windspeed

SUPPORTING DECISIONS

SPatial Deployment of offshore WIND Energy in Europe (WINDSPEED)

EIE/07/759/S12.499460

Horizontal Key Actions

"Methodological Framework of the DSS"

WP4 Report D4.2

January 2011

Supported by

INTELLIGENT ENERGY EUROPE

Methodological Framework of the DSS

GIS - processing structure
Data management, input and output data
GIS - calculation rules
Results

Dr. Christoph Schillings
Thomas Wanderer
Marlene O'Sullivan

DLR – German Aerospace Center
Institute of Technical Thermodynamics
Pfaffenwaldring 38-40
70569 Stuttgart

++49 711 6862 784
christoph.schillings@dlr.de

Table of contents

Tables

Figures

Executive summary

Within the WINDSPEED project, a Decision Support System (DSS) based on a Geographical Information System (GIS) is developed. Its results are used to assist the preparation of a roadmap for the deployment of offshore wind energy in the North Sea.

The DSS uses next to existing data of sea use functions in the North Sea (as shipping routes, nature conservation areas, fishery effort etc.) a user-driven cost model and spatial strategies to determine available space and costs for offshore wind farms.

The DSS generally generates answers to the following questions:
which areas are not suitable for the usage of offshore wind platforms?
which costs are assumed for offshore wind platforms at suitable areas?

The DSS process is triggered by the submission of user defined scenarios, either stored in local files or via an online web-interface (http://www.windspeed.eu/dss/dsstool.php).

The determination of offshore wind energy potential is done by a spatial analysis utilising a GIS. This process negotiates available space on the basis of user-defined categorical and gradual criteria whereas the latter ones comprise spatial strategies and economic parameters.

The results consist of maps showing the spatial distribution of (non-) suitable areas for offshore wind farms, together with their costs and other related statistics. Results are available for download and viewing on the online web-interface (Google Earth KML-format, statistics in XML-format) or as local datasets which can be further analysed in a desktop GIS (for project team only).

1 Introduction

In the deliverable report D4.1 “Specification of the GIS-based Decision Support System” the general idea and specification of the DSS-tool developed within the WINDSPEED project is described.

This deliverable report D4.2 “Methodological Framework of the DSS” describes the architecture and structure of the DSS and the implementation of the provided input data and provided functions within the DSS. It also describes the conversion of the input data and the calculation rules into the DSS. Furthermore, the provided results and output data are explained in detail.

All equations for calculating the costs for the erection of an OWP are described in detailed in the report D2.2 provided by project partner Garrad Hassan. All information on input data and calculation rules for non-wind sea functions are described in detail in the reports D3.1, D3.2 and D3.3 provided by project partner IMARES.

The following list summarizes the demands which were requested from the project and the research objective with respect to the DSS tool development:

Allow the definition of scenarios which could represent current/future sea use developments.

Indicate suitable areas for offshore wind energy in a coarse resolution and based on categorical as well as gradual criteria.

Negotiate areas by an assessment method, for instance by economical or sustainable measures.

Indicate possible measurements, sea use forms or areas to reach preconditioned numbers for offshore wind energy.

Utilise a GIS as tool for the spatial calculations within the decision finding process.

Name approximate total potential, electricity yields, costs and optimal allocation for certain scenarios.

Provide results in the form of maps and statistics.

The tool should be designed for the use within a smaller project group but leave the option for a later release, respecting the issue of confidential data.

2 The Architecture, Processing Structure and Data Management of the DSS

2.1 DSS Architecture

To provide a flexible architecture of the DSS that fulfils the requirements of the project, a "hybrid" solution of a desktop GIS with a network-bound interface was considered. Figure 1 shows the schematic architecture of the DSS approach. This approach benefits from the integrated character of a desktop GIS and secondly enables the optional use of the DSS by external users. As this concept is certainly not adequate for a commercial GIS project or company set-up, it is sufficient for a limited user group (like the WINDSPEED project team) while offering the option to make the DSS public via web client (see also chapter 2.7). Thus, a differentiation between project members (full dissemination of the DSS) and external users can be made when necessary (stakeholder training via web client), and confidential data would be kept within the legitimated user group.

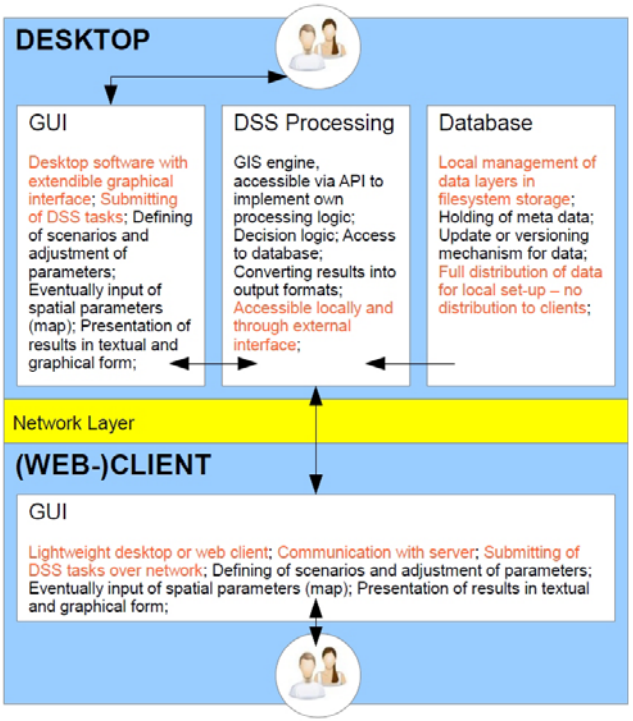


Figure 1: Implemented DSS architecture

For the implementation of the DSS the ArcGIS/ArcInfo software by the Environmental Systems Research Institute, Inc. (ESRI) was chosen. The web-interface is a JavaScript application, interacting with a webserver which stores scenarios for the pull-based DSS-tool.

2.2 Processing Structure

Figure 2 shows the schematic structure of the DSS. The parenthesised digits show the sequence of actions. The first step is the submission of a decision task request by the user via the user interface / Dialogue Box (1). Within the Windspeed project such a decision task is called “scenario”. Chapter 2.4 describes how such a scenario can be defined by the user. Next the DSS accesses the database (2), processes the data and stores it intermediately (3-5). This is done by the geoprocessor tool-chain ArcGIS. Processed final results are stored in an extra database (6) from where they get loaded locally or sent back to the remote client (7, 8).

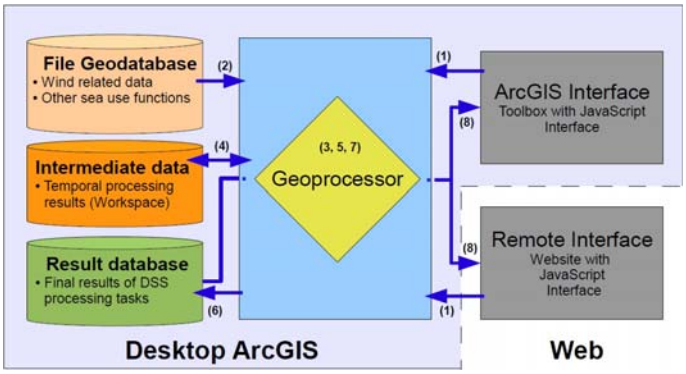


Figure 2: Schematic setup of the DSS

Figure 3 shows a more thematic processing structure of the DSS which is divided into several steps/modules.

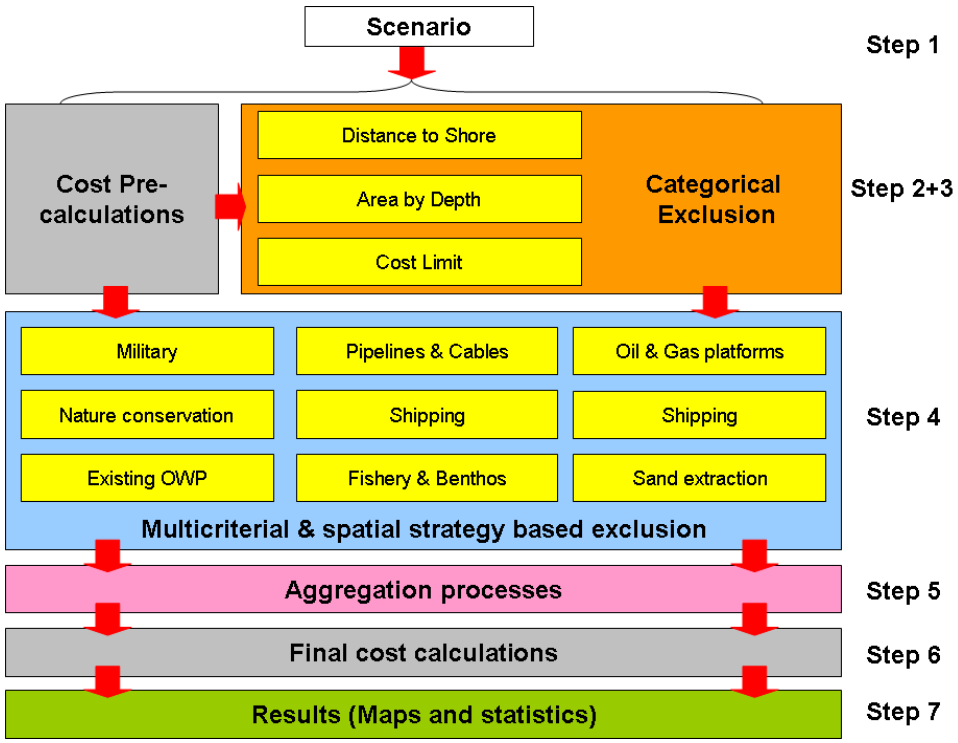


Figure 3: Schematic processing structure of the DSS.

The DSS tool is driven by a scenario file which contains all parameters and values that are set by the user. Step 1 consists of the dialogue box or the user interface (which is equivalent to the Remote or ArcGIS Interface (1) in figure 2 where the user can define and modify parameters and where the scenario file is compiled.

The displayed geoprocessing steps (3, 5, 7) in figure 2 consists of single processing modules which can be grouped in several steps as shown in figure 3:

Step 2: cost pre-calculation
Step 3: Generally excluded
Step 4: exclusion criteria of sea use functions
Step 5: Aggregation process
Step 6: final cost calculation
Step 7: Creating Results

Step 2: The cost calculation needs input parameter that are independent from the scenario settings. These parameters are *distance to shore*, *distance to coast*, *distance to substation* and *depth*. For each 5x5km² grid cell these parameters are calculated in the cost pre-calculation process.

Step 3: In this step the generally excluded zones are determined. Therefore all areas that

- are located within a certain distance to shore,
- are above than a certain sea depth,
- have a Levelized Production Cost (LPC) lower than a defined limit,
- are marked as suitable. All other areas are excluded.

Step 4: After the determination of the generally excluded areas, the DSS tool now takes all other sea use functions into account and excludes the areas that are used by these sea functions.

Step 5 and 6: The tool now has identified excluded and suitable areas. Due to the processing structure, these areas now have to be aggregated and for the remaining suitable areas the final costs are calculated.

Step 7: The tool calculates in step 7 statistics and creates maps for the determined costs and the identified suitable and excluded areas. These results are stored locally or are uploaded to the homepage.

2.3 Structure and Format of Database

All data (input, intermediate and result) are stored in vector-format which means that all information is structured either in point, in line or in polygon features. E.g. information on platforms is stored in point vector-format, information on cables in line vector-format, information on nature conservation in polygon vector-format.

To achieve an optimum of data access, all needed input data are stored in a “File Geodatabase”, which is proprietary data format by ESRI. This geodatabase holds a collection of various types of GIS datasets.

Figure 4 shows the File Geodatabase “windspeed.gdb” containing all input datasets. Small icons show the different data format (point, line, polygon) that underlies the dataset. All datasets processed by the DSS (intermediate and final) are stored in similar File Geodatabases.

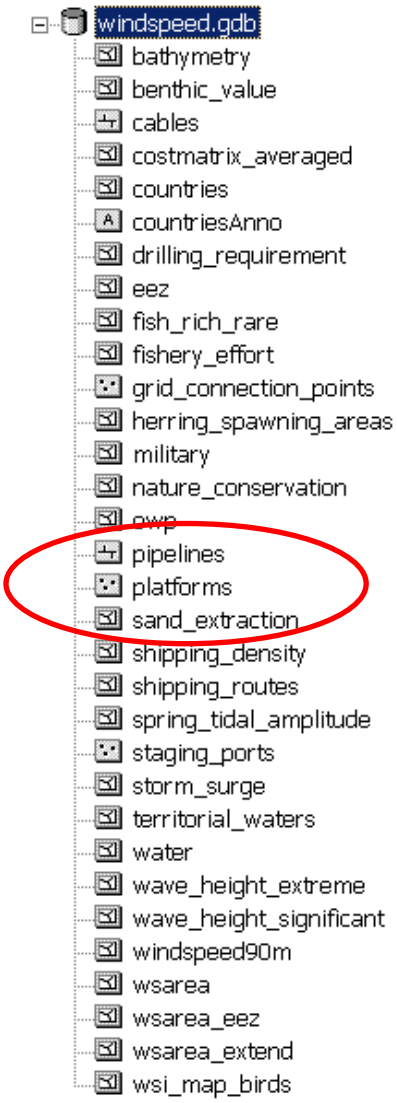


Figure 4: File Geodatabase containing all input data for the DSS.

2.4 Scenario Settings

Using the Dialogue Box (see figure 5), the user can set up her/his scenario by modifying relevant parameters or framing conditions. A first overview how to use the Dialogue Box is given in report D4.1 chapter 2.3. A detailed description of all available modules and options and their underlying calculation rules is given in this report in chapter 3.

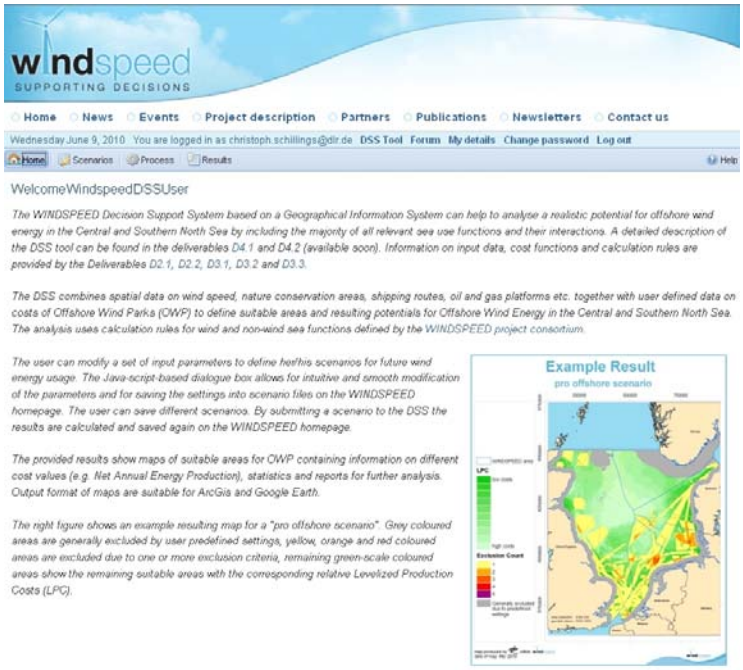


Figure 5: WINDSPEED Dialogue Box, initial view.

The first step of user interaction with the DSS is the definition of a scenario, describing certain use cases, preconditions and model parameters. Based on these scenarios, the DSS will then generate answers for potentially available area and corresponding costs for offshore wind energy in the WINDSPEED areas. Figure 6 shows the user interface with the scenario management where the user can modify, save, load and export scenarios.

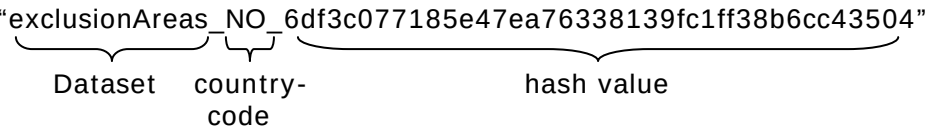
Figure 6: WINDSPEED Dialogue Box, scenario management.

The scenario settings are saved in a scenario file in a textual form. Task of the dialogue box is to support the user with configuring parameters by offering simple text fields, radio/select buttons or drop-down menus. The possible input a user can submit is limited to:

- Adjustment of parameters, controlling the cost calculation model
- Several minimum or maximum distances or ranges as textual input
- Further criteria controlling the negotiation of areas
- Spatial extend(s) to run the DSS country-wise
- Parameters that designate the type and format of the output

To structure the amount of different parameters, a division into thematic blocks is carried out, called modules. Such a module gathers for example all shipping related parameters and is named *Shipping*. To take into account that certain parameters might need to be set individually per country, a further division of the configuration by country is necessary. This applies for instance in the case of different minimum distances for OWPs from shores. While editing a scenario, the user's input is validated automatically and useful hints about possible values or errors are given. In addition before submitting a scenario to the DSS, another validation is executed to avoid running the DSS with wrong parameters and therefore receiving false results.

For running the DSS time-optimized, all the setting parameters of a module are converted into one hash value which is functioning as check sum. All intermediate output is named individually by using this hash value thus becoming recognizable as the result of a certain module and certain configuration. To give an example, the exclusion areas for Norway that where calculated by the DSS using the defined scenario settings are stored in an intermediate file like



This example file contains all exclusion information for Norway (NO) for the specific DSS calculation. The sequence of numbers and letters represent the checking sum (hash value). This sum is unique for the scenario which was used for the calculation.

This is due to documentation issues but also for optimizing the DSS processing. Once the DSS starts, it checks for existing data from earlier runs that can be used. To do so, the DSS searches for already existing results with the hash value according to the current module configuration. If it finds earlier processed data these can be use as input, if not, the module will process the data using the new settings.

2.5 Input Data

All the datasets used in the DSS and their sources are described in detail in other deliverables of the WINDSPEED project. These deliverables are D2.1 “Inventory of wind potential based on sea depth, wind speed and distance from shore” and D2.2 “Inventory of location specific wind energy cost”, both from WP2, and D3.1 “Inventory of current and future presence of other sea functions and identification of interactions” from WP3.

As data are provided from different sources, a common format and a common attribute structure have to be defined to make the DSS functional. Each dataset (e.g. staging ports) contains many attributes that can be used by the DSS. The attributes are stored in a Table like shown in figure 7. Following fields describe the attributes for the dataset/feature "staging ports":

OBJECTID	Internal object number for ArcGIS software
Shape	Data format (Vector)
Name	Name of staging ports
CountryCode	Acronym of the country
CountryName	Name of the country
POINT_X	Geographical longitude in degree
POINT_Y	Geographical latitude in degree

OBJECTID *	Shape *	Name	CountryCode	CountryName	POINT_X	POINT_Y
1	Point	Bergen	NO	Norway	5.288996	60.397254
2	Point	Kristiansand	NO	Norway	8.003472	58.141642
3	Point	Great Yarmouth	UK	United Kingdom	1.741566	52.604244
4	Point	Cromarty Firth	UK	United Kingdom	-4.045296	57.685734
5	Point	Peterhead	UK	United Kingdom	-1.781939	57.497626
6	Point	Montrose	UK	United Kingdom	-2.458701	56.701012
7	Point	Dundee	UK	United Kingdom	-2.899391	56.45698
8	Point	Tyneside	UK	United Kingdom	-1.414723	55.011245
9	Point	Hartepool	UK	United Kingdom	-1.189717	54.69239
10	Point	Humber	UK	United Kingdom	-0.068384	53.577361
11	Point	Harwich	UK	United Kingdom	1.292293	51.934213
12	Point	Ramsgate	UK	United Kingdom	1.420121	51.329566
13	Point	Thyboron	DK	Denmark	8.227307	56.703631
14	Point	Hirtshals	DK	Denmark	9.962081	57.595844
15	Point	Frederikshavn	DK	Denmark	10.551339	57.441146
16	Point	Esbjerg	DK	Denmark	8.421408	55.471617
17	Point	Eemshaven	NE	Netherlands	6.836487	53.452811
18	Point	Bremerhaven	DE	Germany	8.569228	53.543075
19	Point	IJmuiden	NE	Netherlands	4.595633	52.465473
20	Point	Rotterdam	NE	Netherlands	4.112989	51.972245
21	Point	Antwerp	BE	Belgium	4.308593	51.293495
22	Point	Zeebrugge	BE	Belgium	3.206223	51.337947
23	Point	Oostende	BE	Belgium	2.923799	51.234979
24	Point	Dunkirk	FR	France	2.338749	51.054478

Figure 7: Attribute Table for the feature "staging ports".

Mandatory attributes for all datasets (e.g. nature conservation areas, shipping routes, platforms, staging ports etc.) are OBJECTID, Shape, CountryCode and CountryName.

Most of the datasets contain further attributes that are needed for the DSS processing but these are not mandatory from the technical point of view of the DSS.

Table 1 identifies the input data that are collected by the project partners IMARES, Garrad Hassan and DLR.

WIND / COST		NON-WIND		BASIC	
Parameter	Dataset	Parameter	Dataset	Parameter	Dataset
Planned / Existing OWP	owp opw_poly	Nature Conservation Areas	nature_conservation	Coastline	countries
Wind speed at 90m hub height	windspeed90m	Fishery / Fish / Spawning Areas	fish_rich_rare fishery_effort	EEZ	wsarea_eez
Sea Depth	bathymetry	Benthos	benthic_value	Project Area	wsarea
Spring Tidal Amplitude	STA	Birds	wsi_map_birds		
Storm Surge	StS	Military Use	military		

Wave Height	Hs, HS50	Shipping Routes/Density	shipping_routes shipping_density		
Drilling Requirement	Drill	Anchorage Areas	shipping_routes		
Grid Connection Points	grid_connection_points	Platforms	platform		
Staging Ports	staging_ports	Pipelines	pipelines		
		Cables	cables		
		Sand Extraction / Dredging	sandextractiondredging		

Table 1: Used input parameters and their datasets for the DSS.

2.6 Calculation of results

After submitting the scenario to the geoprocessor, the DSS starts to calculate the results. To reduce the area for which the cost and potential of OWP will be calculated, all relevant general sea use functions are taken into account as a priori exclusion criteria. Beginning with the modules *distance to shore*, *area by depth* and *cost cap*, all other exclusion criteria are applied subsequent using the user defined settings. For the remaining suitable area, the costs are calculated. Each module is described in detail in chapter 3.

Due to data usage restrications not all input data (like e.g. military zones) can be freely disseminated. Therefore the provided output maps do not show the type of exclusion criteria. Only the number of existing exclusion types is given in the maps.

2.7 Output data

General

As some of the used input data are restricted for publication or for free access, the DSS tool and the underlying data can not be disseminated outside of the project consortium. On the other hand it is of great importance that as many stakeholder as possible can use the tool to open up the discussion on realistic offshore wind potential in the North Sea. As the DSS tool provides many options for modifying parameter and calculation rules, each stakeholder/user of the DSS can create his/her own scenario.

A good compromise in respecting the restrictions of using the input data and the need of a broad visibility and use of the tool is in developing the Dialogue Box of the DSS for using as an online application in a general web browser like Internet Explorer or Firefox (see also chapter 2.1). The web Dialogue Box is available on the WINDSPEED homepage for registered users. After using the Dialogue Box to define a new scenario by modifying input parameter, the web interface of the Dialogue Box saves the scenario file on the WINDSPEED server. The DSS tool itself is running on a PC hosted at DLR in Stuttgart and at IMARES in Wageningen. The DSS tool periodically checks for new scenarios on the WINDSPEED server and processes the pending scenarios. The results are transferred back to the WINDPSEED server where they can be downloaded by the user. The user will be informed by email as soon as results have been uploaded to the server.

The user and its defined scenarios are clearly defined by an ID and scenario numbers that are also used for identifying the results. This allows for correctly allocating the user and the results.

A Quick-Start Manual how to use the online interface is provided at the Appendix.

On the WINDSPEED homepage, the online DSS interface lists results that are processed for the submitted user scenarios (see figure 8). In this example three results are available: *DK_input_D42_report*, *DK_input_D42_report_v1* and *DK_input_D42_report_v2*. By pressing on the "+"-sign, the available resulting files for the scenario are shown. In the following results for the country Denmark are presented.

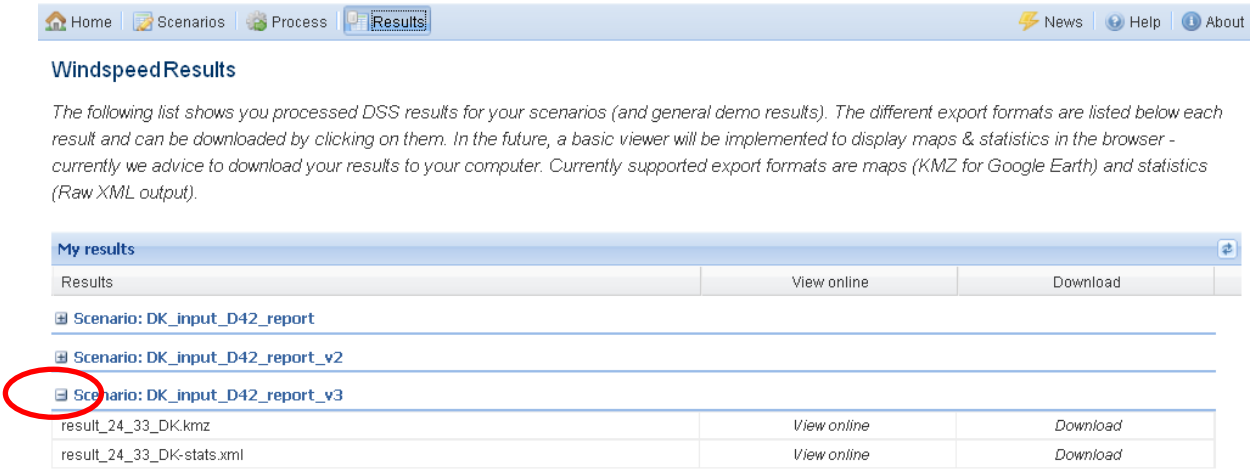


Figure 8: Online DSS interface showing results for different processed scenarios.

The files can be downloaded (*Download*) and can be accessed online (*View online*) by a viewer application (e.g. Google Earth). Following results/files are provided:

Overview Google Earth kmz-file

A kmz-file is provided to the user showing:

1.) Generally excluded areas due for instance to area by depth and distance to shore (grey scale),
2.) Excluded areas due to other sea use functions like military, shipping etc. (red-orange scale),
3.) LPC [€/MWh] for remaining suitable area (green/yellow/orange rank)

To use the kmz-file, Google Earth has to be installed on local PC. As mentioned above, three layers of information are provided in three separate layers so the user can activate and deactivate these layers within Google Earth. Each value (e.g. LPC class 100-105 €/MWh, number of exclusion criteria) can also be activated and deactivated.

Figure 9 shows the example results for an analysis for Denmark. The name of the kmz-file is *result_24_33_DK.kmz*. The number *24* identifies the user, the number *33* identifies the scenario and *DK* identifies the analyzed country. The yellow/orange coloured layer shows the number of existing exclusion criteria (like shipping, military zones etc.), the grey coloured layer shows the number of existing general exclusion criteria (sea depth, distance

to shore, cost cap) and the green coloured layer shows the available remaining area with corresponding LPC. As mentioned before, the resulting output maps (Google Earth file) do not show the type of exclusion criteria. Only the number of existing exclusion types is provided in the maps.

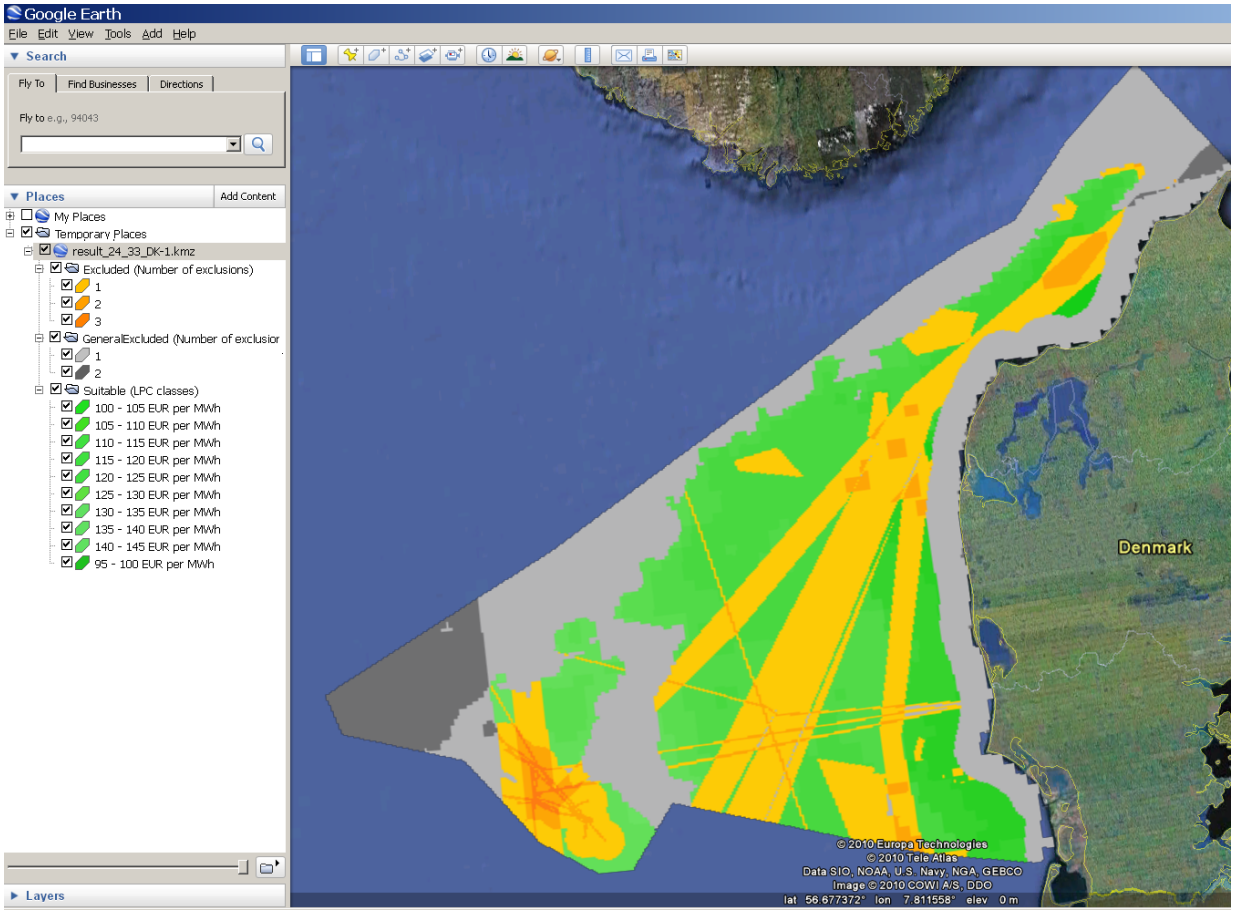


Figure 9: Example of Google kmz-image for online DSS results.

Statistics as Table and Graphs:

Statistics on the results are provided by the "*-stats.xml*"-files (in this example: *DK_input_D42_report_v3*). By pressing on *View online* an online viewer application is started showing an overview statistic. In the *Statistics* register Figures like "size of excluded and suitable areas", "summary of Annual Energy Production" and "total processing runtime of the scenario" are displayed (see figure 10).

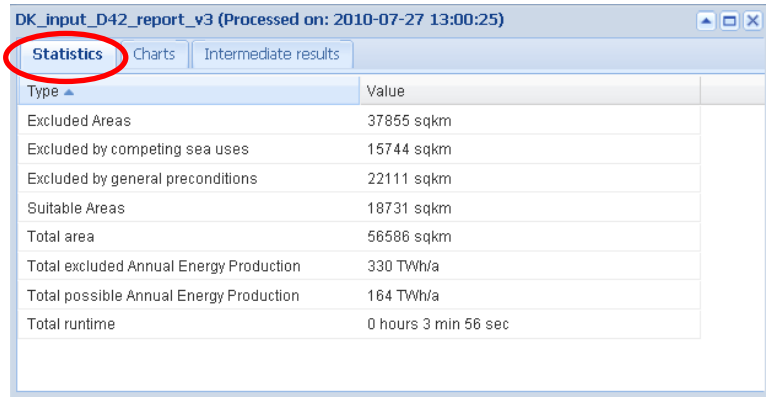


Figure 10: Overview statistics of results.

In the tab *Charts*, several charts can be chosen showing detailed information on suitable and excluded areas, on annual energy production and on cost curves.

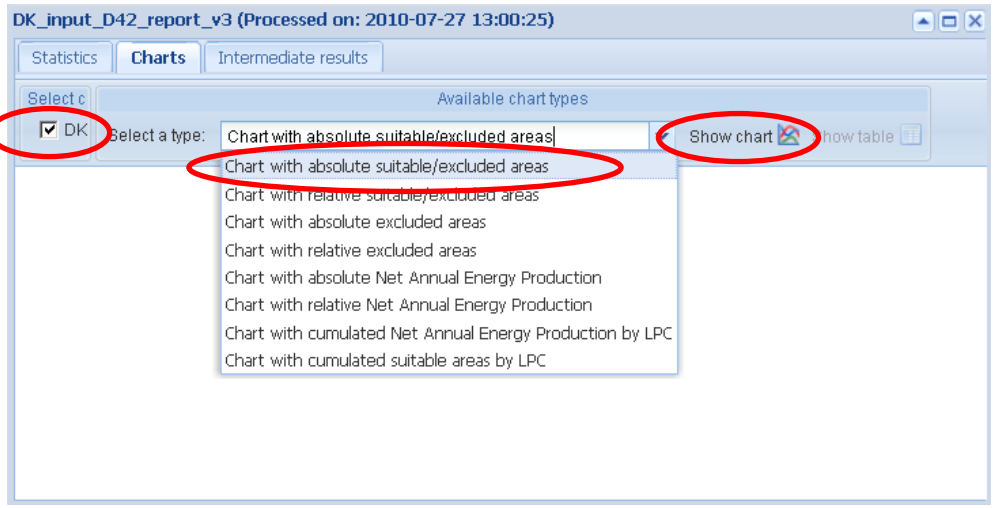


Figure 11: Selection countries and type of chart.

If the user has chosen more than one country in the scenario, the charts gets build up from the data of all countries, for each country separately or for any combination of countries. The user can activate the requested countries by tagging according check boxes. In the example scenario shown in figure 11 only Denmark was analysed therefore only Denmark can be chosen.

Following charts are provided:

Charts with absolute and relative suitable/ excluded areas

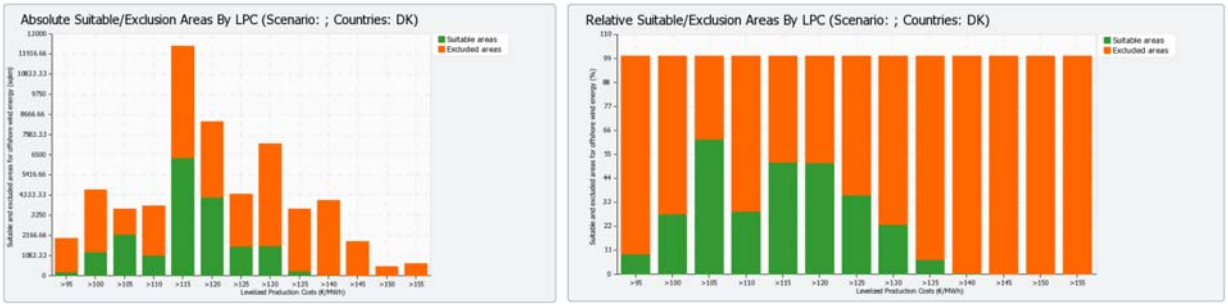


Figure 12: Absolute (left) and relative (right) km² of suitable/excluded areas by Levelized Production Costs in steps of 5 €/MWh for Denmark.

Charts with absolute and relative excluded areas:

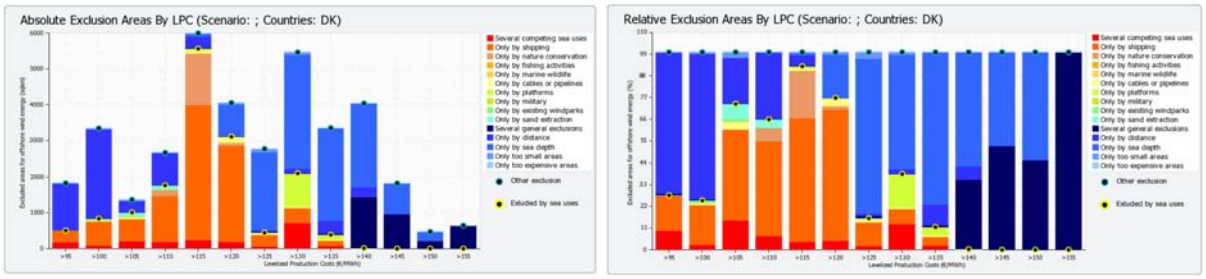


Figure 13: Absolute (left) and relative (right) km² of excluded areas by Levelized Production Costs in steps of 5 €/MWh for Denmark and differentiated by exclusion criterions.

The exclusion criterions are separated in groups of "competing sea uses" (red colour scale) and "other exclusions" (blue colour scale). Areas excluded by more than one exclusion criterion are illustrated as "several competing sea uses" or "several other exclusions". Please note that the group of "competing sea uses" is calculated after the elimination of "other exclusion" areas. Therefore a change of the settings for criterions summarised in "other exclusions" may not only add to a larger suitable area but also to a larger area of "competing sea uses".

Charts with absolute and relative Net Annual Energy Production

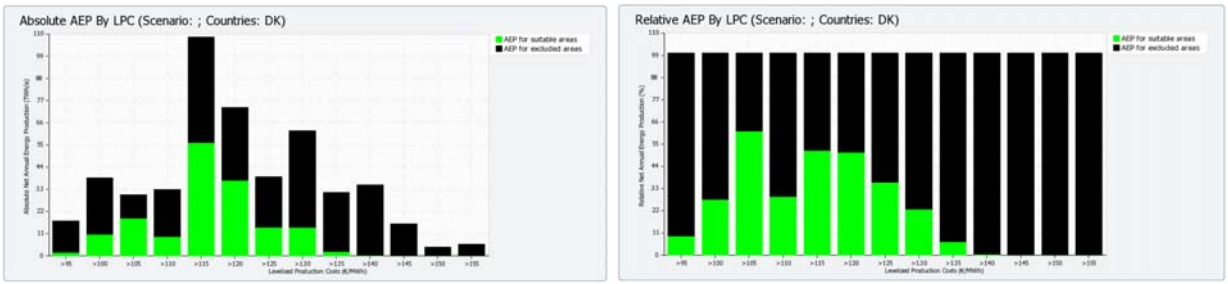


Figure 14: Absolute (left) and relative (right) Net Annual Energy Producion of suitable/excluded areas by Levelized Production Costs in steps of 5 €/MWh for Denmark.

Charts with cumulated Net Annual Energy Production by LPC

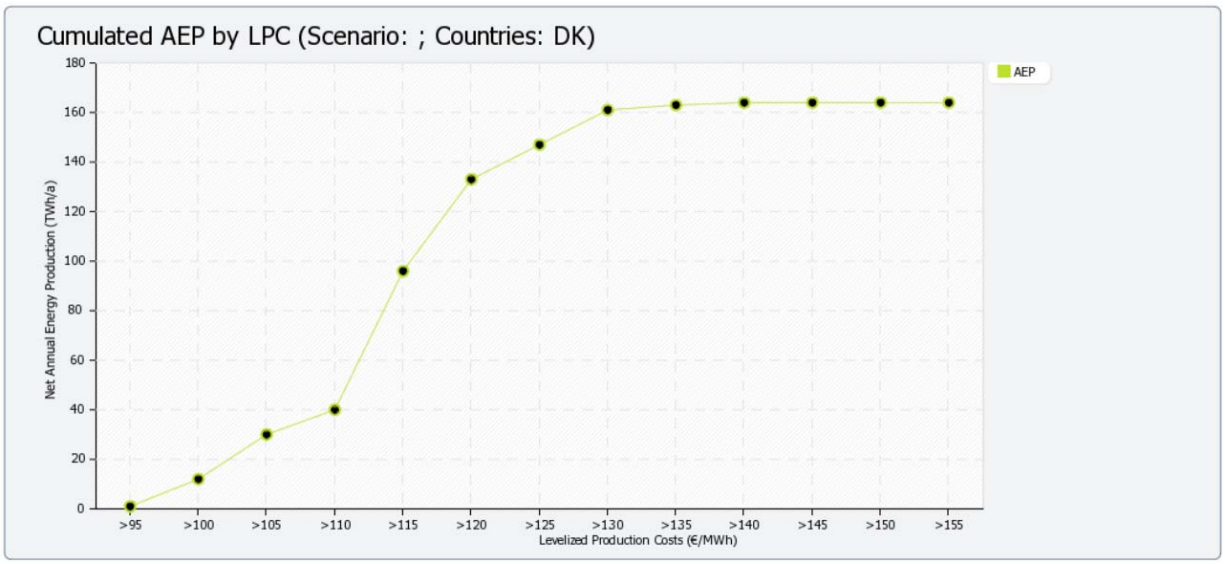


Figure 15 Cost potential curve of the suitable area detected by the chosen scenario for Denmark. It shows the cumulated Annual Energy Production of the available area by Levelized Production Costs in steps of 5 € / MWh.

Charts with cumulated suitable areas by LPC

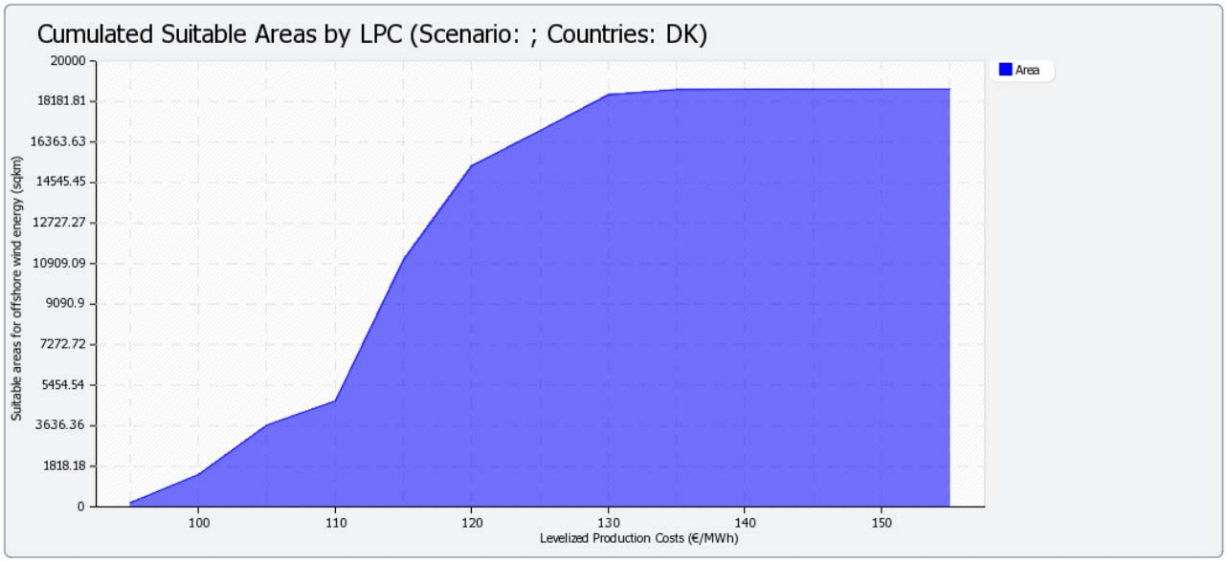


Figure 16: Cost curve of the suitable area detected by the chosen scenario for Denmark. It shows the cumulated suitable sqkm of the available area by Levelized Production Costs in steps of 5 € / MWh.

Results as GIS-Geodatabase for further processing within ArcGIS-Software

The resulting GIS-Geodatabase contains all information on exclusion criteria and cost parameters and the corresponding geometry. With the geodatabase the user can perform further advanced analysis and calculations exercises on a local PC. For this, a ArcGIS software is needed.
This output option is not yet implemented in the web-interface and will be only available for project team members.

3 GIS - Calculation Rules

In the following chapters, all functions and calculation rules used within the DSS process are described in more detail. To make this chapter coherent and easily readable, as an example, each function and its parameters and corresponding results are shown for the country Denmark.

The functions are described in the chronology of their use in the DSS process. All shown values are only examples to explain the functionality of the DSS. The following settings are used for in the example:

Country Selection	Denmark
Distance to Shore	distances to shore <15km or >225km are excluded
Area by Depth	sea depths >50m are excluded
Cost Cap Limitation	no cost cap applied
Shipping	routes with highest vessel frequentation are excluded
Platforms	9260m buffer for helipad platforms, 500m for other types of platforms are excluded
Cables & Pipelines	500m buffer around cables and pipelines are excluded
Military Zone	50% of firing areas with best wind potential are suitable
Nature Cons. Area	20% of natura2000 areas with best wind potential are suitable
Sand Extraction	excluded
Birds	some areas with best wind potential are suitable
Fish species richness	some areas with best wind potential are suitable
Benthic values	some areas with best wind potential are suitable
Fishery effort	some areas with best wind potential are suitable

These criteria are used to calculate the exclusion map and to define the remaining suitable area for offshore wind energy deployment, for which the cost calculation is performed.

3.1 General Functions

Country Selection

The DSS tool aims to provide information on the Central and Southern North Sea. Countries included are Belgium, Denmark, Germany, the Netherlands, Norway and UK. Nevertheless, the DSS can process results for one or more selected countries within this area. Therefore, the user must start by selecting the countries to be included in the analysis using the user dialogue. The DSS will then take all country-relevant information into account and processes the results for the chosen country/countries. Figure 17 shows the Graphical User Interface for country selection, in this example only Denmark is selected for the analysis.

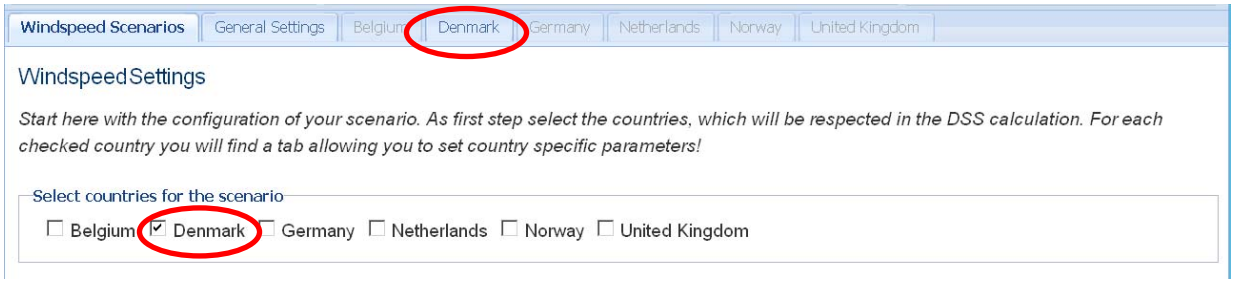


Figure 17: Country selection using the Graphical User Interface.

Each dataset includes information by country and is encoded by CountryCode and CountryName. The DSS functions will process the selected countries only and all other countries are neglected. Figure 18 shows the resulting area due to this selection marked in green. The selected area comprises the EEZ of Denmark.

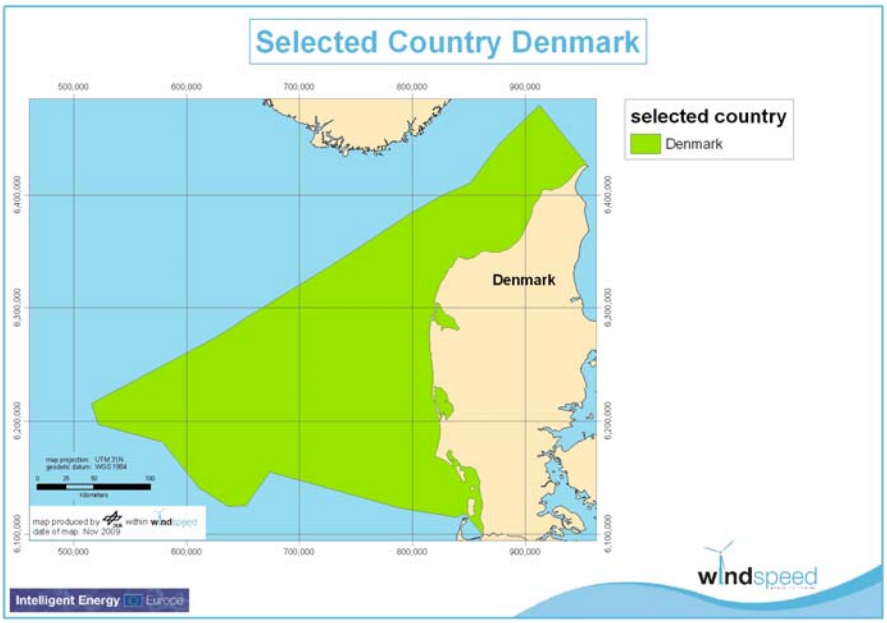


Figure 18: Exclusive Economic Zone (EEZ) in the WINDSPEED analysis area for selected country Denmark.

Distance to Shore

Distance to shore affects the maintenance cost/operating expenditure (OpEx). Therefore, this parameter is used within the cost calculation step. The user has the option to define a minimum and maximum distance for suitable areas for OWP which affects the size of the area to be analyzed. This is due to the fact that some countries define a minimum or maximum distance for OWP. table 2 shows the relevant datasets, attributes and functions needed for the analysis relating to "distance to shore". To perform this function, data on country boarders ("countries") and on EEZ ("wsarea_eez") is needed. The user defined settings on minimum and maximum distances are stored on the variable "minDistance" and "maxDistance". Input data and variables are needed for the GIS functions "select", "buffer" and "clip".

dataset	parameters/ settings	example value	mathematical operator /GIS function
wsarea_eez countries	minDistance maxDistance	15 225	select buffer clip (extraction)

Table 2: Relevant parameters and functions for the analysis "distance to shore".

Figure 19 shows the graphical user interface of this module. The user can modify the minimum and maximum values within a defined range. The interface automatically checks the values and warns the user if the value is not valid (out of range, not a number etc.). The shown example defines the distance range of 15km – 225km which would be the suitable area for OWP for Denmark.

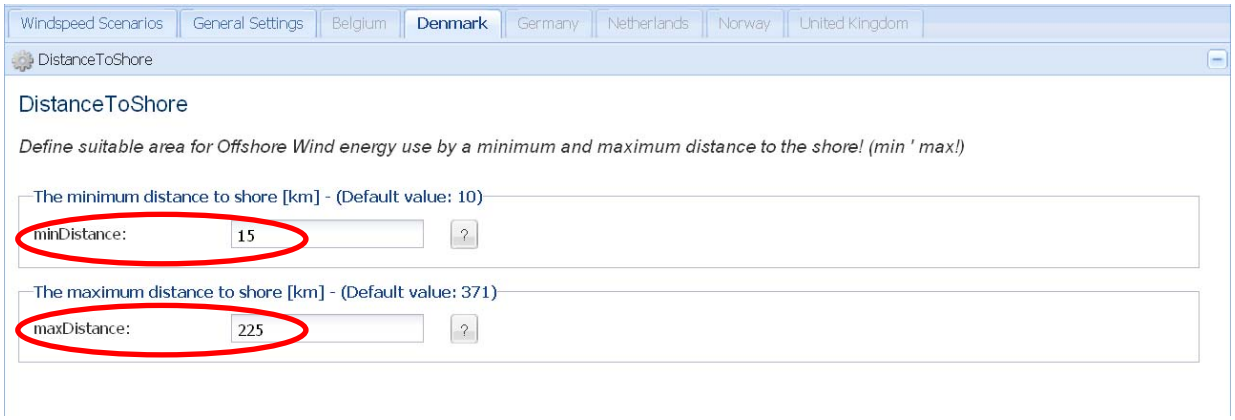


Figure 19: Graphical User Interface of module "Distance to Shore". As example values, minimum distance of 15km and maximum distance of 225km are defined.

Figure 20 shows the resulting map of this module. The remaining suitable area is marked in green color the area excluded by the "Distance to Shore" module is marked in grey color.

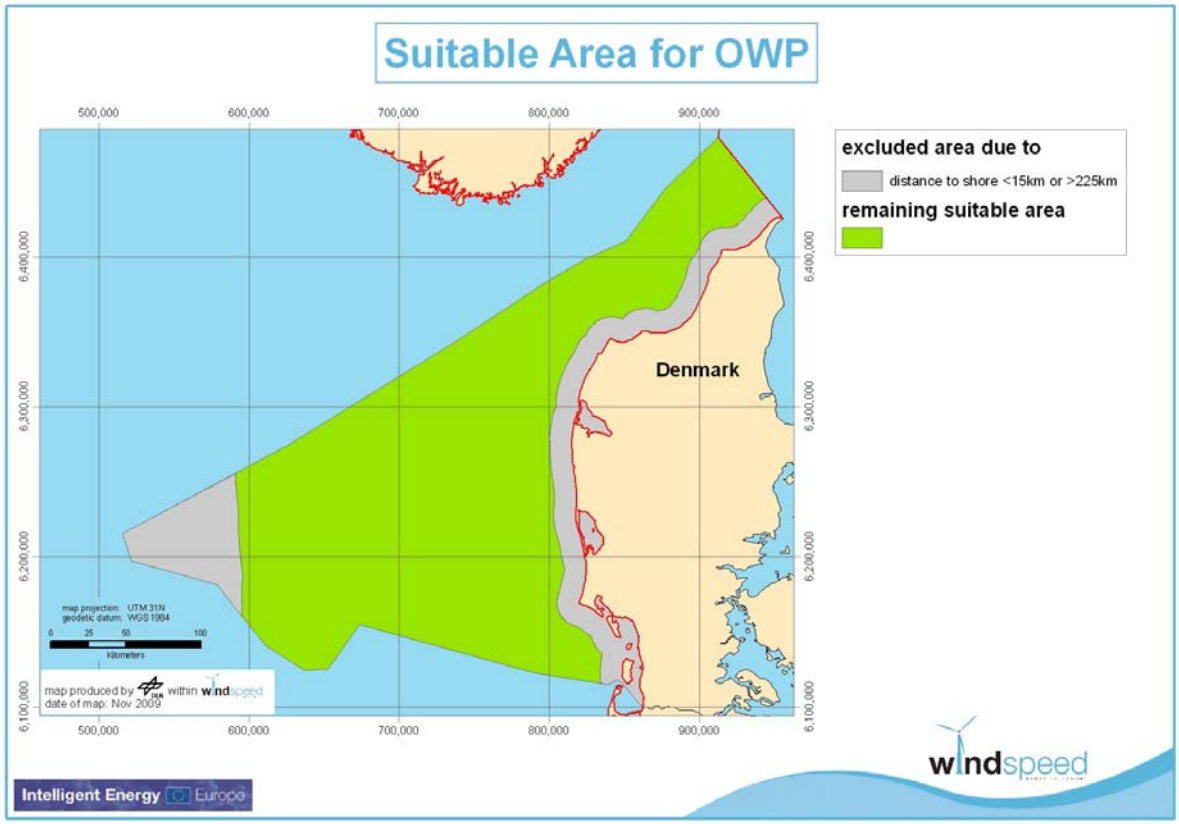


Figure 20: Resulting example map for suitable areas for OWP in Denmark with respect to "distance to shore". The map shows the remaining suitable area within the distance of 15km – 225km from shore.

Sea Depth

Sea depth is a key driver for the installation costs/initial capital expenditure (CapEx) as it is an important determinant for choice of foundation. The DSS gives the option to exclude areas beyond a given sea depth in advance. The following table 3 shows the relevant datasets, attributes and functions needed for the analysis "Sea depth".

dataset	parameters/ settings	example value	mathematical operator /GIS function
bathymetry	maxDepth	50	< (lower than)

Table 3: Relevant parameters and functions for the analysis "Sea depth".

Figure 21 shows the graphical user interface of this module. The user can modify the maximum sea depth that is suitable for OWP. The shown example defines the maximum sea depth of 50m. The default value is set to 100m which is a reasonable maximum sea depth in general.

Figure 21: Graphical User Interface of module "AreaByDepth". As example value a maximum of 50m of sea depth is defined.

Figure 22 shows the resulting map of this module, in the left map as single exclusion criteria, in the right map as combination of already excluded criteria (here distance to shore). The blue-marked area is excluded by sea depth greater than 50m.

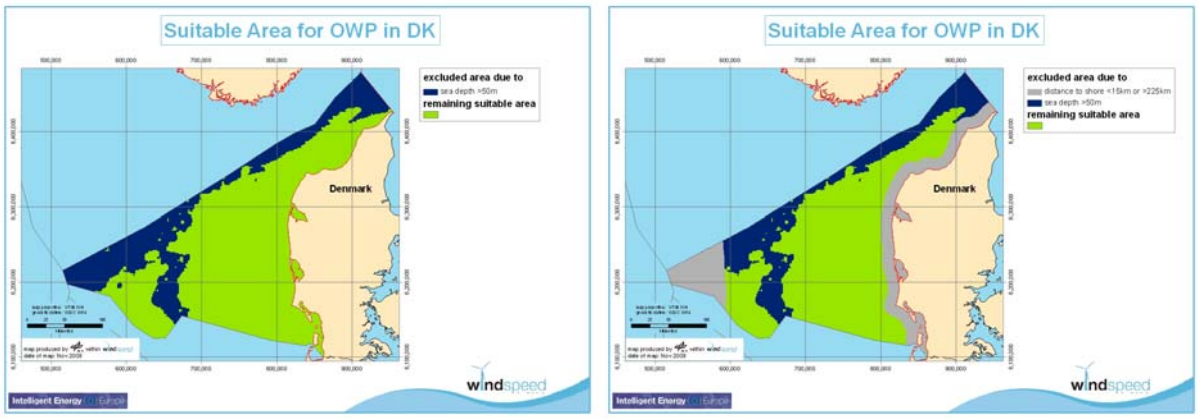


Figure 22: Resulting example map for suitable areas for OWP in Denmark with respect to "area by depth" (left) and in addition with respect to "area by depth" and "distance to shore" (right).

Cost Cap Limitation

Regarding the cost calculation, a maximum cost threshold (cap) can be defined. Areas that exceed the defined cost cap are excluded. One of three cost types (LPC, CapEx or OpeEx) can be select and the corresponding maximum values can be defined (see figure 23). As no cost cap is defined in this example, all areas are suitable regarding the cost limit and no relevant map is shown.

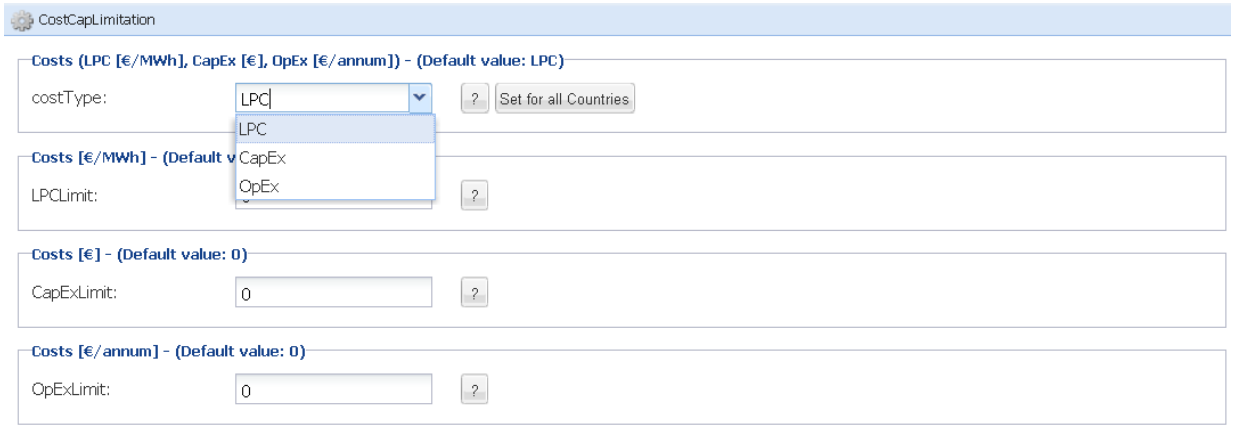


Figure 23: Graphical User Interface of module "CostCapLimitation". For the chosen cost type a maximum cost value can be defined.

Minimum Size for OWP (Suitable Areas)

The user can define a minimum size of area which is required for an OWP. A default value has been set at 50km². This function is useful to avoid single very small and scattered areas which cannot be used for OWP, which could otherwise appear after the exclusion analysis and would lead to an error in the statistics for suitable areas. The user interface for setting the minimum size of area is shown in Figure 24.

Figure 24: Graphical User Interface of module "SuiTable Areas". In this example all areas with a size lower than 50km² are neglected for the analysis.

3.2 Non-Wind Sea Functions

Within the WINDSPEED project, calculation rules for the following sea functions are defined:

Shipping
Oil and gas platforms
Cables and pipelines
Military activities
Sand extraction
Nature conservation zones
Marine Wildlife (birds, fish, benthos)
Fishery effort

The calculation rules are explained in detail in the WINDSPEED deliverable D3.1 “Inventory of current and future presence of non-wind sea use functions”, and deliverable D3.3 “Calculation rules for the DSS”

Shipping

Shipping activities may lead to exclusion areas for Within WINDSPEED, following calculation rules are defined to identify exclusion areas:

Shipping routes	routes plus additional 2nm safety zone are mandatorily excluded
Anchorage areas	areas plus additional 4nm safety zone are mandatorily excluded
Shipping densities	“major” routes are optionally excluded “medium to major” routes are optionally excluded “medium to minor” routes are optionally excluded “minor” routes are optionally excluded

For the routes based on shipping density an additional safety buffer can be applied. The following Table 4 shows the relevant datasets, attributes and functions needed for the analysis “Shipping”.

dataset	parameters/ settings	example value	mathematical operator /GIS function
shipping_routes shipping_routes shipping_density	route anchorage density-classes	excluded + 2nm excluded + 4nm major routes excluded	 clip buffer

Table 4: Relevant parameters and functions for the analysis “Shipping”.

Figure 25 shows the example setting in the web-interface. Only the major routes with highest vessel frequentation (“shipping density”) are excluded for OWP. Areas that lie within shipping routes with medium, low and very low shipping density are suitable for OWP.

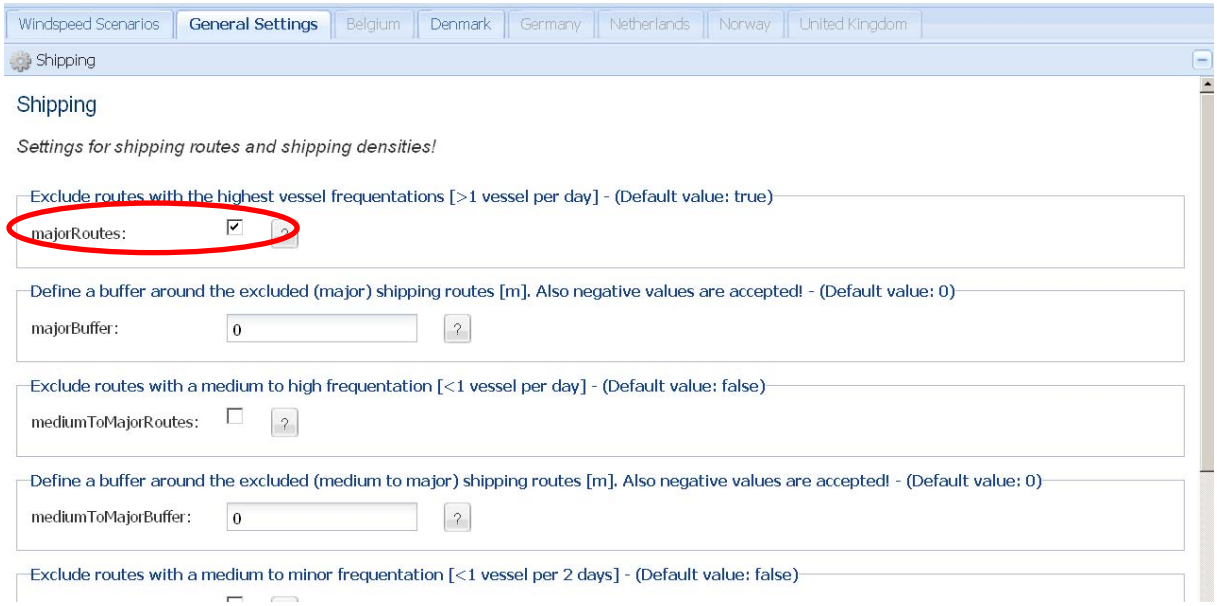


Figure 25: Graphical User Interface of module "Shipping".

Figure 26 shows the resulting map of this module, in the left map as single exclusion criteria, in the right map as combination of already excluded criteria. The yellow-orange marked area is excluded by shipping routes with highest vessel frequentation.

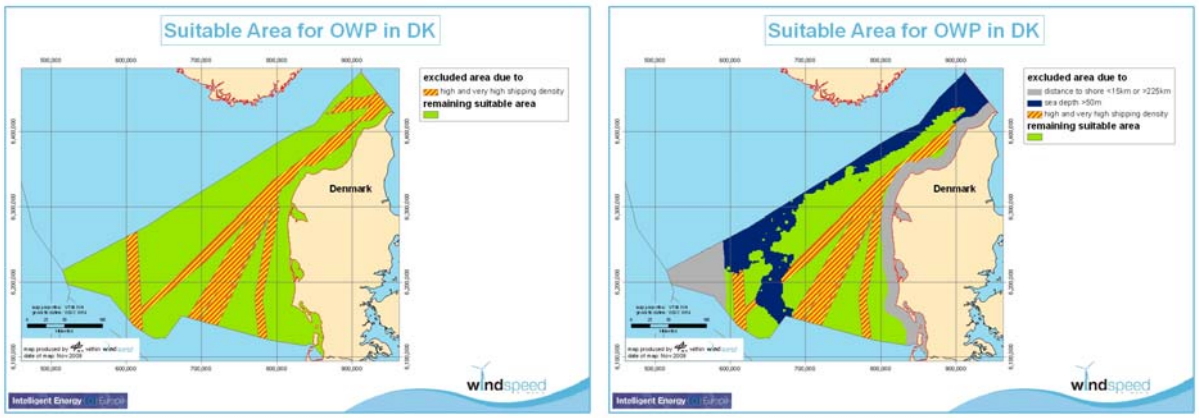


Figure 26: Resulting example map for suitable areas for OWP in Denmark with respect to "shipping" (left) and in addition with respect to "distance to shore", "area by depth" and "shipping" (right).

Oil and Gas Platforms

Areas where oil and gas platforms exist cannot be used for OWP. In the used dataset all platforms are defined as points. To achieve a realistic spatial expansion of the platforms, a default radial buffer with a radius of 25m is applied for each platform.
Around existing platforms a safety zone of 500m is defined in which no shipping is allowed (excluding standby vessels and supply ships). This safety zone is defined in accordance with the United Nations Convention on the Law of the Sea (UNCLOS). For offshore platforms with helipads, a safety zone of up to 5nm is advisable. For further details, see

WINDSPEED deliverable D3.1 “Inventory of current and future presence of non-wind sea use functions”. The DSS allows the user to define the safety zone by defining a buffer around the three different platform types (subsurface, surface and platforms with a helipad) (see figure 27). The following table 5 shows the relevant datasets, attributes and functions needed for the analysis “Oil and gas platforms”

dataset	parameters/ settings	mathematical operator /GIS function
platform	platforms_subsurface platforms_surface platforms_helipad	buffer

Table 5: Relevant parameters and functions for the analysis “Oil and gas platforms”.

Figure 27 shows the example setting in the web-interface. For this example, the default values are taken which means that a safety buffer of 500m is defined for all platforms. If a surface platform has a helipad, 5 nautical miles (9260m) are defined as safety buffer.

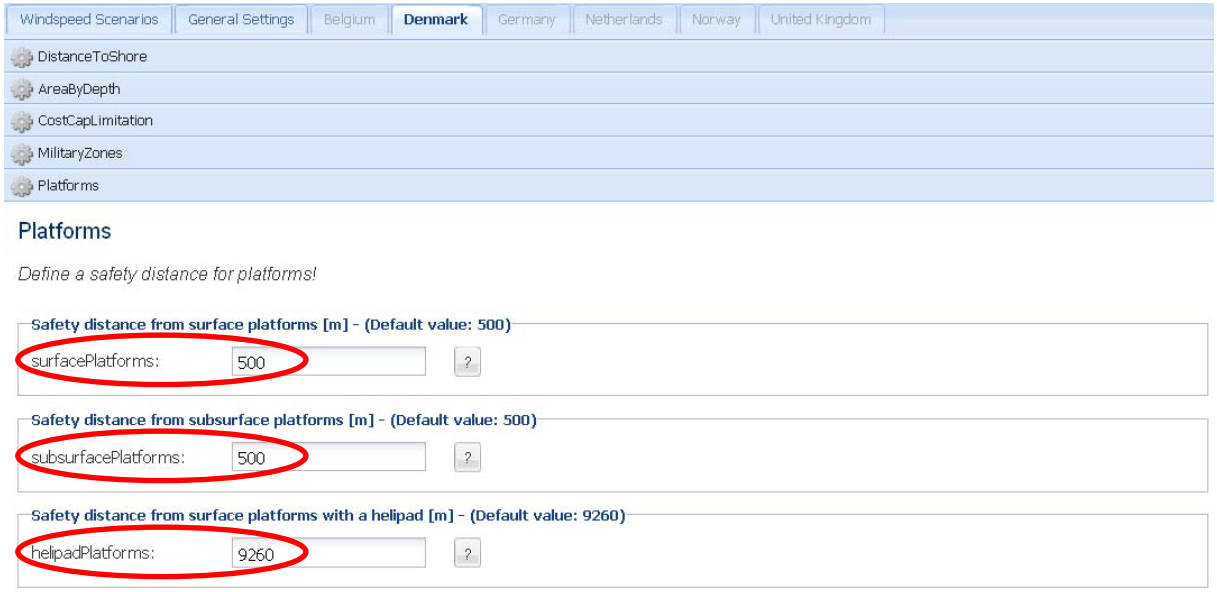


Figure 27: Graphical User Interface of module “Platforms”. In this example, the default values for the buffer zone around platforms are defined. The security buffer will be excluded in the analysis.

Figure 28 shows the resulting map of this module. The red dots (in the South-West of the Danish EEZ) area is excluded by oil and gas platforms and their security buffer. As you can see there are many platforms in the Danish EEZ that are already excluded by former exclusion analysis of “distance to shore”, “area by depth” and/or “shipping”. This fact applies also to the following sea use functions, which are not visible in the exclusion mask as their corresponding area has been already excluded already (right map of figure 28).

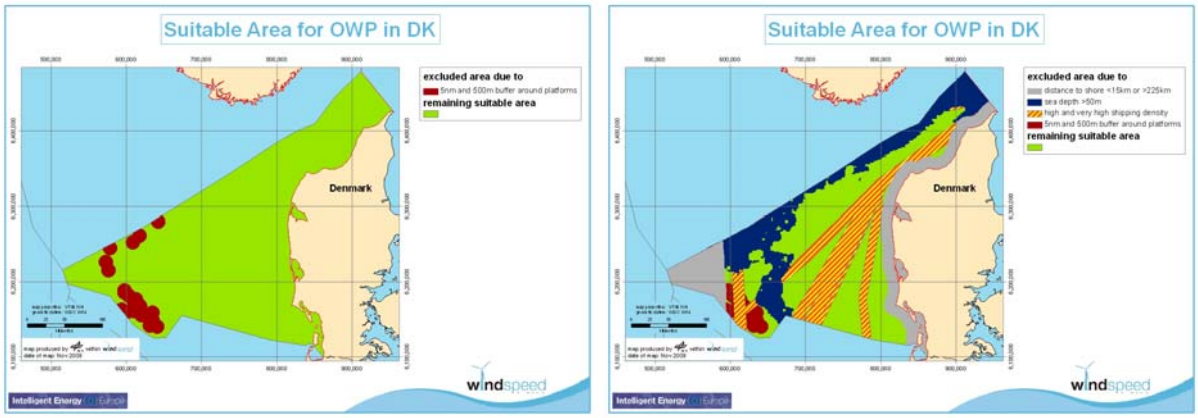


Figure 28: Resulting example map for suitable areas for OWP in Denmark with respect to "platforms" (left) and in addition with respect to "distance to shore", "area by depth", "shipping" and "platforms" (right).

Cable and Pipelines

Cables in the North Sea are either power cables (electricity) or telecommunication cables. The majority of pipelines present in the North Sea transport gas. For further details see WINDSPEED deliverable D3.1 "Inventory of current and future presence of non-wind sea use functions".

In the used dataset all cables and pipelines are defined as a line with. A maintenance and security zone of 500m is defined by UNCLOS for both cables and pipelines. As for platforms, the user can modify the buffer zone. In Figure 29, a 500m security buffer is defined, which will then be excluded in the analysis. The following Table 6 shows the relevant datasets, attributes and functions needed for the analysis "cables and pipelines"

dataset	parameters/ settings	mathematical operator /GIS function
pipelines	pipelineDistance	buffer

Table 6: Relevant parameters and functions for the analysis "Cables and Pipelines".

Figure 29 shows the example setting in the web-interface. For this example, the default value is taken which means that a safety buffer of 500m is defined for cables and pipelines.

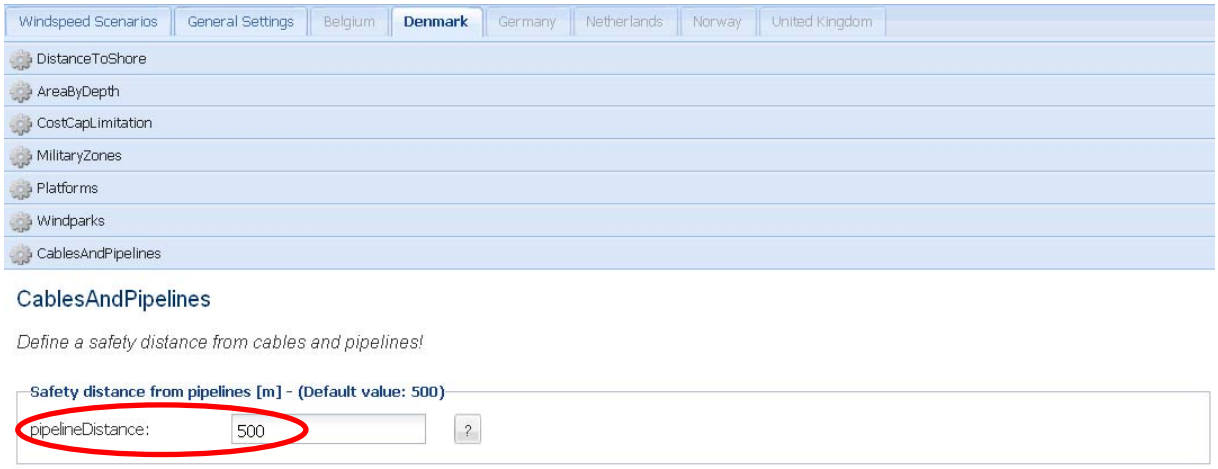


Figure 29: Graphical User Interface of module "Cable and Pipelines".

Figure 30 shows the resulting map of this module. The black lines area is excluded by cables and pipelines and their security buffer.

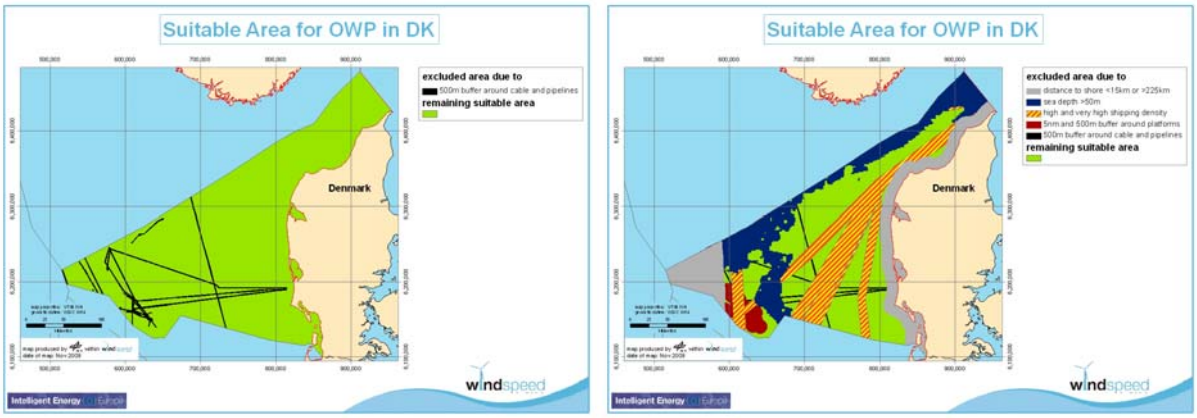


Figure 30: Resulting example map for suitable areas for OWP in Denmark with respect to "cables and pipelines" (left) and in addition with respect to "distance to shore", "area by depth", "shipping", "platforms" and "cables and pipelines" (right).

Military Zones

Military activities include port activities, open water ship and submarine activities, construction and upkeep of the fleet, underwater disposal of weapons and munitions (fishery protection patrols by the respective navies), and manoeuvres and firing exercises. Firing exercises are held within clearly identified zones. As in D3.1 (pg 41), most of the military area cannot be used for OWP. The user can define whether a specific military zone should be suitable for OWP or not and how much of the area could be used. Table 7 shows the relevant datasets, attributes and functions needed for the analysis "military zones"

dataset	parameters/ settings	mathematical operator /GIS function
military	percentagedUse UseStrategy	clip

Table 7: Relevant parameters and functions for the module "Military Zones".

As shown in the example in figure 31, the user defines that 50% of the firing areas could be used for OWP. To identify the 50% area, the strategy "best wind potential" is chosen. This means that the DSS chooses 50% of the firing areas with the highest wind potential within the complete firing areas in terms of MWh/km^2.

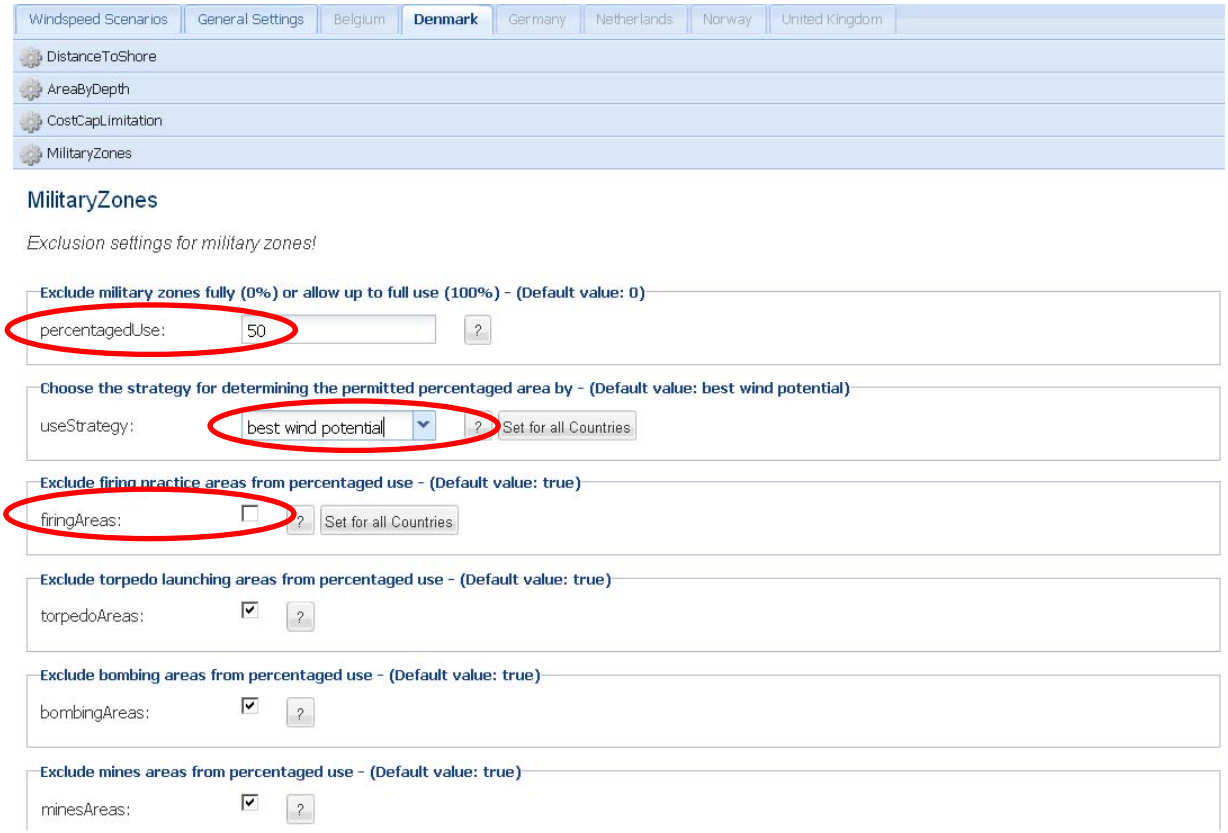


Figure 31: Graphical User Interface of module "MilitaryZones". In this example, 50% of firing areas are suitable for OWP.

Figure 32 shows the resulting map of this module. The small white area with the black cross pattern in the South-Eastern part of the Danish EEZ is excluded by military for the given example.

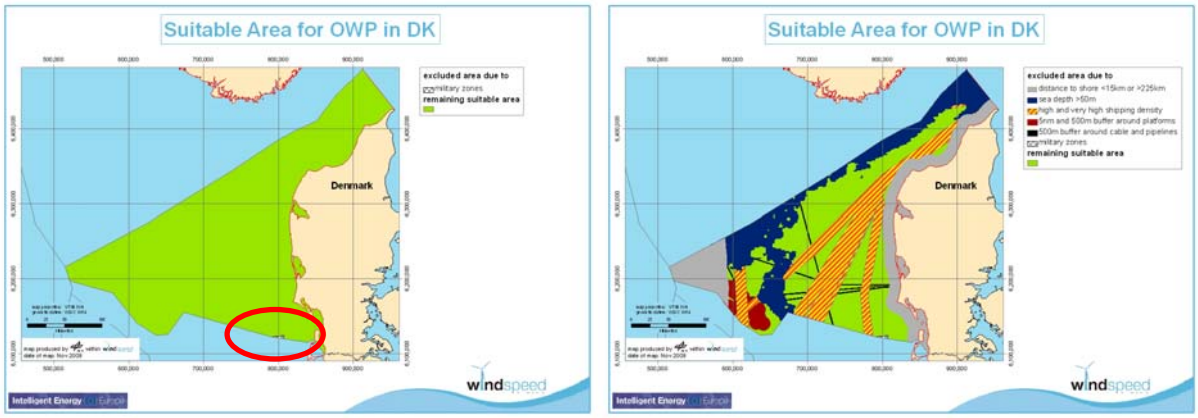
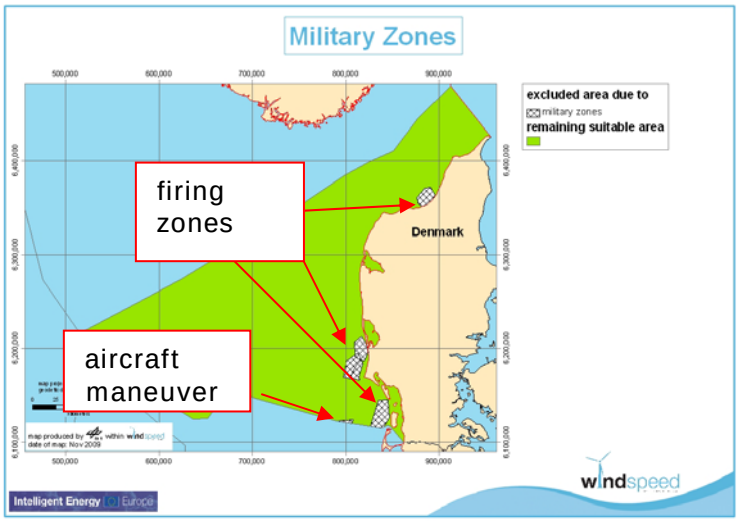


Figure 32: Resulting example map for suitable areas for OWP in Denmark with respect to "military zones" (left) and in addition with respect to "distance to shore", "area by depth", "shipping", "platforms", "cables and pipelines" and "military zones" (right).

For this module the user can define a percentage share (0 - 100 %) of certain area types to be allowed for wind energy usage. By adjusting the shares, the users can iteratively increase the available space for OWP such that a desired amount of capacity or area for offshore wind energy is reached. While the percentage value is set by the user, the spatial pattern of these endorsed areas has to be answered by the DSS. For instance, the DSS has to solve which 50 % of an area type can be used for wind energy and how are this 50 % is distributed? For this purpose, users have to choose a so-called strategy together with the share of area in their scenario. The strategies can be considered as an instruction for the DSS to solve the mentioned problem. Following strategies are provided:

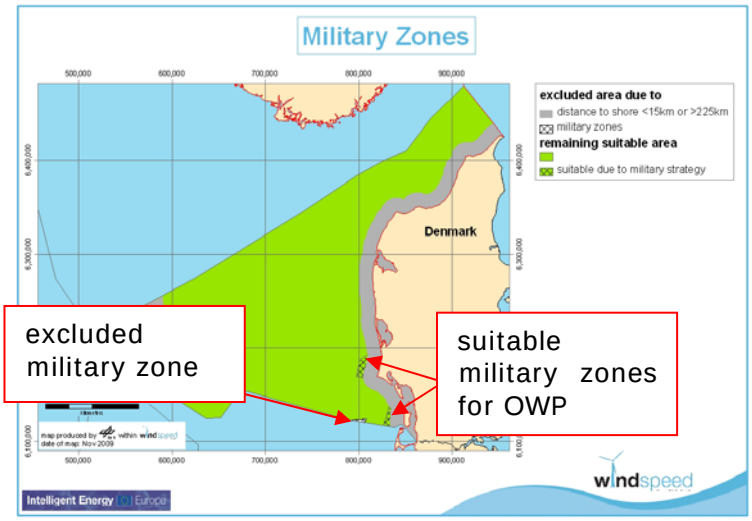
Best wind potential: The DSS looks at the wind conditions in the endorsed areas types and identifies the desired share of areas with the best wind speeds.
Best economical yield: Similar to the best wind potential, the DSS assesses areas by their costs and only selects the best parts of them. For this reason, the cost calculation model, which will be explained below, is utilised.
Best depth conditions: Here the areas with the lowest depths within the military zones are identified as suitable.

By this approach, the tool is now able to exclude areas on a categorical exclusion criteria and additionally designate unsuited areas by a percentage limit and selected strategy. As shown in figure 31 the user has chosen 50% of the military zones (firing areas) to be used for offshore wind energy. All other specially labelled zones (torpedo areas, bombing areas etc.) are marked as excluded and are therefore not suitable for offshore wind energy. The following illustration explains the procedure of how the 50% suitable area is determined by the DSS tool, given that the criteria for selection "best wind potential" is chosen.



The left Figure shows all military zones for Denmark. The overall size of these zones is 1388 km². Most of the zones are firing zones, only a small zone in the South is used for aircraft manoeuvres. The military zones that are marked as excluded in the online interface (see figure 31) are deducted for the further analysis (here: aircraft manoeuvres).

The remaining areas (here: firing zones) are checked with respect to overlapping areas of the generally exclusion criteria (distance to shore, sea depth and cost cap limitation). In this example, most of the firing zones lie within the excluded are of the distance to shore criteria (grey coloured). These parts of the firing zones are deleted and only two smaller parts remain for further analysis.



In this example up to 50% (~694km²) of the military zones can be used for OWP. The strategy to find this space is defined by the user as “best wind potential”. The DSS tool now identifies the suitable area with the highest wind speed within the remaining firing zones. As the remaining firing zones have a size of ~252km² all of this area is freed for OWP usage. Only the small military zone in the South (aircraft manoeuvres) remains as excluded area.

Nature Conservation Zones

For nature conservation in the marine environment all countries have designated areas of sea that should be treated as some type of reserve. The actual regime (what is protected by what measures and/or restriction) may differ between the countries even where the reasons for designation are the same and often based on European legislation. The two most important pieces of European legislation relating to nature conservation are the Habitats Directive and the Birds Directive. Member States are required to implement these directives in national legislation. A Special Area of Conservation (SAC) is an area designated for reasons outlined in the Habitat Directive. A Special Protection Area (SPA) is based on the Bird Directive. These SAC and SPA may overlap and together underpin a European network of protected areas known as Natura2000. Countries can also protect additional areas by national laws.
Similar to the military zones, within the DSS the user can look for available space for OWP within nature conservation zones. Therefore a percentaged use and a use strategy have to be defined. As shown in the example in figure 33, the user defines that 20% of the Natura2000 areas could be made available for OWP. To identify the 20% area, the strategy "best wind potential" is chosen. As for the military zones, best economical yield and best depth conditions could also be used as selection criteria for identifying additional space within nature conservation zones for offshore wind deployment.

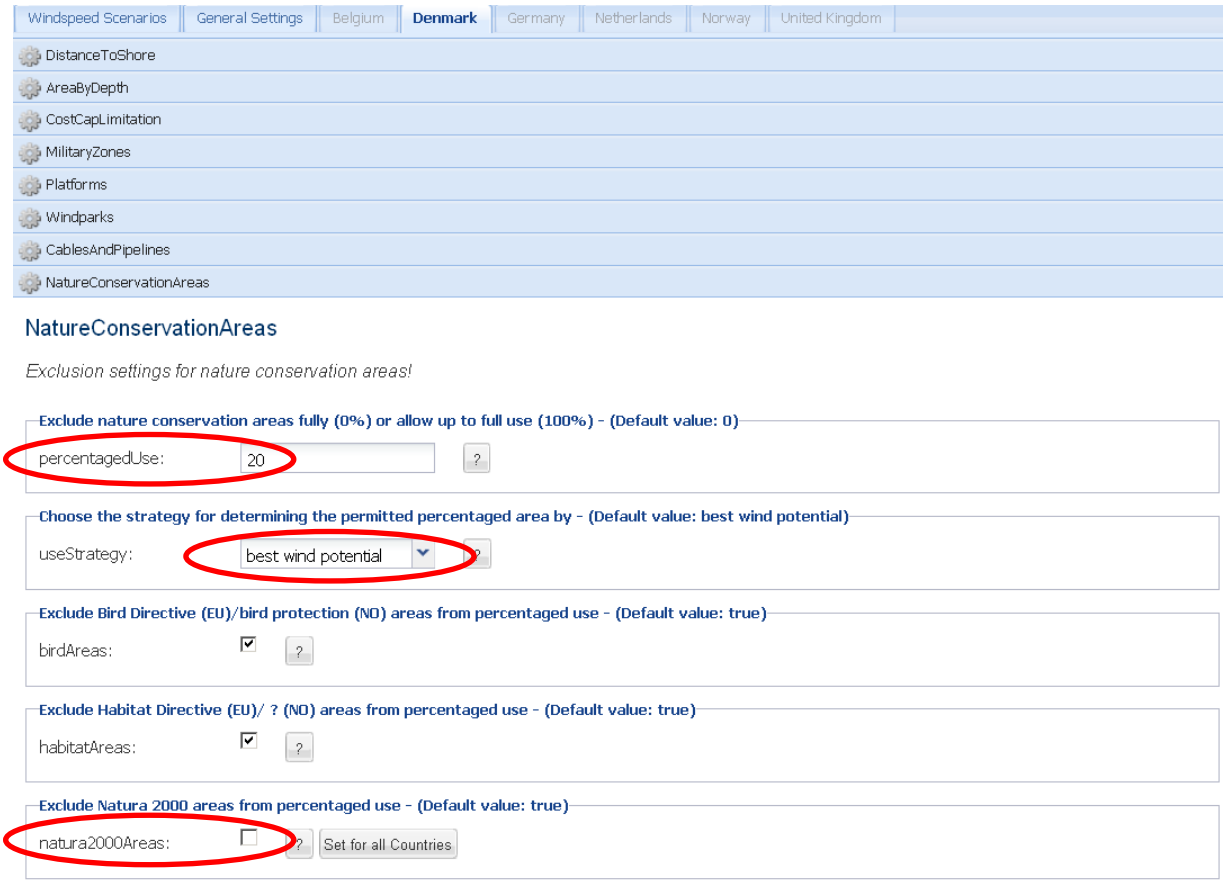


Figure 33: Graphical User Interface of module "NatureConservationAreas". In this example, bird directive and habitat directive areas are excluded, 20% of Natura 2000 areas with best wind potential can be used.

Figure 34 shows the resulting map of this module. The white areas with the blue line-pattern in the South-Eastern part of the Danish EEZ are excluded by nature conservation zones.

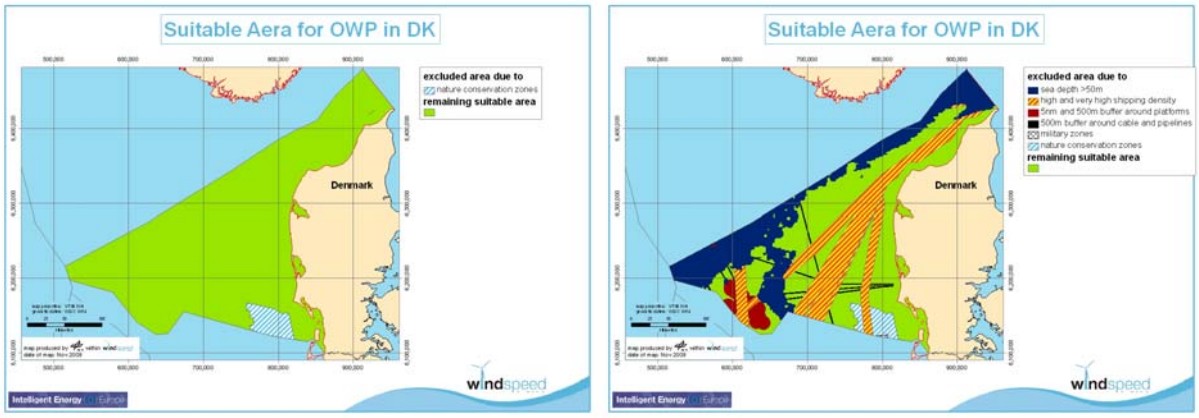
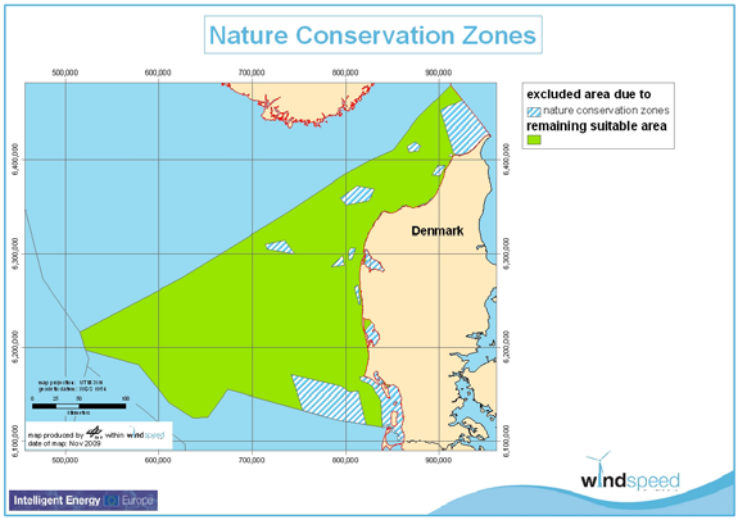
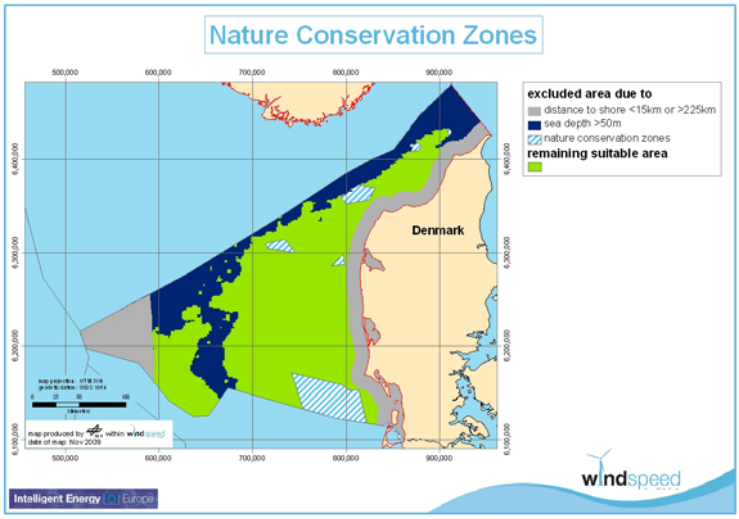


Figure 34: Resulting example map for suitable areas for OWP in Denmark with respect to "nature conservation areas" (left) and in addition with respect to "distance to shore", "area by depth", "shipping", "platforms", "cables and pipelines", "military zones" and "nature conservation areas" (right).

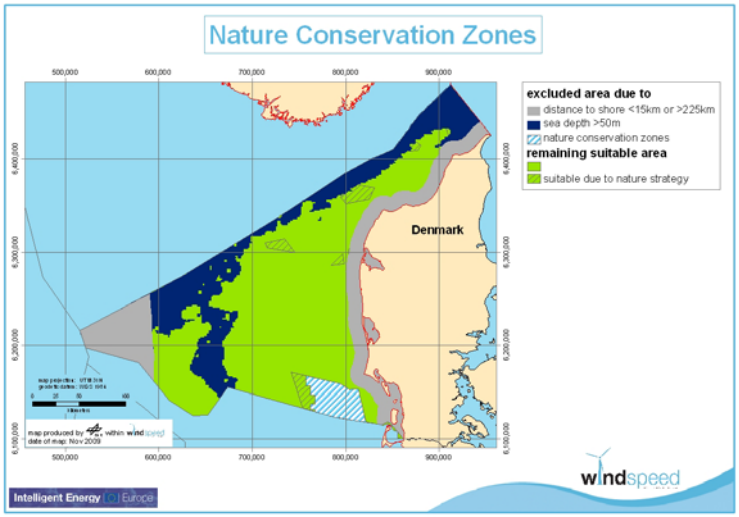
Following illustration explains the procedure of finding 20% of Nature2000 areas with strategy "best wind potential" for OWP:



The left Figure shows all nature conservation zones for Denmark. The overall size of these zones is 10104 km². All zones are declared as Natura2000. In our example, Natura2000 areas will be investigated to find suitable space for OWP (see Figure 33, <natura2000> is not tagged).



All Natura2000 areas are checked with respect to overlapping areas of the general exclusion criteria (distance to shore, sea depth and cost cap limitation). In this example, some of the Natura2000 areas lie within the generally excluded areas of the distance to shore criteria (grey coloured) and sea depth criteria (blue coloured). These parts are therefore excluded from further search for suitable space for OWP.



In this example up to 20% (~2020km²) of the nature conservation zones can be used for OWP. The strategy to find this space is defined by the user as “best wind potential”. The DSS tool now identifies the suitable area with the highest wind speed within the remaining Natura2000 zones. The Figure to the left shows the suitable areas for OWP, including the nature conservation areas which are made available as a result of the 20% nature strategy.

Sand Extraction

The calculation rule for sand extraction is one single rule: ”Areas designated as in use or potentially in use for sand extraction are excluded.” As there is no parameter (like “buffer”) available for this sea use function that could be modified by the user, this module is not shown as a module in the Graphical User Interface. Figure 35 shows the resulting map of this module.

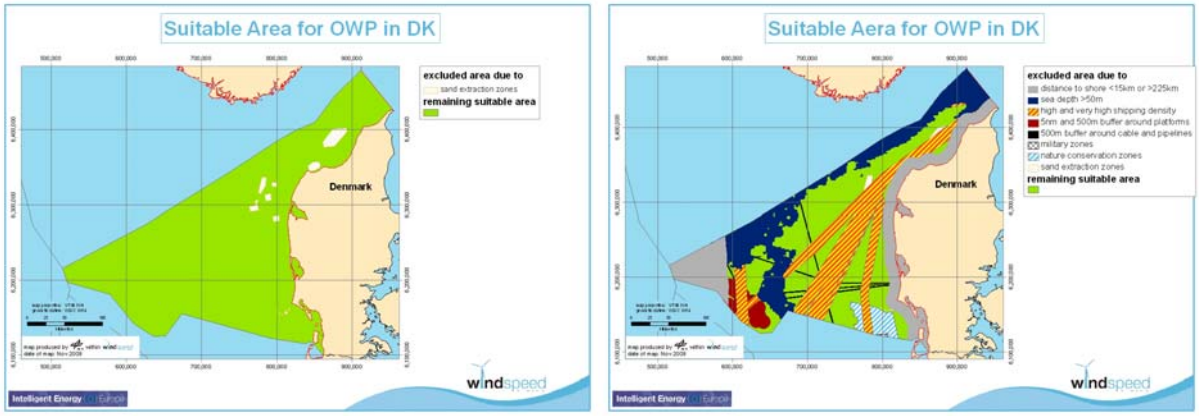


Figure 35: Resulting example map for suitable areas for OWP in Denmark with respect to “sand extraction” (left) and in addition with respect to “distance to shore”, “area by depth”, “shipping”, “platforms”, “cables and pipelines” and “military zones”, nature conservation zones” and “sand extraction” (right).

Marine Wildlife (fish species richness, birds (wind farm sensitivity index) and benthic Values)

The term Marine Wildlife covers the regard of fish species richness, appearance of birds and of Benthos. Contrary to the module “nature conservation zones” which takes into account official nature conservation areas, the data behind the module marine wildlife are based on sensitivity and vulnerability analysis for fish, birds and benthos with respect to OWP. For more details please refer to D3.1.

Similar to the military zones and nature conservation zones, the user can define available space for OWP within marine wildlife zones. Therefore a use strategy has to be defined. As shown in the example in figure 36, the user defines the strategy “best wind potential”. The usable percentage depends on the “level of concern” for each marine wildlife type. The percentage which can be used is defined in the WINDSPEED deliverable D3.3 “Calculation rules for the DSS” report and cannot be changed. Figure 37 shows the corresponding area for the example Denmark.

Figure 36: Graphical User Interface of module “MarineWildlife”. In this example, the free space for OWP is analyzed with the strategy “best wind potential”.

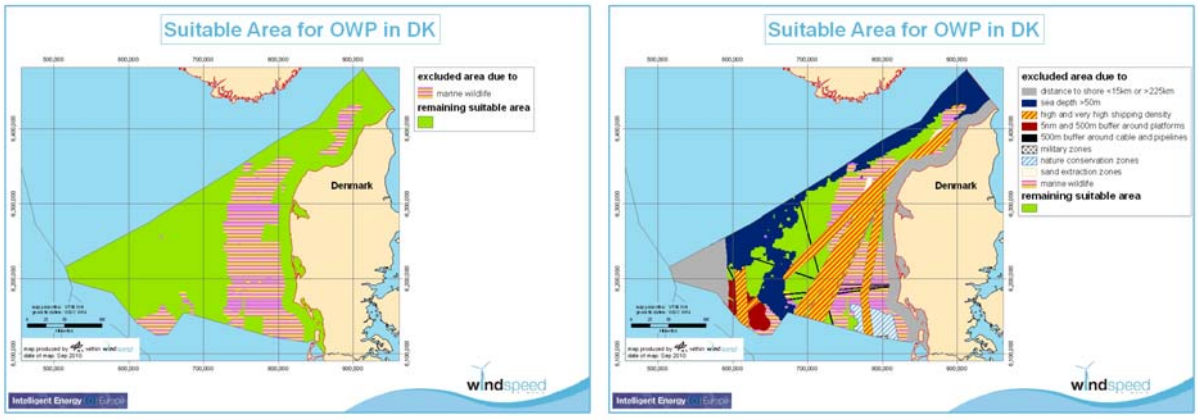


Figure 37: Resulting example map for suitable areas for OWP in Denmark with respect to “marine wildlife” (left) and in addition with respect to “distance to shore”, “area by depth”, “shipping”, “platforms”, “cables and pipelines” and “military zones”, nature conservation zones”, “sand extraction” and “marine wildlife” (right).

Fishery Effort

The term Fishery Effort describes the fishing activities of the national fishing fleets. As for military and nature conservation zones and “marine wildlife”, the user can define available space for OWP with respect to the fishery effort. Again, a use strategy has to be defined. As shown in the example in figure 38, the user defines the strategy “best wind potential”. The percentage which can be used is defined in the WINDSPEED D3.3 report and cannot be changed. Figure 39 shows the corresponding area for the example Denmark.

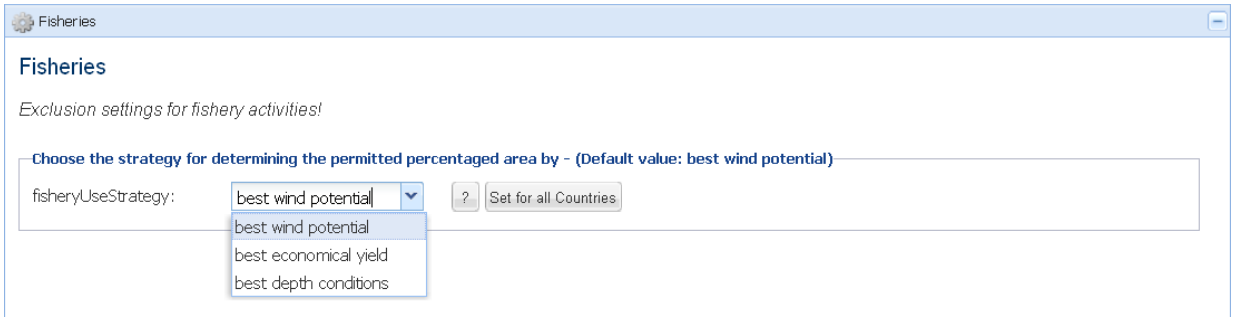


Figure 38: Graphical User Interface of module “Fisheries”. In this example, the free space for OWP is analyzed with the strategy “best wind potential”.

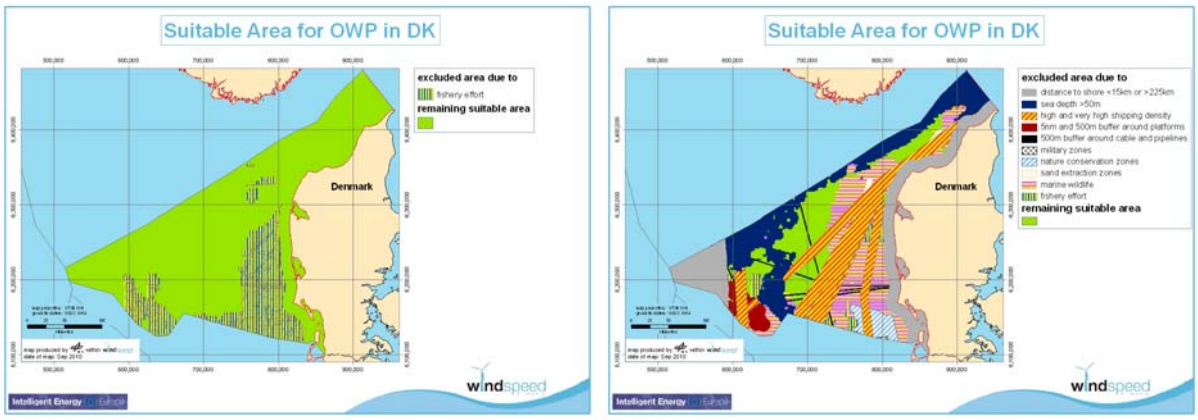


Figure 39: Resulting example map for suitable areas for OWP in Denmark with respect to “fishery effort” (left) and in addition with respect to “distance to shore”, “area by depth”, “shipping”, “platforms”, “cables and pipelines” and “military zones”, nature conservation zones”, “sand extraction”, “marine wildlife” and “fishery effort” (right).

3.3 Cost Functions

The cost functions are developed and described in detail by Garrad Hassan in the WINDSPEED deliverable D2.2
The following external input parameters are used as input for the cost calculation:

Parameter	Acronym	Type	Default value	Unit	User control	Permissible range
Fixed Charge Rate	FCR	User input	12	%	Yes	8 – 15
Packing density	De	User input	2	MW / km2	Yes	1 – 3
Concrete Rate	ConcRate	User input	125	€ / tonnes	Yes	>0
Reinforcement Rate	ReinfRate	User input	1300	€ / tonnes	Yes	>0
Pile steel Rate	PsRate	User input	2600	€ / tonnes	Yes	>0
Secondary steel Rate	SsRate	User input	3600	€ / tonnes	Yes	>0
Jacket steel Rate	JsRate	User input	3800	€ / tonnes	Yes	>0
TLP steel Rate	TsRate	User input	3200	€ / tonnes	Yes	>0
Mooring steel Rate	MsRate	User input	6000	€ / tonnes	Yes	>0
Ballast Rate	BalRate	User input	100	€ / tonnes	Yes	>0
Progress ratio turbines	NPRt	User input	92	%	Yes	80 – 100
	NPRs	User input	90	%	Yes	80 – 100
Progress ratio structures	NPRi	User input	88	%	Yes	80 – 100
	NPRelec	User input	85	%	Yes	80 – 100
Progress ratio installation						
Progress ratio Elec						
Progress ratio O&M	NPRo&m	User input	85	%	Yes	80 – 100
Depth	Dph	GIS dataset	variable	metres	No	N/A
Spring tidal amplitude	STA	GIS dataset	variable	metres	No	N/A
Storm surge	StS	GIS dataset	variable	metres	No	N/A
Significant wave height	Hs	GIS dataset	variable	metres	No	N/A
Extreme wave height	Hs50	GIS dataset	variable	metres	No	N/A
Mean wind speed	MWS	GIS dataset	variable	m/s	No	N/A
Drilling requirement	Drill	GIS dataset	variable	binary	No	N/A
Distance to	DTP	GIS	variable	km	No	N/A

nearest port		calculation	e			
Distance to coastline	DTC	GIS calculation	variable	km	Yes	N/A
Distance to substation	DTS	GIS calculation	variable	km	Yes	N/A
Project area	Area	GIS calculation	variable	km2	No	N/A

Table 8: Detail of input parameters used for the WINDSPEED project (source D2.2 Table 3.1)..

In table 8 the type of input is shown. Some of the parameters are defined by the user via the dialogue box (User input), some are provided by GIS datasets (GIS dataset) and some are calculated by using the GIS functions (GIS calculation).

Spatial Grid for Cost Calculation

To perform the cost calculation in an accurate way, a common grid has to be defined, taking all different spatial input data into account. For each defined grid cell the cost will be calculated by the DSS. Following spatial information for the input data is provided as GIS dataset:

Parameter	Acronym	Type	grid resolution
Depth	Dph	GIS dataset	1 x 1 km²
Spring tidal amplitude	STA	GIS dataset	5 x 5 km²
Storm surge	StS	GIS dataset	5 x 5 km²
Significant wave height	Hs	GIS dataset	5 x 5 km²
Extreme wave height	Hs50	GIS dataset	5 x 5 km²
Mean wind speed	MWS	GIS dataset	5 x 5 km²
Drilling requirement	Drill	GIS dataset	no grid

Table 9: Input data with a spatial resolution.

The cost calculation is intended to be performed using the 5km x 5km grid of GIS dataset provided by GH. Therefore, all other GIS datasets have to be adapted to this grid. As “drilling requirement” is only one single area (polygon) near the East coast of UK, its spatial information is overlaid with the 5 x 5 km² grid. Some of the 5 x 5km² grid boxes are therefore divided into two parts. Figure 40 shows the example for selected cost grid box (numbered from 1 - 9). Some of them are divided into part “a” and “b”. As parts “a” require drilling, the cost will be calculated in a different way as for parts “b” where no drilling equipment is required.

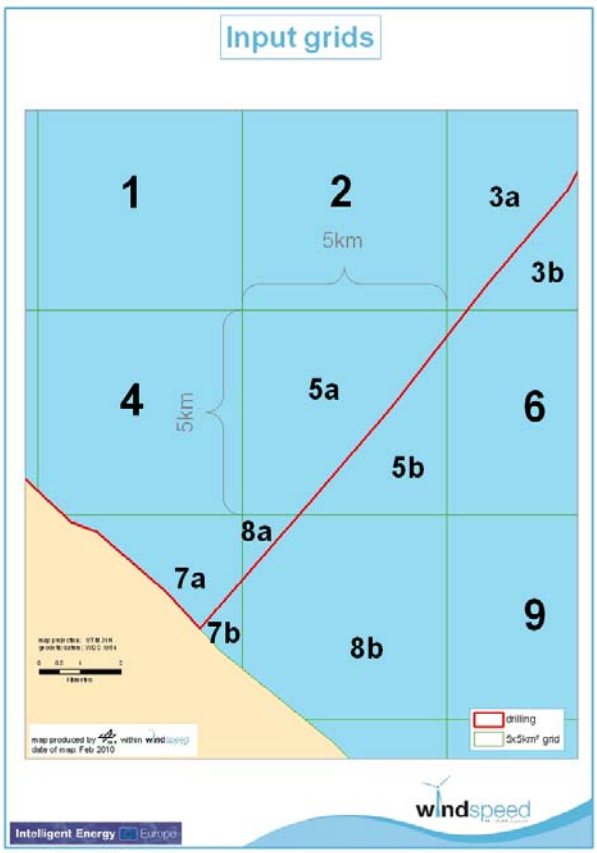


Figure 40: Overlay of 5x5km² cost grid (green) and drilling polygon (red).

The water depth influences the cost of an OWP due to the needed fundament structure. Higher depths are more expensive than lower depths. With respect to depth information, following approach is chosen:
The information on depth is given in the bathymetry dataset with a spatial resolution of 1 km². As the cost calculation is performed for a 5 x 5 km² grid, the information on depth has to be appropriately aggregated to this lower resolution. Figure 41 shows as an example, how this is done for one 5 x 5 km² grid box.

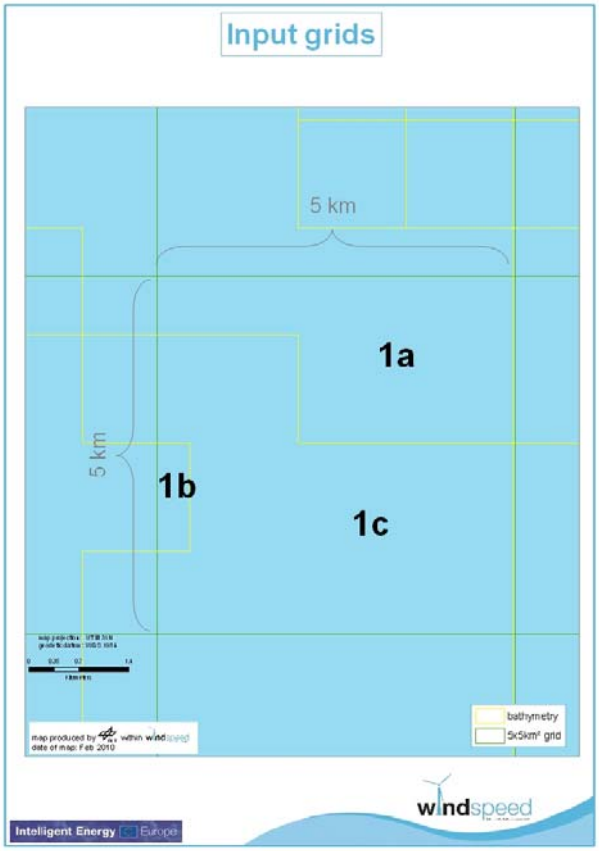


Figure 41: Overlay of 5x5km² cost grid (green) and bathymetry grid (yellow).

The shown grid box (green marked) contains three parts (1a – 1c) with different depths defined by the overlaid bathymetry data (yellow marked). The depths of these parts are averaged with respect to the fraction of area for each part. Table 10 gives example values for the weighted average for one grid box as shown in figure 41.

part #	depth [m]	area [km²]	fraction of area/weighting
1a	-15	9	0.36
1b	-17	2	0.08
1c	-16	14	0.56
weighted average	-15.72	25	1

Table 10: Example for weighting the water depth information.

A very important input parameter for cost calculation is the distance from OWP to the next staging port and to next grid connection point. To perform the spatial analysis, for each grid cell the distance to the nearest port and the nearest grid connection point is calculated.
Following steps are performed to define the nearest distances:

DTC and DTS - Distance to Cost and Distance to Substation

Lines from each grid cell to all grid connection points are defined. The line with the shortest distance is used for the cost calculation for grid connection. The used cost functions distinguish between costs for onshore and offshore grid connection. Therefore, the calculated distance is divided into two parts: the one that is lying in the sea and the other one that is onshore. Figure 42 shows the example lines which represent the nearest distance to coast and substation. The lines start from the centre of each grid cell and end at the substation. In the example only two lines are shown which are divided into the distance to coast part (DTC – blue line) and distance to substation (DTS – green line). For the right line the distance in km is given as example. The km-values for distance are used for the cost calculation.

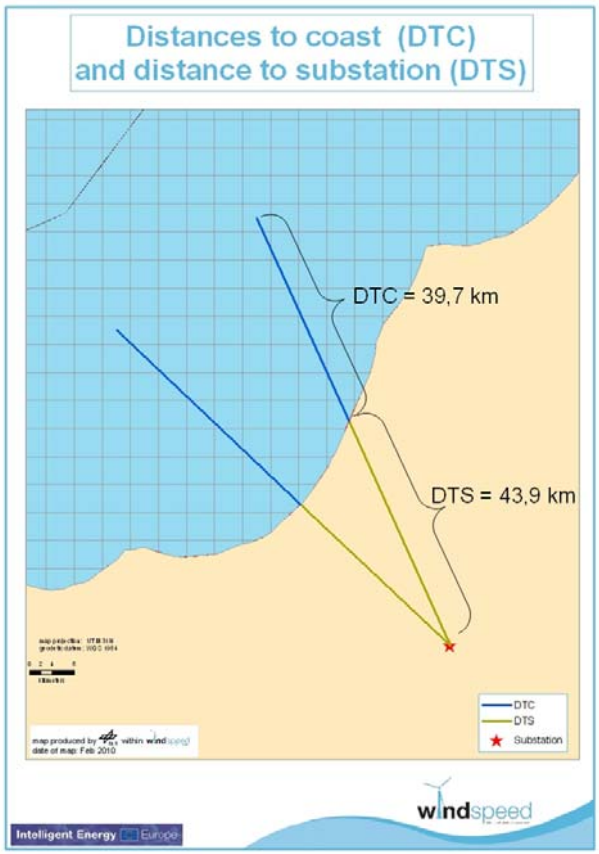


Figure 42: Example for distance to coast (DTC) and distance to substation (DTS).

DTP - Distance to Port

Similar to the DTC and DTS a line from each grid cell to all staging ports is calculated. The line with the shortest distance is used for the DTP which is simplified approach Therefore in some cases the distances are calculated in a non-reasonable way (see figure 43).
Ships can't follow the suggest direct connection (red line) but must route along the coast until they reach the next port (green line).

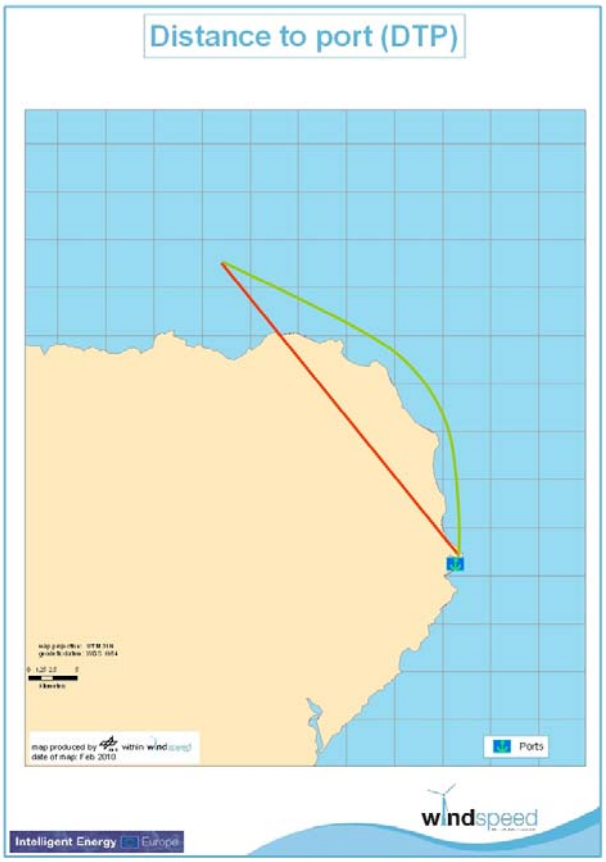


Figure 43: Example for different approaches for DTP calculation. Red line is the direct nearest distance (actual approach), green line shows the more realistic approach (not yet implemented).

In an update of the DSS tool the GIS function <cost path> could be used for solving the issue. With this function, a path from a starting point (grid cell) to an end point (nearest staging port) is calculated based on a "cost distance relief". The "costs" are defined here as value 1 for water and 10000 for land. This means that the lowest cost path always uses water and not land pixel which is realistic as the vessels will use the sea and not land. Figure 44 shows the cost distance image (blue values) and the calculated route (red line) from one example grid cell (green dot) to the nearest port (blue sign). The cost distance relief needs to be calculated for each single grid cell. This is quite time consuming but would have to be done only once (independent from the user defined input parameters in the case of static ports and grid scenario assumptions).

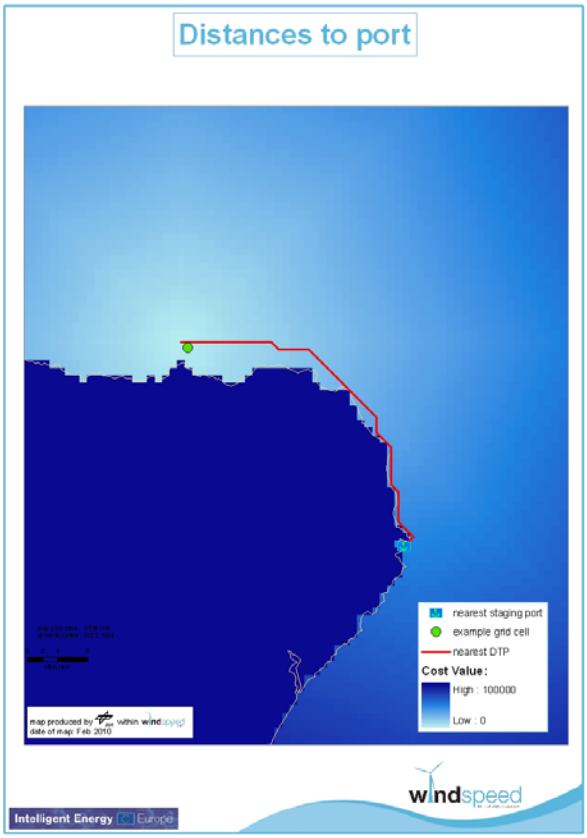


Figure 44: The DTP is determined by using cost path functions. From the example starting grid cell (green dot) the nearest DTP (red line) to the next staging port (blue sign) is calculated. The red line represents the calculated nearest route as shown in figure 43 (green line).

Also for DTC and DTS the distances might be not realistic, e.g. by crossing islands or by crossing several times the coast. These mistakes are actually neglected and might be addressed in an update of the DSS tool.

Cost Calculation

Based on the cost functions in the WINDSPEED deliverable D2.2, the following parameters are calculated by the DSS:

LPC – Levelized Production Cost

CapEx – Initial Capital Expenditure
AEP – Net Annual Energy Production
OpEx – Operating Expenditure

Units – number of units in the project
TSC – Turbine Supply Cost
ESC – Electrical System Cost

TIC – Turbine Installation Cost
MFC & MIC – Monopile Fabrication Cost and Monopile Installation Cost
JFC & JIC – Jacket Fabrication Cost and Jacket Installation Cost
GFC & GIC – Gravity Fabrication Cost and Gravity Installation Cost
SFC & SIC – Spar Fabrication Cost and Spar Installation Cost
TFC & TIC2 – TLP Fabrication Cost and TLP Installation Cost
Avai – total wind farm operational availability
Elec – electrical losses in the collection and export system

With respect to the optimisation of the processing structure, data for the complete WINDSPEED area are pre-processed by the DSS and are assigned to each grid cell (e.g. Nearest Distance to Port, Drilling requirements, Storm Surge etc.) before the exclusion criterias are applied (see also chapter “Spatial Grid for Cost Calculation”). After identifying all suitable areas using all exlclusion criteria, the tool calculates all costs for the remaining suitable areas. Some grid cells are split into subsets smaller than 25km² which is the size the calculation rules are developed for. Therefore, all area-specific cost parameters like Net Annual Energy Production (AEP), Initial Capital Expenditure (CapEx) and Operating Expenditure (OpEx) are corrected taking into account the real size of the subset grid area.

The DSS calculates all parameters using mathematical functions in Python scripting. The following equation gives an example code for calculating the AEP. Within Python scripting, static data (like the user defined input paramter <DENSITY>) are used as input together with spatial GIS data (<MWS> = Mean Wind Speed) and further data (<Avai>, <ELEC> etc.).

row.AEP = 5 * UNITS * AVAI * ELEC * 8766 * ((((0.000536 * 3 * DENSITY) + 0.0577) * MWS) + ((-0.0115 * 3 * DENSITY) - 0.0355))

After applying all cost functions for all grid cells within the suitable areas information on LPC, CapEx, OpEx and AEP are available.

4 Exemplary results

As exemplary result, the default scenario provided by the online interface is shown in detail. In Table 11 all parameters and their values are given.

Parameter	Variable	Value
Countries for which the analysis will be performed	countries	all countries
Shipping routes (Exclusion)	MajorRoutes MediumToMajorRoutes MediumToMinorRoutes minRoutes	excluded + 0m buffer suitable + 0m buffer suitable + 0m buffer suitable + 0m buffer
Fixed Charge Rate (Cost Calculation)	fcr	12
Installed Density (Cost Calculation)	density	2
Concrete Rate (Cost Calculation)	concrete	125
Reinforcement Rate (Cost Calculation)	reinfRate	1300
Pile Steel Rate (Cost Calculation)	psRate	2600
Secondary Steel Rate (Cost Calculation)	ssRate	3600
Jacket Steel Rate (Cost Calculation)	jsRate	3800
TLP Steel Rate (Cost Calculation)	tsRate	3200
Mooring Steel Rate (Cost Calculation)	msRate	6000
Ballast Rate (Cost Calculation)	balRate	100
Electrical System Costs (Cost Calculation)	elecSysCosts	included
Progress Ratio Turbines (Cost Calculation)	NPRt	92
Progress Ratio Structures (Cost Calculation)	NPRs	90
Progress Ratio Installation (Cost Calculation)	NPRi	88
Progress Ratio Electrical Infrastructure (Cost Calculation)	NPRelec	85
Progress Ratio Operation and Maintenance (Cost Calculation)	NPRom	85
Minimum suitable Area for OWP (General Exclusion)	Minimum Size	50
Distance to Shore (General Exclusion)	Min and Max Distance	min = 10, max = 371
Area by Depth (General Exclusion)	Max Depth	100
Cost Cap Limitation (General Exclusion)	Cost Type and Cost Limit	no limit

Military Zones (Sea Use Exclusion)	Percentaged Use, Used Strategy and special zones	exclude fully (0%) and exclude all special zones
Oil and Gas Platforms (Sea Use Exclusion)	Safety Distance	surface and subsurface 500meters, helipad 5nautical miles
Offshore Windparks (Sea Use Exclusion)	Exclusion of OWP which are operational, under construction, developed, authorized, applied, proposed.	excluded: operational, construction, development, authorised, not excluded: application, proposed
Electric Cables and Oil and Gas Pipelines (Sea Use Exclusion)	Safety Distance	500
Nature Conservation Zones (Sea Use Exclusion)	Percentaged Use, Used Strategy and Special Zones	exclude fully (0%) and exclude all special zones
Marine Wildlife (Sea Use Exclusion)	Used Strategy for birds fish benthos	best wind best wind best wind
Fisheries (Sea Use Exclusion)	Used Strategy for fisheries	best wind

Table 11: Parameter setting for the default scenario.

Figure 45 presents the Google Earth file for the default scenario. The green scaled area shows the remaining area which could be used for OWP.

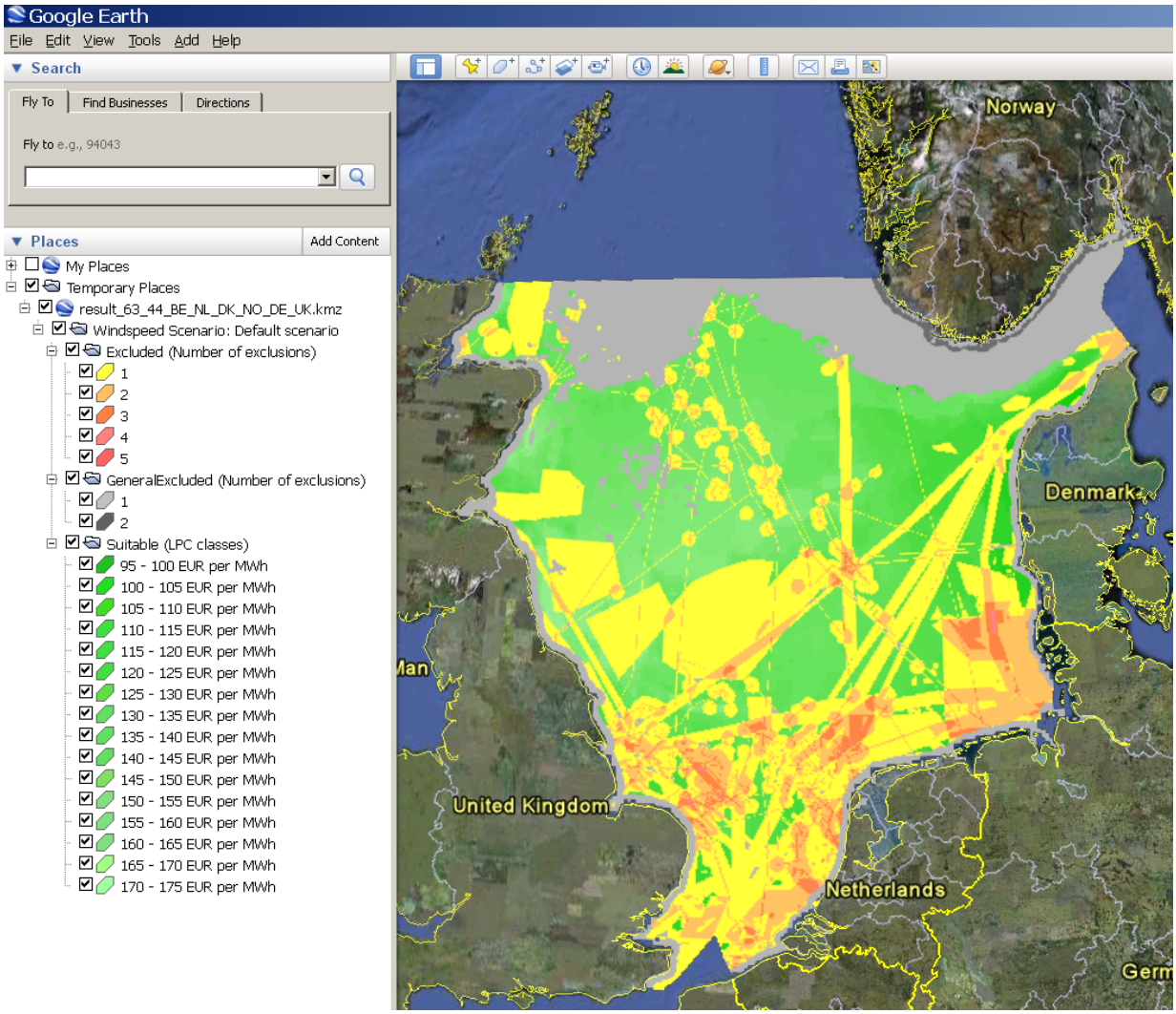


Figure 45: Google-Earth file for example default scenario.

If the user is only interested in the best areas (regarding LPC), he can easily deactivate the unwanted LPC classes (see figure 46). Now the remaining best areas can be easily identified. The same can be done with the exclusion criteria. If the user is interested in the areas where only one exclusion criteria exists, he can deactivate the appropriate classes two to five as shown in figure 47. Due to data usage restriction (as mentioned in chapter 2.6), only the number of exclusion types can be shown in the maps but not the actual type itself.

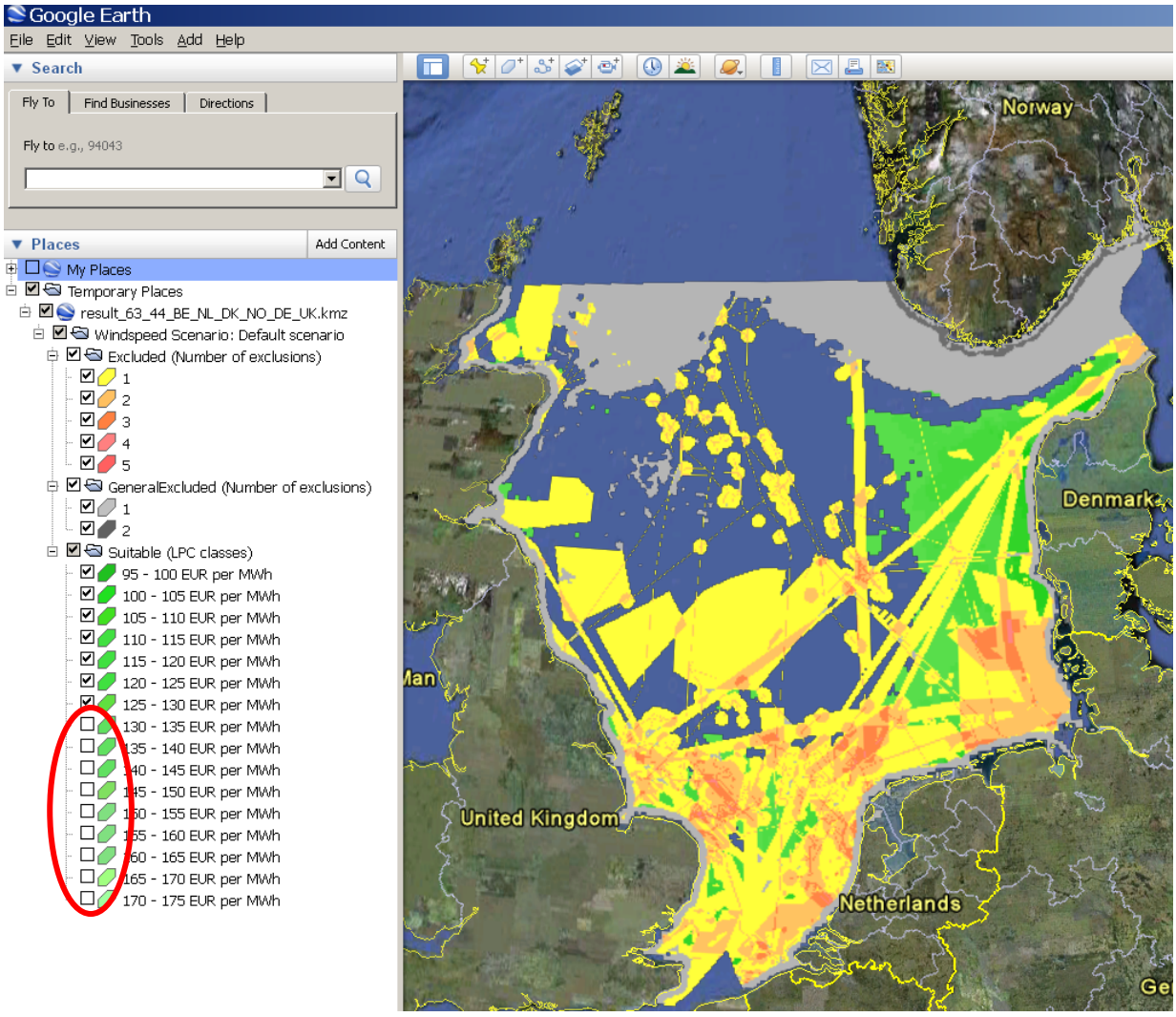


Figure 46: Showing only the best areas with LPC classes from 95 - 130€/MWh.

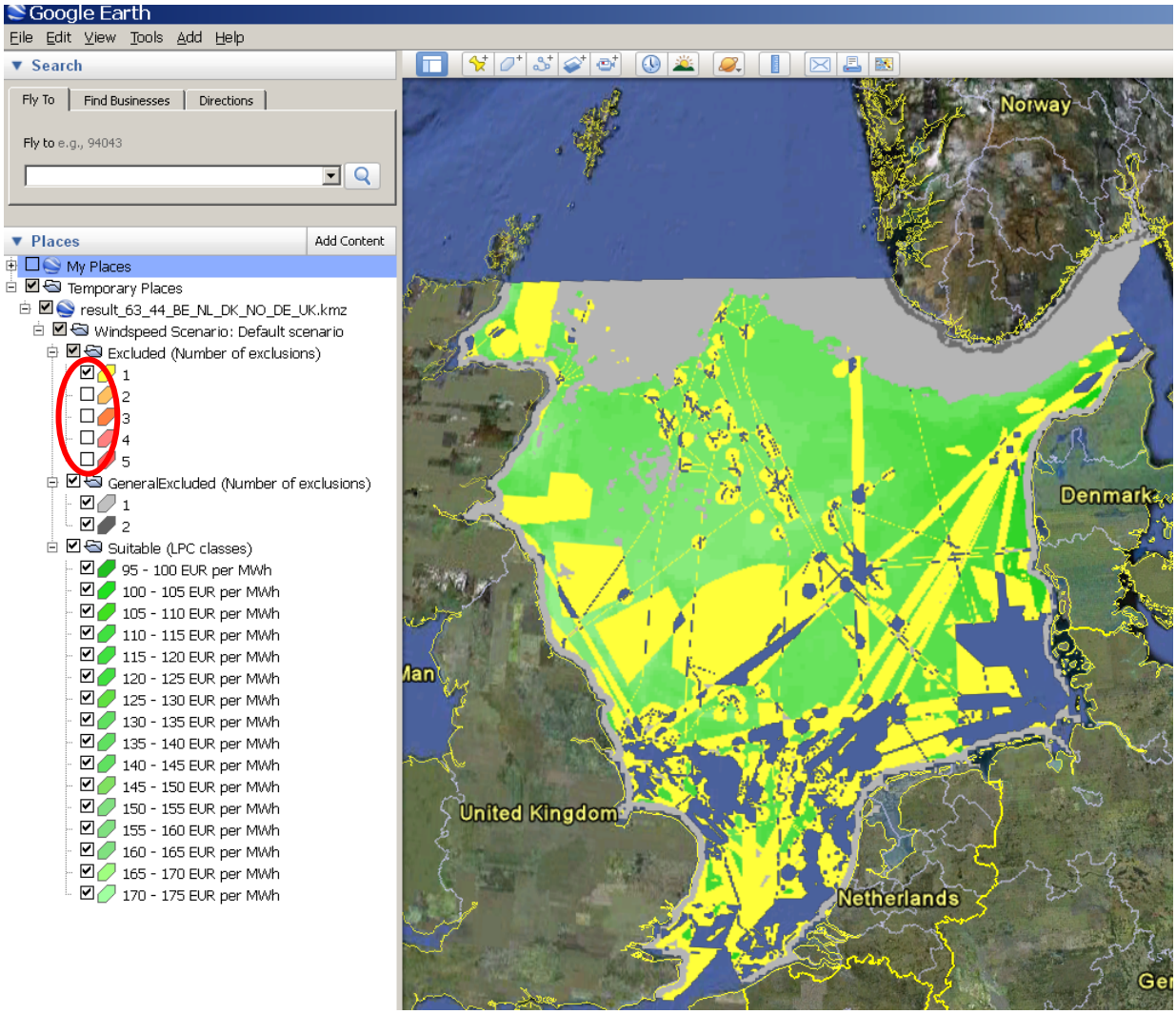


Figure 47: Example result showing only the excluded areas with one exclusion criteria.

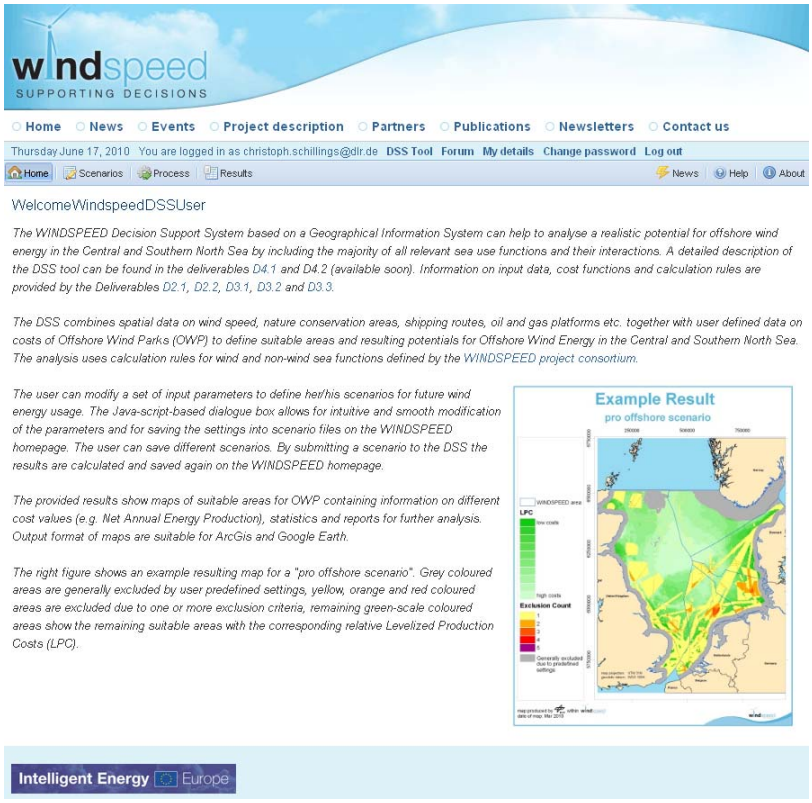
5 Appendix

Quick-Start Manual

This Quick Start – Manual for the WINDSPEED-DSS online interface is available as a pdf-document on the DSS online user interface at www.windspeed.eu/dss/dsstool.php by clicking on *Help*. This short introduction will assist the user to quickly start working with the DSS online interface. The DSS processing procedure is structured in three steps:

User defines an Offshore Wind scenario
User submits the scenario to the DSS tool
Results are processed and a notification e-mail is sent to the user to inform her/him that results are available

Welcome Window
The Welcome Window shows seven main tabs. These are: *Home*, *Scenarios*, *Process*, *Results*, *News*, *Help* and *About*. The Welcome Window also gives a short introduction of the objectives and functionality of the DSS.

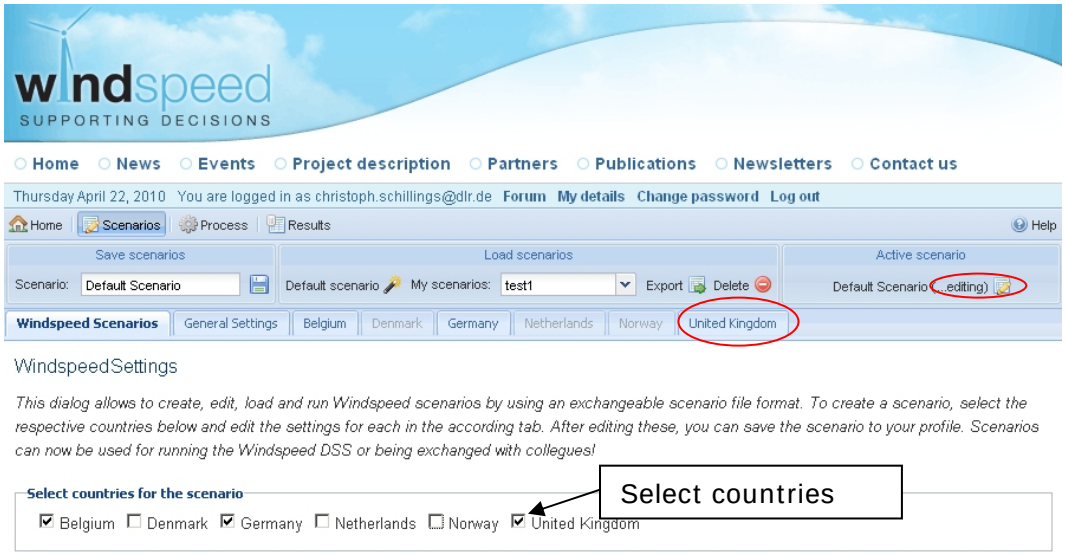


Clicking on *Scenarios* opens the dialogue box for scenario management (Save, Load etc.) and for the definition of scenario settings.

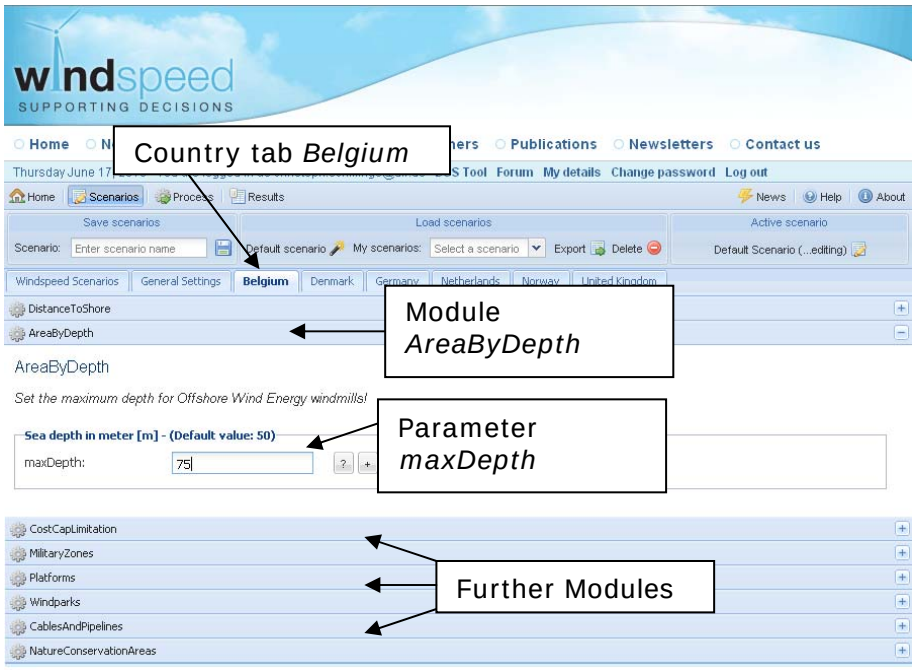
Now the user can define her/his own scenario. On the right hand the name of the active scenario is given. A *Default Scenario*, is provided to the user as starting point.

Modifying Settings and Changing Parameters

The user can change the parameters listed in the Table on page 5. As an example, the user can select the countries for which the analysis should be performed by clicking the check box (the example shown in the window shows the selection of *Belgium*, *Germany*, and *United Kingdom*). In parallel the corresponding country tabs become highlighted and active for the selected countries. By clicking on the *General Settings* or the highlighted countries, the user can modify cost parameters and exclusion settings. As soon as a scenario is modified the name of the scenario (here *Default Scenario*) is labelled as *(…editing)*.



Following this, the user can define additional settings by clicking on the country tab (in this example: *Belgium)*. In the module *AreaByDepth* the maximum sea depth that is suitable for OWP usage is defined with the parameter (*maxDepth*) as 75m. There are several modules available for changing relevant input parameters. These are shown in the example below.



The list below summarises all parameters that can be modified by the user. For each parameter, the register and modules where theses parameter can be found in the DSS online interface are also listed.

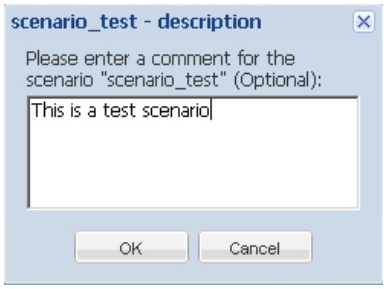
Parameter	Variable	Register	Module
Countries for which the analysis will be performed	countries	WINDSPEED Scenarios	-
Minimum Area for OWP (Exclusion)	Minimum Size	General Settings	SuiTable Areas
Distance to Shore (General Exclusion)	Min and Max Distance	Countries	Distance to Shore
Area by Depth (General Exclusion)	Max Depth	Countries	Area by Depth
Cost Cap Limitation (General Exclusion)	Cost Type and Cost Limit	Countries	Cost Cap Limitation
Shipping routes (Exclusion)	MediumToMajorRoutes MediumToMinorRoutes minRoutes +buffer	General Settings	Shipping
Military Zones (Exclusion)	Percentaged Use, Used Strategy and special zones	Countries	Military Zones
Oil and Gas Platforms (Exclusion)	Safety Distance	Countries	Platforms
Offhsore Windparks (Exclusion)	Exclusion of OWP which are operational, under construction, developed, authorized, applied, proposed.	Countries	Windparks
Electric Cables and Oil and Gas Pipelines (Exclusion)	Safety Distance	Countries	Cables and Pipelines
Nature Conservation Zones (Exclusion)	Percentaged Use, Used Strategy and Special Zones	Countries	Nature Conservation Zones
Marine Wildlife (Exclusion)	Used Strategy	Countries	Marine Wildlife
Fisheries (Exclusion)	Used Strategy	Countries	Fisheries
Fixed Charge Rate (Cost Calculation)	fcr	General Settings	CostCalculation
Installed Density (Cost Calculation)	density	General Settings	CostCalculation
Concrete Rate (Cost Calculation)	concrete	General Settings	CostCalculation
Reinforcement Rate (Cost Calculation)	reinfRate	General Settings	CostCalculation
Pile Steel Rate (Cost Calculation)	psRate	General Settings	CostCalculation
Secondary Steel Rate (Cost Calculation)	ssRate	General Settings	CostCalculation
Jacket Steel Rate (Cost Calculation)	jsRate	General Settings	CostCalculation

TLP Steel Rate (Cost Calculation)	tsRate	General Settings	CostCalculation
Mooring Steel Rate (Cost Calculation)	msRate	General Settings	CostCalculation
Ballast Rate (Cost Calculation)	balRate	General Settings	CostCalculation
Electrical System Costs (Cost Calculation)	elecSysCosts	General Settings	CostCalculation
Progress Ratio Turbines (Cost Calculation)	NPRt	General Settings	CostCalculation
Progress Ratio Structures (Cost Calculation)	NPRs	General Settings	CostCalculation
Progress Ratio Installation (Cost Calculation)	NPRi	General Settings	CostCalculation
Progress Ratio Electrical Infrastructure (Cost Calculation)	NPRelec	General Settings	CostCalculation
Progress Ratio Operation and Maintenance (Cost Calculation)	NPRom	General Settings	CostCalculation

Save/Load/Export a Scenario

After defining a scenario by modifying some or all of the parameters listed in the Table above, the user must save the scenario under a specific name (e.g. *scenario_test* in the example below).

By clicking on the floppy-disk symbol, a small window opens where the user can add a comment to the saved scenario which allows for a quick scenario description. This comment can help to distinguish between different scenarios if more than one scenario is defined and saved by the user.



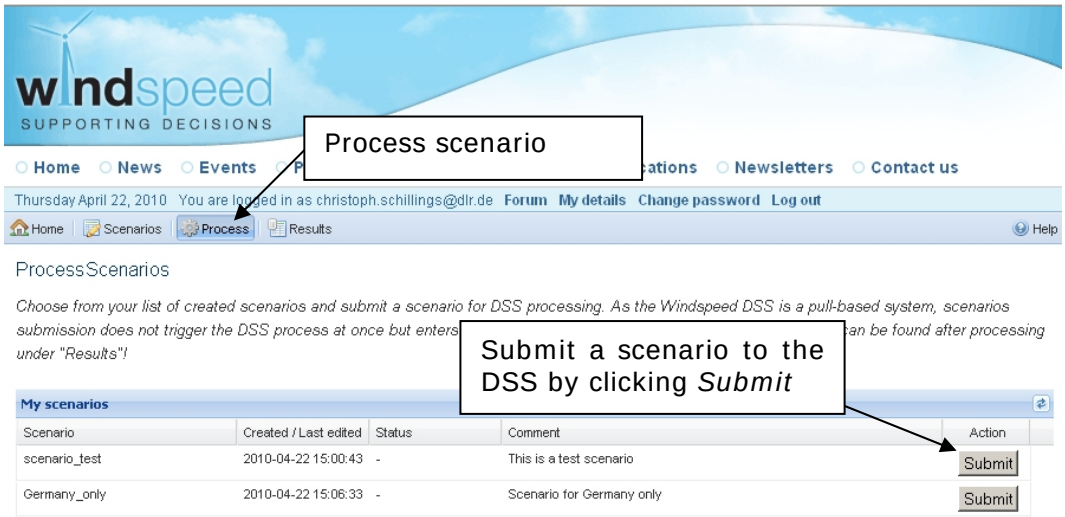
The scenario files are saved on the WINDPSEED homepage. If the user wants to save her/his scenario on the local PC she/he has to export the scenario.

To load a saved scenario the user can select a saved scenario file by using the pull-down menu. The user can also delete existing scenarios.

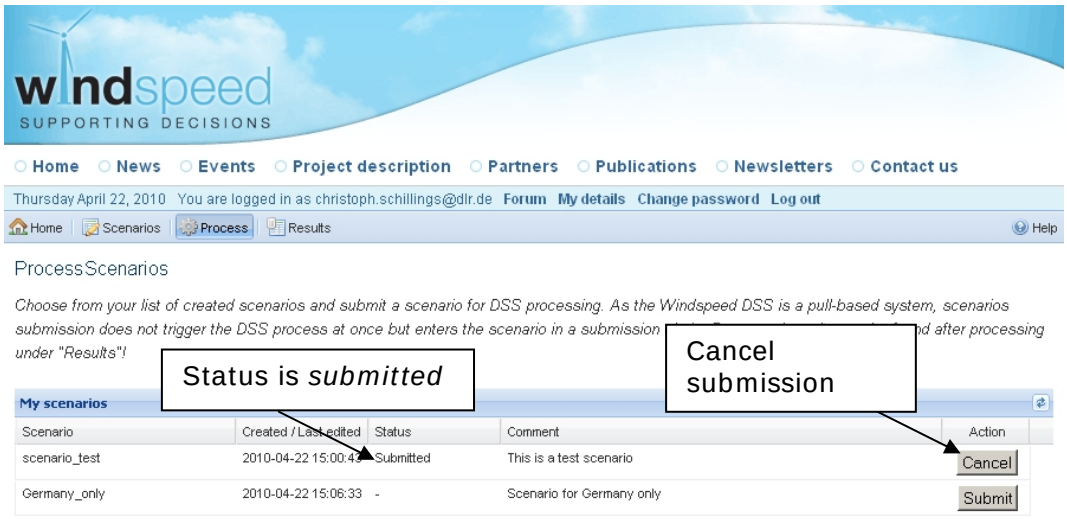
Export/Import Scenario: (not yet implemented)
If the user wants to share her/his scenario settings with other people or if she/he wants to use a scenario file provided by others she/he can use the export/import functions. This allows one to save and load scenario files to/from your local PC.

This functionality is not yet implemented but will be available soon.

Process a Scenario
Once the user has finished defining a scenario she/he can submit the scenario to the DSS tool for being processed. This function is provided in the *Process* tab. Here, all saved scenarios are shown with related comments (given by the user when saving) and status.



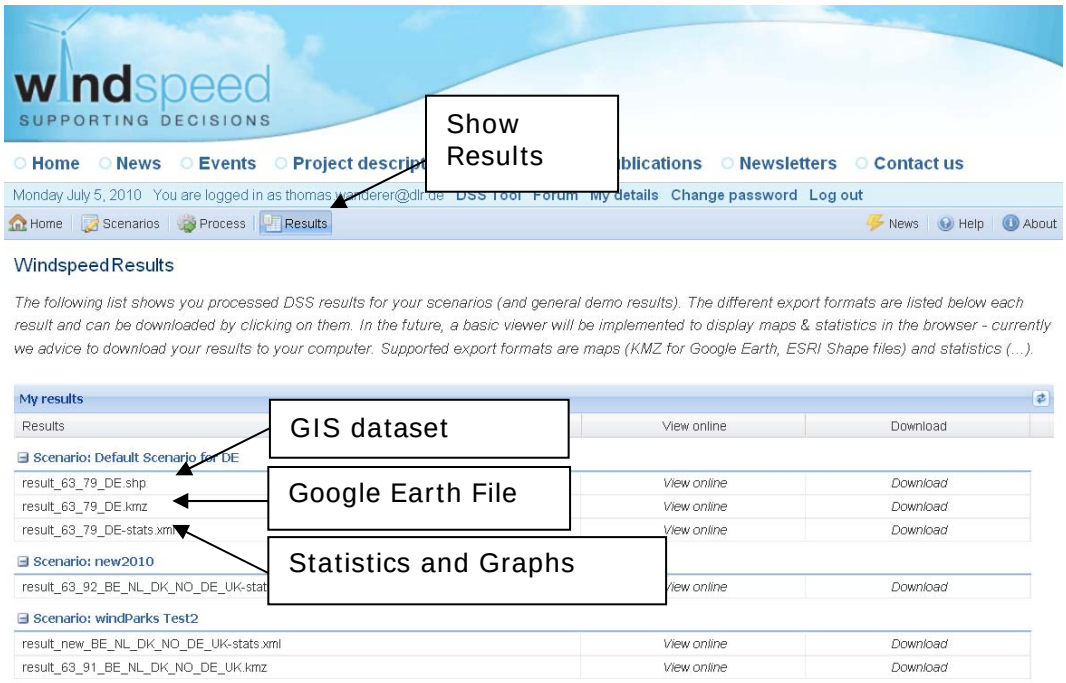
By clicking *Submit* the status of the chosen scenario will be changed to *submitted*. Up until the point that a scenario is undergoing processing or has finished processing the user can cancel a scenario by clicking on *Cancel* to resume editing.



If the results for a submitted scenario are available, the status of the scenario will be changed to *processed*. The user will receive a notification email to the email address provided during registration and the results are uploaded to the WINDSPEED homepage.

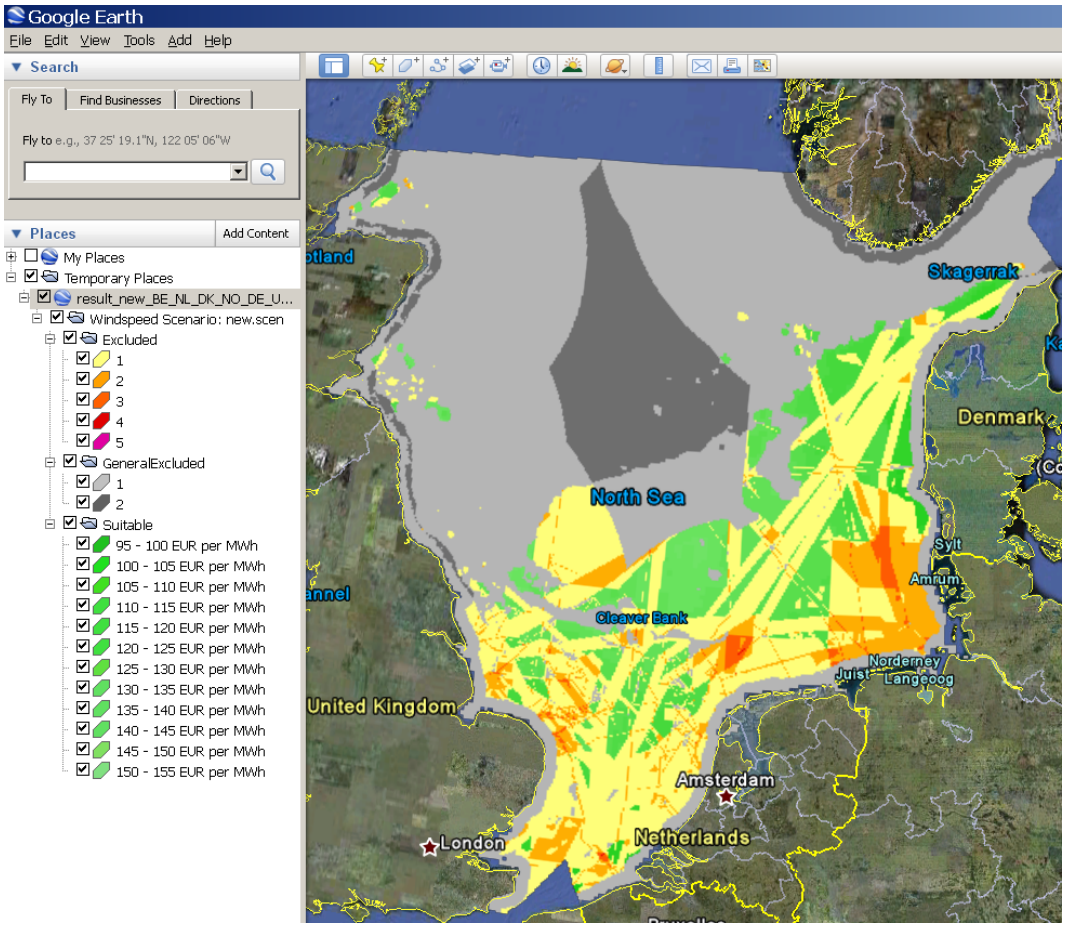
Results

To view the results of processed scenarios the user has to click on the *Results* tab. Here the results of all processed scenarios are listed.

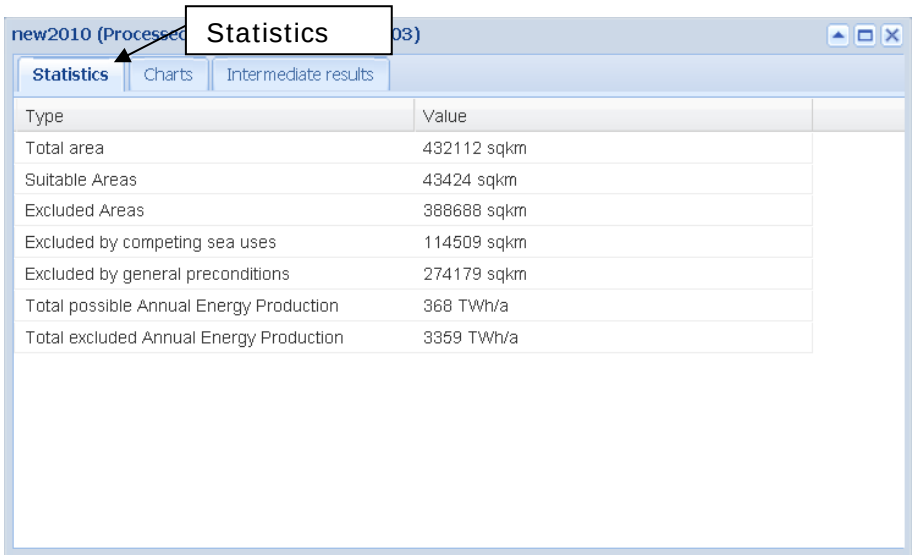


1-2 files are provided to the user according to the desired output in the settings. A Google Earth file and an xml-file containing statistics and graphs. The kmz-file and the xml-file can be downloaded or can be viewed online.

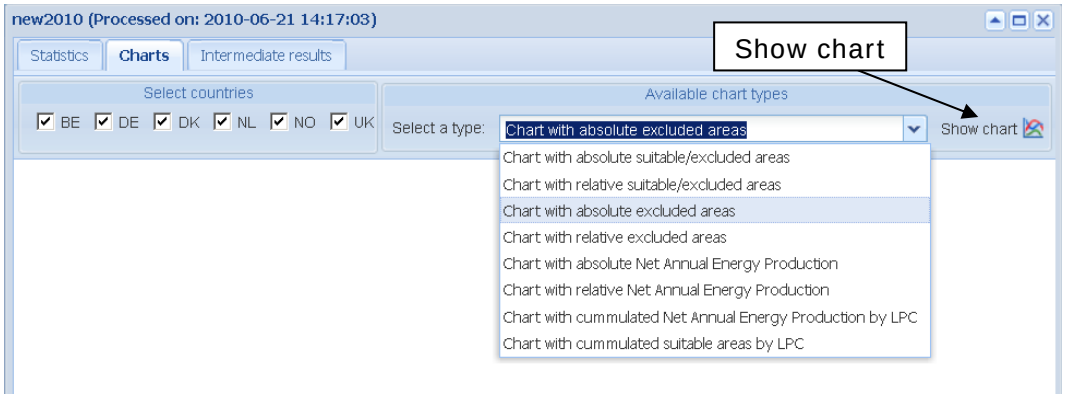
The Google Earth kmz-file allows for an overview of the resulting excluded and suitable areas. To use this file Google Earth must be installed on your computer. The kmz-file contains three layers showing generally excluded zones, non-wind-function excluded zones and areas potentially suitable for offshore wind farm development. The exclusion layers display the number of exclusion criteria that are identified for each of the analysed areas. The 'suitable' layer displays the Levelized Production Cost (LPC) for the remaining suitable areas. The different bands of LPC can be turned on or off to easily identify the exact locations.


Google Earth
File Edit View Tools Add Help
Search
Fly To
Find Businesses
Directions
Fly to e.g., 37 25' 19.1"N, 122 05' 06"W
Places
Add Content
My Places
Temporary Places
result_new_BE_NL_DK_NO_DE_U...
Windspeed Scenario: new.scen
Excluded
1
2
3
4
5
GeneralExcluded
1
2
Suitable
95 - 100 EUR per MWh
100 - 105 EUR per MWh
105 - 110 EUR per MWh
110 - 115 EUR per MWh
115 - 120 EUR per MWh
120 - 125 EUR per MWh
125 - 130 EUR per MWh
130 - 135 EUR per MWh
135 - 140 EUR per MWh
140 - 145 EUR per MWh
145 - 150 EUR per MWh
150 - 155 EUR per MWh
Skagerrak
Denmark
North Sea
Sylt
Amrum
Cleaver Bank
Norderney
Juist
Langeoog
United Kingdom
Amsterdam
London
Netherlands

The xml-file contains graphs covering offshore wind deployment and exclusion statistics. By clicking on *View online* a new windows appears. The tab *Statistics* show the overall information for the selected scenario like “total area”, “suitable area” etc.



Clicking on tab *Charts*, the user can now select the chart type and the country which will be shown in the graph. In this example the chart for absolute excluded areas is chosen. By clicking on *Show charts*, the chosen chart will be displayed.

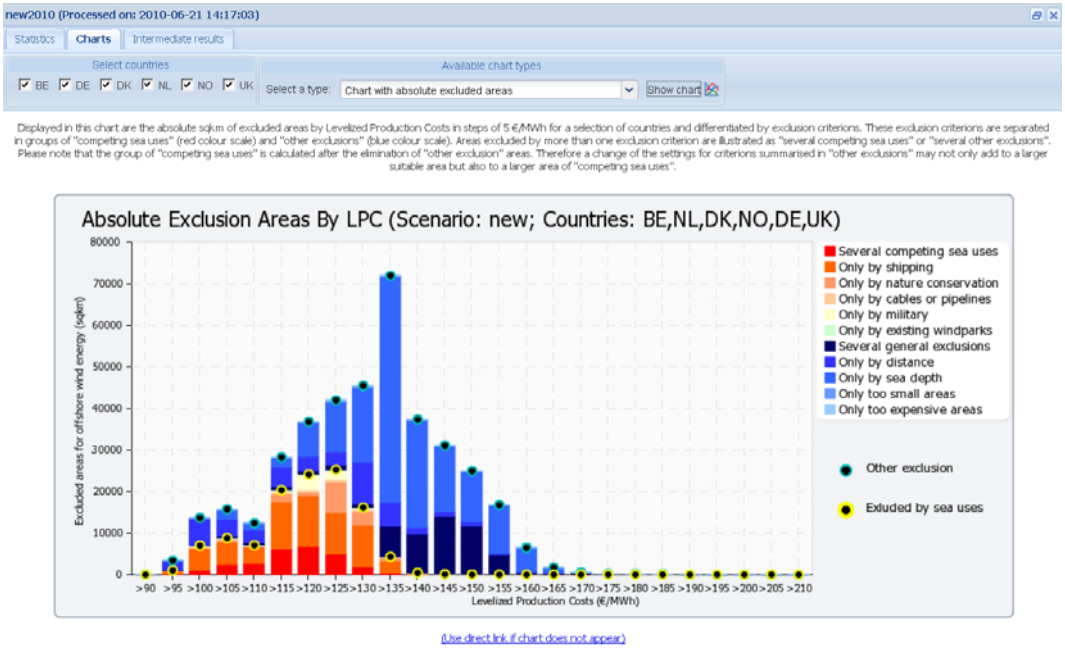


The following charts are currently available:
Absolute and relative suitable/excluded areas
Absolute and relative excluded areas (with detailed exclusion criteria)
Absolute and relative Net Annual Energy Production
Cost curve (Cumulated Net Annual Energy Production by LPC)
Cumulated suitable areas by LPC

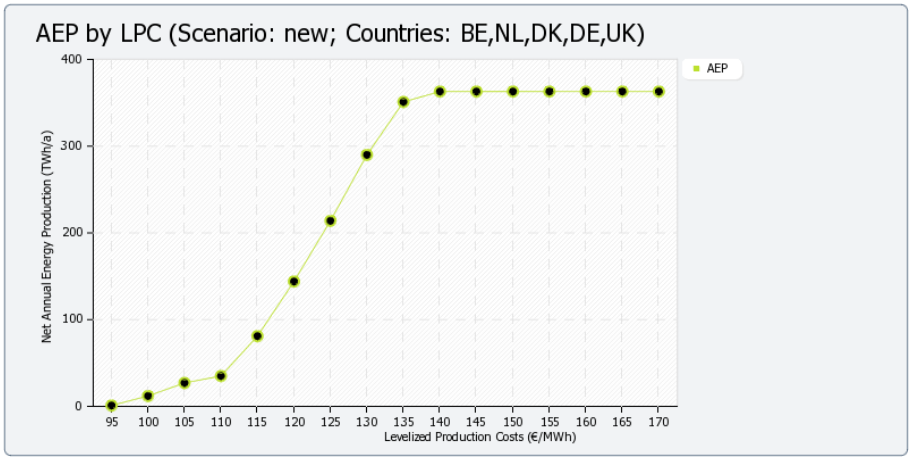
All graphs provide a representation based on the defined LPC classes.

In the example below, for each LPC class the absolute (km^2) size of area with respect to the exclusion criteria is shown. One can easily identify the exclusion criteria that

would significantly increase the OWP potential should those constraints somehow be relaxed/removed. For this scenario most of the interesting (cheapest) areas for OWP are excluded due to shipping. On the other hand, the most expensive areas that are excluded in this scenario are excluded due to sea depth.



The cost curve graph shows the overall Net Annual Energy Production (AEP) that can be achieved at a certain LPC.



For each processed scenario a results window can be opened in parallel by clicking on the *View online* button.

Contact WINDSPEED
Energy research Centre of the Netherlands (ECN)
P.O. Box 1
1755 ZG Petten
The Netherlands
+31 (0)224 56 82 08
www.windspeed.eu