst the motives for personal membership of RECs may differ, it is generally expected that it would be financially compensating and larger in scale than the individual turbines proposed for UH. With little to no potential for supplying the national grid it is not expected at this stage that RECs would represent a suitable ownership model for SWTs. As such, for the reminder of the section, when referring to community energy it is in the individual (or collection of individuals) sense rather than an organised collective form.

Community-operated energy is still at a beginning stage in the Netherlands. Studies in Germany point to the necessity for policymakers to strengthen the legislative and support mechanisms needed to help facilitate individual or community-owned wind turbines, in addition to any technological drive (Li et al, 2013). It is important to note that legislation does not become effective at a community level through its legal implication until it is conducive to inspiring and enabling a bottom up approach to local renewable energy projects, which may be especially true for SWTs. Once technical and economic conditions have been met, feasibility studies assessing the conditions for successful local energy transitions in the Netherlands have concluded that collective interactions are as important as any other requirement. The extent to which SWTs can provide a significant contribution to UH's electricity requirements depends on the collective belief and vision in the project at a community level which cannot be generated from government or investors alone.

"We find that the creation of a committed local organization, with a shared vision and concrete goals, is at the start of the change process. Many local initiatives went through a formalization process, which in turn strengthened the organization. Further-more, the level of activities, including communication efforts, is an important indicator of local team effectiveness. To be successful, local organizations need to entertain strong and continuous relations both on the local as well as on the global level" (Van der Schoor & Scholtens, 2015: p. 673).

Despite these conclusions, discrepancies and uncertainties remain about applying successes of community energy from other countries, or even other provinces in the Netherlands, as a basis for SWTs in UH. A comparative study of energy cooperatives in the Netherlands concluded that "the active or even passive support of citizens and social groups on Goeree-Overflakkee seems to be rather the exception than the rule. In many other local communities, serious obstacles arise such the acceptance of wind turbines, spatial planning problems, and legal procedures and protest" (Hufen & Koppenjan, 2015: p. 13). Ultimately the literature at this stage, though pointing to the importance of LEI's as a significant condition for success and the positive potential of community-based ownership models, is too inconclusive to say that UH will certainly benefit from this approach. However, removing bottlenecks to finance, planning and permit distribution are promising measures to provide smarter opportunities for SWTs.

5.4.2. Recommendations

Table 6 summarises the social feasibility of various SWTs based on economic data from the study and ownership models and social acceptance derived from literature and case studies. Corporate providers and renewable energy cooperatives and deemed to be none applicable as no turbine has the capacity to supply power to the national grid. Of the other three ownership models - all grassroots - feasibility is based on power capacity and investment requirements only and does not consider payback time, which deems all turbines to be economically infeasible. The results therefore are merely an indication of best-practice ownership models and social feasibility if technical and economic criteria were able to be met.

What governance strategies exist for managing SWT projects?

The municipality should conduct a full stakeholder analysis once technically and economically feasible sites have been located. This will determine who has stakes and interest in SWTs, before considering legislative or support gaps that exist for different stakeholders. This may involve subsidies or policies specific to certain stakeholders such as farmers, small businesses or communities. Additionally, it would highlight the main barriers or sources of opposition that would need to be addressed as part of the governance strategy. Importantly the legislation process needs to be smoother as EAZ claims it often as a mediator between communities/individuals and municipality for those who wish to purchase SWT's by advising on legislation. This difficult nature of the process was also reiterated by Samenwind. Finally, incorporating SWT's into a LEI would provide a comprehensive and consistent framework for managing projects at different sites across UH that considers and addresses all four aspects of the study.

Samenwind, a small, local energy cooperative promoting renewable energy in Groningen was able to provide some anecdotal analysis of barriers to social acceptance. The cooperative was instrumental in encouraging wind energy uptake in the province and organised the implementation of a neighbourhood turbine. The literature supports their claim that community consultation is key in the governance process of renewable energy uptake, and especially in wind energy projects due to the aesthetic nature of wind turbines. As such working closely with proponents of SWTs to settle upon locations, timescales and policy will be key to the governance process in UH.

Additionally, we propose generating an indicator of social acceptance through the comprehensive use of surveys once the technical feasibilities have been calculated. An example survey can be found in Appendix 3 and considers acceptance towards various models of turbines, proximity to residential and natural areas and whether owning or managing a turbine would alter their views towards them. This can be used to make final decisions on location and model once technical and economic feasibility has been satisfied and a social feasibility layer can be added to final maps. The criteria of Libau (Appendix 7), the independent advisory organisation utilised by E.A.Z., was an important reference point for deciding on the spatial and technical specifications with regards to social acceptance once other technical criteria have been satisfied.

Type of SWT	Corporate Provider	Energy Cooperative	Community-owned	Individually owned	Business-owned	Social Acceptance
Energy Ball	N/A	N/A	No	Yes	Yes	Yes
Turby	N/A	N/A	No	-	Yes	Yes
Aventa LoWind	N/A	N/A	-	-	-	Maybe
EAZ Wind 12	N/A	N/A	Yes	Maybe	Yes	Yes
Solid Wind 25	N/A	N/A	-	-	-	Maybe
WES 80	N/A	N/A	Maybe	No	Maybe	Maybe
SkyStream 3.7	N/A	N/A	Yes	Maybe	Yes	Yes
InnoVentum Dalifant	N/A	N/A	Maybe	No	Maybe	Yes

Table 6 Social feasibility of SWTs, incorporating ownership models and social acceptance.

What are the best practice ownership models of SWT’s?

Literature points to renewable energy cooperatives, whether members are citizens or collective commercial interests, as a general best-practice method of renewable energy ownership. However due to limited energy capacity of SWTs it is not possible to utilise them for supplying electricity to households through the grid. Additionally, wind speed limitations in urban areas makes SWTs unviable in such locations. As such national or corporate ownership are incompatible models of ownership, whilst garnering sufficient community investment in rural areas, will be limited and challenging. Furthermore, with a small number of turbines expected to be built across UH and the limited capacity to sell back to the grid, it is unlikely there will be significant support for investment through energy cooperatives. The most suitable model of ownership is therefore individually owned turbines that are managed at the local level. This may include farmers, rural businesses or small rural neighbourhoods who possess the financial resources to invest. Electricity generated from the grid will specifically be used on site.

5.5. Environmental Impact

5.5.1 Bird and Bat Mortality

Case Study: Scotland

Minderman et al. (2012) did field investigations on bird and bat mortality caused by SWTs in central and southern Scotland. For bird activities, the results showed that no significant difference between the number of flights in the two distance ranges. In addition, no significant difference between the amount of bird flights between SWTs operation and non-operation situations. These findings suit for all bird species observed at the study sites. Therefore, the research by Minderman et al. (2012) suggests that (1) birds do not avoid the area within 20 meters in radius around SWTs, and that (2) the presence of SWTs do not affect habitat use by the birds.

For bat activities, the results showed that (1) during SWT operation, no significant difference of the number of bats observed between the two distance ranges was found, and that (2) the number of bats observed under SWT operation was significantly lower than that under SWT non-operation. This effect was further found to depend on the SWT proximity. Specifically, the decrease at the shorter distance range (i.e., 0 to 5 meters) was found substantial, while the gap shrank as the distance went further (i.e., 20 to 25 meters). Moreover, it was further found that as wind speed rose, the number of bats observed around the operating SWTs underwent a greater decrease. These findings imply that the areas in the vicinity of SWTs are avoided by bats, and such avoidance can reach a larger extent as wind speed rises.

Case Study: Netherlands

Brenninkmeijer and Klop (2017) investigated the 'how' (1) wind farm location, (2) turbine layout, (3) surrounding terrain, and (4) other obstacles (e.g. power lines) affect bird mortality. Although this study aimed at large-scale wind turbines, it can serve as reference for SWTs. By comparing bird mortality in a coastal wind farm Eemshaven and an inland wind farm Delfzijl, Brenninkmeijer and Klop (2017) have found that (1) "the fatality rate per turbine per year at Eemshaven was roughly six to ten times the number at Delfzijl", (2) the bird fatality at Eemshaven wind farm displayed significant spatial variation, where the highest fatality rates were witnessed at the turbines bordering Wadden Sea because these turbines were located on the concentrated migration routes, (3) no significant spatial variation in bird fatalities were found at Delfzijl wind farm, where the terrain was covered by homogenous agricultural landscape, and (4) the fatality rate per hectare per year caused by power lines was overall three times the number caused by wind turbines, and waterfowls and passerines were mostly found in powerline fatalities, whereas gulls and terns dominated the turbine fatalities.

It can be implied from the above mentioned observations that (1) inland wind turbines generally cause little bird mortality compared to coastal wind turbines, (2) for inland wind turbines, power lines may be a more severe threat to birds rather than turbines, and (3) homogenous landscape usually does not result in concentrated bird fatalities at specific sites, and according to Thompson et al. (2017), homogenous grassland cover can help decrease bird and bat mortality, because trees can serve as habitation for birds and tree-roosting bats so that may tend to avoid entering open areas. Moreover, Thompson et al. (2017) further investigated the 'buffer zone' of such homogenous landscape, and found no significant difference in bird and bat mortality between a 500-meter proximity and a one-kilometre proximity to the turbine, which implies that a distance of 500 meters between the nature reserve area and the turbine site, as long as there is homogenous landscape in between, would be safe enough for birds and bats.

Due to the fact that SWTs cause significantly lower bird and bat mortality than large-scale wind turbines, and the fact that Eemshaven wind farm which could lead to 4.2 bird fatalities per turbine per year has obtained permission, it is safe for birds and bats to build SWTs in UH. However, it is noteworthy that (1) it would be better that turbines are built on homogenous grass-cover landscape, and (2) turbines and power lines be kept far away from nature reserve areas and avoid regular migration routes.

5.5.2 Land Use and Property Value Change

There have been limited information discussing the land use change caused by SWTs, but focusing on the impact of large-scale wind farms. According to the available information targeting SWTs, they are unlikely to cause significant land use shift, because (1) a SWT only requires approximately 6 to 10 square meters of area, which is very limited compared to the entire farmland or big backyard, and (2) the landscape can be returned to the prior condition once the wind turbine is decommissioned (NSW, 2011).

On the other hand, property value decline caused by wind turbine construction has been a greater concern. Multiple reports issued by state governments and national laboratories around the world have discussed over this issue. The government of New South Wales in Australia investigated the property value variation from 2003 to 2012 around Wonthaggi, where a wind farm was commissioned in 2005. The result (figure 14) illustrated that no price decline was found. Similar conclusion was also drawn by a study in the USA, where scientists from Ernest Orlando

Lawrence Berkeley National Laboratory investigated over 50,000 home sales across nine states, and found no statistical evidence that these near-turbine property had undergone value changes in post-construction or post-announcement periods (Hoen et al., 2013). However, when we look specifically into households, there is price variation. Sunak and Madlener (2016) used spatial econometric models to account for the spatial dependence of such impact, and found that properties with an extreme or medium view of the turbine would suffer a price decrease by 9% to 14%, whereas properties with minor or marginal view would not result in statistically significant price decline. This implies that proper siting plays an important role in keeping the property value.

The interview with Coen has provided further insight on this issue. According to Coen, farmland area would not be greatly affected, due to the limited base area of a SWT. However, the siting of the SWT on the farmland would be crucial for the property value. Improper siting could lead to huge inconvenience in farming activity and require a larger area of passage to access the wind turbine. Therefore, given that the overall negative impact is limited, careful siting is suggested to further reduce such impact.

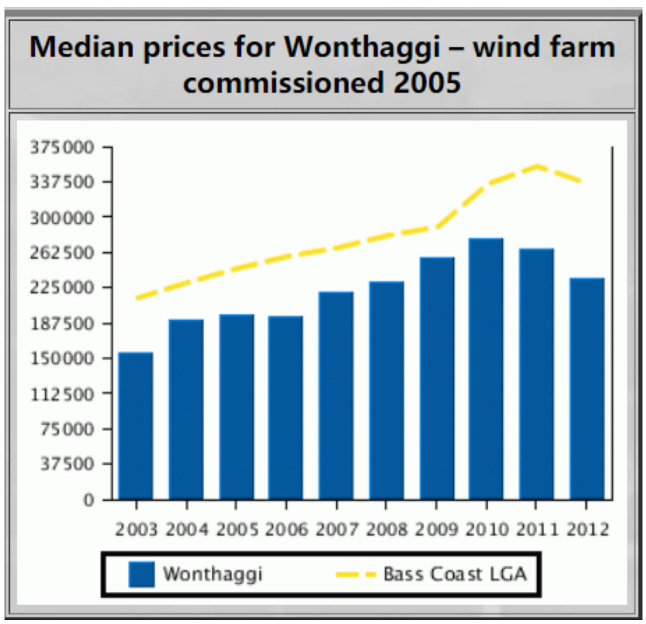

Figure 18 The trend of property value change of Wonthaggi, Australia, before and after wind farm was commissioned in 2005. It shows no significant impact over property value change (retrieved from https://ramblingsdc.net/WindValues.html).

5.5.3 Noise pollution

Information on the sound emitted by several SWTs measured in A-weighted sound level is summarized in table 7 (Wineur, 2017). The Dutch government has set the permitted level of noise emitted by wind turbines at 47 dB during the day and 41 dB at night (Overheid NL., 2010), measured on the surface of the surrounding buildings. This means that, while information for some types of SWTs is unknown, most of the SWTs are able to perform within the standard during the day, while they may have to be turned off at night.

To sum up everything, the investigation results of environmental impact of SWTs on bird and bat mortality, land use and property value change, and noise pollution, and the suggested abatement approaches are listed in table 8. To better visualize the environmentally feasible area for SWT construction, a map has been made (figure 19), where the pink area denotes the available area for SWTs from the perspective of low environmental impact. It is note-worthy that only the constraints of bird and bat mortality was included in this map, because to define the availability in terms of little land-use and property value change and noise-free area is too subtle and subjective. Given that there is specific legislative standards for noise level, noise is still a subjective concept that each individual has different resilience to noise (Rogers et al., 2006).

SSW	Acoustic level
Energy ball	0 dB at 25 m distance with wind speed 10 m/s
Turby	45 dB at 20 m distance with wind speed 10 m/s
Aventa LoWind	30 dB at 50 m distance
E. A. Z. Wind 12	No information
Solis Wind Power	47 dB
WES 80	45 dB at 100 m distance with wind speed 8 m/s
SkyStream 3.7	No information
InnoVentum Dalifant	40 dB at 100 m distance with windspeed 8 m/s

Table 7 The acoustic level in A-weighted sound level of certain SWTs

Environmental issues	Investigation results	Advice
Bird & bat mortality	Significantly lower than coastal wind farms	Proximity to reserve areas ≥ 500 meters, with homogenous bare land or grass landscape
Land use & property value change	No significant variation before and after wind turbine construction	Careful siting: make sure it does not bother regular farming activities
Noise	No violation of legislative standards during the day; violation at night	Apply Energy Ball or shut the SSW at night

Table 8 The investigation result of environmental impact and the suggested abatement approaches.

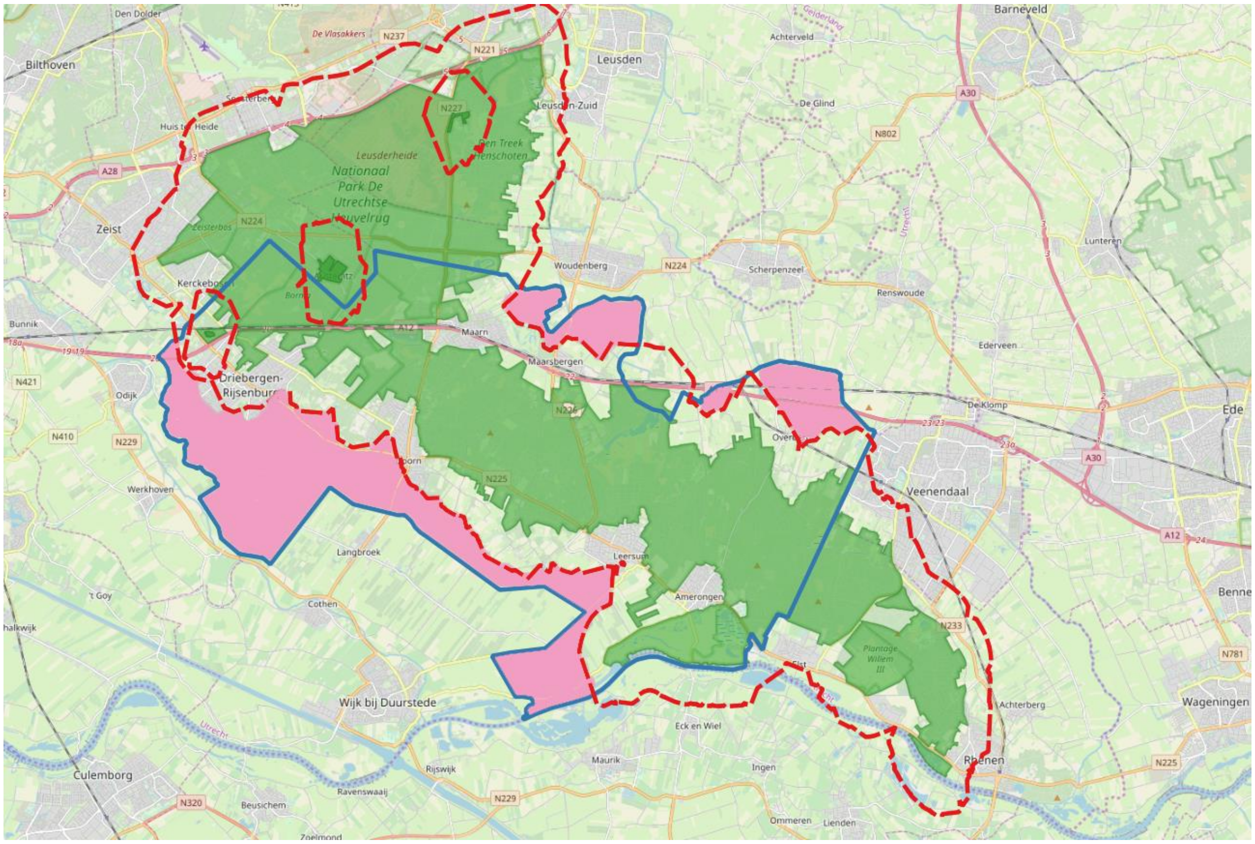

Figure 19 The map of environmentally available land for SWTs in UH. The pink area denotes the available land, which is outside the buffer zone (red dash line) and inside the UH border (blue line), excluding the settlements (grey area). The green area is the UH Na

Overall, applying SWTs do not cause significant environmental impact, though there may be a few exceptions. Due to the limit of time, equipment, and available information, we were not able to conduct field investigation in this study, but in order to obtain more in-depth understanding and more convincing results, a field investigation is still necessary.

5.6 Integration: Total Potential Yield

To answer main research question with respect to technical, economic and environmental aspects, the full potential of each type of wind turbine to contribute to UH's renewable energy target can be estimated. Based on wind conditions and the ecological constraints, the available surface area is 19.8 km^2. This area divided by the surface area required per turbine gives the total amount of turbines that could hypothetically be installed. Table 8 gives a total yield for each turbine, the average of which is 57 GWh, four times the renewable energy target of 14 GWh of the municipality. The map in figure 16 indicates where these should be placed, considering environmental and social constraints and wind conditions. The same amount energy could be produced by a wind park of 10 large scale wind turbines, based on the same method, this would require approximately 2 km^2. The target of 14 GWh could be achieved with 3 large turbines.

	Sterkenburg [MWh/y]	**Leersum [MWh/y]**	**Average [MWh/y]**	**Diameter Roto [m]**	**Area per turbine [km2]**	**N turbines**	**Total yield [MWh/y]**
EnergyBall	0.205	0.1778	0.191	-	-	-	**-**
Turby	1.259	1.025	1.142	-	-	-	**-**
Aventa	22.080	19.570	20.825	13	0.00849056	2332	**48563**
EAZ	23.588	20.049	21.817	12	0.00723456	2737	**59715**
SolidWind	42.495	35.834	39.165	-	-	-	**-**
wes80	68.194	55.574	61.884	18	0.01627776	1216	**75275**
Skystream	2.667	2.183	2.425	4	0.00080384	24632	**59734**
Innoventum	19.817	16.774	18.296	13	0.00849056	2332	**42665**

Table 9 Total yield of assumed available full potential area in UH with SWTs

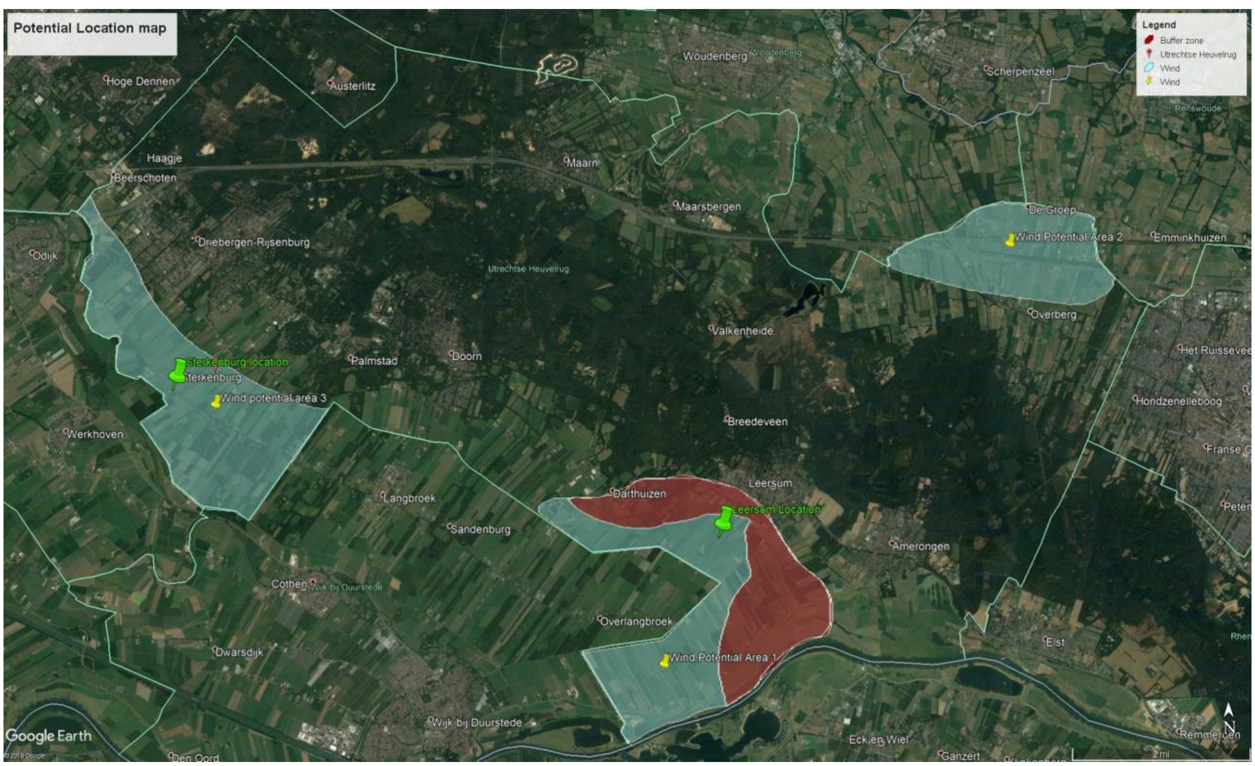

Figure 20 Integration of map of wind speed and the map of environmental impact. Areas in blue shade are selected based on wind speed. The red area is the ecological buffer zone for bird and bat mortality prevention in which building SWTs is not available

6. Discussion

6.1 Reflection and Limitations

In the context of the Netherland's climate change mitigation agenda, this report sheds a light on the potential of small-scale wind turbines (SWTs) to contribute to the renewable electricity generation capacity of the municipality Utrechtse Heuvelrug. The municipality's interest in SWTs, rather than large scale wind turbines, stems from the geographical and social paradigm that these are more likely to be accepted by local stakeholders: the perceived architectural aesthetics of these turbines could facilitate their adoption. This report puts the assumptions underlying this reasoning to the test. It provides a multi-disciplinary overview of the issues of that should be considered before committing to this unestablished technology. Meteorological, technical and economic data was analysed to assess technological and economic potential, and a broad scope of possible ownership models and governance strategies that could facilitate the adoption of SWTs has been reviewed, as well as expected environmental impacts. Interviews were scheduled with representatives from comparable wind energy cases in Groningen, Wilnis and Houten to evaluate the established economic and social criteria. These interviews, as well as talking to employees of Samenwind, Libau, Natuur en Milieu Federation, Miss W. Peek, LTO Noord and Stedin, helped to understand the means by which SWTs are installed, governed, and the most important aspects to evaluate the potential. For example, all interviewees made clear that the available land and the investment costs are the main limitations to the applicability of the SWTs. Since SWTs can only be built on building plots and the return periods are relatively long (i.e. more than 10 years), then the interest group is small. Prior to carrying out the research, funds were expected to be a main limiting factor over that of the location for building the turbine. The findings suggest that the strict rules and regulations around SWT in terms of placement, hub height, narrow the number of possibilities to place SWTs in the UH. Considering wind speeds are higher in Groningen, there is more land to place a larger number of SWTs, especially considering the building restriction (e.g. certain number of meters from the farm owner plot area).

6.1 Limitations

Technological assessment

While the wind data used is sufficiently detailed to be indicative of the general potential for SWT in UH, the site-specific potential of SWT can only be guaranteed by field measurement. Furthermore, SWTs are in a recent market development phase compared to large scale wind turbines, which comprises technical data completeness and accuracy. In most cases, a key performance characteristic as the capacity factor could not be obtained. Therefore, this report could not account for the possible divergence between municipality's air densities and those at the test site of the turbine manufacturer. Due to the limited variability of air density, this should however have a limited impact on the calculations. Whilst the power curve of most SWTs was available instead, this was not the case for EAZ. The robustness of this procedure to approximate this the power curve of this turbine cannot be guaranteed.

Economic feasibility

The business case of wind energy does not only depend on technical data but also on electricity prices, available subsidies, the energy demand of the owner, and the regulatory approval. Many of these aspects had to be estimated to accommodate them for the UH and are subject to uncertainty and policy changes. For the general economic factors (e.g. LCOE, NPV) results of multiple scenarios are provided (in the appendix) to give an overall picture of the economic case. It should be noted that the economic case is built upon the windiest spot in UH, creating the most ideal scenario, and that the reference location also has relatively strong winds. In conclusion these caveats imply that the economic assessment estimate for SWTs is skewed toward the best-case scenario, and that specific cases may differ from the suggested economic values.

Social Feasibility

Given the size of the municipality of UH and the potential number of stakeholders involved in the installation of SWT, the sample size of the expert interviews is low and may be fully representative of all viewpoints. Moreover, the restriction set by the municipality to focus on SWTs limited the study to a comparative analysis of different SWTs, as opposed to comparing small to large-scale wind turbines. Due to privacy issues and political sensitivity, our research could not include a survey in the municipality. Hence, we cannot make a specific judgement about the attitude towards SWT of citizens in UH. Although deployment of SWTs close to urban areas (as opposed to rural farmland) is estimated to be less feasible, it would still be valuable to confirm assumptions regarding attitudes and willingness to invest.

Currently, SWTs can only be built on building plots, and the UH has a minimal industrial area as well as significant is wind obstruction. These limiting factors were disregarded in order to research governance issues. Energy companies and industrial areas were not included as an interest group, firstly because it was suggested by an interviewee from LTO Noord to focus more on farmer groups. Secondly because the cheap price of electricity for large consumers makes wind energy relatively much more expensive. Some of the industrial areas of the UH that were not considered as potential stakeholders are: Driebergen-Rijsenburg: omgeving stationsgebied; Driebergen-Rijsenburg: bedrijventerrein Driebergen; Doorn: bedrijventerrein Boswijklaan; Doorn: bedrijventerrein Vossenstein; Maarsbergen: bedrijventerreinen Heygraaflaan en Ambachtsweg; Amerongen: bedrijventerrein Amerongen. Lastly, wind speeds are generally too low in the industrial areas to align with minimal power capacity needed for the functioning of the turbine.

Finally, applying broad theory regarding social feasibility and insights from cases that may not be fully compatible with the case of UH poses a challenge. Understanding governance strategy or the role of ownership models in managing social acceptance from case study literature may act as a useful foundation, but these are not empirical like the technical or economic results. Social factors that are key to success in Groningen may not be applicable to UH and vice versa. Furthermore, academic literature usually considers large turbines and does not compare different SWTs with respect to social feasibility, while the case study in this report focuses on the E.A.Z.-turbine. Until empirical research on social acceptance and the interactions between key stakeholders is undertaken in UH, understanding will remain partial and theoretical. The understanding can be the basis to examine specific social feasibility, once municipality defines a broad strategy, and shortlists potential locations, SWT-models and governance approaches.

Environmental Impact

The major ecological barriers encountered in the literature regard large wind turbines, so there are shortcomings for settling the findings as a primary basis for implementing SWTs in UH. Additionally, the lack of research targeting the environmental impact from SWTs can be explained by the fact that (1) small wooden turbines have been gradually replaced by more advanced large turbines, because of more effective power generation, and (2) SWTs, which usually are not built at a wind farm scale, do not occupy a large area of land, and thus hold less significant impact as large-scale wind turbines (AWWI, 2019).

6.3 Recommendations for further research

Since the potential for SWTs was analysed within the current context, opportunities can only be considered in relation to current legislation around turbine height and material; assumed levels of acceptance; and the spatial context of protected sites, amongst other criteria. To generate a more comprehensive study and to assess the true scope of opportunities, analysis should be made of different heights and consider alternative sites. This may result in a more optimistic potential for SWTs in UH where legislation, policy and strategic management could be edited accordingly. This suggestion goes beyond the scope of this paper, but future research showing technical and economic potential at different heights and/or sites would help the municipality to consider adjustments to the current legislation. Alternatively, the municipality may decide that its forests and green spaces are of ecological value and important to its climate target, so electricity generation should come from other sources, possibly outside of the municipality, thus incorporating its own strategy into national targets.

7. Conclusion

The municipality of the Utrechtse Heuvelrug (UH) faces fundamental questions about the social, economic and environmental aspects it's future energy supply, making the energy transition inherently multidisciplinary. In the spirit of examining everything, and holding fast to that which is good, this report analyses the potential of small wind turbines to contribute to a cost-effective, carbon-neutral energy system that meets energy demand without heavily impacting the municipality's residential environment and natural capital. Table 21 summarizes the results of this analysis. Taking stock of each requirement, as well as the governance strategies available to facilitate the adoption of SWTs, this report finds that the potential of SWTs in UH is not overwhelming.

This is mostly due to the techno-economic performance, which depends crucially on wind speeds. Within ecological limits, wind speeds are sufficient for SWTs to be technically feasible on 19,88 km2 of the municipality's territory. The areas are found in the North East, South East and South West of the municipality, alongside the municipal borders, see figures 9, 10 and 19 in section 5.1 The total potential electricity yield is considered moderate for the Aventa LoWind (20,6 GWh), EAZ Wind 12 (18,0 GWh) and good for the WES 80(60,6 GWh). These figures largely exceed the Municipality's renewable energy target set in Routekaart Klimaatneutraal Grondgebied 2035. However, these estimates are based on the hypothetical example of using all the available space to install more than 2000 SWTs. Nonetheless, these figures are indicative: 10 conventional, 100m-turbines are expected to supply the same amount of energy. This is due to the larger rotor diameter, and the higher wind speed at higher altitude.

While the technical scope of SWTs to contribute to the municipal renewable energy targets appears to be limited, SWT may be appropriate for some stakeholder. Technologically, Innoventum Dalifant and Aventa Lowind are most suitable in UH. E.A.Z., SolidWind and SkyStream have second-best capacity factors. However, the economic assessment favours the WES 80 and E.A.Z. wind 12, which have the lowest prices per kWh (€0.18/kWh and €0.15/kWh), a positive Net Present Value, and a payback period of 11 and 13 years. However, at (slightly) less optimal wind speeds, the net present values are negative. This renders the business case very location specific, and subject to various sources of uncertainty, such as local turbulence, which is included in the wind speed data. The economic potential further depends on current energy prices, subsidies available, energy demands of the owner, and regulatory approval.

Due to VAT, SWT are not financially attractive for private consumers, while for farmers, the rather long payback period is would be a barrier. However, SWTs in combination with solar panels are generally considered as an interesting option. The WES 80 could be advantageous for companies with a high energy demand (60,000 kWh/year), and E.A.Z. Wind 12 for smaller consumers (18,000 kWh/year). The POP3 subsidy scheme improves the business case, reducing the payback period of both the WES 80 and E.A.Z. Wind 12 to less than 10 years.

Beyond economic feasibility, interest in SWTs also stems from environmental awareness and a desire for autonomy from the national grid. However, complicated legislative processes are a social main barrier. Hence, improved communication about legislative requirements is recommended. Several case studies made clear that in areas where SWTs are technologically and economically feasible, stakeholder engagement is essential, and may be guided by surveys gaging social acceptance levels and reasons for opposition. However, since 400 farmers from the LTO Noord community have shown interest in SWTs, the impact of SWTs on the landscape is limited, and the public opinion with respect to the municipality's role in the energy transition is generally positive, general social acceptance is expected. That is not to say that transparency about possible SWT-project should not be prioritized, as 'rumours' about windmill projects may still cause opposition. Involving citizens in decision-making processes early on and communicating about the room for input will lead to more support.[10]

There is limited case for individual ownership of very small and micro wind turbines (<3kW), such as the energy ball. The appropriate model for larger SWTs (E.A.Z. Wind 12 and WES 80) is farmer- or small business-ownership, supported by the POP3 subsidy scheme. Nonetheless, due to general economic infeasibility of all turbines this report does not recommend one best-practice ownership model for the current widespread uptake of SWTs. Grassroot uptake will likely be limited to technically feasible locations by stakeholders with investment capacity and sustainability ambitions.

The environmental impact caused by SWTs is expected to be minimal. Specifically, SWT-caused bird- and bat-mortality will likely be significantly lower than the number of birds and bats killed by large-scale (especially coastal) wind farms. Nonetheless, a 'buffer zone' of 500 meters away from bird- and bat-habitats should be observed to abate any negative impacts.

Land use conversion is also no concern when installing SWTs. Globally, property values do not significantly decline after wind farm construction or commissioning. None of the selected SWTs exceed the standard with respect to noise-levels during the day, but the Turby-, Solis Wind-, and WES80-turbines are expected to violate the standard during the night. While proper siting could circumvent this, possible solutions for turbines near the built environment include installing the generally noise-free *Energy Ball* or shutting down the violating turbines at night.

In conclusion, this study finds that the technical and economic feasibility of SWTs in the Utrechtse Heuvelrug is generally scarce, and SWT are unlikely to contribute the municipality's renewable energy targets. The time and effort required for planning, legislative restructuring and municipal

[10] Several dutch guidelines for public participation exist: Handleiding Participatieplan Windenergie op Land, Gedragscode Windenergie op Land, Gedragscode Draagvlak en Participatie Wind op Land

implication as well as the monetary investment, appear to outweigh the power output, environmental benefits and social benefits of the widespread uptake of SWTs. Theoretically, individual stakeholders could benefit from installing a SWT, as the wind is powerful enough to yield a (slightly) positive net present value on the most optimal locations. Provided the investment required decreases due to either subsidies, cost reductions or higher electricity prices, SWTs could thus play a limited role in specific locations. It is recommended that especially the combination with solar systems, energy storage (at individual farm- or business-level) and with conventional wind turbines (at the municipal-scale), is further examined.

	criteria	grading		
Technological aspects	Annual Yield (MWh)	High (>30)	moderate (10 - 30)	Low (<10)
		Wes80	Innoventum, Aventa Lowind E.A.Z.	Energy ball, Turby, Skystream
	Capacity factor	> 20%	10-20%	<10%
		Innoventum, Aventa Lowind	E.A.Z., SolidWind, SkyStream	Energy ball, Turby, Wes80
Economic aspects	Payback Period (years)	<10	10 to 20	>20
			WES80 E.A.Z.	EnergyBall, Turby, Skystream, Innoventum
	LCOE (Euro)	< €0,20	€0,20 to €0,30	> €0,30
		Wes80, E.A.Z.	Skystream, Innoventum	EnergyBall, Turby
Social Aspects	Support Base	General opinion positive		General opinion negative
Environmental Aspects	Expected Bird & bat mortality	acceptable		Not acceptable
		all		
	Land use & property value change	acceptable		Not acceptable
		all		
	Noise polution	No violation[11]		Limited violation[12]
		Innoventum, Aventa Lowind, E.A.Z., Skystream, Energy Ball		Turby, Solis Wind Power, and WES80

Figure 21 results overview (based on wind data at Sterkenburg)

[11] lower than the standard (47 dB during the day and 41 dB at night)

[12] Higher than the standard during the night

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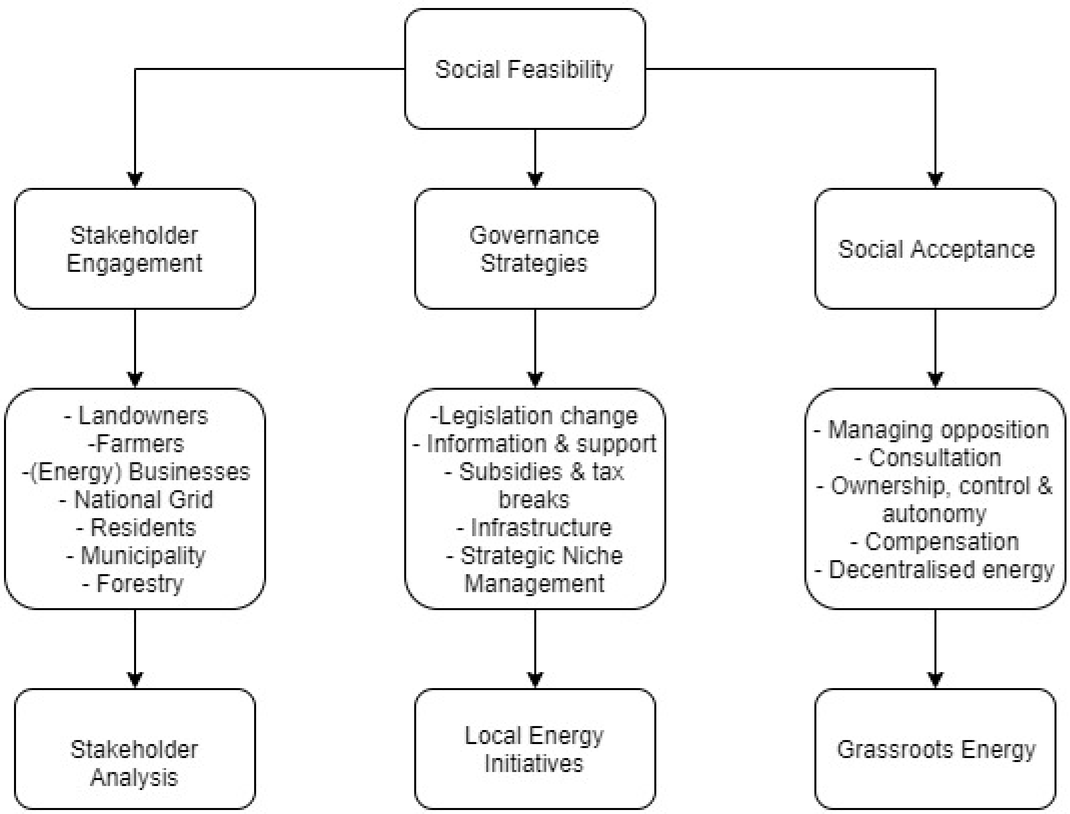
Appendices

Appendix 1 -Social Feasibility Analytical Framework



Appendix 2 – Technical Data

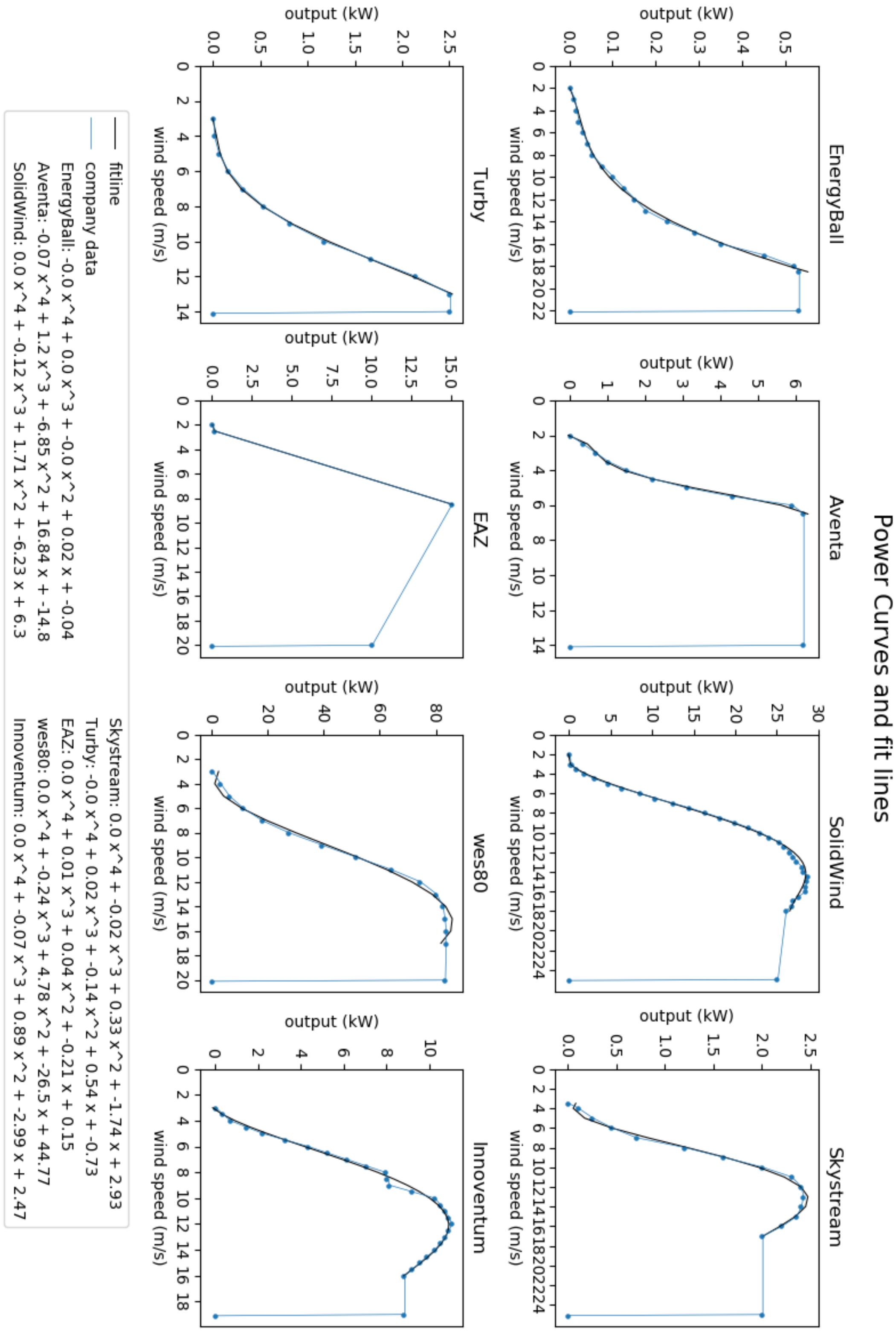


Figure 22 power curves of all turbines, incl. the polynomials fitted to the data

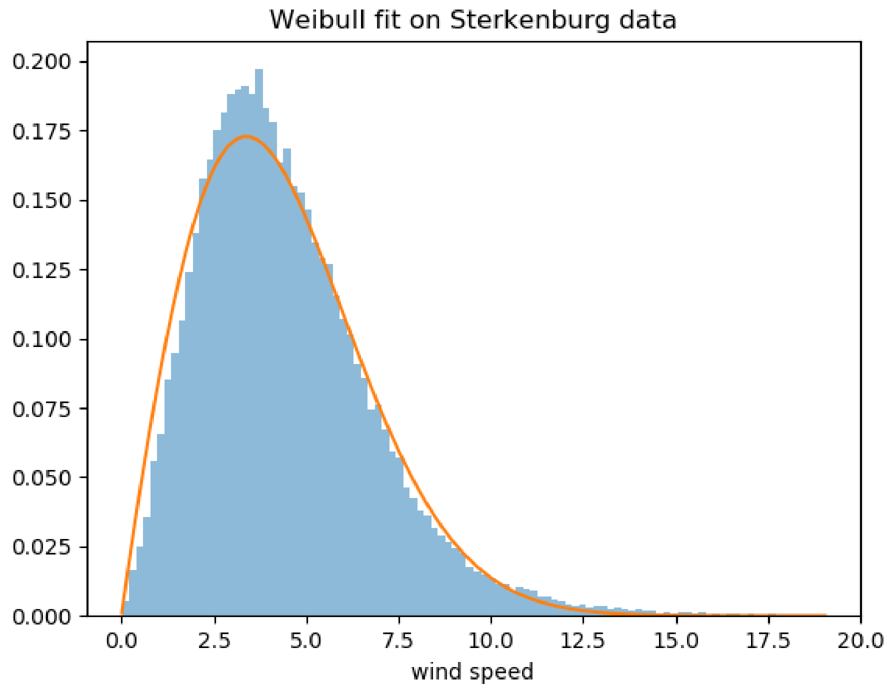


Figure 23 frequency distribution of wind speeds (m/s)

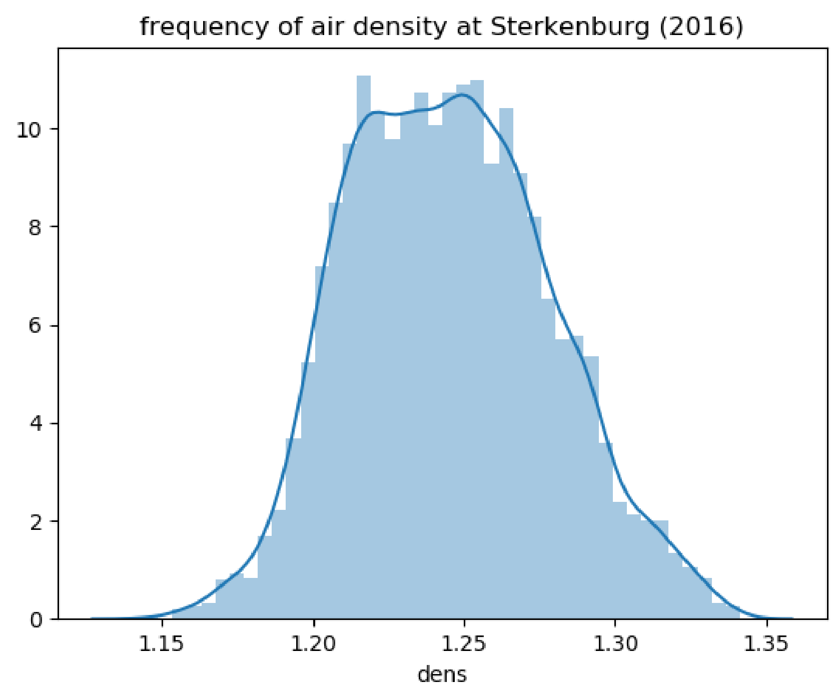


Figure 24 frequency distribution of air density (kg/m^3)

Appendix 3 - Indicators of Social Acceptance Survey

Below is a sample survey that would aim to understand the views towards wind energy and specifically SWTs in UH. It would firstly aim to establish if there is an enthusiasm for renewable energy and wind energy and what the views are towards 'classic' large wind turbines. Next it would aim to understand the awareness of alternative small-scale turbines and the views of different types to see if there is more social acceptance of SWTs over large turbines and if there is a general preference towards a certain style. In addition to this, it would be useful to understand where, if anywhere, the public would be willing to accept a turbine. This would include the proximity to their own house, whether they are able to see it and whether they would accept it on public land such as national parks. Finally, if there is enough social acceptance, it is important if there is an enthusiasm for uptake of SWTs and a willingness to invest in an individual or community turbine, or whether people would prefer to purchase clean energy from the grid, or even whether they value the origins of their electricity supply. From the survey data, a regression analysis would highlight prominent significances, including whether certain groups (e.g. farmers) or certain neighbourhoods have more positive views towards SWT's. From this a more accurate understanding of social feasibility can be gained and if certain barriers still exist. A GIS map can then be drawn which highlights socially feasible locations and this layer can be added to technical, economic and environmental maps. As a final point this survey data can also direct governance strategy such as stakeholder engagement; the management process; and any potential legislative or policy change such as height restrictions and subsidy availability.

Age:

18-29 30-44 45-64 65+

Gender:

Male Female

Profession:

Student Farmer Professional Manufacturing Services

Other

Neighbourhood:

1. Which is your energy provider?

2. What is your preferred energy source for electricity generation?

Gas Coal Wind Solar Other Doesn't Matter

3. Do you value access to renewable energy?

Yes No

4. What is your view on wind energy for electricity generation?

Strongly Against Against Neutral In Favour Strongly In Favour

5. How would you respond to a wind turbine in your neighbourhood?

Strongly Against Against Neutral In Favour Strongly In Favour

6. Which of these turbines have you come across in the past? (Pictures of types)

7. How would you respond to one or more of these turbines in your neighbourhood? (For each)

Strong Against Against Neutral In Favour Strongly In Favour

8. Would the specific location of the turbine influence your opinion?

Yes No Don't Know

9. What is the optimal proximity, if any, to your house of a small-scale wind turbine?

Doesn't Matter > 100m >1km >5km >10km Nowhere

10. Where would you prefer to see a turbine?

Neighbourhood Farm Industrial area Natural area Other

11. Would you consider investing in a turbine, either individually or collectively if sufficient subsidies were available?

Yes No Don't Know

12. What would be the reason for investing in a turbine? Select all that apply

Cheaper energy Energy ownership Clean energy Other

13. Would owning and managing a turbine make you more likely to accept it?

Yes No Don't Know

14. Are you or have you ever been part of a renewable energy cooperative?

Yes No

15. Do you think the municipality is doing enough to meet its target of being carbon neutral by 2035?

Yes No Don't Know

Appendix 4 - Economic Data (LCOE, NPV and Payback Period)

E.A.Z. Wind 12

Price: €56,000	LCOE	Payback Period (in years, r in €/kWh)			
		r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, no subsidies	€ 0,24	-	-	-	-
No VAT, SDE+	€ 0,21	>20	>20	>20	17.5
No VAT, SDE+, POP3	€ 0,12	>20	20	12	9
VAT, no subsidies	€ 0,29	-	-	-	-
VAT, SDE+	€ 0,26	>20	>20	>20	>20

	NPV (20 years, r in €/kWh)			
	r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, SDE+	€ -39.148,00	€ -22.195,42	€ -7.346,63	€ 4.884,66
No VAT, SDE+, POP3	€ -16.748,00	€ 204,58	€ 15.053,37	€ 27.284,66
VAT, SDE+	€ -50.908,00	€ -33.955,42	€ -19.106,63	€ -6.875,34

WES 80

Price: €178,000	LCOE	Payback Period (in years, r in €/kWh)			
		r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, no subsidies	€ 0,22	-	-	-	-
No VAT, SDE+	€ 0,19	>20	>20	>20	15.5
No VAT, SDE+, POP3	€ 0,10	>20	17	11	8
VAT, no subsidies	€ 0,26	-	-	-	-
VAT, SDE+	€ 0,23	>20	>20	>20	>20

	NPV (20 years, r in €/kWh)			
	r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, SDE+	€ -114.783,24	€ -57.667,19	€ -7.639,14	€ 33.570,12
No VAT, SDE+, POP3	€ -43.583,24	€ 13.532,81	€ 63.560,86	€ 104.770,12
VAT, SDE+	€ -152.163,24	€ -95.047,19	€ -45.019,14	€ -3.809,88

SkyStream 3.7

Price: €10,742	LCOE	Payback Period (in years, r in €/kWh)			
		r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, no subsidies	€ 0,40	-	-	-	-
No VAT, SDE+	€ 0,37	>20	>20	>20	>20
No VAT, SDE+, POP3	€ 0,23	>20	>20	>20	20
VAT, no subsidies	€ 0,48	-	-	-	-
VAT, SDE+	€ 0,45	>20	>20	>20	>20

	NPV (20 years, r in €/kWh)			
	r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, SDE+	€ -9.700,44	€ -7.620,92	€ -5.799,47	€ -4.299,10
No VAT, SDE+, POP3	€ -5.403,64	€ -3.324,12	€ -1.502,67	€ -2,30
VAT, SDE+	€ -11.956,26	€ -9.876,74	€ -8.055,29	€ -6.554,92

InnoVentum Dalifant

Price: €88,000	LCOE	Payback Period (in years, r in €/kWh)			
		r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, no subsidies	€ 0,37	-	-	-	-
No VAT, SDE+	€ 0,34	>20	>20	>20	>20
No VAT, SDE+, POP3	€ 0,20	>20	>20	>20	16
VAT, no subsidies	€ 0,44	-	-	-	-
VAT, SDE+	€ 0,41	>20	>20	>20	>20

	NPV (20 years, r in €/kWh)			
	r = 0.05	r = 0.12	r = 0.18	r = 0.23
No VAT, SDE+	€ -70.995,78	€ -53.911,36	€ -38.947,08	€ -26.620,65
No VAT, SDE+, POP3	€ -35.795,78	€ -18.711,36	€ -3.747,08	€ 8.579,35
VAT, SDE+	€ -89.475,78	€ -72.391,36	€ -57.427,08	€ -45.100,65

Appendix 5 - Environmental Study: field investigation of bird and bat mortality

Minderman et al. (2012) have elaborated in detail the procedure of field investigation over SWT-caused bird and bat mortality. In this case study, 20 SWTs sites in central Scotland and northern England which possess both building-mounted SWTs and free-standing SWTs of 6 to 18 meters in hub height (mean value 8.2 meters) and 1.5 to 13 meters in blade diameter (mean value 3.4 meters). In order to collect data on bird activities without turbine operating as the control group, SWT owners were asked to pause their turbines for two 24-hour periods. This was alternated with 24-hour periods of SWT operation. Bird activities were recorded through vantage point observations (VPs), which usually took place on a parked car at a distance ranging from 20 to 30 meters.

In order to be in accordance with the bat activity data recording, the flights were divided according to the distance of the bird the turbine; namely, ‘‘near’’ refers to 0 to 10 meters and ‘‘far’’ refers to 10 to 20 meters. The time, number of individuals, and species in these distances were counted respectively, and recorded for each flight.

Bat activity was automatically recorded using two bat detectors during all nights of the observation period at each site. Similar to the way of recording bird activities, two bat detectors were installed at different distances for each turbine—the nearer one was installed 0 to 5 meters away from the turbine and the further one was installed 20 to 25 meters away from the turbine. Special treatments were taken to avoid interference of turbine noise, and to eliminate potential overlap in detection ranges between the nearer and further detectors. Sequences of more than one echolocation calls with at least one-second interval were recorded as one bat passing.

Appendix 6 - Case Studies

6.1 Case Study I: Groningen

In Groningen, E.A.Z. Wind provides windmills for individuals interested in purchasing E.A.Z. windmills. The company takes care of the ‘documentation till the final installation’ (EAZ, 2018). One organisation that works together with E.A.Z wind, is Samenwind. Samenwind is the local citizen/energy cooperation that aims to motivate sustainable energy initiatives and create an energy neutral region. Samenwind informs and invites people to learn the possibilities for implementing green energy, like wind, and help organise groups of potential buyers of one windmill. Samenwind then presents the proposition of buyer(s) to E.A.Z, who builds the windmill, and once usable, allows everyone to receive a share of energy, depending on the number of buy ins purchased. Only two windmills have been built with this shared payment structure, which amounted to about 27 people for one windmill.

1] Phone Interview with Wim van den Born, Samenwind. (October 4th, 2019)

On a phone call with Wim van den Born on October 4th, 2019 , our group asked about the current status of SWTs in Groningen. In short, the interviewee said that the main obstacle for building SWTs is the complicated and long-winded procedure an initiator would have to go through.

In other words, if all involved members who have a decisive power are not prepared for the request of building a SWT, the request has to pass through many different administrative levels (i.e. municipality, insurance, electricity company, welstandscommissie) to be approved. This may slow down the anticipated time frame of expected energy return of the initiator. According to Mr. vd Born, strategizing in a timely manner is important to delegate a representative and responsible for the extensive process and avoid such a logistical burden on the initiators or organised group of citizens/corporations. The second most important factor is informing and organising people. Mr. vd Born thinks there are more than enough people with ideological ambitions about green energy, and are willing to participate if the process is made clear and easy for them to carry out. People are more willing to participate if the 'business case' is ready, and the only thing they have to do is say: "Yes, sign me up!".

2] Phone Interview with Michiel Mulder, Natuur & Milieu federatie Groningen. (October 4th, 2019)

Michiel Mulder is a project manager at Climate & Energy for the Natuur & Milieu federatie Groningen. In contrast to what we thought, the 'Natuur en Milieu' federation has little relation with the SWTs. Since the federation is small in size, they often do not need an environmental impact assessment, which explains the motive to remain a smaller size, according to Mr. Mulder.

Is is only in the case that the federation is located within a National conservation area such as Natura 2000 areas, that an additional impact assessment is required. According to Mr. Mulder, a mix of factors contribute to the emergence of the SWTs. Groningen has a long history of gas extraction, which has caused earthquakes and damages to houses (NAM NL, 2019). People feel the urgency to change to a new and alternative source of energy. Additionally, since the province is extremely flat and with little obstruction, wind is a good power source alternative. E.A.Z. wind is a product from Groningen, made in Groningen, which creates the competitive advantage and selling point to locals, as suggested by Mr. Mulder. Another consequence of the earthquakes is the unification of people and formation if corporations. People do not want their province to be exploited another time as in the past case with gas, for example with wind or solar farm for electricity generation, so several small energy cooperatives now exist (GrEK, SamenWind, Ús Koöperaasje, Drentse Kei).

The history and events in Groningen are aspects that resulted in a greater awareness of the energy transition that is needed in the coming years. Currently most purchasers of the SWTs are farmers, as they do not share the turbine not the electricity output with others, so the financial procedure is a lot easier than in a group construct. Within this context, The '*Natuur & Milieu' federatie* is also searching for a balance of energy production with renewables (e.g. solar, wind, biogas). Currently, the grid is 'full', with very little space for large scale wind farms, where the SWTs may be advantageous to help reduce the pressure on the network.

3] Phone Interview with Tim-Willems Kruize from Libau, area and placement advice foundation (October 21st, 2019) .

Libau is a foundation that gives advice on the placement of SWTs. Libeau works together with E.A.Z. wind to identify the most ideal spot and the building ground in a way that the turbine can be part of the farm, and is not evident when looked upon from the road or in the landscape. Libau performs a spatial assessment, on the basis of qualitative selection criteria. According to mister Kruize, E.A.Z. cares for the public opinion about spatial disturbance, as they do not want to be viewed as horizon polluters. The criteria Libau uses for placing, shape, and layout are found in appendix X.

Mr. Kruize argues that the size of buildings in the surrounding area determines whether a wind turbine is out of place. For instance, near a harbour or large industry, wind turbines fit better than in an open space. Close to large buildings, such as factories, larger wind turbines are allowed because they fit better with the size of the buildings. A lesson that can be learned here is that the Utrechtse Welstandsadvies (Mooisticht) can be involved in evaluating locations for SWTs. One aspect in Groningen and especially the national landscape of Middag Humsterland, is that line placements of SWTs are to be avoided, as it ia not in line with the the tortuous landscape elements of the 'old' landscape with subtile height differences. It is suggested that a maximum amount of two SWTs that can be placed on a single farm to avoid disturbance in the landscape view.

6.2 Case Study II: Wilnis

At the time of writing, four SWTs from supplier E.A.Z. have been installed in the province of Utrecht, of which one in Vinkeveen, one in Wilnis and two in Oudewater. Utrecht holds an interesting case, as wind speeds are generally lower than in Groningen. Because the margin of profit is quite narrow for the SWTs, wind speeds and choice of location are important factors to consider in the case for UH. The price for the foundation also differs between Utrecht and Groningen. In the province of Utrecht, there has been an increase of prices for placement (From interview with W. Peek)

Interview with Willeke Peek from dairy farm Peek in Wilnis. (October 9th, 2019)

Dairy farmer Mrs. Peek in Wilnis has installed a SWT from E.A.Z. wind in 2019. The farm currently holds just over 150 milking cows, but is planning to expand to 200 cows over the next year. The cows' milk is labeled with the 'planet proof' quality, which is a label that serves as an indication of a sum of sustainable practices by the farmer. Mrs. Peek shared that she and her husband have been pursuing sustainable practices for a long time, from an ideological point of view which she prefers to call 'rekenschap geven' (leaving the world as you found it) rather than sustainability or 'duurzaamheid'. They want a healthy farm with good care for the animals, reduced energy consumption and only the necessary chemical products to be able to run the farm efficiently. Also, they want to 'electrify' the farm, with more robots to help them in their daily farming practises and all electrical machinery rather than fossil fuel based. This will result in a more around-the-clock energy consumption, which is why she is interested in wind and solar as alternative energy sources.

The family's main reason to build the SWT was to be more self sustaining and therewith less dependent on market volatility such as the availability of fossil fuels and the policies surrounding them. EAZ Wind, the supplier of this specific SWT, delivers a so called 'full package'. This includes everything from installing and maintaining the turbine to dealing with the administrative workload. For the Peek family E.A.Z. estimated the annual production to be around 25,000 kWh minimum. E.A.Z. wind uses wind maps to calculate the energy potential, for which they take the lower end of the modelled wind speeds as a guideline, to not overestimate the potential energy generation.

According to Mrs. Peek, after placement of the windmills, several other farmers in the area are now interested in purchasing one as well. The main reason for this is similar to that of the Peek family; that farmers want to be more self sufficient, rather than worry about the impacts of climate change. The main barriers to farmers deciding to install a windmill is, the upfront investment costs (costs have risen from roughly €46,000 in 2018 to €56,000 now), and the insecurity surrounding present and future policy decisions, such as the current nitrogen debate and subsidies.

Also, Mrs. Peek noted that, if a SWT is not yet included in the 'bestemmingsplan' it becomes quite strenuous to get all the required permits, even with the 'full package' support E.A.Z. Wind offers to its customers. Overall, the procedure of purchasing a SWTs (from E.A.Z. wind) is relatively easy, with good service and minimal yearly (i.e. maintenance and insurance) costs (€250/year). The design is appreciable and another benefit is that the turbine is built using locally sourced wood and is manufactured locally.

Interview with Erwin Haveman, LTO Noord (West Region) (October 21st, 2019).

Erwin Haveman works for LTO Noord, a member-based association of agricultural entrepreneurs, and is responsible for sustainability within the farming and horticulture organisation. The association represent over 10.000 farmers spread throughout Flevoland, Utrecht, Noord-Holland and Zuid-Holland. The members of LTO have asked for the potential of wind energy and renewable energy, because the sector wants and needs to become more sustainable. A survey showed that around 400-to 450 of these farmers are interested in SWTs. In their search for potential SWTs, it became clear that there are many factors to consider before any advice can be given to an individual. First of all, the rules for height and permits is different in every province, and is not nationally managed. Within the province, the municipality might have different rules. Secondly, there are many different SWTs, and different locations ask for different windmills with different heights. Thirdly, the investment cost of some windmills is high, but the promised power output is much higher than the less expensive models. Fourthly, the grid has influence on the price in installation. All these factors combined make it difficult to give a general advice, but rather becomes case specific.

One of the aspects that holds back large scale implementation of SWTs is the 'bestemmingsplannen', zoning areas (e.g. conservation) of municipalities. There is not enough geographical area to place the turbines, and the height limit of the SWT limits the potential energy production drastically. This often leads to a weak business case and long payback periods. According to Haveman, interest to invest in new projects is usually found when payback periods are for 10 years or less. This is not yet the case for most SWTs.

Another, more general remark is that sustainable development is a long term project. Only a combination of multiple renewable energy sources will we be able to replace the present fossil fuel outputs. Solar needs to be combined with wind in order to make optimal use of the power grid, which means the grid needs to be upgraded to support large solar power generation. Municipalities need to make it easier for renewable energy initiatives to be developed, by simplifying the process of permits, more location options and cooperation with electricity companies.

6.3 Case Study III: Houten

Wind farm (Windpark) Houten has a long history. In 2001, the local council of Houten decided to place wind turbines. In 2005, the location of the wind turbines was decided and late 2013, the wind farm was in use with 3 turbines with an axis height of 105 meter and a rotor blade length of 45 meter, producing 2MW each. In 2015, the University of Utrecht conducted an evaluation of the windpark commissioned by the municipality of Houten.

Power generation

The windpark produced 7,4 GWh in 2013 from July to December. The year 2014 was the first full operational year, in which the windpark produced 11,1 GWh. The estimated production for 2014 was 17-18,5 GWh. Two studies by Eneco and Uwind in 2008, and Ecofys in 2013 grossly overestimated the production of the windpark. Since the windpark Houten has one of the most strict rules and regulations for noise- and light flickering, the operating scheme is not optimal. This has resulted in a 4,8 GWh decrease of potential yield. The influence of the strict norms is thus substantial, and has also resulted in a lower share of wind energy in the total energy production. In 2015, the windpark delivered 4,1% of the used energy in the municipality of Houten. This is about a quarter of the goal of 16% renewable energy. An average household in the Netherlands uses 3.500 Kwh of electricity and 10.555 Kwh of energy from gas. On the basis of 19.152 household, the wind farm with 11.1 Gwh delivers electricity to about 3.171 households (R.Harmsen et al., 2015). This is about 17% of the households that use electricity provided by the wind farm.

Social acceptance

One important aspect in the energy transition is that renewable energy production alters the landscape. All renewable energy production methods alter the landscape in some way, causing noise, light flickering, or other nuisance. The problem is that, generally, people are in favor of green energy over fossil fuel energy, but do not want to incur the downsides of renewable energy production, such as the pre-mentioned nuisances. Finding and accomplishing social acceptance for the deployment of wind turbine projects can thus be difficult. Governments and project developers can take steps to improve the acceptance of wind farms. A few initiatives over the past 15 years are (in Dutch):

- “Gedragscode Draagvlak en Participatie Wind op Land" from the NWEA (Dutch wind & energy associations)
- "Gedragscode Windenergie op Land" from the NLVOW Dutch asociation of locals around windturbines)
- "Handleiding Participatieplan Windenergie op Land" from Ecofys en Houthoff Buruma.

From the case in Houten it has become clear that finding support in the municipality and the community is different from finding local support locally of those living nearby the wind turbines. This is a valuable insight when creating an image of the social acceptance of SWT. Creating support is more than just providing people with a lot of information. Instead, people need to be involved in the decision making in the planning phase, and need to be informed on what decisions are already made and where there is room for participation. An inactive role does not necessarily mean that people are in agreement. As such, in instances where the suggestions of people cannot be implemented, there is a need for justification.
A survey held under citizens of Houten (with 90-95% confidence) living close to the wind turbines gave insight into the general opinion. A few things can be learned from the wind farm in Houten:

1) Support strongly depends on whether people encounter nuisance of the Windpark. All people within a radius of one km experience the negative effects (mostly noise during the night) and give a substantially lower rating to the windpark.

This finding is likely to translate to the implementation of SWTs, although nuisance will be much less since the turbines do not make noise and their small size makes it negligible in the landscape.

2) The nuisance ranked in terms of percentage of complaints are firstly attribute to visibility 52% (horizon pollution), then light flickering (34%) and lastly to noise (33%).

Thes nuisances of light flickering and noise will not apply for SWTs only that of visibility. Light flickering will be minimized to a small scale, and likely only present when in close proximity to the SWT. Currently there is no research done on all the possible nuisances of the SWT.

Appendix 7 - Placement Criteria from Libau (Welstand advice)

Libau is an independent advisory organization for spatial quality and cultural heritage in Groningen and Drenthe. Criteria from Libau for placing, shape and layout of a small scale wind turbine are.

[Placing]

- to be placed in the back or on the sides of the property, not in the front in the living area of a standard farm.
- choose a logical location that support the current structure of the building
- cluster turbines on one location in case of multiple turbines.
- make sure that valuable existing greenery stays in tact.
- prevent placing the turbine in sight lines on higher ground such as dikes.

[Shape]

- preferably a rank design.
- the turbine is placed between the column and rotor blade, so at the axis.
- a balanced amount of rotor blades, preferably 3.
- a suitable ratio between height and rotor blade length (2:1)

[Layout]

- in case of new building development, both turbine and buildings need to be designed together.
- neutral coloring that won’t stand out in the landscape.
- no commercials attached to the turbine
- suiting material, like metal, wood, or plastic.