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Evaluation of the Wind Energy Potential in the province of North Holland

A study of Theoretical Energy Output from Wind Turbines

Introduction

In response to the ongoing global warming, there is a growing demand for renewable energy sources. There are numerous ways to generate clean energy, one of which is through the use of wind. Wind farms are widely recognized as one of the most common and efficient renewable energy sources *(Which energy source is most efficient? 2020)*. However, deciding where to place such an investment involves a number of factors. Scholars focus on different aspects such as the geographical, technical, and economic potentials in order to determine the best suitable location *(Hoogwijk et al., 2004; Bennui et al., 2007; van Haaren & Fthenakis, 2011)*. In such cases, the constraints may include land use, nature, the cost of building wind turbines, or the hub height of the turbine. Furthermore, electricity output appears to be an important factor. In such cases, multiple technical aspects of the turbines and wind are considered to assess the energy profiles of the turbines and the energy supply *(Nortier et al., 2022)*. These may include wind speed or regime, as well as the attitude of turbine builders *(Hoogwijk et al., 2004)*. In order to assess areas in terms of those aspects, a common method is to combine GIS maps with those criteria. Those overlays enable determining the appropriate location to then add the next function that restricts the feasible locations even more. This can be accomplished by employing, for example, a suitability function *(Bennui et al., 2007)* or the cost of wind energy *(Hoogwijk et al., 2004)*. Another strategy is to link GIS to evaluations such as Spatial Multi-Criteria Analysis (SMCA) *(van Haaren & Fthenakis, 2011)* or Multi-Criteria Decision Analysis (MCDA) *(Bennui et Al., 2007)*.

Countries have been discussing potential solutions for sustainability for several years. The Sustainable Development Goals are one of the common initiatives (SDGs). They aim to set targets in order to limit climate change. One of the goals, goal 7 is to provide affordable, clean and sustainable energy *(The 17 goals | sustainable development, n.d.)*. Furthermore, the Netherlands appears to be one of the countries putting in significant effort to achieve them *(Europe Sustainable Development Report 2021, 2021)*. This country not only follows European laws and goals, but also creates them. The provincial government of North Holland, for example, has set ambitious targets for renewable energy deployment, with plans to increase production capacity to 6,3 Terra Watt (TW) by 2030 *(Noord-Holland Province, 2022)*. The issue is determining an appropriate location for them, which must be carefully considered in order to minimise their impact on the environment and local communities. This problem leads to the paper's research question:

How much energy can suitable wind turbine areas in the province of North Holland produce?

The purpose of this study is to determine the suitable areas for wind turbines as well as evaluate the theoretical maximum energy production within these places. We conducted this study in the province of North Holland and based it on the region's topographical and spatial limits as well as the wind speed.

Methodology

This research consists of two parts. The first one is to determine the exclusion zones based on the criteria assigned and therefore find suitable places. The second one is the evaluation of the energy output.

First part

Criteria

One of the first steps in the analysis is to identify the criteria and constraints that will determine the best location for wind turbines. Based on them, exclusion zones will be established in order to calculate the energy output within the feasible areas. Nature (protected) areas are one of the first factors considered. There are several places designated by Dutch law where no infrastructure can be built *(Natuur en Ecologie Windenergie Op Land, 2108)*. Furthermore, there are constraints in terms of the European Environment Agency (2009), such as Nature 2000, that establish various rules aimed at protecting the environment. Furthermore, the exclusion of areas in terms of land use is critical, it is the built-up areas and the distance from them in this case. Wind turbine construction is hampered in such areas due to high urbanisation and population density *(Hoogwijk et al., 2004)*. Furthermore, the buildings would cause wind disturbance, limiting the potential for such investment *(Rynne et al., 2011)*. The distance from roads, waterways and railways is strictly limited. Finally, wind speed is a criterion for determining the feasible location for wind turbines. It is one of the most technical potentials of wind turbines, and it allows us to look at locations in terms of the best wind resources *(Hoogwijk et al., 2004)*. Table 1 summarises all the criteria and the constraints considered.

Criteria	Constrains
Large average wind speed	Not within 100 meters of build-up areas
Large distance form residential areas	Not within nature areas
Large distance form nature (protected) areas	Not within 50 meters form roads, waterways and rail tracks

Table 1 Criteria and constrains taken into account.

Collecting the data

Data was gathered from various online databases and then tailored to the requirements of this paper. The layout of waterways and bodies of water was extracted from the same database, that is PDOK. In this case, however, the map was clipped to fit only North Holland. Open Street Map (OSM) was used to collect data for railways and roads. For this layer, clipping was needed as well. The build-up area and nature were obtained from the Province North Holland Data Portal. Finally, the raster from Global Wind Atlas is used to determine wind speed, see Appendix 3 for the average wind speed of North Holland. Even though data is provided for the entire province, only areas with an average speed of 7.5 m/s or higher are relevant. Appendix 1 contains precise source information.

Processing the data

QGIS was used to load intermediate maps of roads, trains, waterways, and residential areas, and they were expanded with buffer regions following the methodology's criteria. These layers were combined with the Natura 2000 regions to create one vector layer. It represented every region in North Holland that was prohibited from having wind turbines there. This layer was subsequently turned into a raster map. Simultaneously, the raster map of wind speed was transformed using the raster calculator to leave out the areas that were below 7.5 m/s. The last step was to combine all the excluded areas with the wind speed ones via the raster calculator in order to create suitable places. In order to make perform the analysis of the second part, the suitable areas are converted into a vector. The exact workflow can be observed in Figure 1. See Appendix 2

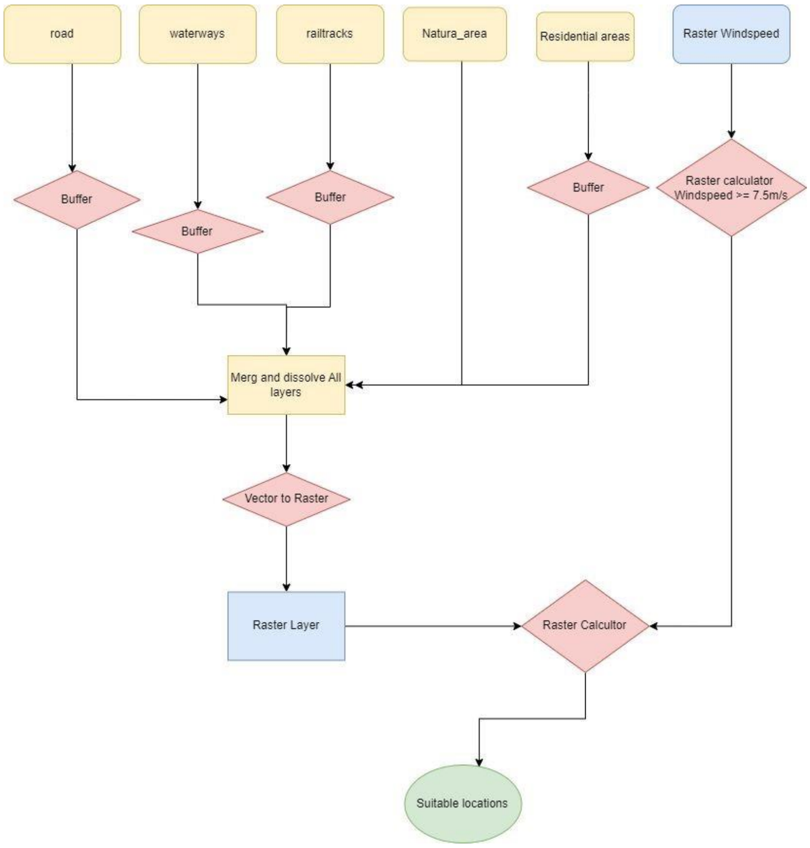


Figure 1 Workflow of processing the data.

Second part

Wind Turbine model

For this research, the Nordex N117/3600 wind turbine was chosen. It is a model that is presently in operation in the Prinses Ariane wind park in North Holland *(WindStats, n.d.)*. This wind turbine is 117 metres in diameter and 118 metres in height at the hub. Therefore, it is classified as a class III wind turbine by the International Electrotechnical Commission (IEC), with an operating range of 7.5 m/s and higher for yearly wind speeds.

Evaluation of energy output

From *McKenna et al. (2021)* we obtained the ideal spacing between turbines that is shown in Figure 2. We used the area of the grid that can be drawn between 4 turbines as the total area for placing four turbines. Then to get the area needed for the 1 wind turbine, the total area was divided by 4. It is important to note that this is a rectangle/square and not a realistic field.

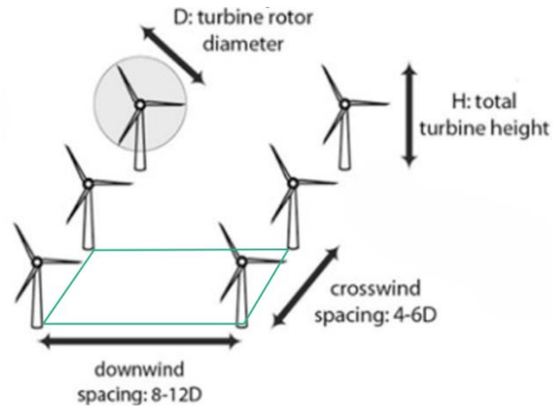
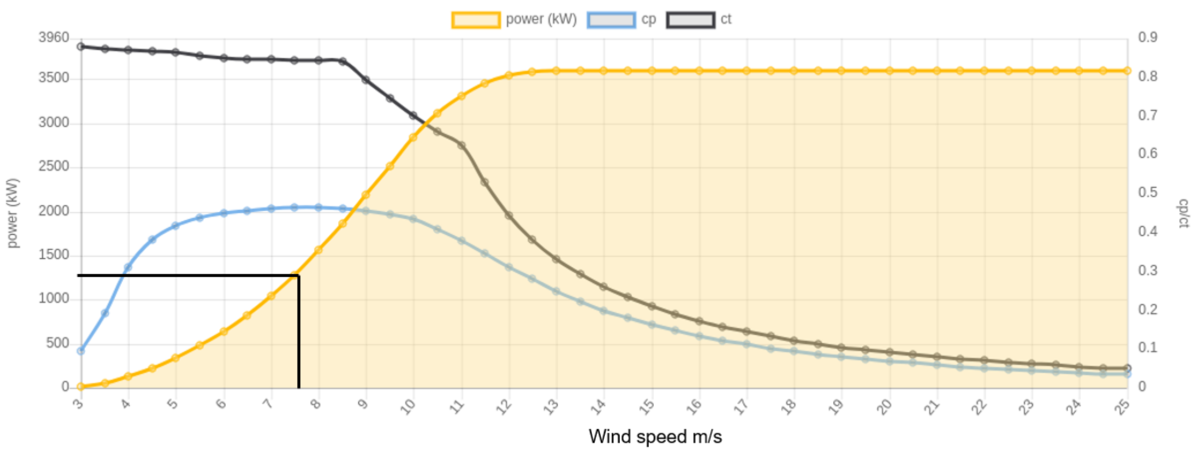


Figure 2 The ideal spacing between turbines based on McKenna et al. (2021).

Next, based on the suitable areas achieved through GIS overlay maps, we obtained the area of each suitable location m^2. Then this area was divided by the total area of 1 wind turbine to get the total amount of wind turbines that can fit there. It is important to remember, also in this case, that in the calculation we divide two rectangular areas by each other.

Then, again using the QGIS overlay maps from the first part of the assignment, the value for the average annual wind speed (for each suitable area) was estimated. Graph 1 presents the power curve that allows that by looking at the value of annual energy output in kW. based on the specific value of wind speed.



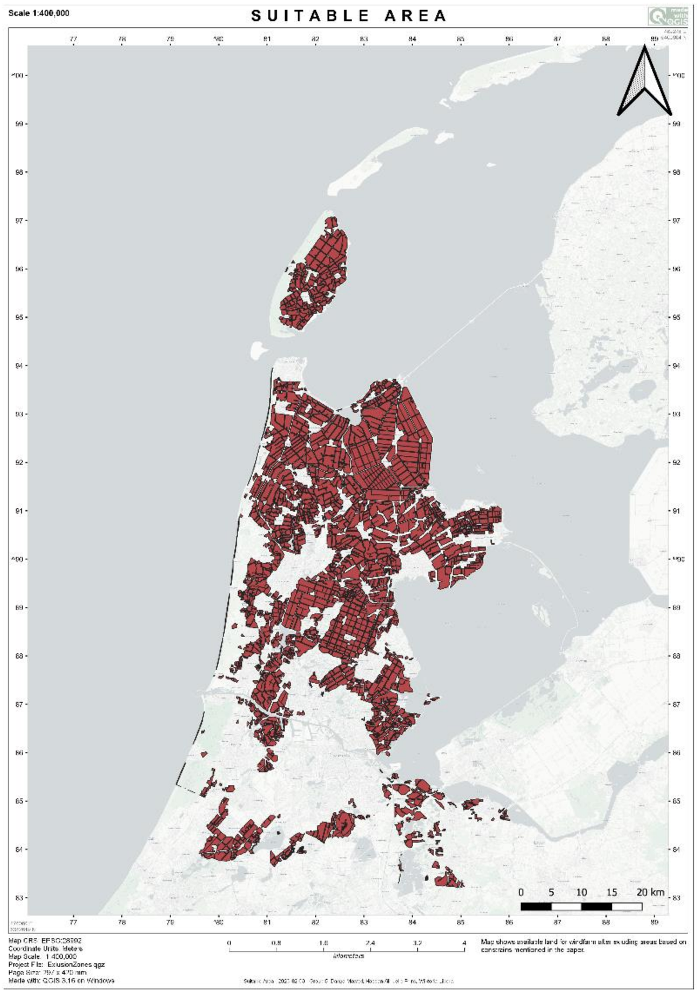
Graph 1 Power curve of the Nordex N117/3600 wind turbine[1]

We then took the number of wind turbines in each individual area and multiplied this by the obtained output in kW that corresponds to the wind speed of that area, thus obtaining the maximum potential energy output in kW (kilo Watt) for that area. We then divided the output in kW by 1000 to get the output in MW (Mega Watt).

[1] *Nordex N117/3600 delta*. Nordex N117/3600 Delta - 3,60 MW - Wind turbine. (n.d.). Retrieved February 3, 2023, from https://en.wind-turbine-models.com/turbines/1472-nordex-n117-3600-delta

Results and analysis

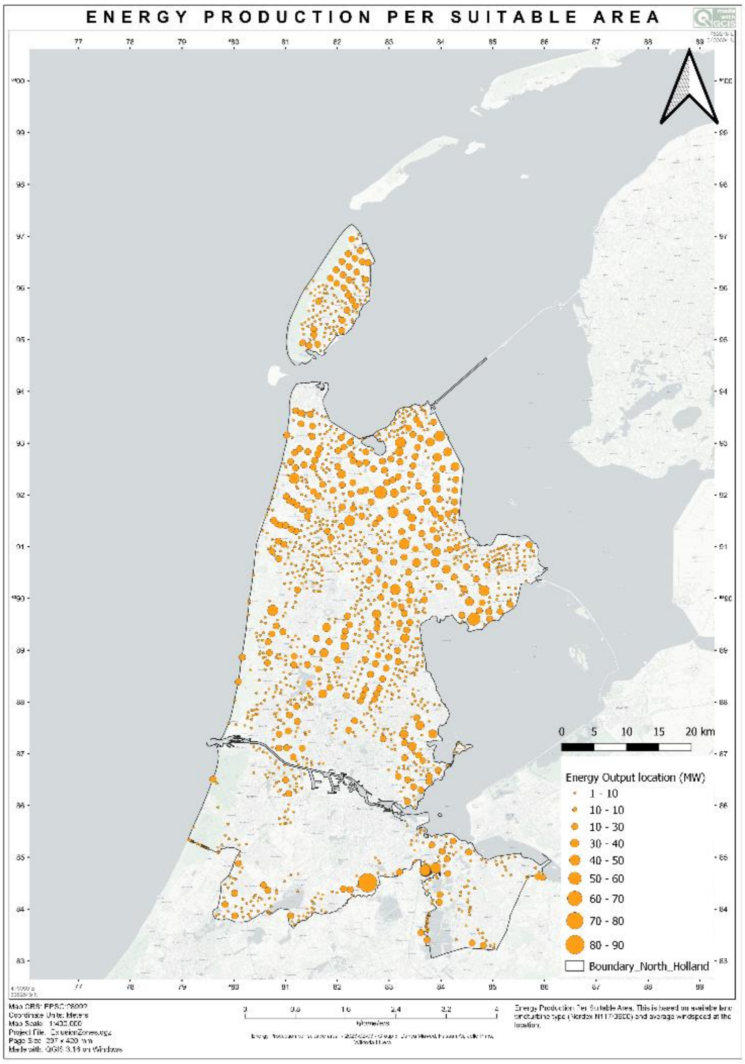
The results of the case study present a comprehensive evaluation of the wind energy potential in North Holland through the use of maps generated with QGIS. The first thing to consider is the areas feasible for wind turbine installation. The outcome of this is presented in Map 1.



Map 1 Suitable areas for building wind turbines based on criteria and constrains.

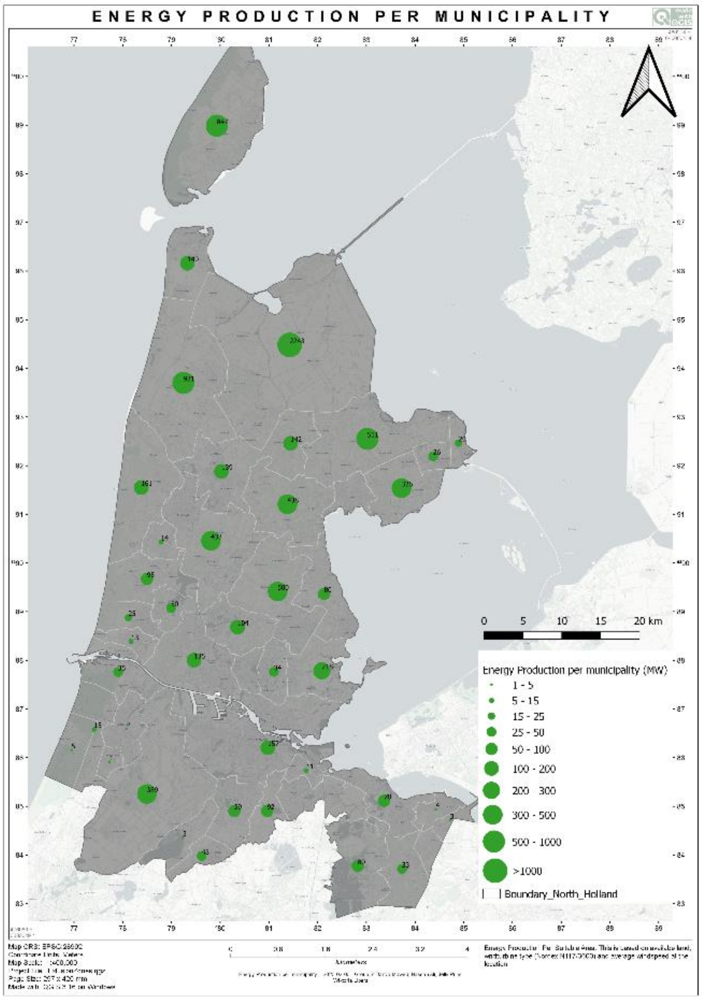
To begin, this map includes all constraints and criteria, as well as the wind speed criterion. As a result, it appears that the most suitable areas are in this province's north-western corner. Surprisingly, not all of them are located near the coast. However, it is clear that the areas closest to larger cities, such as Amsterdam, have no available space, which is justified by high urbanisation *(Hoogwijk et al., 2004)*. Finally, there does not appear to be much space in the province's south, but some is possible.

Knowing the suitable places for installing a wind turbine, was the first part of this study. The second one is to determine the theoretical maximized energy output within those areas. The result for this is shown in Map 2.



Map 2 Energy output per suitable area in MW.

However, it is better to analyse the results for energy production at the municipality level. For that Map 3 was created.



Map 3 Energy production (output) per municipality in MW.

As was demonstrated above, power production in different municipalities does not differ significantly. To begin, with a value of 2241MV, Wieringermeer municipality produces the most energy, while Heemstede municipality produces the least (1MW). On the West Coast, it appears that the least amount of possible energy output was estimated. Because there are fewer suitable areas, this outcome is entirely predictable. In general, our findings indicate that the total theoretical power production is estimated to be 9,700 MW, requiring approximately 6,500 wind turbines. In comparison, North Holland currently has 352 wind turbines producing 720 MW of energy, which is roughly 20 times less than what was estimated in this paper.

Discussion

The following paper is merely an exploratory case study to determine how much energy can be generated annually from wind production under certain constraints. There are limitations, such as restrictions. First and foremost, the number of wind turbines within the appropriate area was estimated using a rectangular shape, which is rarely the case. As a result, it would be advantageous to take that into account for feature research, for example, by writing an algorithm that would fit a wind turbine (with specific dimensions) into an area until it is no longer possible.

Secondly, to obtain more accurate results, the technical potential of the area in terms of wind density or direction should be added. Some of the areas further away from the cost appeared to be more energy efficient to us, but this may not be the case due to those factors. This raises the possibility of additional constraints, such as placement distance from power infrastructure, exclusion of bird habitat zones, or exclusion of zones connected to Schiphol Airport. The lost one would almost certainly eliminate some of the suitable spaces in the province's south.

Finally, the economic aspect was left out of this analysis. Investing in wind turbines can be extremely expensive. According to Paardekooper (2015), the total cost of constructing an 18-turbine wind farm, including infrastructure and other non-generic costs, is €76,535,700. Based on our findings and this estimate, the construction of nearly 6,500 wind turbines would cost close to €28 billion. This expense far exceeds the North Holland provincial government's projected budget of €157 million for the next three years *(Provincie Noord Holland, 2022)*.

Conclusion

This paper was divided into two parts: finding suitable locations for wind turbines in North Holland and evaluating their potential energy output. We were able to estimate the theoretical maximum output of energy produced by wind turbines in the province of North Holland based on the research provided. The goal was to find a specific number, and we succeeded. The issue lies in the constraints that were considered. However, with the changes suggested in the Discussion section, this research could be explored further and possibly adapted to find even more precise energy output.

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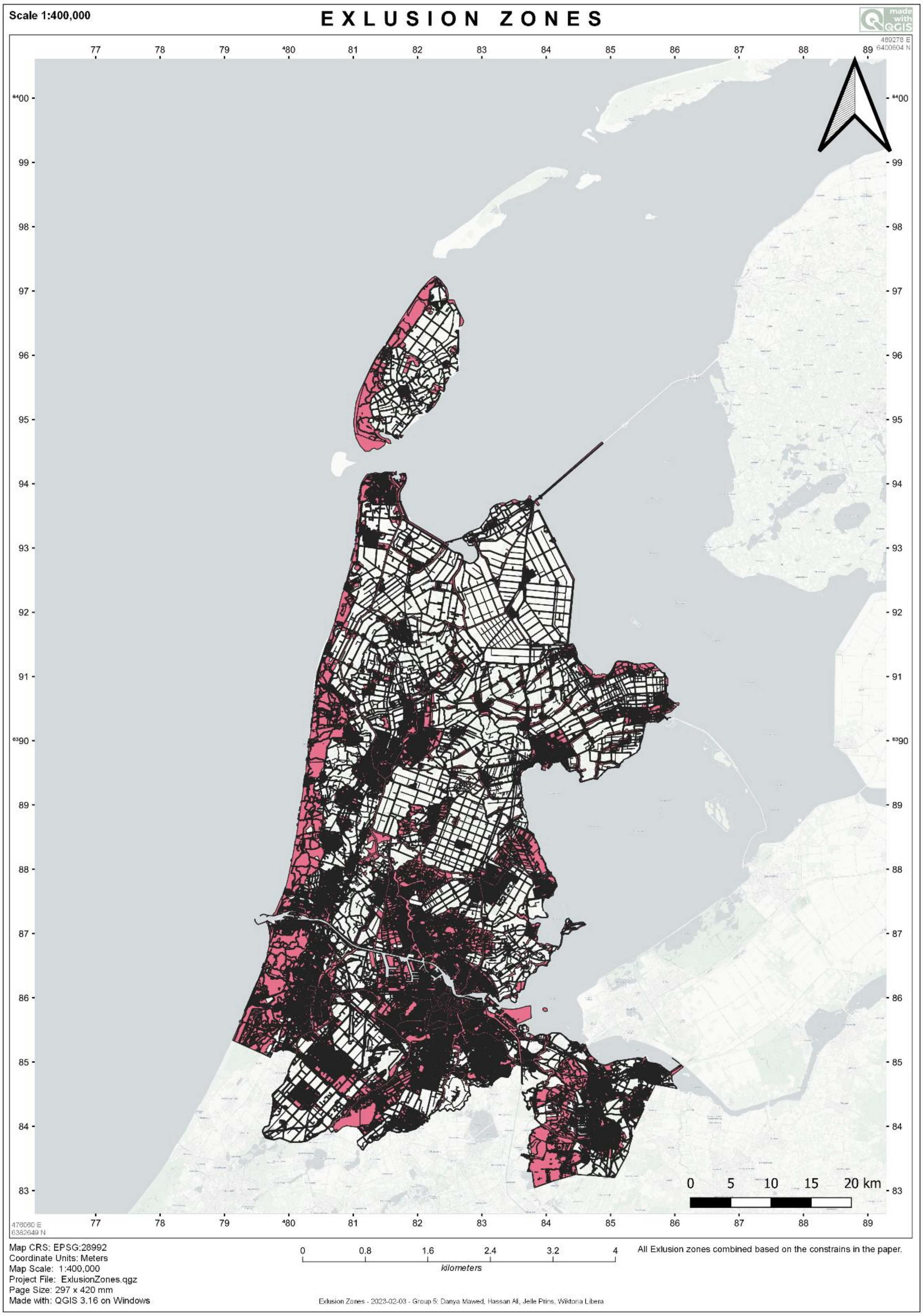
Appendix

Appendix 1. Sources of data collected.

What	Source	Additional information
Railways	OSM	Buffer zone 50 m and clipped to fit only North Holland
Roads	OSM	Buffer zone 50 m and clipped to fit only North Holland
Waterways	PDOK:https://www.pdok.nl/introductie/-/article/kaderrichtlijn-water ("KRW Oppervlaktewaterlichamen Nederland EU2015 lijnen")	Buffer zone 50 m and clipped to fit only North Holland
Waterbodies	PDOK: https://www.pdok.nl/geo-services/-/article/vaarweg-informatie-nederland-vin- ("Vaarwegen") And Binnenwater - Bestand Bodemgebruik 2017 (BBG2017)	Buffer zone 50 m and clipped to fit only North Holland
Residential Area	Province North Holland Data portal: https://geoapps.noord-holland.nl/kaartenportaal/apps/MapSeries/index.html?appid=e85fc52939f240ba9ef5164b5e203fb2&entry=4) ("Bebouwdekomgrens wegenwet")	Buffer zone of 100 m
Natura 200 (preserved areas)	Province North Holland Data portal: https://geoapps.noord-holland.nl/kaartenportaal/apps/MapSeries/index.html?appid=e85fc52939f240ba9ef5164b5e203fb2&entry=4 ("Natura 2000 gebieden")	No buffer
Wind speed	Global Wind Atlas: https://globalwindatlas.info/en/area/Netherlands/Noord-Holland	In the analysis only areas with speed >= 7.5 m/s is used.
Province of North Holland	PDOK: https://www.pdok.nl/introductie/-/article/bestuurlijke-grenzen)	-

Appendix 2. Map of the exclusion zones[2]



[2] Note that this map contains only the land use constraints only and area with wind speed above 7.5 m/s is not included yet.

Appendix 3. Wind speed map.