

# GIS analysis of the technical potential of wind energy in the Netherlands

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## Abstract

Incorporating the spatial aspects of wind energy towards 2050, in terms of determining the technical potential of wind turbines, requires rather advanced GIS analysis techniques. Wind energy in the Netherlands is characterised by many regulations, which makes finding suitable locations for wind turbines quite challenging. We calculated the technical potential for wind energy in megawatts (MW) within certain ranges by looking at different restriction levels and possible suitable areas. A spatial algorithm was used to act as a proxy to calculate the number and exact locations of wind turbines within such a suitable area. This also provides an idea of the effect on the landscape, on both meso and micro levels. The bandwidth of this potential could also be compared with already known future land claims for wind energy in certain areas, which gives an indication of how realistic such land claims would be in practice. Complexing factors in the GIS analysis include the already placed wind turbines in a certain area, which may restrict the placing of additional wind turbines. Furthermore, new urban areas, the modelling outcome of scenarios, may further restrict future wind energy locations. For this study, spatial urban development plans according to the so-called Delta-scenarios were also taken into account. The GIS framework used is also suitable for comparing the differences between outcomes for areas where wind energy is leading in spatial planning, which may thus limit future urban development. This study only looks at the technical potential for a certain part of the Netherlands (Goeree-Overflakkee, 527 km<sup>2</sup>), but the method could be scaled up to include the whole of the Netherlands.

*Keywords:* wind energy, GIS, modelling, technical potential, spatial algorithm, restriction

## 1 Introduction

In recent years, in GIS and spatial modelling, there has been an increasing need to include the spatial aspects of the realisation of renewable energy in favour of the energy transition. In particular, the land claims for future wind farms are increasing substantially, in the Netherlands, and will also affect the landscape (Maslov et al., 2017), among other things. This type of renewable energy is characterised by a mixing of functions in the field and their own spatial dynamics, on both meso and micro levels, which makes the spatial GIS modelling process more challenging, to some degree. Recent studies of the allocation-problem of wind turbines, mostly use GIS-oriented Multi Criteria Analyses (MCA) (Van Haaren and Fthenakis, 2011; Mardani et al., 2017; Eichhorn et al., 2016).

This study uses a method of exploring the technical potential of wind energy under various combinations of restrictions and suitability levels. This could be confronted with any known claims in megawatts for wind energy. This provides a possible bandwidth of the potential. By exactly placing the new wind turbines in GIS (in this case, GeoDMS) using a spatial algorithm, the effect on the landscape can be determined. Spatial development of the urban area up to 2050 is taken into account, under various so-called Delta Scenarios (Wolters et al. 2018). These scenarios are geographically allocated by using the Land Use Scanner (Hilferink and Rietveld, 1999; Koomen et al., 2008) in time steps of 10 years. As this is also programmed in GeoDMS software, it forms a fully integrated GIS platform to explore the technical

potential of wind energy. The new urban area further limits the possibilities of renewable energy (mainly because of the Wind Turbine Noise Regulation), and this aspect is not always included in other, similar studies. In the GIS framework used, the renewable energy in the model still follows the already submitted land claims, instead of being leading in land-claim fulfilment.

## 2 Restrictions and preferred areas

The Netherlands already has many regulations on wind energy (Nieuwenhuizen and Köhl, 2015), compared with, for example, those on solar energy. A whole series of restrictions are substantially limiting the spatial possibilities for wind energy. These include noise and external safety contours, as well as those around existing wind turbines. Preferred areas, for example, include locations along existing infrastructure (e.g. motorways, high-voltage electricity grid) and parallel to dykes, as well as areas where, according to public opinion, the landscape is less interesting. From an economic perspective, particularly interesting are areas that can compete with agricultural revenues.

## 3 Spatial algorithm

To obtain an impression of the technical potential's visual impact on the landscape, a sophisticated spatial algorithm was developed for placing wind turbines (2 MW and a rotor with a diameter of 80 metres) in suitable areas. This spatial

allocation problem can be seen as an optimization issue. Around each wind turbine, an area of six times its rotor diameter is restricted for another wind turbine, in the direction of the predominant wind (southwest). Perpendicular to the predominant wind direction (northwest to south-east) this is four times the rotor diameter. Moreover, the rows of wind turbines are placed in a staggered configuration to make optimum use of wind energy. The minimum and maximum number of wind turbines that could be placed in suitable areas for wind turbines is determined by a proxy with for example 36 so-called wind turbine location stamps, in the form of ovals. Each oval represents a wind turbine. Each stamp is shifted by 80 meters in x direction or y direction or combined. The maximum number of stamps is reached when six times the rotor diameter is met in the shifting ( $480 \text{ meter } x\text{-dir} / 80 \text{ meter } y\text{-dir} * 480 \text{ meter } y\text{-dir} / 80 \text{ meter } x\text{-dir} = 36 \text{ stamps}$ ). The number of wind turbines in a stamp falling in suitable areas is the result of a stamp. The amount of megawatts can then be determined very easily as the megawatt of a wind turbine is known (2MW). The stamp-model can be run in two ways, spatially seen:

- In once for the whole study area. Number of stamps in this case are 576 (shifting of 20 meters).
- In smaller spatial units; A spatial unit is considered to be a number of suitable areas taking together if this was considered one contiguous polygon if the suitable areas are buffered with the rotor diameter. The number of stamps in this case was 36 (explained example above). The number of stamps is lower compared to study-area run because of longer calculation times.

The maximum occurring value in the series of stamps can be considered as the lowest limit of the theoretical maximum. It is still a suboptimal solution for this optimization issue. For example, for very elongated narrow polygons, it may be more advantageous to cut them into smaller spatial units. Less value must be attached to the minimum; it represents a stamp that leads to the least number of wind turbines.

The spatial configuration of wind turbines within a location result stamp also gives an idea of the degree of fragmentation of the placed wind turbines in the field. Additional conditions can be entered into the algorithm to form groups of minimal number of wind turbines.

#### 4 Results technical potential

First, the technical potential of wind energy on land is determined by considering land use, restrictions and preferred areas, and the assumed key data on energy yield— megawatt per hectare or per wind turbine. A case study was worked out for an island (527 km<sup>2</sup>) in the southwestern part of the Netherlands, called Goeree-Overflakkee (see Figure 1). This rather rural island is known to be a suitable location for renewable energy. After GIS analysis the potential in MW, could be compared with the current estimated land claim for renewable energy (per region, 225 MW in 2020, for the island). The bandwidth indicates whether the claim is realistic.

This method differs from the more traditional method whereby the allocation is determined by the submitted claims.

The results are illustrated in Figures 1, 2 and 3 below. Per scenario (STOOM and DRUK), the bandwidth of the technical potential, in megawatts, is given for the case study area, for the various restriction levels. The base year is given as a reference. In addition, the figures also indicate which restriction levels suit the storyline of the scenario the best (green boxes in figure 3 and 4). STOOM, in general, is a scenario with liberal viewpoints and wide-spread urban areas. The chosen restriction level with partly legally hard restrictions and limitation due to noise contours fit best within this storyline. The DRUK scenario contains more regulation and concentrated urban areas. All hard and soft restrictions (among other things Natura 2000, National parks) are taken into account in this storyline. As there is more regulation in DRUK; preferred areas for wind energy are active in the model.

The effect of the spatial algorithm (results of the wind turbine location stamps) is shown spatially in figure 1 (STOOM) and 2 (DRUK) and in graph form in figure 3. The two restriction levels which fits the storylines the best for the two mentioned scenarios were calculated with smaller spatial units stamp-model. Differences in the minimum and maximum values for number of wind turbines and the corresponding MW are maybe rather small for STOOM but spatially it makes a difference. The minimum and maximum values are reasonably close to each other for STOOM (14%) but differs more for DRUK (372%). For the DRUK-scenario the technical potential (406 MW) is above the already known claim of 225 MW in 2020. For STOOM this is much higher (around 2662 MW) although a very substantial amount is in inland water. The number of spatial units for restriction level ‘hard restrictions with sound contour’ was 60 and for ‘in preferred area outside all restrictions’ 64. Running the stamp-model with spatial units instead of the whole study area in once increased the number of megawatts in the STOOM-scenario within restriction level ‘hard restrictions with sound contour’ with 153 MW (from 2509 MW tot 2662 MW).

For completeness another two restrictions levels are given in figure 3 to gain insight. One less restricted with the highest number of wind turbines. And another ‘in preferred area outside hard restrictions’ with slightly higher number of wind turbines compared to the restriction level ‘in preferred area outside all restrictions’. These restriction levels were calculated with the less time intensive study area stamp-model. The very small differences between base year, STOOM and DRUK within an restriction level is caused by the very limited growth of urban area in this rural area.

Furthermore, planning damage (Lang et al., 2014) is determined as an indicator of the impact of placing wind turbines by counting the number of homes within a buffer zone of 1.0 km around wind turbines, and an assumed 1.4% damage per home (partly based on Dröes and Koster, 2016), as is shown in Figure 4. The minimum and maximum values are further apart, in this case, because of the spatial configuration of the more differentiated, existing urban area.

## 5 Conclusion

An advanced GIS framework for integrating future scenarios, restriction–suitability levels and spatial algorithms for the allocation of wind turbines seems to be suitable for analysing the technical potential of wind energy. This is done without using the more traditional method in which claims (in megawatts) for renewable energy are allocated. A straightforward method of addressing the potential by looking at the demand and suitable locations for wind turbines will provide realistic insight into the bandwidth of possibilities for wind energy per region. A sophisticated spatial algorithm, subsequently, provides the actual placement of wind turbines. The algorithm model is set up in such a way that the size of the wind turbines can be taken into account, in addition, the stamp size can also be adjusted.

## 6 Acknowledgments

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## 7 References

- Dröes, M.I. and Koster, H.R.A. (2016). *Journal of Urban Economics*, 96 (2016) 121–141.
- Eichhorn, M., Tafartea P., Thränab, D. *Energy* Volume 134, 1 September 2017, Pages 611-621 Towards energy landscapes – “Pathfinder for sustainable wind power locations”
- GeoDMS <http://www.objectvision.nl/geodms>
- Hilferink, M. and Rietveld, P. (1999) LAND USE SCANNER: An integrated GIS based model for long term projections of land use in urban and rural areas. *Journal of Geographical Systems*, 1(2):155–177, 1999. doi:10.1007/s101090050010.
- Koomen, E., Loonen, W. and Hilferink, M. (2008) Climate-change adaptations in land-use planning; a scenario-based approach. In: Bernard, L., Friis-Christensen, A. and Pundt, H. (eds.), *The European Information Society; Taking Geoinformation Science One Step Further*. Springer, Berlin, pp. 261-282.
- Lang, C. , Opaluch, J.J. , Sfinarolakis, G. , 2014. The Windy city: property value impacts of wind turbines in an urban setting. *Energy Econ.* 44, 413–421.
- Mardani, A., Zavadskas, E.K., Khalifah, Z. Zakuan, N., Jusoh, A., Nor, K.M., et al. A review of multi-criteria decision-making applications to solve energy management problems: two decades from 1995 to 2015 *Renew Sustain Energy Rev*, 71 (2017), pp. 216-256
- Maslov, Nicolas & Claramunt, Christophe & Wang, Tianzhen & Tang, Tianhao. (2017). Method to estimate the visual impact of an offshore wind farm. *Applied Energy*. 10.1016/j.apenergy.2017.05.053.
- Nieuwenhuizen, E, Köhl M (2015) Differences in noise regulations for wind turbines in four European countries 2015. *Euro Noise 2015* 31 May - 3 June Maastricht .
- Van Haaren, R., Thenakis, V. GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): *Evaluating the case for New York State* Volume 15, Issue 7, September 2011, Pages 3332-3340
- H.A Wolters, G.J. van den Born, E. Dammers, S. Reinhard, 2018, *Deltascenario's voor de 21e eeuw, actualisering 2017*, Deltares, Utrecht

Figure 1: Overview wind turbines Goeree-Overflakkee: present, planned and modelled and minimum and maximum modelled wind turbines (rotor 80 meter-2MW) for scenario STOOM 2050

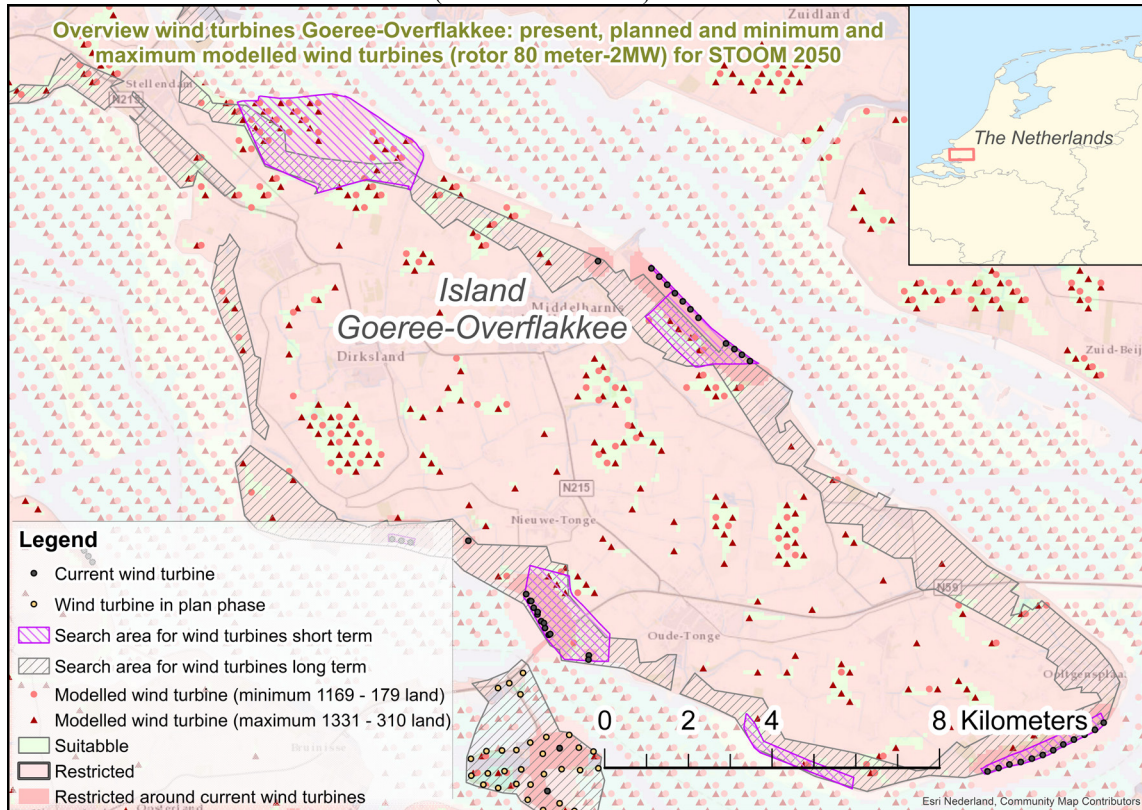


Figure 2: Overview wind turbines Goeree-Overflakkee: present, planned and modelled and minimum and maximum modelled wind turbines (rotor 80 meter-2MW) for scenario DRUK 2050

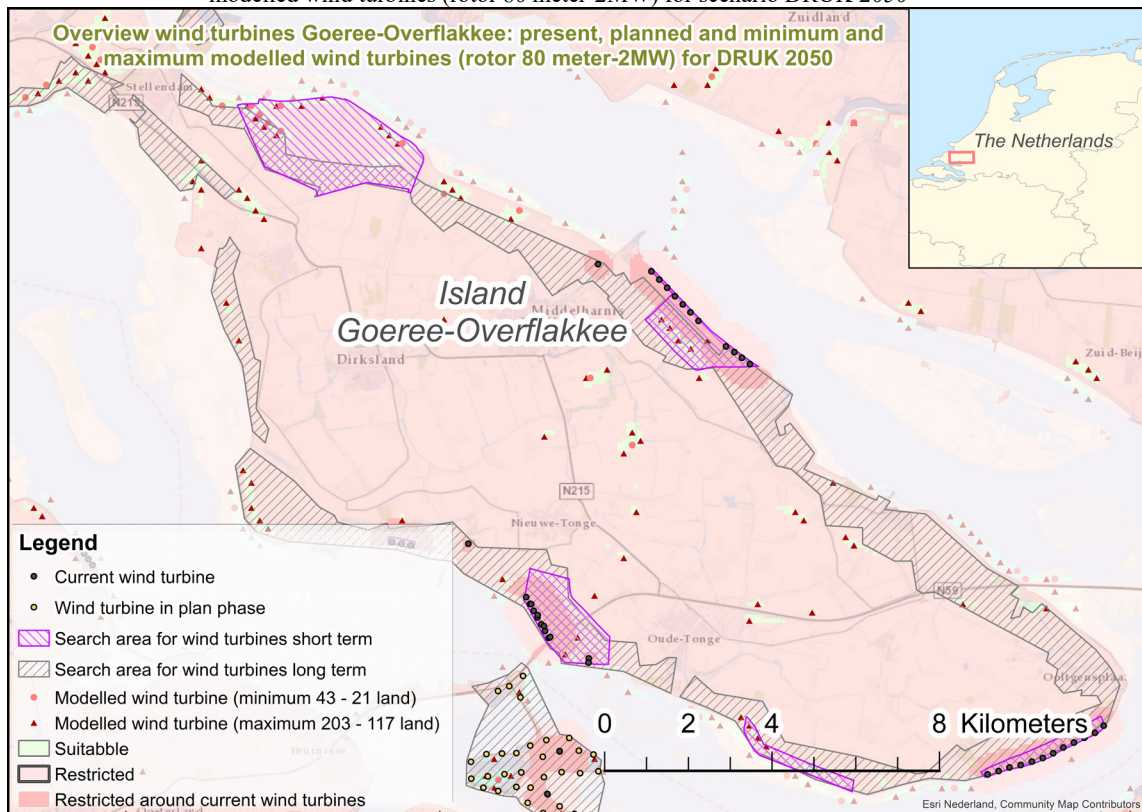


Figure 3: Technical potential wind turbines 4 levels of restriction for Baseyear, STOOM 2050 and DRUK 2050

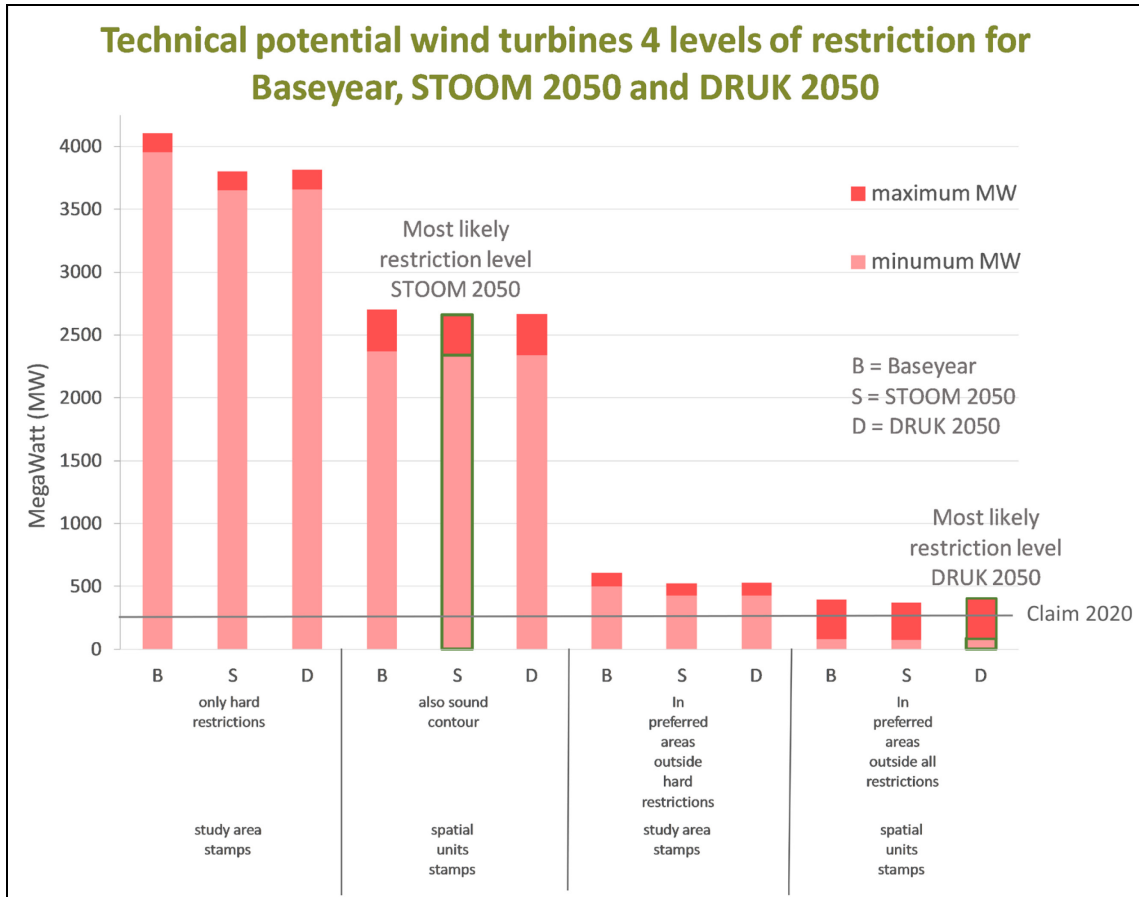


Figure 4: Planning damage to homes by wind turbines 4 levels of restriction for Baseyear, STOOM 2050, DRUK 2050

