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Measuring and visualizing environmental and social impacts of wind energy projects

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Contents

Executive summary

European targets advocate the increase from 40% to 55% net greenhouse gas (GHG) emission reduction with respect to 1990 levels by 2030. The Netherlands, with the aim to reduce at least 49% of GHG by 2030, has agreed that thirty energy regions will investigate where and how in the best way sustainable electricity on land and inland lakes (wind and solar) can be generated.

One of the main causes of delays and challenges of wind energy projects for new wind farm development are the social acceptance and the environmental impacts, in particular impact on birds. In recent years, public consultation has been defined as integral part of environmental and socio-economic assessments and of maritime spatial planning processes. Early involvement of all groups is deemed crucial for the timely deployment of new capacity.

However, social acceptance is difficult to represent in spatial assessments, due primarily to the lack of existing methodologies to capture representative data. Participatory methodologies, which engage with community and societal actors, should be employed as early as possible when developing renewable energy projects, thereby decreasing risks due to opposition or lack of societal support at later stage.

With regards to the environment, the real impact of wind energy in the air habitats is quantified by assumptions that are not validated with real and accurate data. The lack of reliable data challenges the inclusion of constraints in spatial analysis. These impacts based on assumptions reduce the potentially available area for new projects and require curtailments strategies, limitations and penalties to wind farm developers and owners, impacting the business case of the project. The lack of accurate data on the actual fatality rate resulting from bird collisions, bird behaviour, and the change of habitat reflects an urgent need for a standard methodology for assessing impact and measurement technology to accurately quantify the real impact. There is a clear need for further research to better understand the real impact of the wind turbines on air habitat and consequently,

- Conclude what the most suitable wind turbine control strategies are to minimize the impacts and,
- Adapt the design of the wind farms located in nature protected areas to specific environmental constraints.

This study provides a methodological approach and analysis on assessing suitable geographical areas for onshore wind energy deployment, considering a comprehensive set of criteria on land use, protected areas, and wind resource characteristics combined with specific environmental impacts such as bird migration routes, grid constraints such as power grid congestions and social acceptance of local communities.

The framework provides, on the one side, a complete overview of the challenges and barriers, and, on the other side the drivers and potentials (alt. success factors) for the deployment of onshore wind energy in the Netherlands, with a focus on a specific regional case: Energy Region Noord-Holland Noord.

1 Introduction

1.1 Background of the problem

European targets advocate the increase from 40% to 55% net greenhouse gas (GHG) emission reduction with respect to 1990 levels by 2030 [1], [2], [3]. The Netherlands is one of the most ambitious European (EU) countries with the aim to reduce by at least 49% of GHG by 2030 [4].

For wind energy deployment the goals are translated into fivefold increase in capacity by 2030 with respect of today. Such ambitious targets entail overarching challenges to mitigate, being the social acceptance and environmental impact the main reasons of delays for both offshore and onshore wind projects. In recent years, public consultation has been defined as integral part of environmental and socio-economic assessments and of maritime spatial planning processes. Early involvement of all groups is crucial for the timely deployment of new capacity (Figure 1).

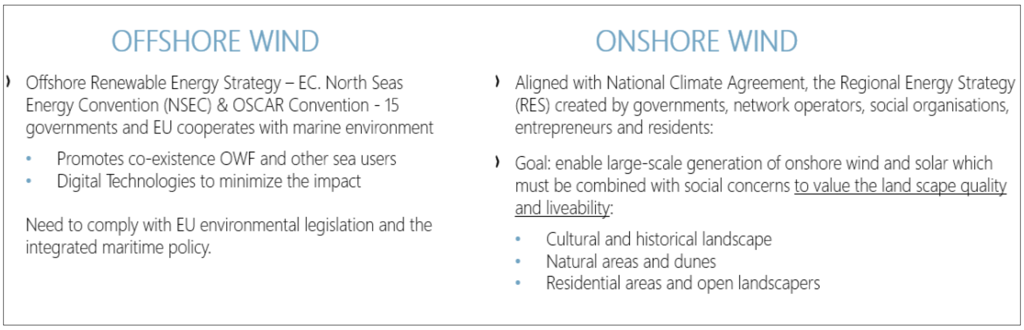

Figure 1 Measures promoted to overcome environmental and social impact in wind energy projects [5], [6], [7]

The National Programme Regional Energy Strategy [8] supports the development of Regional Energy Strategies (RES) in thirty energy regions in the Netherlands in order to investigate where and how best renewable energy (RE) sources on land (wind and solar) can be generated and which heat sources can be used so that neighbourhoods and buildings can move away from natural gas

However, social acceptance is difficult to represent in spatial assessments, due primarily to the lack of existing methodologies to capture representative data. Participatory methodologies which engage with community and societal actors should be employed as early as possible in renewable energy projects, thereby decreasing risks due to opposition or lack of societal support at later stage.

With regards to the environment: the real impact of wind energy in air habitats is quantified by assumptions that are not validated with real and accurate data. The lack of data challenges the inclusion of these constraints in spatial analysis. These impacts based on assumptions, reduce the potentially available area for new projects and require curtailments strategies, limitations and penalties to wind farm developers and owners, impacting the business case of the project. The lack of accurate data on the actual fatality rate resulting from bird collisions, bird behaviour and the change of habitat reflects an urgent need for a standard methodology for assessing impact and measurement technology to accurately quantify the real impact. There is a clear need for further research to better understand the real impact of the wind turbines on air habitat and consequently,

- what the most suitable wind turbine control strategies are to minimize the impacts and,
- how the designs of the wind farms, located in nature protected areas, need to be adapted to specific environmental constraints.

1.2 Research questions and challenges

In recent years attention towards social acceptance and environmental impact (in particular, impact on birds) has grown and initiatives for early stage citizen participation has begun to occur more frequently. Typically however, environmental and social aspects are not addressed until the execution phase of RE projects, resulting in costly delays and challenges for new wind farm developments.

In terms of spatial mapping, these aspects are not yet implemented as an integrated framework with existing onshore wind resources, technical and economic potential atlases. Thus, the research questions addressed here are:

- How can the impact on air habitats be included in the wind resource and technical potential estimations before the execution phase of a project?
- How can the social acceptance of societal and community actors be quantified for a new potential area for wind deployment?
- Which are the potential environmental and social challenges that face the potential RE deployment areas in the Netherlands?

Addressing such questions would support the National RES Program [8] in the Netherlands, by developing and sharing knowledge, offering process support and facilitating a learning community with the inclusion of social participation; This would contribute to better balancing optimal RE deployment and community needs and values.

1.3 Goals of the project and opportunities

The goal of this study is to develop:

1. an integrated framework to estimate available sites for onshore wind deployment resulting from a detailed assessment of the most relevant information and data to address resource, technical, topographical, environmental and social constraints;
2. a methodology to capture social acceptance of potential RE deployment which can be quantified and represented using spatial mapping techniques.

To reach the goals, a geographic information system (GIS) tool is applied to spatially analyse and define the potential areas for Renewable Energy Sources deployment with a focus on onshore wind energy. Specifically, it aims to combine different aspects in one framework for the deployment of new wind turbines including:

- Ecological aspects and bird impacts, referring to collisions, risks areas for several species of birds and migration routes,
- Land use potential and infrastructure constraints, referring to grid and grid congestions areas,
- RE and technical information focussing on wind and solar resource,

- Levels of social acceptance, based on land use types, community values and a comprehensive categorisation of acceptance factors.

The integrated framework (Figure 2) is organized in two different scales: on a national level, providing the main constraints for onshore wind deployment, and on a regional scale: the Noord-Holland Noord region, where local constraints are addressed in a more detailed analysis of layers.

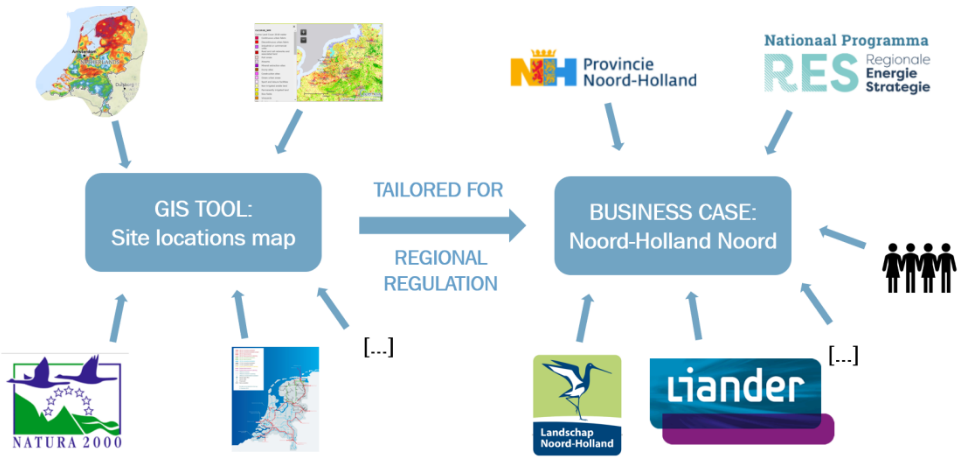

Figure 2 Diagram of the overview of the integrated framework based on the GIS-tool.

The results present the identification and visualization through high-resolution mapping of selected potential land available for RE projects while highlighting limitations, barriers and drivers. This integrated framework will:

- provide the basis for future analysis to increase the value of wind energy with other RE technologies, minimizing costs and considering the environmental impact and social acceptance;
- support spatial decision-making based on technical, geographical and administrative considerations, combined with social and environmental acceptance;
- support the government and the regions to define the needed area for RE deployment, speeding up the process while considering at early stage major challenges and potentials to assess RE adaptation and mitigation of local barriers and drivers.

This document is structured as follows: Chapter 2 describes the case study selected for the analysis on the Noord-Holland Noord Energy Region; Chapter 3 describes the tool and data used to create the spatial analysis and the social acceptance methodology to identify the most suitable areas to build onshore wind farms. Chapter 4 focuses on the results of the analysis and on the maps obtained and finally, Chapter 5 presents conclusions and next steps for further research.

2 State-of-the-art

There is extensive literature on evaluating the areas where RE can be deployed to reach 2030 targets. Most of the studies present techno-economical potential analyses of onshore wind energy at global, EU or country level. For example, at global level, Bosch et al. [9] considered the land use, topographical features and environmental constraints and combine wind resources and the technology. Eurek J et al. [10] added to the analysis the resource accessibility as the distance from the transmission network and applied the potential for integrated assessment models.

At the European level, Zappa et al. [11] introduced a methodology to assess RE spatial distribution for power system modelling where technical and spatial constraints were addressed to extract suitable land based on the Corine Landcover dataset [12] and protected areas. Ryberg et al. [13] investigated onshore wind energy capacity and generation based on land eligibility and placement analysis based on location-specific wind turbines and predict potential capacity, generation and LCOE to investigate the economic potential. A similar analysis by McKenna [14] focused only on large onshore wind turbines.

Existing European wind atlases at high-resolution scale were compared and evaluated by Pian [15] to estimate onshore wind potential and the ENSPRESSO dataset [16] developed by European Commission addressed different scenarios towards 2050 of wind and solar energy technical potential.

However, few are the research studies including social or environmental aspects beyond the techno-economic potential. Regarding the social side, Harper [17] addressed the United-Kingdom (UK) onshore wind potential considering technological, legislative and social constraints. Jäger in [18] considered as social acceptance the landscape aesthetical aspects for evaluating potential areas in the Baden-Württemberg state, southwest Germany; and in [19] by Siya particular attention was given to determine Swedish areas excluded for onshore wind suitability as: protected areas, areas of national interest for nature, culture and recreation values.

Furthermore, such studies including environmental constraints for wind energy deployment are limited to the European protected areas for biodiversity, birds and habitat protection designated in the Natura 2000 network [20]. Whereas wind turbine impacts on air habitats are defined by direct collisions of birds and bats, barriers for migration routes and local flying movements and habitat loss due to disturbance and habitat change. These specific impacts are difficult to evaluate and quantify and are often based on assumptions [21], [22], [23], [24], [25], [26].

Overall, social impact and acceptance and a real estimation on the impact of air habitats are still major gaps to bridge by additional research.

3 Case study: Noord-Holland Noord Region

Noord-Holland Noord (NHN) is part of the Noord-Holland Province formed by 17 municipalities with a total surface of 1353.6 km^2 and a population of 1.724 million. Within the National Climate agreement, Noord-Holland Noord has a production target by 2030 of 3.6 TWh of renewable energy generation. With the current generation of 2.1 TWh, an additional 1.5 TWh must be realised in the near future [27].

The first version of the Regional Energy Strategy (RES) of Noord-Holland Noord (hereinafter, RES 1.0), was created by governments, network operators, social organisations, entrepreneurs and residents together. The RES 1.0 aims to facilitate large-scale generation of solar and wind energy on land. In addition, the RES 1.0 explores the possibilities for using sustainable heat sources and techniques replacing natural gas.

The RES 1.0 discusses the need to connect supply to demand, for example by locating new generation facilities close to transformer stations or grid connections with sufficient capacity. It also attempts to optimise space and opportunities for generation by, where possible, co-locating wind and solar installations [27].

The RES 1.0 also takes into account societal concerns and local values [27]. For example, some areas have already been excluded from consideration for potential RE deployment – such as residential areas, natural areas, dunes and open landscapes and sites of cultural or historical significance – highlighting the importance of liveability and scenic quality.

4 Methodology

The existing datasets (listed below) are merged and organized into two different maps: at a national and regional scale. The maps cover the onshore area of the Netherlands and the onshore energy region of Noord-Holland Noord, part of the Noord-Holland Province.

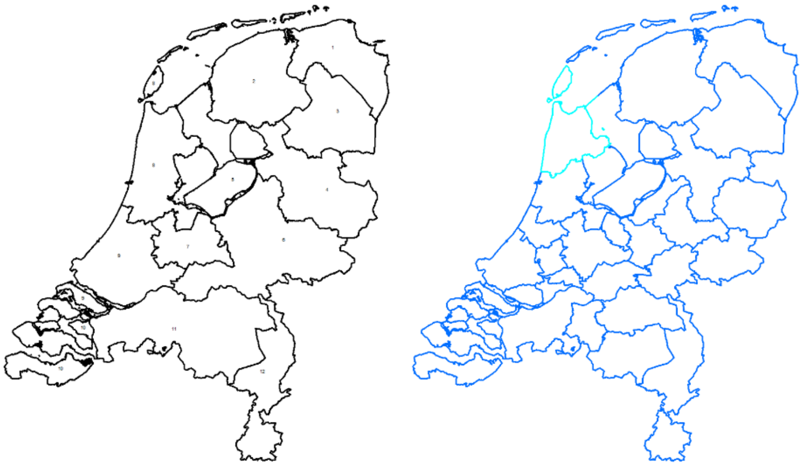

Figure 3 Example maps showing (left) the 12 provinces of the Netherlands and (right) the 30 energy regions with the Noord-Holland Noord region the highlighted in light blue.

4.1 Geo-reference system and data used

Geographical Information System (GIS) is a software that provides a variety of tools to assess spatial modelling. This study utilises ESRI's ArcMap 10.8.1 software [28], to display information which may be used to evaluate the future deployment of onshore wind farms, in particular, ecological and birds impacts, land use, system services and barriers. The datasets applied in this assessment are the following:

- **Ecological and birds impact**
  - Natura 2000 [20]. The European ecological protected areas are collected in a network that contains information on protected sites, natural habitats and protected species to preserve their biodiversity. These protected areas are not legally excluded for wind energy deployment, but in the case of a wind farm construction proposal, a deep and extensive analysis of its impacts has to be carried out [29]. In potential estimation studies, these areas are often excluded.
  - Migration zones [30]. Migrating birds can be affected by the location of wind farms in their migration corridors by collision and change of habitat. Sovon Vogelonderzoek Nederland, is an organization responsible for national bird counts for nature policy, management and research purposes. It has produced for the Ministry of Agriculture, Nature and Food Quality (LNV) maps on risk areas for collisions with wind turbines for migrating birds.
  - Regional risk zone wind energy [30] by Sovon. They have developed a map for risk zones for bird collisions and impacts on habitats due to wind turbines for both breeding birds and non-breeding birds. A more detailed description of Sovon's maps can be found in Section 5.1.

- **Land-use potential and infrastructure: grids and power congestion areas**
  - Grid connection, Liander [31]. The map provides the grid connection for the medium voltage network and the location of the transformer stations in the Noord-Holland Noord region controlled by Liander, the energy network operator for the Noord-Holland Province.
  - Grid congestion, Liander [32]. Liander produces bi-weekly maps to report bottlenecks concerning large-scale connections, where power grid capacity has reached its limit. This is illustrated in the “Reduced available capacity map”. Consequently, generated electricity cannot always be fed into the grid; this is illustrated in the “Returned available capacity map”. This information is applied to identify whether a potential area for a wind turbine installation is viable based on the grid availability.
  - Land use, OpenStreetMap [33]. OpenStreetMap provides free spatial data and databases containing information on land use specifications for the entire country. In this database, infrastructure, building, parks and other categories are represented and detailed information are reported. Although it is produced by inputs from users, and may therefore be incomplete or inaccurate, this analysis is considered a valuable source to define available land for wind energy deployment.
- **Renewable resource and technical information, with focus on wind, solar and geothermal energy**
  - Wind resources such as wind speeds at different heights, from Global Wind Atlas 3, GWA [34]. GWA is a web-based application that provides information regarding the wind climate at 250 meters’ resolution for the entire globe. The datasets available are the results of a modelling procedure from downscaling reanalysis data by DTU [35], through mesoscale simulation, where atmosphere’s complex flows and weather features are applied through the Weather Research and Forecasting (WRF) model, [36]. The results are generalized, removing the terrain effects and obtaining a generalized wind climate, and finally, applying the WAsP modelling, high resolution terrain features are simulated producing a high-resolution wind climate.
  - Global horizontal irradiation (GHI), from Global solar atlas [37], with temporal aggregation of annual average and spatial resolution of 250m. GHI is shown in kWh/m^2.
- **Social acceptance**
  - A preliminary social acceptance layer was created based on a pilot application of the methodology presented in Section 4.3, applied to a group of sample participants. This first iteration of the social acceptance layer shows the extent to which the various land use types were considered acceptable for renewable energy deployment.
- **Governmental layers**
  - Political boundaries [38]. The regions, the municipalities and the provinces in the Netherlands updated in 2020.
  - Energy regions boundaries, EBN [39]. It provides boundaries of the 30 energy regions defined in the Climate Agreement.

4.2 Geo-spatial analysis

The datasets imported into GIS are converted into a common reference system:

- Standard Geographic Coordinate Reference System: GCS_Amersfoort.
- Boundaries of the mapping: Netherlands and Noord-Holland Noord energy region, see Figure 3.

Spatial analysis is carried out on each of the layers by applying the following GIS tools:

1. *Project and transform:* from the Data Management tool the shape file or raster file is transformed into the same coordinate system. It converts all the layers into the same georeferenced system, allowing overlapping of boundaries.
2. *Clip* from the Analysis tool is applied to extract the area within the study boundaries.
3. *Merge* tool is applied to merge the information from two or more datasets, keeping the attributes which define the information.
4. *Split* from the Analysis tool allows splitting of datasets by attribute names.
5. *Dissolve from* the Data Management tool allows aggregation features based on specific attributes.
6. *Georeferenced* from the Georeferencing tool provides the tools to georeferenced figures. Data that are not provided as a dataset or as a map for GIS, but are available as a figure, can be translated from an image to a new layer. (This is done by first adding the figure to the ArcGIS framework using *Insert.* Then it is georeferenced through the boundary layer of the region. Subsequently, the selected figure can be saved as a new layer.)
7. *Buffer* from the Analysis tool creates an area around a chosen subject based on a fixed distance. In wind energy, these buffer areas are very relevant as they represent the distance which is often applied as exclusion zones around structures for safety reasons. These setback distances are not fixed and, in many cases, depend on the type and size of wind turbine installed.

Some setback distances are applied to the implemented layer. In particular, the information regarding the fixed setback distances applied in the Netherlands is reported in the "Handboek Risicozonering Windturbines" [40]. The overview of the setback distances applied is presented in Table 1 Setback distances applied in the analysis, provided in the "Handboek Risicozonering Windturbines" to set the minimum distance for wind turbine installation for security reasons. Note that only the fixed distances are applied, whereas variable distances, depending on wind turbine specification such as nominal power and size, are excluded.

Table 1 Setback distances applied in the analysis, provided in the "Handboek Risicozonering Windturbines" to set the minimum distance for wind turbine installation for security reasons. [40].

Zone description	Setback distances
Roads	30 m
Railways	30 m
Waterways	50 m from the centre

4.3 Social acceptance rating

In order to evaluate levels of social acceptance and determine the success factors and barriers to the implementation of renewable energy deployment in general and the proposed RES plans in particular, the following methodological framework was developed. This methodology enables social acceptance to be addressed for any renewable source, including new technologies, such as Power2X. The overall methodology is based on the principles of participatory ergonomics, human-centred design and technology acceptance [41], [42] [43] in which early, continuous and iterative participation of end users (i.e., those affected or impacted by the development or implementation of an innovation) is well-established as best practice.

The primary aim is to provide a common format and structure to enable all societal actors (regardless of actor group or scale, background, resources, education etc.) to express their acceptance of renewable energy and to participate in decision-making processes around deployment in their area. It is essentially a framework for data collection, the outcome of which is the presentation and visualisation of data, which may then provide input to further analysis, discussion, and decision-making. Although initially intended for use by policymakers and regional decision-makers within the RES context, it is designed to be equally suitable for use by all stakeholders, market and non-market parties including (environmental) NGOs and community groups.

The methodology consists of two main parts:
- A taxonomy of influencing factors for social acceptance (acceptance factors) and an associated evaluation matrix.
- A participatory process in which societal actors discuss and assess the impact of the various influencing factors on their acceptance of renewable energy in their respective areas or communities.

4.3.1 Evaluation matrix

A taxonomy of influencing factors for social acceptance was developed, based on a synthesis of influencing factors found in the literature [44], [45], [46], [47], [48], [49]. Some minor adaptations to the generic taxonomy were made for the Noord-Holland Noord case study region, based on specific knowledge of deployment of renewable energy in the Netherlands gained from discussions with internal experts, previous projects and discussions within the public RES consultation process. The finalised taxonomy is shown in Figure 4. Note that this visualisation shows the influencing factors included in the taxonomy, but not the relationships or interdependencies between them.

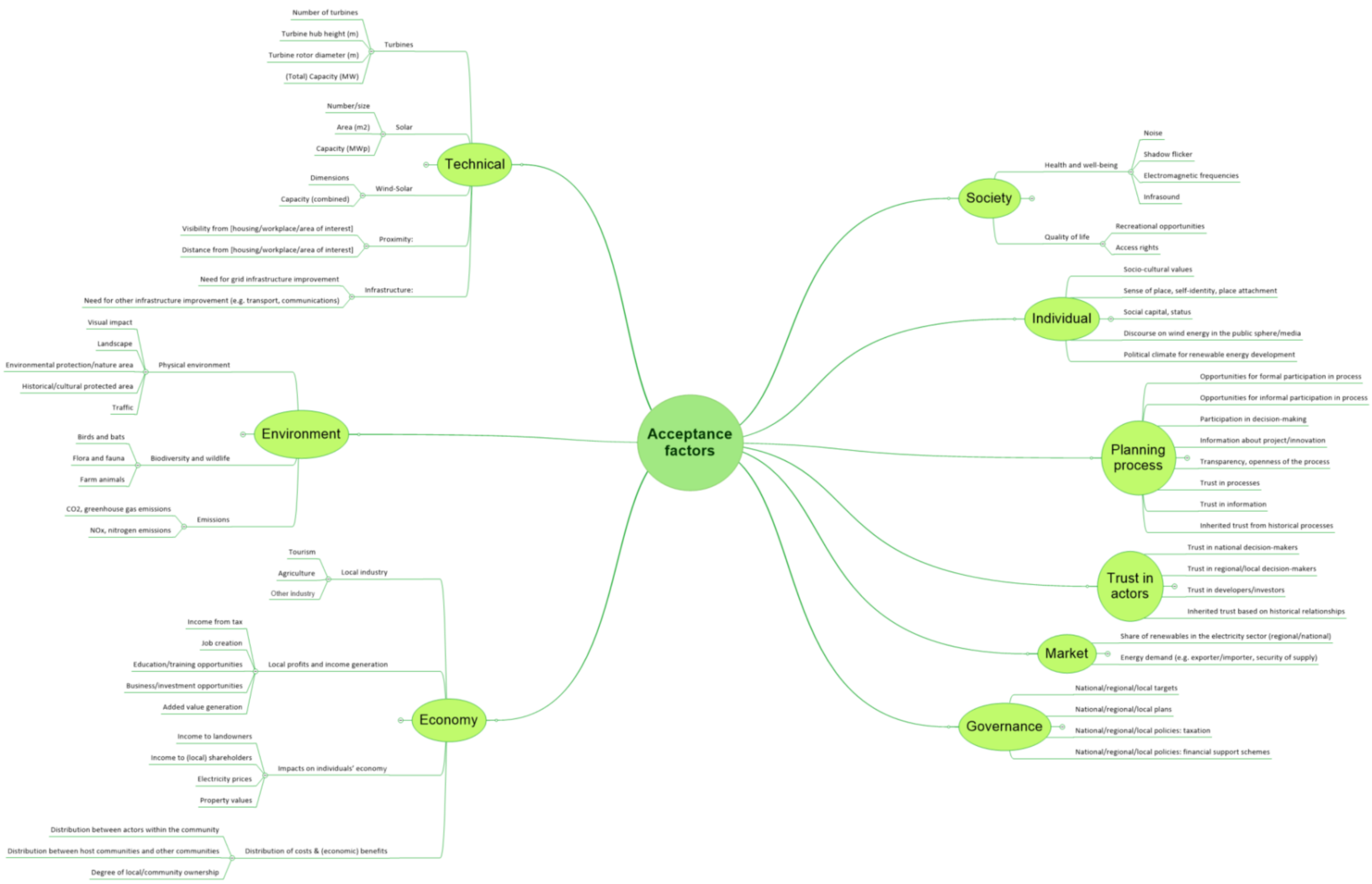

Figure 4 taxonomy of influencing factors for social acceptance for RE

To utilise this taxonomy as a tool for assessment and attempt to standardise input received from the various societal actors, an evaluation matrix was developed. This matrix may be used to provide the underlying structure for guiding discussions with actors, and to directly capture and quantify responses received. The general structure of the matrix enables evaluation of acceptance within the (geographical) area(s) described by each actor by:

- first, defining the (geographical) area(s);
- determining the community values and land use types within the area(s);
- identifying the extent to which each land use type within the area(s) is considered suitable for renewable energy deployment;
- assessing, either individually or by category, the impact the various influencing factors have on acceptance within the specified area(s) and land use types, using a rating scale based on [46] Figure 5.

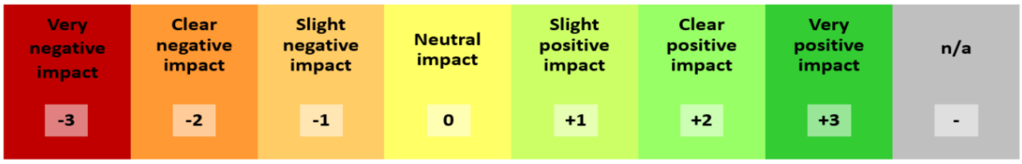

Figure 5 Rating scale for addressing acceptance

4.3.2 Evaluation process: an iterative methodology to evaluate social acceptance

The evaluation process consists of the following steps:

1. Understand the context. Identify:
    a. The (geographical) area of interest
    b. The relevant actors
    c. What has already been done
2. Encourage participation
    a. From the actors identified in Step 1 ensure a representative, well-distributed sample who are willing and able to participate.
    b. Ensure consistency.
    c. Decide which type of intervention(s) is/are most suitable in the context.
3. Conduct interviews/focus groups
    a. Part 1 - Open discussion: actors, values and land use (context)
    b. Part 2 - Detailed discussion/evaluation: impact of acceptance factors, with reference to the taxonomy (and using the rating scale in Figure 5) (see Annexes),
4. Analyse, visualise results
    a. Collect and compile the responses in the evaluation matrices.
    b. Within this project, the data collected was used to provide the basis for a GIS layer for inclusion in the spatial analysis tool described in this report.
    c. The layer shows, per land use type within the sample region, the perceived suitability for renewable energy deployment (expressed as a percentage of the unweighted responses from the pilot study sample, i.e., "X% of the participants considered land use [type] suitable for renewable energy deployment".)
    d. Further details on the community values and evaluation of drivers/barriers for acceptance and supporting information may be found (at present) in attribute tables connected to each area.

   e. In future iterations, options for more in-depth visualisation could include: Acceptance levels per actor group or acceptance factor (Ranking of) drivers or barriers for acceptance (see prototype dashboard contained in Annexes).

5. Present results, discuss
   a. For the presentation of the Social Acceptance layer of this analysis, see Section 5.4. In this case the evaluation refers to the level of acceptance, based on the rating scale in Figure 5 of the different social actors interviewed grouped by a land use categorization. The results were translated into an acceptance coloured map for the different land uses.
   b. Discuss and iterate as required.

5 Results

In this section, the analysis and results for onshore wind maximization are described and illustrated. The section is divided by the different databases applied as mentioned in Section 4.2: Environmental and bird impacts, Land use and infrastructure, Renewable resource and technical potential and the Social acceptance mapping. For each dataset, reasons, potentiality and limitations in regard to onshore wind energy deployment are described. Furthermore, the complete framework, where all these layers are combined in one analysis, is presented with the main conclusion on the area with greatest suitability for future onshore wind energy deployment and the estimation of potential installed capacity.

5.1 Wind energy impact on environment – air habitats

The designated Natura 2000 protected areas represent areas where wind turbine installation is not recommended due to the level of biodiversity and bird populations based on EU environmental legislation, including the Habitats Directive (Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora) and Birds Directive (Council Directive 79/409/EEC on the Conservation of Wild Birds).

These areas are not intended to be restricted for wind deployment. Nevertheless, due to the potential impacts, Natura 2000 areas were considered non-suitable for the initial assessment in this study. The designated area for Natura 2000 in Noord-Holland Noord are highlighted in light green in Figure 6 (left).

In order to select the additional information and maps to be implemented in the study, an extensive analysis of the existing knowledge, tools, methodologies and models was conducted, with a focus on the Dutch situation. From the outputs, two layers were then added to the analysis. From this first analysis, the importance of bat impact assessment became apparent, but as available data on risk zones or collision risks were not found, the impact is not included or evaluated in this framework. Future research to address this lack of knowledge and data is recommended.

5.1.1 Available tools to quantify and minimize the impact

Increasingly, proposed wind farm deployment is challenged on the basis of environment impact assessment, particularly with respect to the risks and impacts for wildlife, especially birds. These impacts can be categorized into:

- **Habitat loss**: the wind turbine can affect the surrounding habitat, impacting the life of birds (limited to specific location and species).
- **Disturbance**: impacts on foraging and resting birds (limited to specific locations and species).
- **Barrier effect**: disturbance on flight patterns (dependent on behaviour).
- **Collision**: direct impact of birds and bats with wind turbines causing injury and/or death (dependent on flight intensity, location, time in the year, species, behaviours).

Currently, these impacts are calculated by visual observation, carcass searches, radar observations, video observations, acoustic monitoring and collision risk models (CRM). The greatest impact of wind energy on birds is caused by the risk of collision.

The main conclusions from the analysis (summary in Table 2) on the challenges, limitations and bottlenecks of the currently available methodology to address bird impact from wind turbines and current technology and tools are:

- **Carcass search** is the most common methodology to assess collision impact onshore. It is very expensive and not highly accurate; corrections factors are therefore often applied. It is not applicable offshore. Its main challenges are:
  - Chance of finding (dependent on effectiveness of search pattern);
  - Chance of predation (predator eats the carcasses before the search);
  - Search surface (accessibility of the sites, limited selection of wind turbines within the wind farm areas);
  - Post-construction monitoring (limits on the comparison with pre-construction, often not available).
  - Duration of the search period/seasonality of the search period.
- **Collision risk models** (CRM) are tools developed to estimate bird collision rates with wind turbines. Several models have been developed and tailored to specific conditions (onshore/offshore) or to specific species. The model which is most applied is the Band model [18], [19], [20]. These models can be applied pre- and post-construction monitoring but have low accuracy as they are based on several assumptions. An empirical model has been developed by Kleyheeg-Hartman from the Bureau Waardenburg [21], where collision rates are calculated based on empirical data; this reduces uncertainty by reducing the number of assumptions, but it strongly depends on the availability of empirical data, which is typically very limited. The main challenges and limitations for CRM are the following:
  - They are based on behavioural assumptions, in particular they tend to standardize bird's behaviour, whereas this can be dependent on topography, species, wind farm layout, wind conditions, etc;
  - Avoidance behaviour is not always considered and when it is, it is largely based on assumptions due to the limited availability of data;
  - The presence of birds can be overestimated, increasing collision numbers estimation;
  - The models often require many inputs, which, because of the lack of knowledge and availability of data, produce high uncertainties;
  - Variability and uncertainties are often excluded and not quantified in the assessment;
  - Validation is often missing, post-process analysis is not always applied;
  - Empirical models rely on accurate measurement data with limited availability;
  - Collision rates are not yet measured on offshore wind farms.
- **Curtailment strategies**. Wind turbines are often forced to curtail (reduce power production) during certain periods of the year and at certain times of the day/night to avoid or mitigate the risk of collision with birds, migratory birds and bats. Curtailment requires turbines to stay in a standstill position during planned hours; however, the planning is often not accurate, resulting in unnecessary production losses for wind farm owners. The main challenges are:

- Strategies are based on model outputs, therefore lack sufficient accuracy;
- Real data are often not available. These could improve the effectiveness of the curtailment strategy, reducing probability of impact and increasing profit;
- Standardized strategies at certain hours and days of the year, not taking into consideration the meteorological conditions which affect migration and behaviour;
- Lack of intelligent standstill optimization strategies which combine knowledge of bird and bat behaviour with other parameters.

5.1.2 Maps for bird migration routes and risks zones

From these results one can see the difficulty to clearly represent the risks and the impacts on birds by wind turbines. To provide better insights, two maps from Sovon [30] were selected and implemented in the framework to better representation of the risks: the *migration risk zone map* and the *risk zones for wind energy map.* The methodology for the creation of the migration map and the wind energy risk zone for birds species is accurately described in the report *"Achtergronddocument windenergie gevoeligheidskaart vogels*" [50]. From this report, it is clear that these maps are based on assumptions and data are not accurately validated, due to the lack of available data and methods for birds impact assessment and migration tracking as mentioned above. Hereafter, a summary of the map description and the methodology is presented:

- *The migration map* developed by Sovon [30] provides an overview of the migration corridor above the Netherlands using a scale of five levels of intensity based on visual counts of migratory birds passing above the area, corresponding to five risk levels. The highest intensity migration corridors are along the coast, with intensity in the Flevoland and Eemshaven areas and along the IJsselmeer region and the southern-east part of the province, illustrated in Figure 6 left.

  In the absence of a national database for bird migration, the migration map uses data sourced from Trektellen.nl. This provides data from over 100 sites where visual counts of migratory birds are conducted daily. Specifically, locations with more than 50 hours of counting per season are considered, and then averaged along the years of measurements (2010-2020). Note that only visual counts are included in the measurements, meaning that migration during the night and at higher altitude air layers are not captured by the radar, the latter is less relevant for wind turbine collision. Furthermore, no difference in the type of birds is applied, only the quantity is evaluated. Once the data is collected, the data points are interpolated to create a map of migration patterns.

- The maps *risks* zones *of breeding and non-breeding birds due to wind energy*, developed by Sovon [30], provide an overview of the locations with the highest and lowest risks of collision with wind turbines, on a scale from 1 to 100 (see Figure 6, right). The Netherlands is a particular area for migration corridors. For this reason a risk zone map has been developed based on the number of migratory birds passing above the country. The Common Tern, Black Tern, Hen Harrier, Marsh Harrier, Red Kite, Oystercatcher and Curlew are the breeding species identified with higher risks for collisions, habitat loss and barrier effect due to wind turbines and therefore: with higher vulnerability. For non-breeding birds those at highest risk are: the Pygmy Goose, Golden Plover and Short-eared owl.

For the risk zones of breeding and non-breeding birds, the data used in this analysis are provided by the Breeding Bird Monitoring Network, Waterfowl Monitoring Network, Ecological Monitoring Network and the Birds Atlas. The classification of bird species as sensitive, is based on the literature available in the Netherlands and in the neighbouring countries and the risks are categorized into collisions, habitat loss and barrier effects. The scores for sensitivity and threat to species are combined into vulnerability scores. The cumulative analysis is weighted to the species' vulnerability having resulted in declining population. The output score illustrates the presence of sensitive species from 1 (low presence) to 100 (high presence). The output is a risk matrix resulting from the combined cumulation of Collision risks and Disruption risks. These maps are available for both breeding and non-breeding species. Non-breeding birds are local birds that reside in the area but do not breed, breeding birds are birds that also reside in the Netherlands and do breed.

Overall, Natura 2000 areas are considered not suitable for onshore wind energy deployment. The same conclusion is applied to the migration risk zone level 5 (the highest classified) these areas are excluded from consideration. The risk zones maps provide an overview of the risks that may be encountered when installing wind turbines based on the presence of species in the local area; no restrictions are produced by these maps, only identification of the risks which must be tackled with a detailed monitoring campaign and specific impact assessment once a project is intended to be realized and an environmental impact assessment has to be addressed.

The result of merging these maps is illustrated in Figure 6, centre, where the suitable area is highlighted after removing the Natura 2000 protected area and the zones with the highest risk for migrating birds. The availability of suitable areas could be further increased by more accurate insights on bird migration through extensive monitoring campaigns and optimization of curtailment strategies, as described by Krijgsveld [24]. The same is true for bat impact assessments and curtailment strategies, which are currently based on very limited available data, as described by Boonman [51].

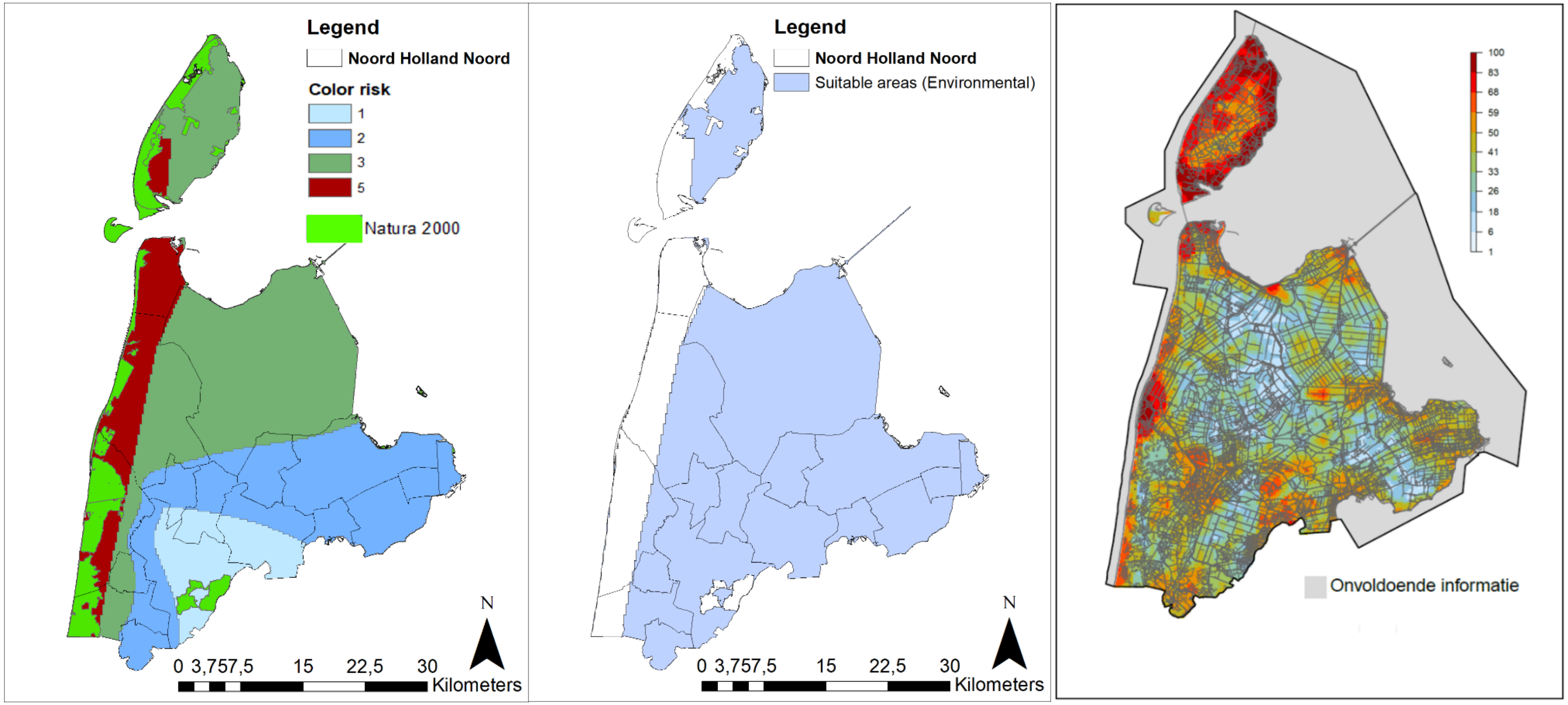

Figure 6 Environmental layer with Natura 2000 and Migration map (left), suitable areas for wind energy deployment (centre) , Sovon risk zones for breeding and non-breeding birds [30] (right) for Noord Holland

Table 2 Analysis overview of the technology, goal, approach and barriers for bird impacts assessment from wind turbines, with focus on the current situation in NL.

Challenge	Approach	Main results	Bottlenecks and barriers	Ref
Collision Risk Assessment	Band model (CRM) Annual bird collision with a WT: no. of birds flying in the swept area x probability of collision depending on bird-specific species information	First model available to address collision rates with basic information	Non-avoidance actions are assumed to need further investigation. The importance and relevance of accurate measurement	[52] [53]
Collision Risk Assessment	Strategic Ornithological Support Services (SOSS) -Band model Extension of Band model tailored for offshore wf (CRM) Monthly bird collision numbers per WT considering: survey of birds (no., height, intensity), behaviour (avoidance/attraction), species (size, speed), WT (rotor size and speed, no., layout)	Standardized methodology applied in several countries. Key model for offshore WF	High uncertainty due to large number of detailed inputs required and low data availability, therefore based on assumptions. It can lead to high overestimations	[54]
Collision Risk Assessment	Empirical Flux Collision Model (CRM) Apply empirical data on collision from real available WF case studies and apply to WF investigated trough correction parameters.	Estimation of impacts of WF improved accuracy thanks to accurate data, reduce uncertainties.	Can be applied only where data from other studies are available and depends on quality of data. Lack of collision data for offshore WF. Avoidance behaviour difficult to estimate and apply.	[55]
Migration Activity Monitoring	Radar monitoring of nocturnal peaks for songbirds Monitor bird mean flux at OWEZ per night (2007-2011) with a vertical radar system (up to 900m) and relate to collision rates. Same measurement at K14	Peak at rotor height <4% annual flux (Mar-before dawn, Sep, Oct, Nov-after dusk). Higher fluxes over OWEZ (Scandinavia/NW EU to SE EU) Lower fluxes at K14 (Scandinavia-UK migration)	Only one radar location per site, low information insights on avoidance, limited information on total migration patterns above North Sea	[24]
Visual Deterrents for Collision	Test different design patterns and colours for blades Analyse layouts (8 patterns and 6 colours) with pattern electroretinogram (PERG) method	Most visible is 1 coloured and 2 blanks. All colours have large variability, black most consistency with all kinds of backgrounds.	Only theoretical study, field test study is needed	[56]
Visual Deterrents for Collision	Test different design patterns and colours for blades Colour one blade black in 4WTs in Smøla WF, analyse effect with BACI methodology [57]. (Monitoring campaign pre 2006-2013, post 2013-2016.)	Fatality rate decreased by 70% (in particular raptor species). Behaviour: no habituation and no deviation to neighbouring WT	Only few tests, short monitoring campaigns, limited quality of impact monitoring data	[25]

Monitoring Collision Victims	Monitoring post-construction carcass search obligation from the Nature Conservation Act permit Delfzijl Zuid WF (2006-20110) & Eemshaven WF2009-2014) conduct monthly carcass search (be-weekly in Spring/Autumn) and apply correction factor (chance of finding, chance of predation, fraction searched area/tot area, fraction n wt/ tot n wt)	Eemshaven: Average 274 victims per year, 89 species of which 20 on the Red List. Predicted 6293 victims, certain victims measured 576, estimate based on the certain victims 2,873 casualties. Total number of collision reliable, correction factor based on trials and studies / Delfzijl per year predicted 800 victims, certain measured on average measured per year 74-227, predicted 800	Collision per species less accurate due to minimum detection probability, correction factor tends to overestimate collision rates, low reliability of predicted values per species, - 50% probability of incorrectly identifying collision with turbine/high voltage line.	[58], [21]
Stand-still	Stand-still facility in night of high migration intensity at Eemshaven Quantify the impact: Main songbirds, (also gulls, waders and geese and ducks). Quantify the reduced impact: by standstill facility over several nights. Quantify the losses: cost calculation Validate and investigate the standstill facility using 3 scenarios: 5, 25 and 45 nights downtime	Collision: a few turbines responsible for the majority of collisions depending on their location and other parameters/characteristics of the specific case study. Standstill: efficient reduction in migration mortality by 75% with 25 nights of activated downtime. Reduced impacts on local birds reduced: by eg creating new breeding zone farther	Limited data, only one test. Models and solutions need to be validated	[23]
Bat Collision Monitoring	Wageningen Marine Research Eneco, Gemini and the Ministry of Economic Affairs Monitoring campaign between 2015-2016 of RWS-project, offshore WF Luchterduinen by Eneco, WF Buitengaats by Gemini and Wintershall platform P6-A and FINO3 by Wageningen Marine Research	High seasonality, from NE Europe toward SW Europe in late summer/autumn. Nathusius pipistrelle is the most recorded species at sea. Timing is essential, weather condition for migrating, Weather parameters considered are: wind speed, wind direction, night in the year and temperature	Curtailment strategies applied to Borssele results inaccurate	[59]
Bat curtailment strategies	Based on output from [59], implement new curtailment strategy taking account of wind speed, wind direction, time of the year and temperature.	Improved curtailment strategies, decreasing bat collisions and increasing WF productivity	Lack of accurate dates lead to wrong curtailment strategy, with higher collision impacts and WF losses	[51]

5.1.3 Birds and bats monitoring of behaviour and migration

TNO Wind has built an environmental laboratory with inhouse instrumentations to measure:

- **birds collisions,** with WT-Bird®, a system for continuous detecting and registering bird collisions at wind turbines, developed by the TNO Wind Energy (ECN) in the early 2000s, a fully automated system which combines acoustic detection of birds collisions, through sensors installed in the blades, combined with a visual camera for species-recognition [60], [61], [62] (Figure 7),
- **birds behaviour,** with the Robin Radar MAX® with a 3D radar continuously covering the complete area around wind farms from the horizon up to 1km height [63],
- **bats activity,** with the Bat Protection System TopWind, continuously detecting bats with ultrasound microphones located at the nacelle base near the rotor [64].

Accurate and real data on impacts, fatality rates and behavioural changes of birds are fundamental to understand and quantify the real impact of wind energy on the ecology. It is necessary to define standards of methodology, consistency and technology to address the impacts. Data, as shown in the above section, can be translated into maps, visualizing the impacts and interactions providing a clear overview of the challenges that wind energy will face in the future installation. There is a large need to understand the interaction of wind farms with the air habitats to mitigate the impacts and optimize wind farm design and operation strategies in symbiosis with the ecosystems

Figure 7 Illustrative representation of the WT-Bird® system with impact detection based on fibre optic vibration sensors and species recognition based on high quality camera images

5.2 Land-use potential

5.2.1 Exclusion zones due to land-use and infrastructure

At national level, the major land use categories from the OSM dataset were selected to define the exclusion areas for wind energy deployment, shown in Table 3. For the NHN map, the national categories in the "Land use land cover" section were re-organized based on directives and feedback provided by the NHN region and presented in the plan for the RES 1.0 [27], see Table 4. From the list in Table 4, restricted areas (where no wind farms may be deployed and setback distances must be applied) are represented by residential areas, protected areas and natural parks. (Note that some Natura 200 areas are classified as land use type Forest, and therefore are not restricted in this layer, but are excluded once the layers are combined in the overall framework). The layers are illustrated in Figure 8.

Table 3 Land use categories applied in the national map

Zone description	**Setback distances**
Roads	30 m
Railways	30 m
Waterways	50 m from the centre
Building	-
Water bodies	-
Airport	-

Table 4 Categorization of land use from OpenStreetMap for NHN case

Code	**Fclass**	**Description**	**New category**
7201	Forest	Forest or woodland	Forest
7202	Park	Park	Park leisure
7203	Residential	Residential area	Residential areas
7204	Industrial	Industrial area	Industrial areas
7206	Cemetery	Cemetery or graveyard	
7207	Allotments	Area with small private gardens	Agricultural land
7208	Meadow	Meadow, cattle	Agricultural land
7209	Commercial	Commercial area	Industrial areas
7210	Nature reserve	Nature reserve	
7211	Recreation ground	Open green space for recreation	Park leisure
7212	Retail	Shops area	Industrial areas
7213	Military	Military land use	
7214	Quarry	Quarry	
7215	Orchard	Fruit-bearing trees area	Agricultural land
7216	Vineyard	Grapes area	Agricultural land
7217	Scrub	Scrubs area	Forest
7218	Grass	Grass area	Forest
7219	Health	Health areas	
7220	National park	National Park	
7228	Farmland	Agricultural land	Agricultural land
7229	Farmyard	Farm buildings and shrubbery	Agricultural land

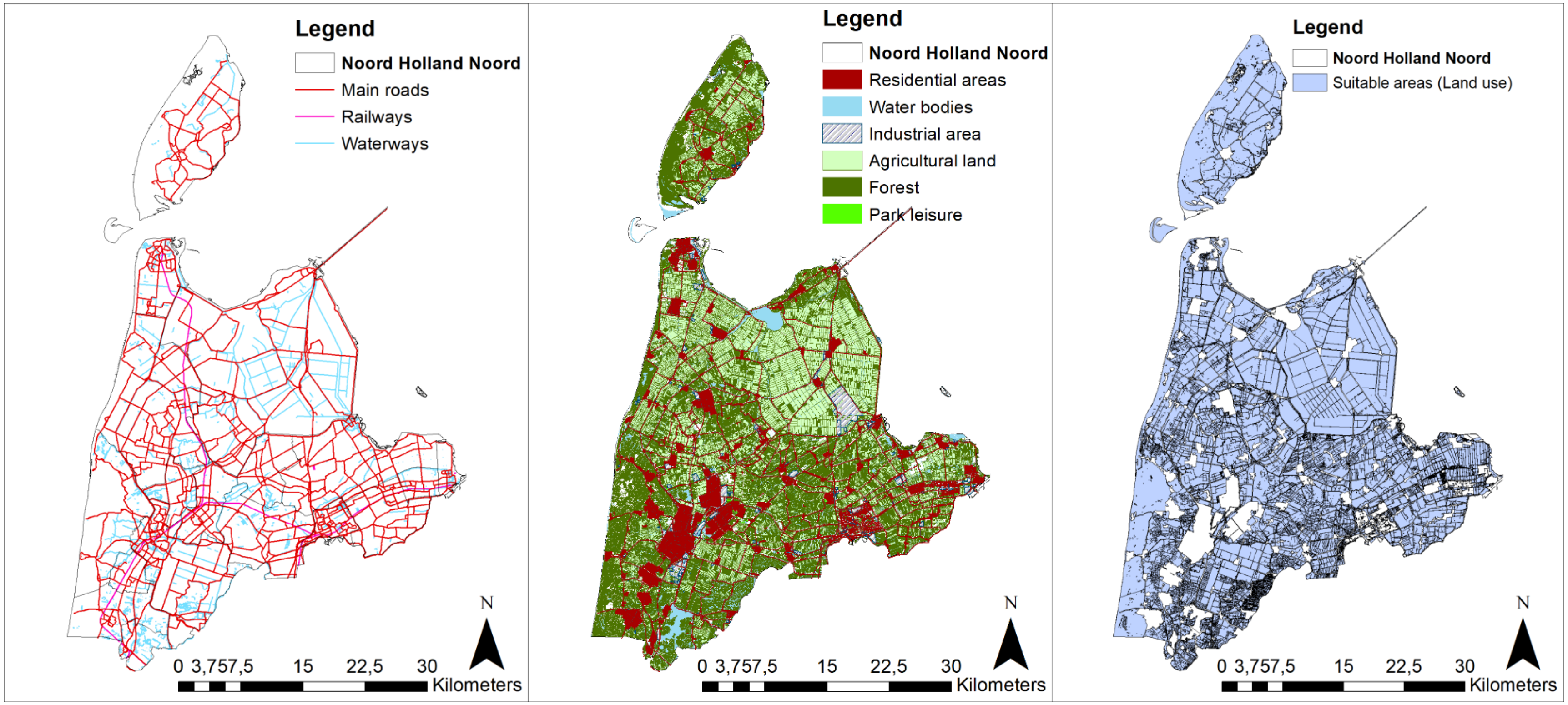

Figure 8 Infrastructure of Noord-Holland Noord energy region: main roads, railways and waterways with setback distances (left); Land use layer for Noord-Holland Noord energy region (centre); Suitable areas for Noord-Holland Noord energy region after excluding constrained areas

5.2.2 *Grid connection and congestion*

Connection to the electricity grid is essential for the feasibility of present day wind farm projects. Minimizing the distance from the suitable existing electrical power grid is fundamental to reducing the cost of construction. The availability and access to the power line must be considered when planning a wind farm. Therefore, distance to the electrical grid is often considered in GIS spatial analysis for wind energy deployment, and distance to the electrical grid is considered a technical constraint in [65], [66], [67]. On the other hand, high voltage transmission lines require a setback distance to ensure their security, as described in [40], with the distance depending on the size of the wind turbine. In this analysis, no setback distances are applied.

As mentioned, in this study the electrical grid of Liander, illustrated in Figure 9 (blue line) and the locations of medium voltage transformers (green dots) are added to the layers and included in this framework, as these are relevant when addressing the economic feasibility of onshore wind projects.

There are other challenges that currently undermine the deployment of future wind farms and solar panels plants: the electrical grid needs to increase in capacity to be able to receive the electricity produced by RE projects. Therefore, two more maps are considered to be relevant in determining suitable areas for wind deployment: gird congestion information maps. The *reduced available capacity* and the *returned available capacity* support the spatial planning by identifying areas where connection to the existing electrical grid is a potential barrier and could stop the project at an early stage. At the same time, it supports the transmission provider (Liander in this case) to define areas where the electrical grid could be expanded in the near future, to meet the increasing energy demand and to support the increased supply of RE production. This could be achieved by increasing the capacity of existing transformers or building new transformer stations, which requires several hectares of land.

These maps are produced by Liander bi-weekly. In this analysis, the maps provided on the 20th of May 2021 were included [31].

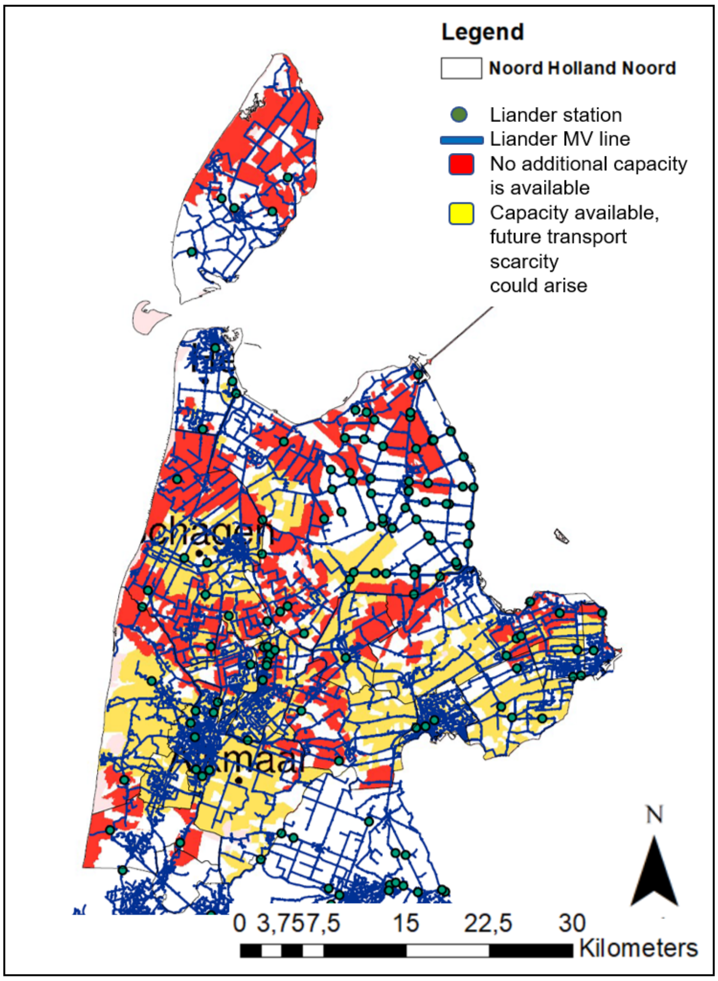

Figure 9 Electrical grid connection lines and medium voltage transformers combined with congestion maps for NHN

5.3 Resource and technical potential

From the open-source Global Wind Atlas (GWA), maps containing high resolution wind resource assessments were downloaded and included to define potential areas, see Figure 10 . The list of layers added to the framework is presented in Table 5 with a short description. The advantage of this source is their high resolution. Using low resolution maps, as is often done (section 1), results in a lower estimation of the wind potential, as demonstrated by Balyk [68] and by Pian [15]. The aim of this layer is to provide the wind resources of the specific sites highlighted by the suitable area assessment, thus enabling investigation of the feasibility of projects based also on their resource availability.

Table 5 Description of the resource layers implemented in the framework

Resource	**Description**	**Source**	**Resolution**
Wind speed 10m	Mean wind speed at 10m height for each location for the 10-year period	Global Wind Atlas [34]	250m
Wind speed 100m	Mean wind speed at 100m height for each location for the 10-year period	Global Wind Atlas [34]	250m
Power Density 10 m	Related to the cube of the wind speed and calculated by taking into account geographical variations of air density	Global Wind Atlas [34]	250m
Power Density 100m	Related to the cube of the wind speed and calculated by taking into account geographical variations of air density	Global Wind Atlas [34]	250m
Capacity factor I	Capacity factor layers calculated for wind turbines with 100m hub height and rotor diameter of 112m (IEC Class 1)	Global Wind Atlas [34]	250m
Capacity factor II	Capacity factor layers for wind turbines with 100m hub height and rotor diameter of 126m (IEC Class 2)	Global Wind Atlas [34]	250m
Capacity factor III	Capacity factor layers for wind turbines with 100m hub height and rotor diameter of 136m (IEC Class 3)	Global Wind Atlas [34]	250m
Global Horizontal Irradiation	Represent the irradiance of the sun on a horizontal surface on Earth, provided as annual average in kWh/m^2	Global Solar Atlas [37]	250m

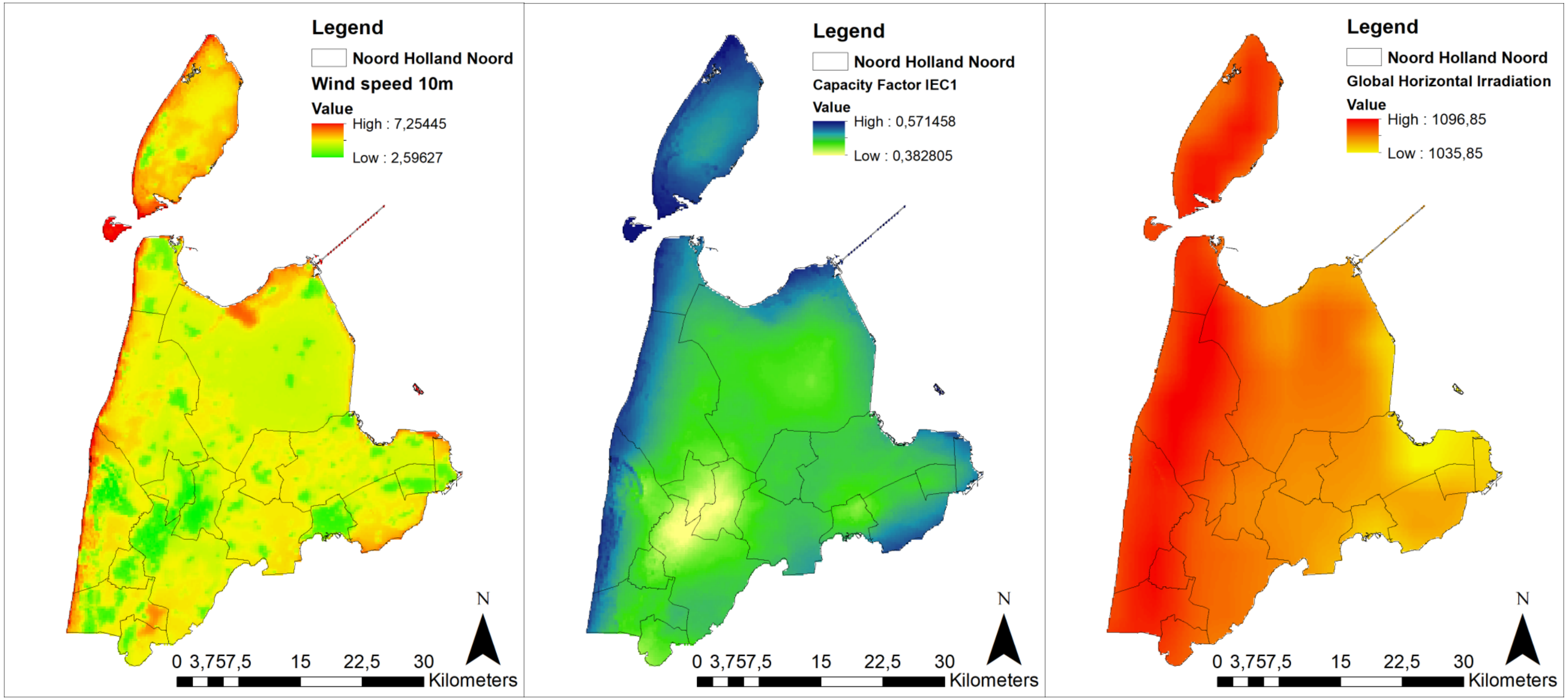

Figure 10 Wind speed at 10m (left), capacity factor class I (centre), global horizontal radiation (right) for NHN

5.4 Social acceptance mapping

Due to project and external constraints, a limited pilot study application of the social acceptance evaluation methodology (Section 4.3) was performed, using internal participants, rather than the intended sample of participants from the Texel and Hollands Kroon areas of the Noord-Holland Noord energy region. An online workshop, in the form of a group interview, was conducted in which 25 participants role-played various societal actors in a sample area, the island of Texel (Table 6).

Table 6 Actor group for pilot study

Actor group	Number of participants	Responses received
Regional policymaker	4	3
Wind/solar developer	4	4
Farmer	4	1
Tourist information	4	4
Environmental group	4	4
Resident	5	5
Total	25	21

Participants were guided through the interview, as described in Section 4.3. Rather than discussing the topics and questions with the interviewers – as envisioned in the original methodology – participants were asked to submit their responses via an online survey tool (Qualitrics [69]). Acceptance factors were assessed on category, rather than individual level. The outcome of the pilot study provided the input to the Social Acceptance layer presented in Figure 11.
For the purpose of illustration within the GIS tool, the output data from the pilot study was extended for the entire region of Noord-Holland Noord and simplified into three categories based on land use type:

- Yes area: area in which the majority (>x%) of the respondents considered the area suitable for RE deployment;
- Yes/No area, where the respondents gave mixed responses regarding the suitability of deployment;
- No area, where the majority (>x%) of the respondents considered the area unsuitable for RE deployment

Although data on the impact of the various acceptance factors on the participants' acceptance was collected, it was not (due to the limited nature of the initial study) included in the preliminary social layer, see Figure 12Figure 12 left.

Since RE deployment is prohibited on historic and cultural areas [27], a historic and cultural layer was added to the framework. This layer combines the areas and points of interest tagged by OpenStreetMap as historic which contains the classes illustrated in Table 7. This layer is considered as no-go zone for onshore wind deployment, Figure 12 centre. (This also corresponds to the pilot study data, in which deployment on historical/cultural areas was considered unsuitable by all respondents.)

		Regional policymaker 1	Regional policymaker 2	Regional policymaker 3	Wind/solar developer 1	Wind/solar developer 2	Wind/solar developer 3	Wind/solar developer 4	Farmer 1	Tourist information 1	Tourist information 2	Tourist information 3	Tourist information 4	Environmental group 1	Environmental group 2	Environmental group 3	Environmental group 4	Resident 1	Resident 2	Resident 3	Resident 4	Resident 5	Unknown 1	Unknown 2	Unknown 3	Unknown 4	Unknown 5
Values	Tourism	1	3	2		3	3			1	1	1	1	3	1			5		3	4	2					
	Local economy	3		4	1	2			1	4	4	5	3	2		1		2		2	1						
	Environmental protection	2	1	1	2	1	1		2	3	5	4		1	2	2	1	4	3	1	2	1					
	Recreation	4	2	5			2			2	3	3	2	4		3		3	1		5	3					
	Local history/culture			3						5	2	2		5	3			1	2		3	4					
	Other			6		4		1						6													
Land use	Residential	x		x	x		x		x	x		x	x	x		x		x	x	x	x	x					
	Industrial	x			x	x				x				x					x		x						
	Agricultural	x	x	x	x	x			x	x	x		x	x	x		x			x	x	x					
	Nature area (env. protection)	x	x	x	x		x			x	x	x	x	x	x					x	x	x					
	Parks, forest (recreational)		x	x	x				x	x	x	x	x	x		x				x	x	x					
	Historical, cultural		x	x					x	x	x	x	x	x	x	x				x	x						
	Other			x				x		x			x	x													
Land use go/no-go	Residential	n	n			n	n	n		n		n	n	y			n	n		n	n	y					
	Industrial	y	y		y	y			y	y	y	y	y	y	y	y	y	y	y	y	y	y					
	Agricultural	y		y	y	y	y	y	n	y		y	y	y	y	y	y	y	y	y		y					
	Nature area (env. protection)	n		n		n	n	n		n	n	n	n	n	n	n		n	n	n	n	n					
	Parks, forest (recreational)			y	y	n	n	y	y	n	n	n		y	n		n	n	n	n	n						
	Historical, cultural	n	n	n		n		n		n	n	n	n	n				n	n	n	n	n					
	Other												y					y									
Acceptance factors	Technical characteristics	-2	2	-2	2	1	3		-2	-1	-1	-2	-2	-1	-1	1		-3	-2	1				-2	-2		-2
	Impact on Environment	-2	3	-1	2	1	1		1	-2	-2	2	0	-2	-1	2		-3	-1	0			-3	0	-1		
	Impact on Economy		1	1	2	2	-1		1	2	1	1	-1	1	2	3		-2	1	1			-2	1	2		
	Impact on Society	-1	2	-1		1	-1		-1	0	-1	-2	-2	-1	-1	-1		-2	-1	-3			3	-2	-2		
	Individual characteristics	0	3	1		-1	1		-1	-1	-3	-1	1	-2	0	1		3	0	0			1	0	0		
	Planning and permitting process	0	2	-1	2	1			1	-2	2	0		2	-1	2		-2	2	-1			0	-2	1	2	
	Trust in key actors	-1	3	-3	0	1			1	3	-2	-1		-2	-1	-1		3	0	1			1	2	1	2	
	Market factors	0	-1	1	2	1			1	0	1	2		-1	2	1		3	2	1			1	0	1	2	
	Governance, regulatory framework	1	0	3	1	2			1	-1	0	-1		-1	1	2		-1	2	1			1	1	0		
	Other	0		3					0	3	1	-1		0	-2	n/a		n/a	-2	1			-1		2		

Figure 11 Output table from pilot study assessment, input for the Social Acceptance layer

Table 7 Feature classes Point of Interests in OpenStreetMap (OSM) [33]

code	fclass	Description	OSM tags
2723	monument	A monument	historic=monument
2724	memorial	A memorial	historic=memorial
2731	castle	A castle	historic=castle
2732	ruins	Ruins of historic significance	historic=ruins
2733	archaeological	An excavation site	historic=archaeological site
2736	battlefield	A historic battlefield	historic=battlefield
2737	fort	A fort	historic=fort
2742	viewpoint	A viewpoint	tourism=viewpoint
2954	windmill	A windmill	Manmade=windmill
2721	attraction	A tourist attraction	Tourism=attraction

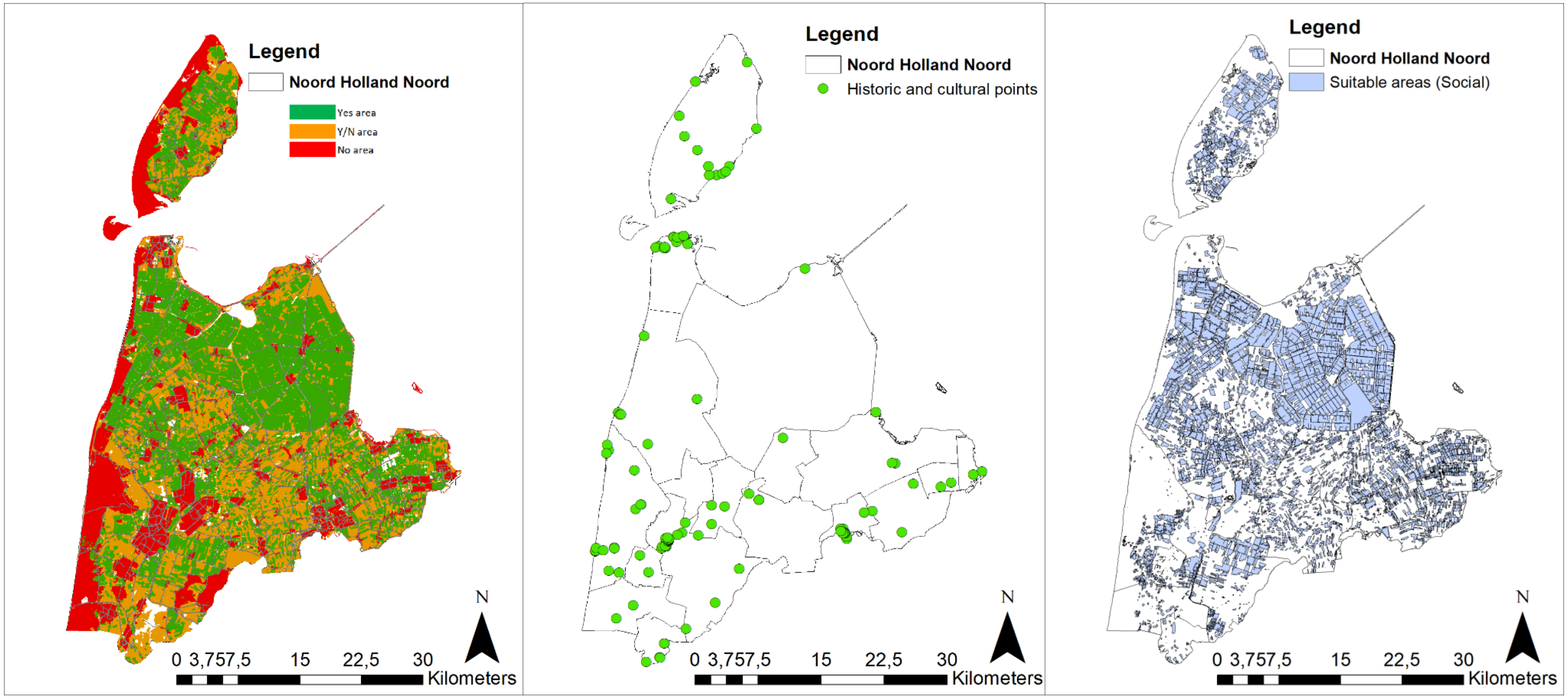

Figure 12 Social Acceptance layer (left) Historic and cultural points layer (centre) and suitable area based on the social acceptance analysis (right)

5.5 Integrated framework mapping for onshore wind deployment

5.5.1 Suitable areas estimation

The integrated framework includes the environmental constraints, land use categorization, renewable resource and social acceptance layers, and is combined to create an onshore wind deployment framework, illustrated in Figure 13.

The **high-risk areas for environmental impacts** are the designated Natura 2000 areas and the areas with a high intensity of migration routes. These areas are concentrated along the west coast of the entire region and the island of Texel. An area designated Natura 2000 is also defined on the east side of the Alkmaar province. **Lower risk areas for migration routes** are typically found in the south/east of the region.

Referring to the **risk zones for birds due to collision risks,** the highest risks are located in the coastal areas of Bergen, Schagen and Den Helder, and the majority of the island of Texel; also smaller areas on the coasts of Hollands Kroon and Koggenland. The areas with the lowest risks are mainly in the rural areas of Schagen, Hollands Kroon, Medemblik and Drechterland.

Regarding the land use: larger residential areas which represent restricted areas for wind energy deployment are located in Alkmaar, Heiloo, Castricum, Hoorn and Den Helder, whereas large agricultural and industrial areas, suitable for deployment, are in Hollands Kroon, Medemblik, Drechterland, Stede Broec and the inland part of Schagen. Residential areas typically contain higher availability of grid lines, except for Castricum, Bergen and Medemblik. Attention should be paid to congestion areas, in particular Texel, the area surrounding Schagen and the northern area of Hollands Kroon. Low risk areas for congestion are found in the areas surrounding Alkmaar and the south/east of the region.

Observing the natural resources (wind/sun) available: **the coastal areas have the highest mean wind speeds and therefore the highest capacity factors**, whereas lower wind potential is located in the inland part of the region, around Alkmaar, Langedijk and Heerhugowaard. Availability of solar radiation appears to be higher on the west coast and seems to decrease toward the east side of the region.

Finally, the **social acceptance** is added as a layer. This identifies the areas where major challenges may be faced due to lack of public support, potentially leading to opposition, delays and increased costs for development projects. These areas typically correspond to residential and leisure areas, cultural and historical points and natural areas – situated mainly around the west coast and larger residential areas in the inland of the region and Texel Island – already identified as no-go areas by virtue of their land use type or increased risk to birds or the environment. At the same time, it **identifies areas with high levels of acceptance,** such as agricultural and industrial areas, in particular around Hollands Kroon, Medemblik, Drechterland and the inland part of Schagen. Some areas (residential and parks/recreational) received mixed responses regarding suitability, thereby opening up the potential to identify new areas previously not considered suitable. Note that, since the social acceptance layer was based on test data only, it is provided solely for the purpose of illustrating how social acceptance may be included in a GIS framework and no conclusions regarding suitability for RE deployment in these areas should be drawn from it.

(Although it was not completed in the pilot study, further work should focus on investigating the interdependencies between the perceived suitability of land use types and the drivers and barriers for deployment in these areas, based on the perceived impact of the acceptance factors in the taxonomy.)

In conclusion, the windiest areas, on the west coast, are limited by environmental and social constraints and the limited availability of grid lines. The inland, characterized by the lowest wind resource, is also the most densely populated area with the major concentration of residential centres. The (North-)Eastern areas, close to the coast, have also high wind resources and contain agricultural and industrial areas, with higher levels of social acceptance.

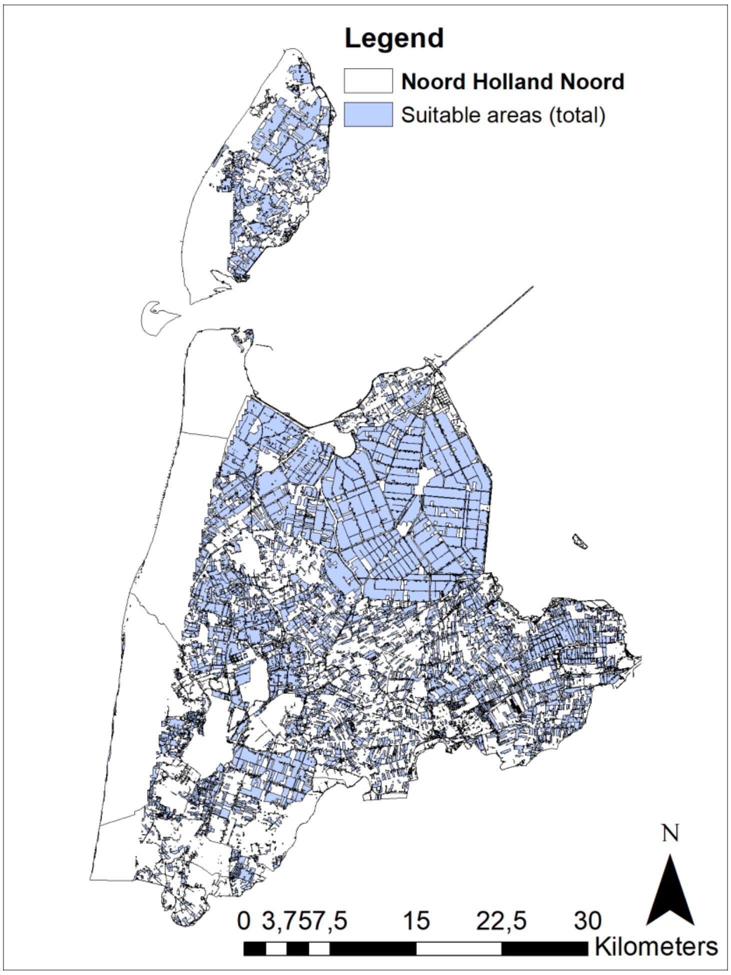

Figure 13 Suitable areas resulting from the assessment framework considering Environmental, Land Use and Social Acceptance constraints.

5.5.2 Analysis of the onshore wind potential capacity and generation

In this section, a final brief remark on the assessment which may be performed based on the outputs of the presented framework, is described.

The suitable and non-suitable surface area is calculated in km^2. Figure 14 illustrates the share of suitable (green bar) and non-suitable (red bar) areas for the NHN region, based on the previous analyses. Environmental and Land use assessments produce almost the same share of suitable and non-suitable areas for wind deployment, about 80% of the total area of NHN results suitable, although the specific area extracted differs from the two analysis (see Figure 6 and Figure 8); the Social acceptance constraints drastically reduce the available area: less than 35% of areas were considered suitable, while a further 33% received mixed responses.

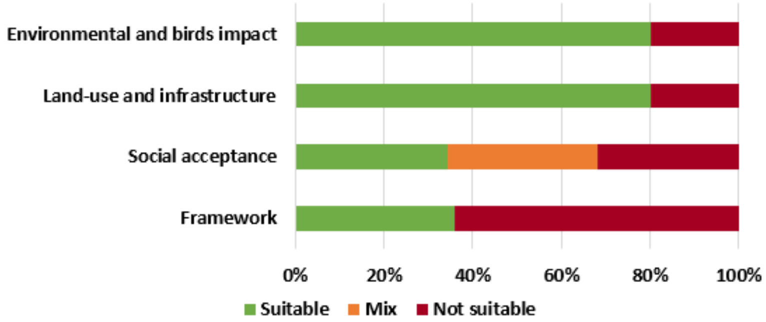

Figure 14 Suitable (green bar) and non-suitable (red bar) area for the NHN in each assessment

Finally, once the total area available is extracted, a simplified estimation can be presented to estimate a potential installed capacity and corresponding energy production in the framework scenario. Capacity density is assumed to estimate the potential installed capacity; this value ranges between 2-10 MW/km^2; as addressed in [15] and in [16], a 5 MW/km^2 is selected for the European countries. From this density value, the installed capacity may be calculated based on the available suitable area. In this case, computed wind deployment was estimated for 100% of the suitable area. Furthermore, installed capacity based on 50%, 30%, 10% and 5% of the suitable areas was also calculated (Figure 15). The current RES 1.0 plan estimates a total new required installation of 42 MW by 2030.

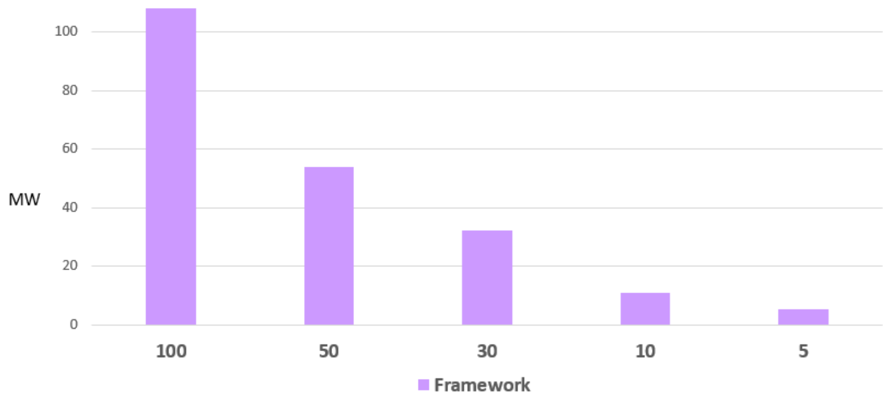

Figure 15 Estimated installed capacity (in MW) considering different share of the suitable area extracted in the framework analysis.

6 Conclusion and further research

This study addresses the onshore wind deployment challenges in an overall framework combining several constraints: more conventional ones such as land use, Natura 2000 and wind resources, and less conventional, such as migration routes, social acceptance and grid congestion. This complete framework proves the potential and the power of such a tool to highlight future challenges and identify opportunities for onshore wind energy deployment.

The main conclusions and bottlenecks from this assessment are:

1) Onshore wind deployment does not progress as fast as planned. Often delays and associated costs are due to environmental limitations, land use constraints and social resistance, challenging the business case of wind farm projects. This often happens because real impacts due to collisions or on migratory birds, grid congestions limitations and social acceptance and engagement of local community are usually not considered at early stages.
2) TNO made an analysis of how wind farm development for these aspects is currently performed in the Netherlands, in doing so identifying bottlenecks and process issues.
3) Based upon the results of this analysis TNO has developed a tool that takes all the most important limiting factors for spatial decision-making for developing an onshore wind farm, reducing uncertainty and delays of future business cases.
4) The tool has been tested for the energy region North Holland Noord and the following conclusions have been made:
    - **Environmental constraints.** There is a need for accurate and real data on impacts, fatality rates and behavioural changes of birds. The real impact of wind turbines on the air habitat needs to be addressed accurately and carefully, through measurements and collaboration between different parties of experts.
    - **Land use**. A close collaboration between developers, governmental parties and grid operators is fundamental to address bottlenecks and future demands on the power grid and to synchronize power grid expansion tailored to future wind, solar and hybrid energy system projects.
    - **Social acceptance**. Lack of acceptance may lead to feelings of social injustice and inequality (and vice versa) and can result in opposition and protest which leads to delay in the wind farm deployment project itself. Through early participation in RE projects, it will be possible to identify and support the drivers, address at an earlier stage any eventual challenges, and thus minimize delays to the deployment.

Looking forward TNO believes that the ability to consider all limiting factors at an earlier stage in the development process will enable faster and more efficient roll out of wind farms and with a higher degree of social acceptance due to the transparency and fact-based approach.

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Annex

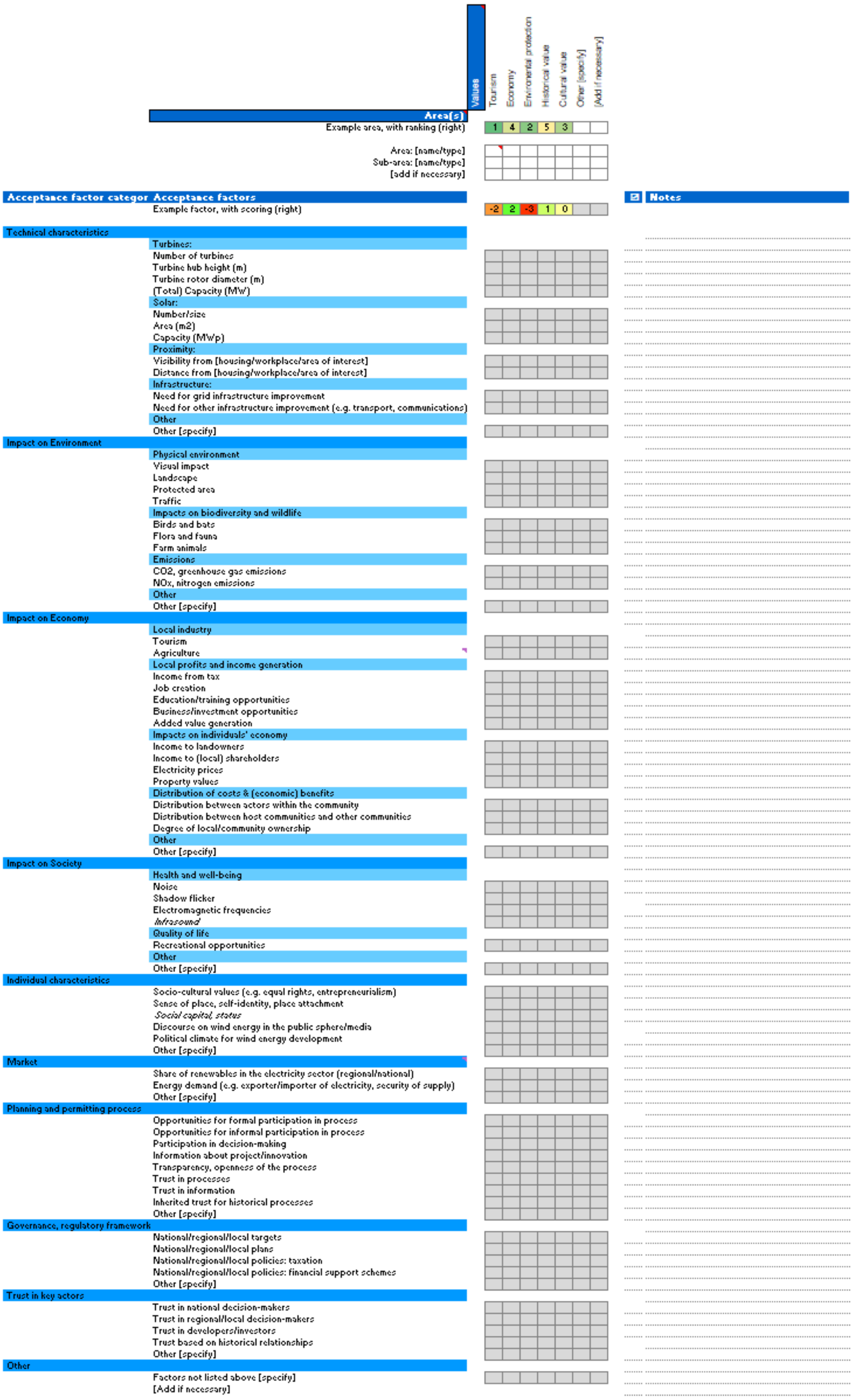

Figure 16 Social acceptance matrix

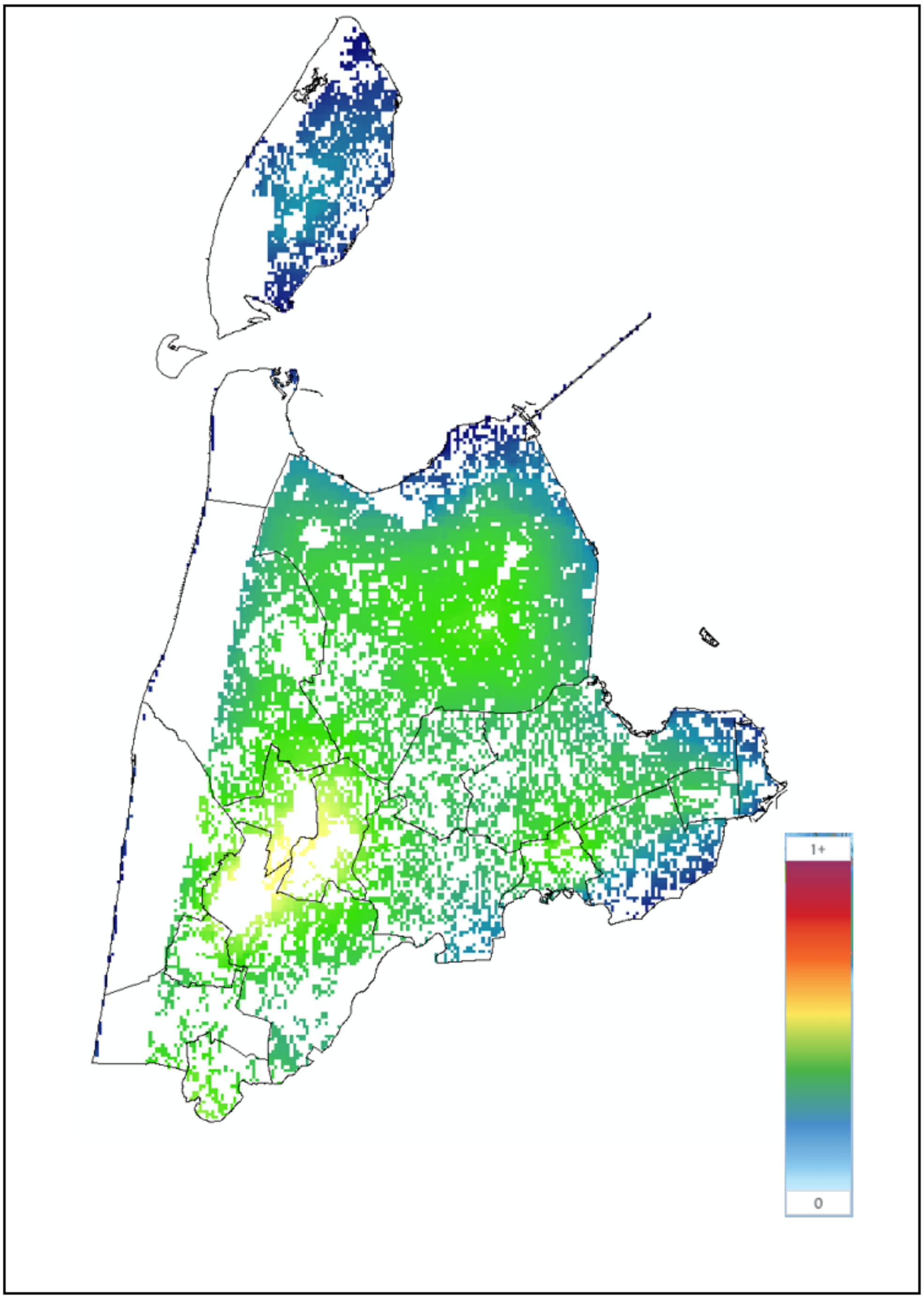

Figure 17 Capacity Factor Class II for suitable area resulted in the complete framework