

Case Study: Systematic site selection for offshore wind power with Marxan in the pilot area Pomeranian Bight

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1. Executive Summary

The development of offshore wind energy is a driving force for designating sea areas for specific uses. Maritime Spatial Planning looks at sea uses in a more integrated way, however specific tools for siting decisions stretching over all relevant sectors are seldom adopted. The decision support tool Marxan is a tool known to be used for systematic selection of sites for nature protection. In this study Marxan was experimentally applied as a tool to identify suitable sites for offshore wind power in the pilot area Pomeranian Bight/Arkona Basin.

The software was successfully tested and scenarios developed which on the one hand support the indicated sites in the national plans but also show options for other developments. Focus was set on working with the planning group of the pilot area so that the model results from Marxan were not perceived prescriptive but as a tool that can be used in a first step to evaluating areas for their suitability for certain uses and then using this information during the development of the spatial plan.

Marxan was found easy to handle and would therefore be recommended by the author to be used as a decision support tool for the whole Baltic Sea in the context of Maritime Spatial Planning.

2. Introduction

2.1 Background and scope of the study

Maritime spatial planners are often confronted with complex situations in which all interests should be balanced and at the same time a healthy marine environment be maintained. Decision support software can help to work in a systematic way and is an accepted tool in conservation planning. The objective of the study was to demonstrate the usefulness and reliability of such a systematic approach to the allocation of sites for spatial claims of the sea area other than nature conservation. The results of decision support tools illustrate options as step in the concrete planning work.

The software Marxan was developed to provide decision support for systematic nature conservation planning (Ball et al. 2009). It uses an optimization method for site selection, designed to find the most cost efficient suggestions for suitable marine conservation areas which meet a number of ecological, social and economic objectives. Unfavourable conditions for the conservation target are integrated into that model as so-called “costs”. Additional to the most cost effective solution, Marxan provides the frequency with which each planning unit was selected during the optimizing process and an overview how good the targets could be met. The results can be further influenced by setting parameters such as clustering, importance of the different targets etc. (Ball et al. 2009, Ardron et al. 2010). In general, this tool generates planning scenarios in way that input parameters (targets and costs) can be made transparent and visible and be compared with other scenarios with altered input parameters.

Offshore wind power plants were chosen as a simple example to apply Marxan to a different topic than marine protected areas within the context of Maritime Spatial Planning. For Denmark and Germany suitable sites for offshore wind power have been identified by the competent authorities prior to this study and in the case of Germany already incorporated in the official planning framework. In Poland the process of exploring the options for offshore wind power was not finished during the study.

Offshore wind power is directly competing with other existing and newly emerging demands for space. The natural geographic situation in the pilot area in this context is manageable, large parts of the area are already taken up by conflicting features, namely habitat and bird areas, shipping and scenic aspects concerning free view from the coast for tourism. The use of Marxan can therefore be demonstrated by a comprehensible situation.

Different scenarios are developed and their results compared with the real case planning documents. Special focus is applied to a cross-country approach with sites that have the lowest construction costs and which at the same time make use of available wind optimally.

Within the pilot area the use of the site selection tool Marxan has been integrated into the process of analysing the potential for offshore wind power in the area. The results from the scenarios can be taken as a basis for finding solutions in the MSP process.

The work was coordinated with the planning group of the pilot area so that the model results from Marxan were not perceived as prescriptive but as a supporting tool that can be used to explore the possibilities of the region as step in the development of the spatial plan.

This report is therefore focusing on the technical side of the work and the use of the available data whereas the scenario outcomes are incorporated in the pilot Maritime Spatial Plan for the Pomeranian Bight and Arkona Basin (Gee (ed.) et al. in preparation). The wording of this report is also

3. Method and Data

focussing on the model work and expressions can have slightly different meanings than in the planning context.

2.2 The Pilot area

The pilot project area Pomeranian Bight/Arkona Basin consists of parts of the EEZs of Denmark, Sweden, Poland and Germany and stretches to their respective shorelines, covering in total an area of ca. 14,100 km² (Figure 1).

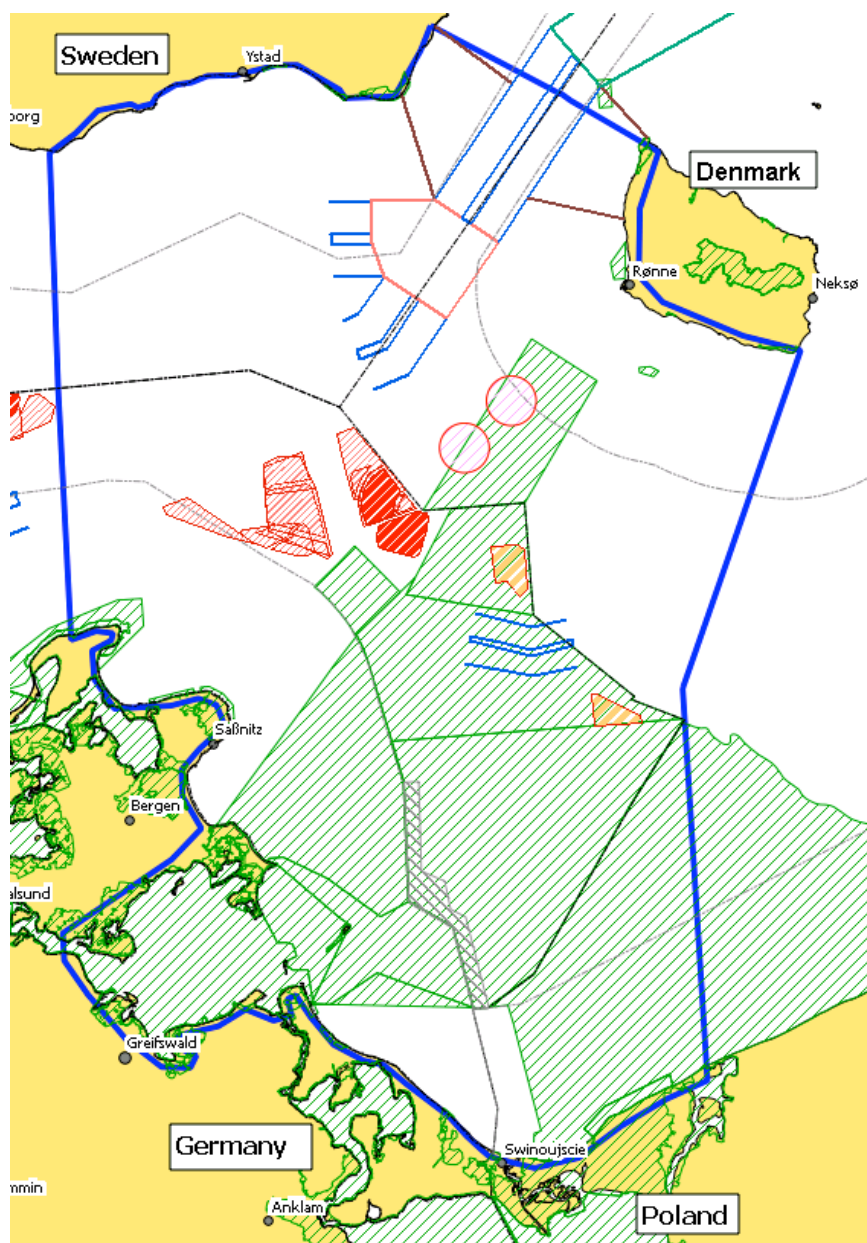


Figure 1 Overview over the pilot area with Natura 2000 areas in green, shipping routes and offshore wind farms (red hatches planned/approved, orange denied). The EEZ border between Denmark and Poland is not drawn due to its unclear legal status. The Northern Approach / Roadstead Seaports of Swinoujscie and Szczecin is hatched in grey

Many different uses and the natural environment are competing for space in the pilot area. Main shipping routes with heavy ship traffic and several ferry lines are crossing the area. Especially the southern part of the pilot area is important for seabirds and accommodates numerous marine habitats. Consequently large areas are designated Natura 2000 areas. The coastal areas are important for tourism and are affected by the developing industries. Other uses that change the seabed and create space are sand and gravel extraction, pipelines and submarine cables.

In the pilot area working group, the focus of the MSP was set on:

- Maintain functional maritime transport and ferry connections: Transport-Link North-South (ferry connections), East-West (transit-) traffic and the relevant ports.
- Secure the value of the area for (maritime/coastal) tourism.
- Protect the sensible and valuable natural environment, among others important wintering birds areas and spawning area of Baltic herring.

Based on the requirements to rely more on renewable energies in future, the claims for offshore wind energy are steadily increasing. Offshore wind power is in direct conflict with other existing and newly arising demands. Safe shipping needs security buffers around the routes and around offshore wind farms to avoid collisions. Windmills visible close to the coast are considered destructive for the tourism sector and windmills can also have influence on the migration patterns of birds even if placed outside Natura 2000 areas.

Additional to the above mentioned uses, other activities occur in the pilot area, which are not considered in the current analysis. Due to resolution of the planning units in this study, the smaller features, e.g. wrecks, cables or pipelines would block more of the area than required. The information level for sediment extraction and military training area was relatively low, so that it was decided to exclude them from the first analysis.

From the Danish side two wind parks of 200 MW each are possible at Rønne Bank. Compared to other sites for wind farms in Denmark, high investment costs are expected for these two sites due to the water depth of the area. The planners are also well aware of the general importance of Rønne Bank for harbour porpoise and in limited extent seals and for birds in a very high degree during winter and spring. The influence of the mills on migrating birds has to be assessed in the course of the concrete planning. The Natura 2000 site however was not established at the time when the Danish strategy for future offshore wind power sites (Danish Energy Authority 2007a and b) was developed.

The German offshore wind development is more advanced. Many applications in the EEZ as well as in the territorial waters of Mecklenburg-Vorpommern have already undergone the planning and permitting procedures. The sites are also part of the spatial plans in the EEZ as well as in the planning documents of Mecklenburg-Vorpommern. Two sites were denied because of the potential conflict with sea bird protection.

In Poland an investigation for suitable sites was carried out parallel to this study. One park is under consideration which would be located in the EEZ of Poland in the pilot area. From the Swedish project partner it was communicated that Sweden does not plan offshore wind parks in the pilot area.

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2.3 Using Marxan for a systematic planning approach

The decision support software Marxan uses an optimization algorithm for site selection. It does not carry out ecological modelling even though it has been developed for the design of an optimal network of marine protected areas nor does it have definitions for conflicts caused by ecological, social and economic objectives (Ardron et al. 2010). Marxan only utilizes those factors and target values that are selected by the user for the modelling process. To run Marxan, the ecological potential of the area, the conservation targets and the influence of conflicting uses have to be determined beforehand. The tool can therefore easily be adopted for other site selection analyses as long as the planning question can be reduced to a setup that meets the way Marxan handles a problem.

The objective of this study is to demonstrate the usefulness and reliability of a systematic approach with the help of other planning aspects than nature conservation in addition to the concrete planning work. Additionally, it can be tested which outputs of the Marxan model can be used during the maritime spatial planning process.

As a decision support tool, modelling with Marxan should be integrated into the planning work. Following the idea of integration, for this study the required input was collected during the stocktaking process and the conflict analysis by the working group of the pilot area. Feedback processes were often necessary, when gaps in the data or in the conflict definitions were identified.

The tool supplies support for the members of a planning group and enables them to simulate the consequences of different planning options. The outputs provide a working document for decision finding and detailed reflections. They do not replace final planning decision about sites by a responsible planner. The resulting maps can be support for stakeholder involvement.

3. Method and Data

Marxan comes along with a set of tools. In this project additional to Marxan, Zonae Cogito which provides an open source user interface for the modelling work with Marxan and other open source GIS programs (GRASS, Saga and Quantum GIS) were used.

Marxan:	Program for the site selection process. No user interface is given. Data is prepared with a common GIS or Zonae Cogito and stored in the appropriate data structure to be run by Marxan.
Zonae Cogito:	Recent development by Watts et al. (2010) as a supplement to Marxan with GIS functionality and interface to Marxan. The program supplies open source data preparation and formatting, data management, calibration and visualization for Marxan.
Additional GIS Software:	Preparation of the input data, analysis and visualization of the results

3.1 Marxan

The terms used in Marxan reflect that it was developed for nature conservation planning. The wording in a different context can therefore be slightly confusing. An explicit translation to the context wind power planning is supplied later in this chapter. The principle of the tool will be explained with the help of the nature conservation case.

For the optimization process, Marxan uses simulated annealing. The method allows moves into the “wrong direction” during the iteration, i.e. allowing “more expensive” (suboptimal) solutions than in the step before for a cost minimizing problem. This assures that Marxan does not get stuck in local minima. The settings steer that during the overall process the solutions consequently get less random and lower in their costs. (Kirkpatrick et al. 1983)

A study area for Marxan is divided into **planning units**. The input features for Marxan are grouped into **target** or **conservation features** and **costs**. Additional parameters can be set. Typical **planning units** for Marxan are often hexagons. Hexagons have the advantage to be of a regular representative size and their real boundaries between the single planning units can be used as an important tuning parameter for Marxan. Other shapes, e.g. irregular shapes, can be used as well. The planning units are selected during the iteration process and all spatial information is aggregated on them. For the planning units a status, e.g. lock into or exclude from site selection, can be set.

For the **target features**, protection targets can be set as percentage or area/amount. The user decides, which features to select for conservation. Different targets are set for the single features and their importance is steered by a penalty factor. For nature conservation the target features are typically information on the habitats and abundance per planning unit as fine filters and ecoregions or even administrative regions as coarse filter if an equal distribution of the sites is wished.

The **costs** are unlike the conservation features merged into one input layer. It is therefore necessary to estimate the influence of the different cost components more thoroughly than for the target features. The cost layer includes additional to the cost of establishing the conservation site, suitability information for the planning units, e.g. pressure by human uses.

There are fine-tuning options, e.g. to handle biological constraints by influencing the distance between selected sites or the size of patches or fine-tuning the output by setting penalties for the different conservation features if not all targets can be met.

3. Method and Data

General Settings require a decision about the number of iterations and the number of runs. These parameters are on the one hand responsible for how good the optimization process is run and for the repeatability of the results and on the other hand for the time each run takes. The number of iterations influences how close Marxan can get to an optimal solution. The number of runs determines the frequency with which planning units are selected in multiple runs and by that gives an indication of the importance of that planning unit for efficiently meeting your reserve targets (Game & Grantham 2008).

3.1.1 How does the Methodology Apply to Offshore Wind Farm Planning?

For the site selection of suitable locations for offshore wind farms, the settings were strongly simplified. To avoid that the costs and revenues differ due to different income levels or tax situations in the different countries, all information was taken from the Danish strategy for future offshore wind power sites (Danish Energy Authority 2007a). It has to be kept in mind that the site selection with Marxan is only an early preparatory step during the planning process to identify the most reasonable site-scenarios based on simplified assumptions. The final areas are selected by the decision makers.

In figure 2 a schematic sketch of the offshore wind farm settings is displayed. The target to produce a specific amount of energy is used as basic **target feature**. The wind availability was used as basis for the potential wind production. Additionally a division into country targets can be used. The **cost layer** comprises investment costs as well as conflicting features.

Only those investment costs that vary due to conditions at the site have been taken into consideration. These are the cable and foundation costs as investment costs. It was discussed in the group to include sediment information for the foundation costs. But without information about the thickness of the top sediment layer, mapped e.g. in the BALANCE project, the information was not included.

Ship traffic, scenic view protection of the coastal area and Natura 2000 areas were considered incompatible with offshore wind parks and were thus identified as the group “conflicting features” in the cost layer.

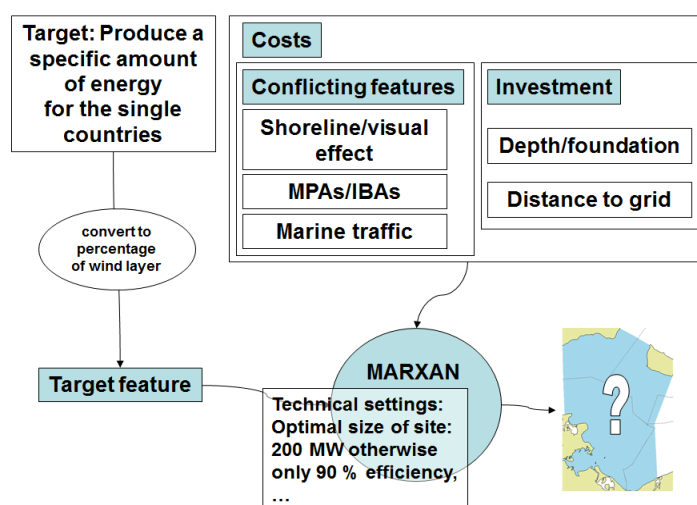


Figure 2 Marxan settings for offshore wind farm

The investment costs are measurable monetary costs that accrue only one time. They are therefore taken as basis to balance all costs with the targets and the conflicting features which are not directly measurable. A factor was used that leads to a class of the value 5 for 50 km cable length.

The targets can be made comparable by calculating the profit for a defined period of time based on the mean wind availability. Thus, the length of the time period has a strong influence on the balance between the target and the cost layer.

For the conflicting features, a range of values with which they contribute to the costs layer needs to be found to represent the importance of the features or how easy they can be moved to a new location. The importance of the single conflicting uses was discussed during the conflict analysis. These decisions have a strong impact on the selection as suitable area.

3.2 Target features

3.2.1 Wind resources as main target feature

For the profit of an offshore wind power plant the wind availability is besides the technical solution the main influence factor for the power production and with that for the revenues.

As a wind layer, a dataset prepared for the Interreg IIIa project POWER (PL/LT/RU) was used (figure 3). In the dataset the mean values at a height of 10 and 100 m for the years 1998 to 2007 were compiled for the Baltic Sea. The data was modelled with the UMPL (Unified Model for PoLand area) model v.4.5 with a resolution of 9 nautical miles (ca. 17 km) and then interpolated to a resolution of 0.01°.

The resolution of the original data is very low compared to the size of the pilot area. The distance between Kap Arkona on Rügen and Sweden (the open sea at the border of the pilot area in the west) is only ca. 40 nm, thus only 4 grid points in the model. To detect features, it is known that the sampling grid has to be at least twice as fine as the feature, five times as fine are recommended. (Tobler, 1988)

Even with the resolution slightly above the minimum requirement, it is expected that the gradient for the differences between open sea and land is underestimated due to the low resolution of the model data and consequently the wind speed at the open sea in the west is underestimated as well.

The wind conditions at the open sea are normally relatively good, especially if a strip close to land is not wished for offshore wind farms due to the visibility. In the used wind layer, the wind is highest on the open sea in the south east of the pilot area and lower closer to the land with the minimum in the Bay of Greifswald. The mean wind speed at 100 m has a maximum of 9.1 m/s and a minimum of 5.2 m/s in the pilot area. The mean of the area is 8.1 m/s.

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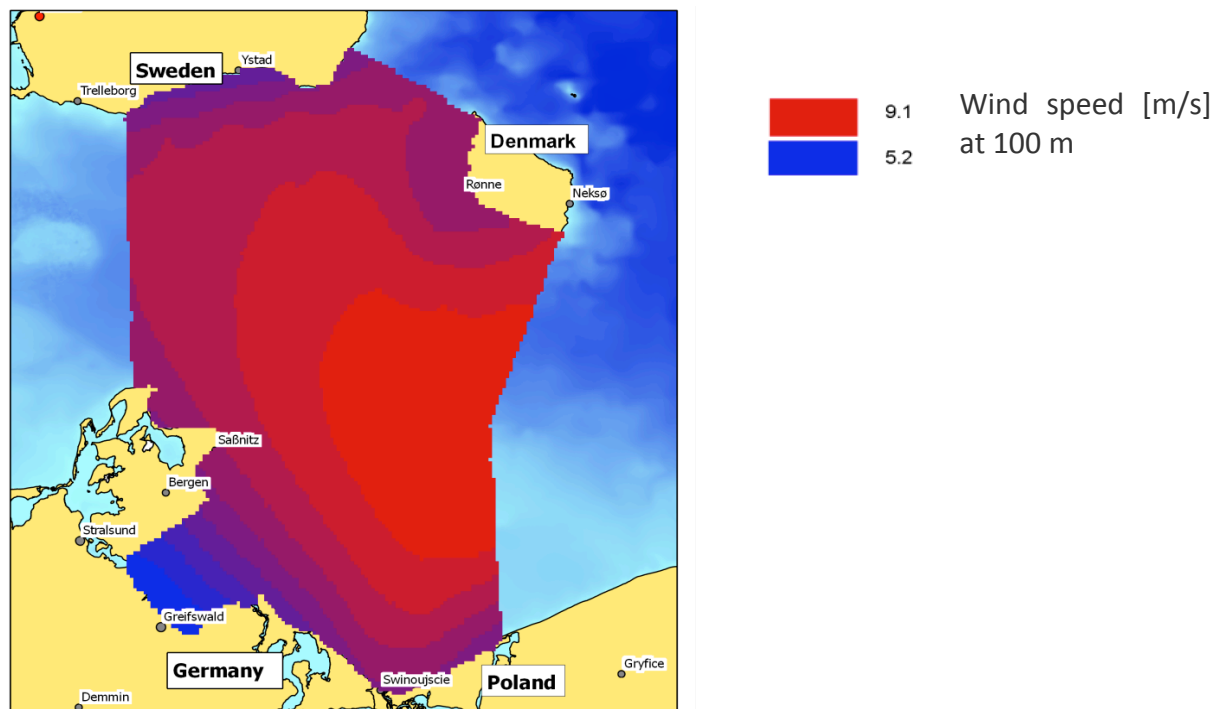


Figure 3 Average wind speed at 100 m height for the years 1998 – 2007

For the estimation of the production capacity of a site in the pilot area a simplified approach is used. Only the mean wind speed at 100 m height was used, differences in the pattern of the wind distribution, air density or the design of the wind farms neglected. The Danish strategy for future offshore wind power sites (Danish Energy Authority 2007a) assumes an energy production of 3900 and 4300 full load hours for 9.4 m/s and 10.3 m/s respectively. With these two value pairs, the approach to estimate the possible energy production from the available wind can only be simplified. The range of the wind availability in the pilot area is also including much lower values than the two samples. The extrapolation of the function has nevertheless relatively little influence on the results since it is expected that mainly sites with higher wind availability will be selected. The minimum wind speed outside the 20 km coast zone which will mainly be selected is 7.7 m/s.

The relationship between investment costs and revenues have an influence on the selection of sites. Whereas the investments are non-reoccurring, the revenues depend on the time the wind park is producing energy. The profit from selling wind energy was calculated for 25 years with assumed 96.5 €/MWh and the results put into relation to the investment costs by a factor that leads to a class of the value 5 for 50 km cable length.

From these assumptions, the linear function

$$y = 444.44x - 277.78$$

was built to estimate the energy production capacity of the single sites as an approximation.

3.2.2 Targets divided per country

The current existing or planned sizes for wind farm areas were converted to target values for the basic scenario with the mean wind availability for the whole area. Denmark has planned 88 km² and Germany 130 km². The wind availability values were used as target feature.

3.3 Costs and conflicting uses

3.3.1 Monetary costs

As monetary costs only those investment costs that are dependent on the physical environment were taken into consideration.

In the Danish strategy for future offshore wind power sites (Danish Energy Authority 2007a) a table with the dependency of foundation costs per wind mill of the bathymetry is given and from this the regression line calculated (Figure 4).

Depth [m]	Costs [mil €/MW]
0	0.40
10	0.40
20	0.62
30	0.94 – 1.01
40	1.34 – 1.75

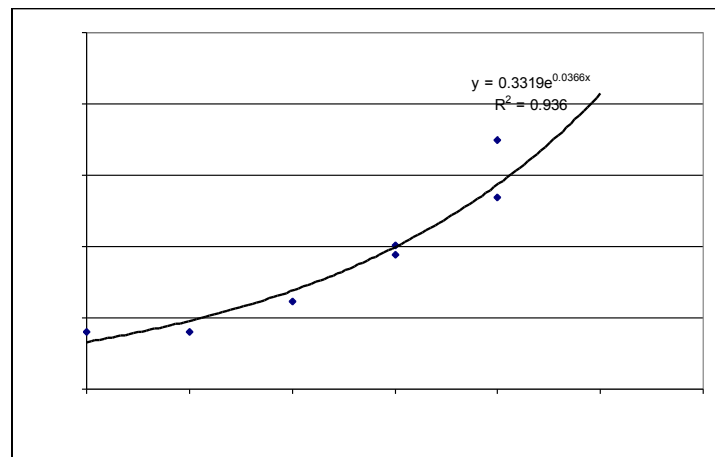


Figure 4 Foundation costs

The second cost factor taken into consideration are the cable costs for the connection to the electrical grid. Since the connection nodes are not known, the shorelines except for Bornholm were used to calculate the distance to the next grid.

The basis for the regression line was taken from the Danish strategy for future offshore wind power sites (Danish Energy Authority 2007a), figure 5.

3. Method and Data

Distance [km]	Costs [mil €/150 or 132 kV]
15	16.80
30	33.60
50	44.35

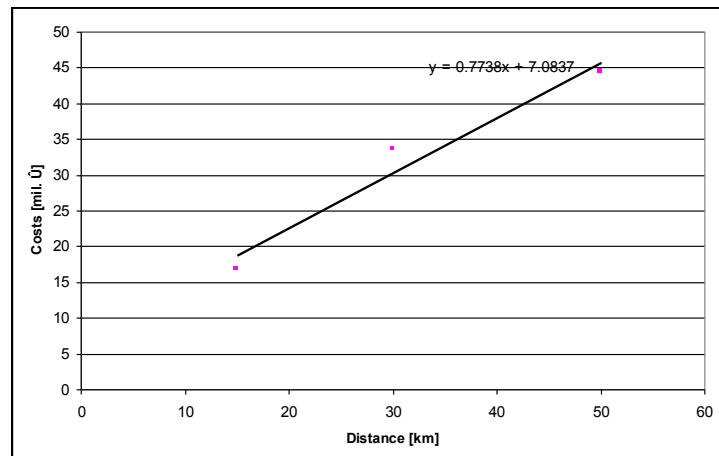


Figure 5 Cable costs

The costs for foundation are given per MW whereas the cable costs are given per cable which can supply a whole offshore wind park. Marxan can only handle the costs which are given by the single grid cells and not check which sites can be connected together to a single cable. It was chosen to set the costs in a way that 200 MW are connected together to one cable.

A factor was used that leads to a class of the value 5 for 50 km cable length. The resulting costs functions are:

Function depth/foundation:

$$class = 5.5852 * e^{0.0447 * depth[km]}$$

Function cable:

$$class = 0.0845 * distance[km] + 0.7738$$

For cable length of more than 50 km, high-voltage direct current (HVDC) is used. Two converter stations are needed for HVDC. A constant of 50 was added for these distances due to lack of information other than that the costs are much higher.

3.3.2 Tourism and local population

Offshore wind parks are considered anaesthetic and having a negative impact for tourism if built too close to the shoreline. Since tourism is one of the most important economic sectors of the pilot area, the cost value was set as a constant of 50 for a zone up to 20 km from the coastline. With more local knowledge it would be possible to differentiate the value of a coastal stretch for tourism.

3.3.3 Shipping

Area description

The pilot area has a high importance for maritime traffic and transport (bulk goods, containers, ferry transport of both goods and passengers). It has a very high density of maritime traffic and transport, especially at the Traffic Separation Scheme/IMO ship route Bornholm's Gat between Sweden and Bornholm as the main east-west connection in the Baltic Sea. The other link lies south of Bornholm, regulated by a new separation scheme. The ferry connections between Sassnitz and Świnoujście/Szczecin in the south, Ystad (and Trelleborg – outside the area) in the north and Rønne on Bornholm act as a transport link north-south. Important ports for freight on the southern coast are Sassnitz and Świnoujście/Szczecin.

Approach for Marxan

Cost for the transport and ferry connections were set according to their importance. The very high frequented routes got a cost value of 30, the ferry connection from Sassnitz to Rønne with 6 the lowest value. A security buffer of 2 nm plus 500m was set for the high frequented routes and traffic separation schemes, 1 nm plus 500 m for all other connections. In the buffer the cost was reduced to 0 with distance from the shipping route.

3.3.4 Ecological importance

Area description

The pilot area is an important bird area for resting and wintering birds. The largest part of the important bird areas extends from Rønne Bank to the south. There are also important spawning areas for commercial fish in the pilot area. Herring spawn in the Bay of Greifswald and cod spawn the deep basin with more than 40 m water depth north of Arkona. It is also assumed that the area is important for the eastern harbour porpoise population of the Baltic, but reliable data is missing. The south is covered by large sandbanks and reefs occur from Adler Grund to Rønne Banke. For bird protection reasons large areas were declared as an SPA (SPA Pommersche Bucht) and for the same reason two wind park permits in the German EEZ were already denied as the likeliness of substantial negative impacts on the seabirds was regarded as too high. Because of its ecological importance, 38.7 % of the marine area are designated Natura 2000 areas.

Approach for Marxan

Natura 2000 areas were chosen to represent areas with ecological importance, because the spatial data for the ecological features was not complete. The spawning areas were not taken into consideration. The existing protected areas were handled by the cost layer, giving them a theoretical chance to be moved in advantage for an offshore wind park. In the first setup, the cost value for an area was set to 50 and in a buffer zone of 1 nm plus 500 m around the protected area reduced to 0. After discussion in the group the buffer was removed.

4. Results

4. Results

4.1 Scenarios

A range of scenarios were chosen to explore the options of different demand for electricity, technical solutions and political decisions. Some of the factors determining the suitability of an area for wind power are physical conditions whilst others are partly political decisions and again others are not known enough so that it is necessary to use scenarios to estimate their influence.

As a starting point, a scenario was set up that is comparable to the present real case planning documents. A cross-country approach was carried out to find sites that have the lowest construction costs and which at the same time also optimally use the available wind. By increasing the targets an increase of the energy demand was simulated and simultaneously alternative sites with slightly higher costs than the most optimal were pointed out. To demonstrate the influence of the state of the art of technical solutions and the influence of other connection options than the existing land-based electrical grid, a scenario demonstrates the differences in the site selection when removing the investment costs for cable connections to the existing grids. (Table 1)

In table 1 and the following target descriptions it is referred to the targets in square kilometres for mean wind availability. The range of settings is not exhaustive. The options to explore the influence by varying targets and conflicts to protect this ecologically important area were limited due to the incomplete data.

Table 1 Scenario overview

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Target	218 km ² wind parks separated to targets for Germany and Denmark	218 km ² wind parks without separation into country targets	436 km ² wind parks without separation into country targets	654 km ² wind parks without separation into country targets	436 km ² wind parks without separation into country targets
Costs	Foundation and connection to grid	Foundation and connection to grid	Foundation and connection to grid	Foundation and connection to grid	Foundation

The outputs are illustrated on the maps as best solutions, i.e. the solution chosen from several runs that is leading to the lowest costs in the Marxan model and the selection frequency, i.e. the percentage with which a planning unit got chosen for the solution from all runs of the respective scenario. For all scenarios 10 mil. iterations and 100 runs were used.

Scenario 1

In the basic scenario it was tested, if Marxan would produce results similar to those in the national plans with the chosen settings. As targets, values were chosen that represent 130 km² for Germany and 88 km² for Denmark.

In figure 6a the results of the Marxan model are compared to the sites considered in the national plans. Even though the sites do not fit the national plans exactly, it can be clearly seen that the national plans as well as Marxan aims for areas with high wind intensity and at the same time shallow water less than 50 km away from the coast. There are some differences which can be explained by different approaches. For the Marxan model, it was decided that offshore wind parks should not lie inside Natura 2000 sites. The Danish indication of suitable sites was made before the Natura 2000 site was established and was made on a broader scale.

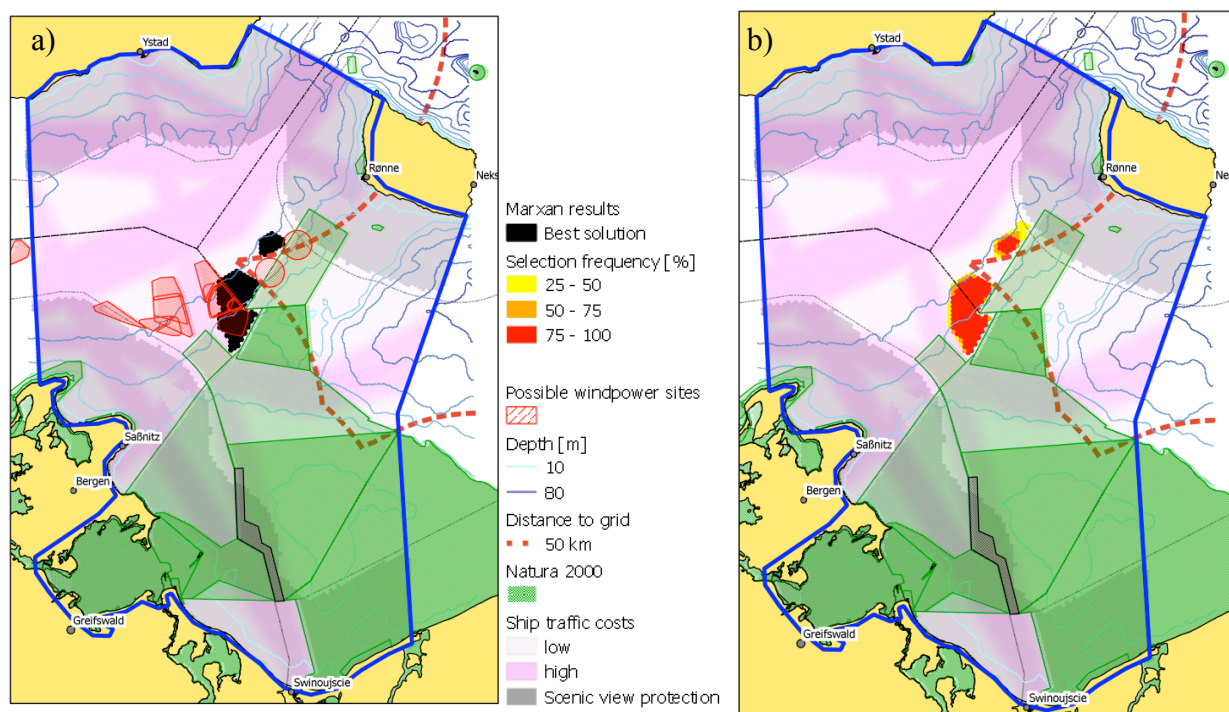


Figure 6 Basic scenario with a target of 218 km², a) best solution by Marxan (black) compared to the sites under consideration by national plans; b) selection frequency from the different runs

4. Results

Scenario 2

For Scenario 2 the targets are not splitted up to country targets. Figure 7 shows that the selected area is approximately the same, a slightly larger part is situated in Germany .

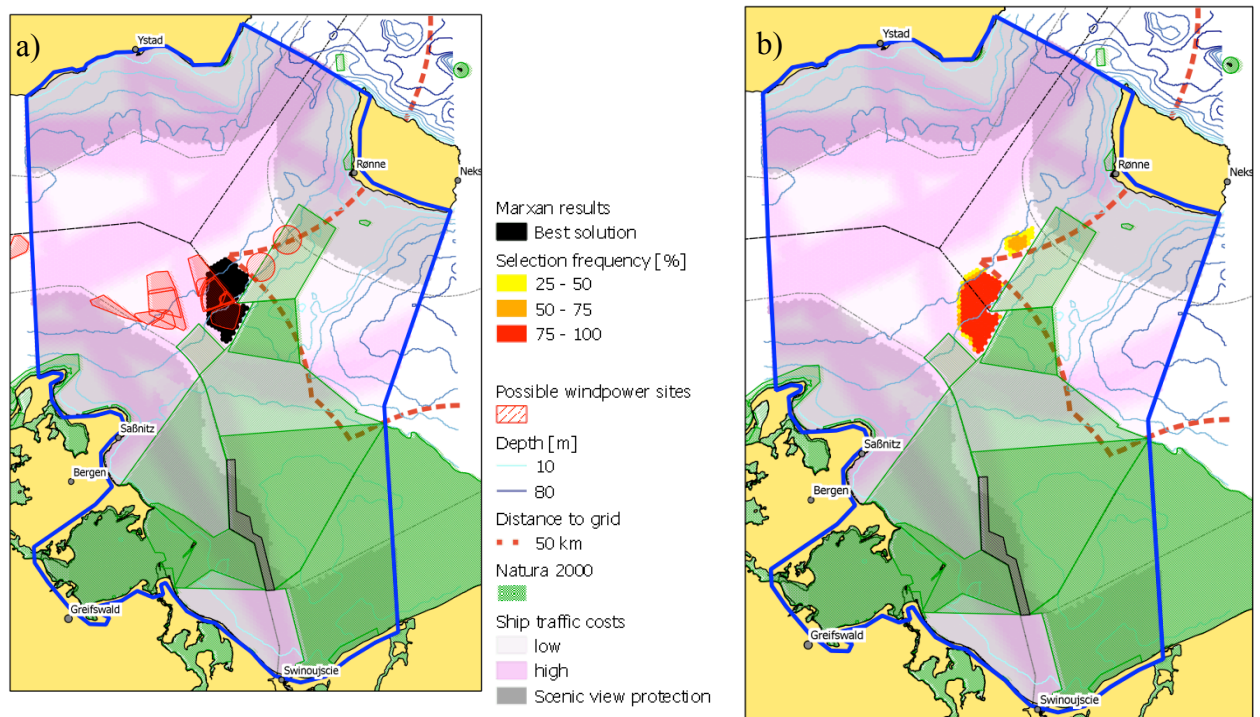


Figure 7 Overall target of 218 km², not split up on countries, a) best solution by Marxan (black) compared to the sites under consideration by national plans; b) selection frequency from the different runs

Scenarios 3 and 4

In Germany, the target was lower than the total area indicated by the national plan. Therefore, in the next scenarios the target was increased. By increasing the target, it can stepwise be tested which areas get selected additional to those in the first scenario. For the interpretation the selected sites, the increasing costs and fulfillment of targets can be compared. The targets were not divided into country targets.

In the third scenario with the target doubled, also the second large area in Germany was chosen by Marxan (figure 8). Still with the chosen settings, the site at the territorial border in Germany will not be chosen. The chosen settings for the scenic view protection are larger than those chosen by Germany/Mecklenburg-Vorpommern and the site lies on the security buffer of relatively important shipping route. Here it has to be remembered that the model result called “best solution” produced by Marxan still is just an option that was produced with specific settings. By increasing the targets to threefold the original target, the selected sites overlap partly with the site at the territorial border. A shallow part in the Swedish waters gets additionally selected.

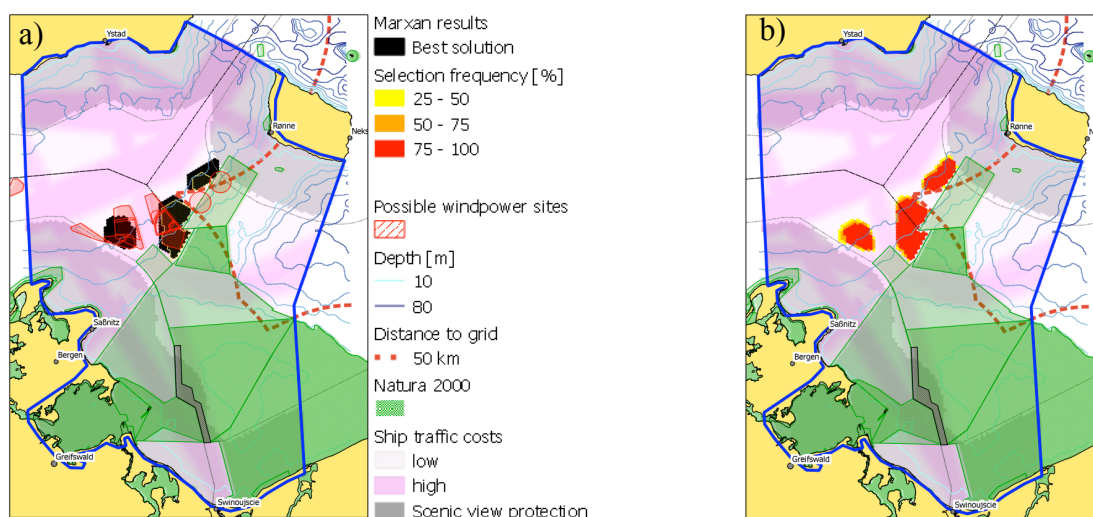


Figure 8 Doubled energy production compare to the basic scenario; a) best solution by Marxan (black) compared to the sites under consideration by national plans and the 1st scenario (indicated by yellow outline); b) selection frequency for the different runs

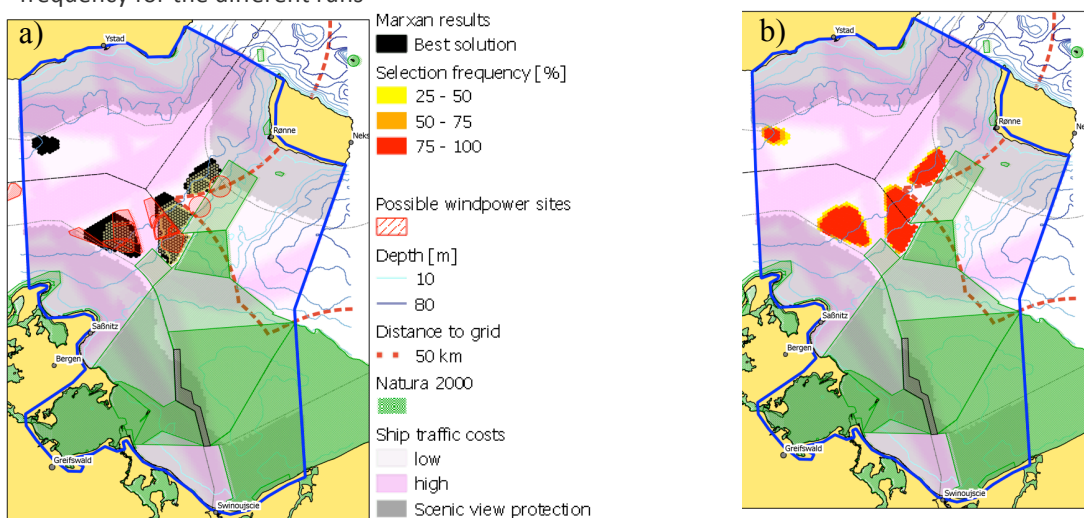


Figure 9 Threefold energy production compared to the basic scenario; a) best solution by Marxan (black) compared to the sites under consideration by national plans and the basic and the double scenario (indicated by yellow and grey hatches); b) selection frequency for the different runs

4. Results

Scenario 5

In the last scenario it is tested how the optimal position of offshore wind farms in the pilot area would be without the connection to the electricity grid. This can be interesting if a super grid is installed close to the pilot area, if the single farms from the different countries are connected to each other or if the connection costs for distances longer than 50 km become less expensive. To remove the influence of the cable connection the costs for connection are neglected and the double target was used. Figure 10 shows that in this case the relative shallow area east of the Natura 2000 site in Denmark is selected and also for Poland a site outside the Natura 2000 site would have good conditions.

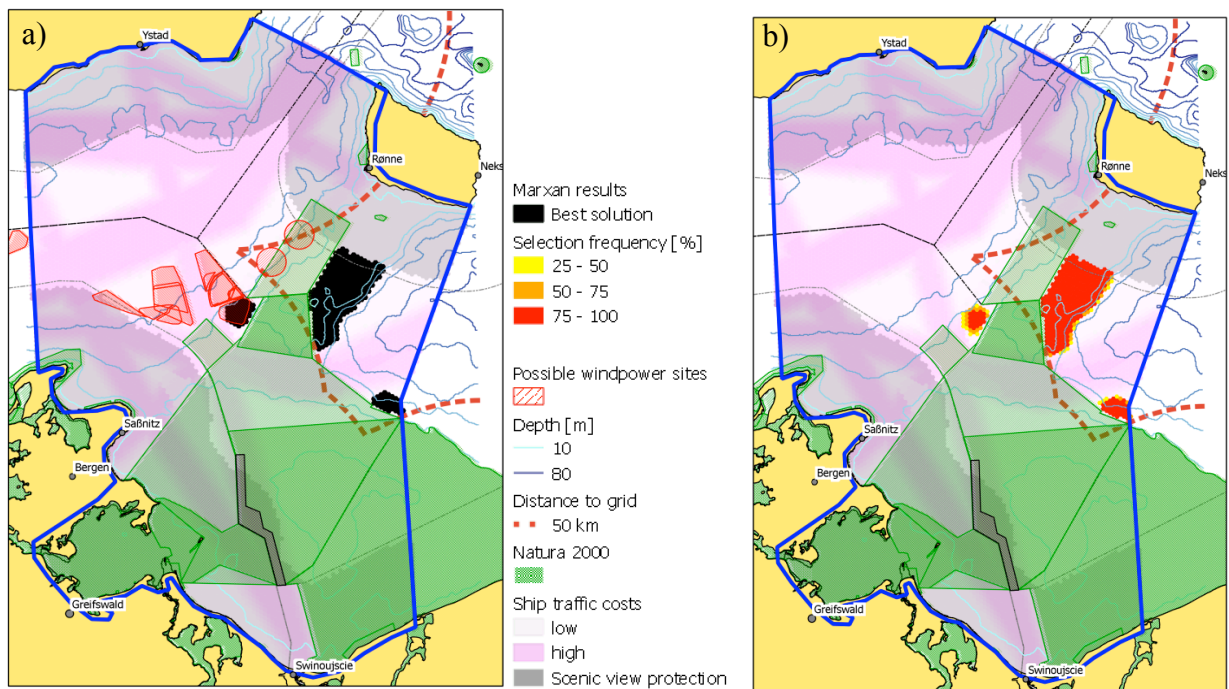


Figure 10 In this scenario the cable costs are neglected, total site size is the same as in basic scenario. a) best solution by Marxan (black) compared to the sites under consideration by national plans; b) selection frequency for the different runs

4.2 Comparison of the scenarios

In the comparison of the efficiency of the solutions, the scenario 5, neglecting the costs for the cable connection is excluded. Monetary costs for construction and suitability are combined into one layer. It is therefore not possible to evaluate the suitability and costs separately with the help of Marxan, but this comparison could be performed with a regular GIS.

In table 2 the results of the scenarios are compared. It is compared at which costs how much of the targets are reached for the single scenarios. With the chosen setup, the costs are determined per planning unit (PU) for the costs defined in the cost layer and costs adjusted by a boundary length modifier (BLM) for planning units that do not share boundaries with other selected planning units. To the total a penalty per target feature for not reaching the targets adjusted by a factor per target feature (SPF) is added:

$$Costs = \sum_{PUs} Cost + BLM \sum_{PUs} Boundary + \sum_{Target\ Feature} SPF \times Penalty$$

Table 2 is divided into costs and shortfall, i.e. the amount by which the targets have not been met in the scenario.

Table 2 Comparison of Scenario 1 – 4. The costs and shortfall are for the last two scenarios given as total and in relation to the basic target, to be comparable to the first scenarios. The table does not show the original units of costs and shortfall but they are set into relation to reach the target 1.

Scenario	Target		Costs	Shortfall	Total
1: Basic scenario	1		0.216	0.0008	0.217
2: Not divided into country targets	1		0.217	0.0004	0.217
3: Double target	2	Comparable to target 1	0.240	0.0004	0.240
		Total	0.479	0.0009	0.480
4: Threefold target	3	Comparable to target 1	0.257	0.0001	0.257
		Total	0.771	0.0004	0.772

The suitability and shortfall for the first scenario and the second are approximately the same. It was expected that the second scenario would have slightly better values, but it shows that small deviations from the optimal solution are possible. Increasing the target to the double increases the costs for the best solution with approximately 11 %, i.e. those areas that are additional to the basic scenario are 22% more expensive. Scenario 4 with threefold the target compared to the basic scenario has 19 % higher costs to produce the same amount energy or for those that are selected additional to the basic scenario 28 % more.

4. Results

4.3 Overlay with additional information

The chosen approach for the scenarios is very simplified. The reasons were on the one hand the scope of the study and on the other hand data availability and resolution. Additional to the included parameters, other biological, chemical or physical data or data about human uses could be included. This would allow for a more complex integration of the different ecological and geomorphological features of the sea area and in consequence further increase the reliability of the scenarios. In figure 11 the results of the scenarios with increased energy production (scenario 3 and 4) and no cable costs (scenario 5) are overlaid with oxygen concentration, the sediment types from the Balance project and wintering bird abundances from German bird surveys collected in the German "Seabirds at Sea" database.

The sites selected in those scenarios overlap both with specific sediment types that indicate valuable habitats and wintering areas for birds. The bird species shown in the map are collected for a study on fisheries and represent therefore mainly diving species and not species which are specifically endangered or sensible to wind farms. Data with habitat types or more detailed data on bird migration was not available for the complete area.

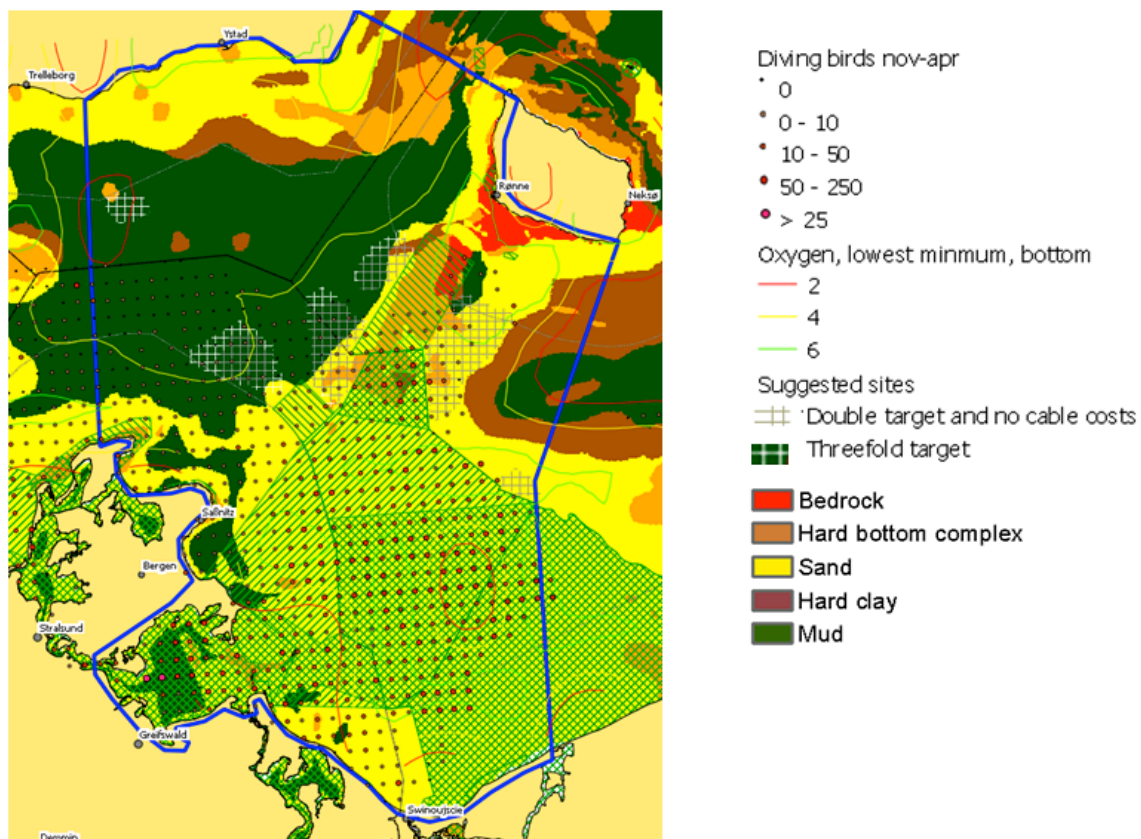


Figure 11 Overlay of the results of several scenarios with data on the winter abundance of diving birds (source German Seabird at Sea database), bottom substrate (BALANCE) and areas with oxygen deficiency 2002 - 2008 (Mohn et al., in preparation)

The data on bottom oxygen concentration has a low resolution and became available for the analysis relatively late. Low oxygen concentration could have been chosen as a positive precondition for site selection, in the expectation that the environment is already disturbed in the area. Furthermore the wind park foundations might as a hard substrate increase favourable conditions for hard bottom species and communities. The ecological value has to be judged by specialists.

In the pilot area, most of the areas with low oxygen concentrations are not suitable for offshore wind parks because they are situated in the deeper parts of the basin, close to the coast or within Natura 2000 areas. Only the area at the western border of the pilot area coincides with other conditions that make the area relatively suitable and is therefore selected in scenario 4.

The impact on the migrating and wintering birds has to be evaluated in more detail. Some of the selected sites from the scenarios overlap with high bird abundances while other sites are situated inside important bird areas (not shown in the map, e.g. the area in Poland) and for yet others the situation is not known. The Natura 2000 sites were used to represent those areas which have a high ecological value because specific habitats occur or birds are highly abundant. Within the Natura 2000 sites the protection is obligatory, but the EU Guidance on wind energy development in accordance with the EU nature legislation requires that for species that are vulnerable to wind farms the impact of activities outside Natura 2000 areas should be taken into consideration, e.g. if offshore wind farms are planned along migration routes of protected species sensible to wind farms. (European Commission, 2010). In the pilot Maritime Spatial Plan for the Pomeranian Bight and Arkona Basin (Gee et al., in preparation) the large migrating routes are outlined but the data was not detailed enough to be used for an analysis at the scale of the pilot area. Additional to the data of bird abundances and migration routes, the conflict between the birds and offshore wind power needs to be quantified to make it possible to use the information in a model like Marxan.

Additional uses could be included to show the full complexity of the situation, e.g. sites licensed for sand/gravel extraction or military sites. Those uses included in the model could be described better. The scenic view protection for example could be parameterized estimating the necessary distance from the coast by the height. Additionally, coasts close to port or other industries are probably perceived as less valuable and therefore would wind parks closer to them not disturb in the same degree as they do in areas of great natural beauty.

5. Discussion and conclusion

Marxan was successfully applied for modelling scenarios for offshore wind parks and integrated into the planning process. Different settings were tested, e.g. to demonstrate the influence of targets per country compared to an overall target for energy production in the pilot area, an increase of the demand or the influence of the state of the art of technology for cable connections and super grid design. Other settings, e.g. steering the patch size or minimum separation distance of the selected sites that are connected with each other, could not be tested with the chosen basic settings. The reason for this was the chosen amount of planning units which lead to a too large matrix.

There are other problems which cannot be handled with Marxan, typically questions that are important for offshore wind power sites but not for protected areas as the original purpose of Marxan. There are parameters to steer the grouping of the selected sites, e.g. boundary length modifier to give advantage to PUs that are connected, minimum patch size, minimum distances, etc. But with all these options a completely reliable solution for the cable costs which depend on how many mills are connected via the same cable could not be found. Even if the size of single patches is limited, several patches could be connected via the same cable.

The work within the planning group and their understanding of how to use a decision support tool is essential. Therefore close contact between modeler and planning group is advantageous. During all phases of the work, it has to be kept in mind that the results are directly influenced by the chosen simplifying settings and should not be over-interpreted.

Marxan turned out to be a tool that already helps to refine targets and potential conflicts. During the first runs some of the settings were changed due to unexpected effects of some of the target or conflict definitions. By using Marxan, changes can easily be documented and several settings tested so that the whole process of finding suitable sites becomes transparent.

It still has to be kept in mind that the model is not completely objective. The input parameters are based on experience of the modeler and definitions are made for weighting the influence of the different factors. In the current context, the investment costs are relatively easy to quantify as monetary costs whereas all non-measurable factors had to be quantified based on experience.

Another insecurity is caused by the input datasets. Even for datasets that are covering the whole area, it is not exactly clear how good their original input was. Even in the case that targets and conflicts can be defined easily, there is an influence of data completeness, quality and scale. This is especially the case for the targets that are set in percent of its occurrence. If the target is applied to a dataset with gaps, the size of the gaps has to be estimated and the target accordingly increased.

The question how much of the area is available for a specific use cannot be answered with Marxan. By using a scenario series with increasing targets, it can be checked, if the targets still can be reached or how much the costs increase. Since this analysis is dependent on quantifying non-measurable input data, all such analyses should be handled with much care.

Whereas it can be evaluated if the targets for every single target feature were reached, the suitability/costs can only be evaluated as a combined value. It is therefore in Marxan only possible to say that a target could not be reached, not if a single suitability or cost factor has reached a critical level, e.g. in this case if it was investment costs or conflicts with the natural environment. For more sophisticated questions Marxan with Zones can be considered, where each cost is handled separately and the relevance of the single cost for the single target features can be defined. Marxan with zones

is very complex and the influence of the single parameter settings is not as obvious as in Marxan. Therefore Marxan (without Zones) with its limitations is considered as a helpful tool which easily allows to model questions of MSP if it is properly integrated in the planning process and care is taken with the interpretation of the results particularly with regard to data availability and conflict settings.

During the first discussion of the results in the planning group of the pilot area, it was focused on the comparison between the model results and the existing national plans. Even though the selected areas do not correlate exactly with the plans of Germany and Denmark, they support the general placement of sites. The small differences can easily be explained with slight differences in the used definitions and the flexibility of manual designation of areas compared to the full automatic modelling.

A good example is the site assigned in the territorial waters of Germany. Due to the chosen settings for scenic view protection in Marxan, which were set about 2 km closer to the shoreline than the border for the territorial waters, no areas were chosen in the territorial waters. Additionally, a security buffer for a shipping route extends into the assigned area (Figure 9). Generally, the scenario with the threefold energy production shows that the physical conditions are suitable nearby. In the decision of a planner, this area can thus get a higher priority and a solution for the shipping route can be found whereas in the modelling process, the input dataset or parameters would need to be changed.

Even though a risk analysis for collisions was not performed in this study, the model results coincide with a risk analysis performed in Germany (Dr. Nico Nolte, BSH, personal communication). A security buffer for safe ship traffic around the highly frequented routes was defined for the use with Marxan. In the risk analysis a higher risk for ship collisions was found for the sites that are situated south of the shipping route that connects to the Bornholm Gat. In the Marxan model it was found not very suitable either due to high depth of the basin causing high foundation costs.

In the case of Pomeranian Bight if Marxan was run with more detailed ecological data (e.g. bird abundance), it could be possible that the competition for shallow waters between sea birds and wind parks could shift the best positions for offshore wind power after all to the deeper parts. Then a weighting of the risk for ship collisions and impact on the natural space for birds becomes critical in respect to quantifying non-measurable parameters. Risk zones should therefore be included in such studies where available.

Overall, the basic setup of Marxan was relatively easy and it can therefore be recommended as a very simple tool for MSP in the whole Baltic Sea. Guidelines how to use the model results have to be clearly communicated. It has to be kept in mind that Marxan is a supporting tool and does not provide solutions for a spatial plan. More detailed data should be considered especially for conflicts with the natural environment but also for the wind availability, seabed composition or to evaluate the conflict with other human interests and uses. Building of a knowledge base for MSP should not be limited to a database with documentation of the methods, scale and completeness of the input data but also include methods for creating sensibility indexes, conflict descriptions and similar.

Lessons learned

- Marxan represents a valuable and manageable tool for developing and visualizing scenarios for wind park planning.
- The complexity of factors that influence the siting of wind parks can be included into the system, however to do this, good data are needed in the respective coverage and resolution.

5. Discussion and conclusions

- The results for such a suitability evaluation depend much on the definition for targets and translation of suitability and potential conflicts into parameters that can be used in the model.
- Some parameters are political/planning decisions whereas others are quantitative and can be converted directly for use in Marxan
- Therefore a careful selection of these input values in the planning team has to be done and the chosen values and priorities should be clearly documented. If done so, the tool offers a very transparent and logical decision support for planners and visualization and awareness building tool for stakeholders.
- The integration of more features into the system is possible and is advisable to even better mirror and integrate all relevant factors for wind park siting decisions.
- The tool Marxan only displays scenarios and options and creates transparency – decisions have to be made by the responsible planners and have to be backed up in the political decision making process.

6. Acknowledgements and resources

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The Marxan software and Zonae cogito can be freely downloaded at <http://www.ecology.uq.edu.au>

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The BaltSeaPlan project in general

Activities

BaltSeaPlan activities were designed to support all major aspects of maritime spatial planning within the Baltic Sea region:

> Improving the joint information base / stocktaking for maritime spatial planning:

A forum for dialogue bringing together spatial planners and scientists to identify sources of data / information. Compiling current uses, conflicts and natural values of the Baltic Sea. Filling data gaps, exchange of data, improve integration of ecological and socio-economic data sets, identify relevant modelling methods, clarify MSP data needs.

> Including Spatial Planning in National Maritime Strategies

Assessment of national frameworks, methodologies and sectoral strategies that influence the use of sea space (e.g. energy, fishery, transport, tourism, as well as nature conservation)

Developing recommendations on spatial issues within National Maritime Strategies.

Exploiting the visions to foster a national cross-sectoral debate, discussing goals & targets for dealing with space and filling gaps in national sectoral policies & strategies

> Develop a Vision for Maritime Spatial Planning in the Baltic Sea 2030

taking into account transnational interdependencies and cumulative impacts

initiate a Baltic Sea region wide campaign as to discuss the BaltSeaPlan Vision 2030

> Demonstrate MSP in 8 pilot areas

- Danish Straights / T-Route (DK)
- Pomeranian Bight (DE/DK/SE/PL)
- Western Gulf of Gdansk (PL)
- Middle Bank (SE/PL)
- Lithuanian Sea (LT)
- Latvian Sea (LV)
- Pärnu Bay (EE)
- Hiiumaa and Saaremaa Islands (EE)

> Lobbying and capacity building for MSP

- stakeholder involvement & participative planning methods
- BaltSeaPlan series of guidelines & policy recommendations
- workshops & conferences for decision-makers

Partners

Germany

- Federal Maritime and Hydrographic Agency (BSH), Lead Partner
- Ministry of Energy, Infrastructure and Regional Development of Mecklenburg-Vorpommern
- WWF Germany, Baltic Sea Unit

Poland

- Maritime Office in Szczecin
- Maritime Office in Gdynia
- Maritime Institute in Gdańsk

Denmark

- Department of Bioscience, Aarhus University (formerly National Environmental Research Institute – NERI)

Sweden

- Royal Institute of Technology (KTH)
- Swedish Environmental Protection Agency

Estonia

- Estonian Marine Institute of University of Tartu
- Baltic Environmental Forum Estonia

Lithuania

- Klaipėda University Coastal Research and Planning Institute (CORPI)
- Baltic Environmental Forum Lithuania

Latvia

- Baltic Environmental Forum Latvia

BaltSeaPlan Publications

BaltSeaPlan Reports

- BaltSeaPlan Findings
- BaltSeaPlan Vision 2030 – Towards the sustainable planning of Baltic Sea space
- Become a Maritime Spatialist within 10 Minutes (EN, DE, LV, LT, PL, EE)
- BaltSeaPlan Bulletin #1
- BaltSeaPlan Bulletin #2
- BaltSeaPlan Project Flyer (EN, DE, LV, LT, PL, EE, SE)

Impact Assessments

- 1 - Strategies with relevance for Estonian maritime space
- 2 - Strategies with relevance for German maritime space
- 3 - Strategies with relevance for Latvian maritime space
- 4 - Strategies with relevance for Lithuanian maritime space
- 5 - Strategies with relevance for Polish maritime space
- 6 - Strategies with relevance for Russian maritime space
- 7 - Strategies with relevance for Swedish maritime space
- 8 - Implications of the international and national policy context for Baltic Sea space and MSP

Pilot MSP reports

- 9 - Developing a Pilot MSP for the Pomeranian Bight and Arkona Basin
- 10 - Developing a Pilot MSP for the Middle Bank
- 11 - Developing a Pilot SEA for the Western Gulf of Gdansk
- 12 - Preparing for a MSP at the Danish Straits
- 13 - Towards a Pilot MSP for the Pärnu Bay
- 14 - Towards a Pilot MSP for the Saaremaa and Hiiumaa Islands
- 15 - Towards a Pilot MSP for the Lithuanian Sea
- 16 - Developing a Pilot MSP for the Western Coast of Latvia

MSPs and SEA

- 17 - Pilot MSP for the Western Coast of Latvia (LV)
- 18 - SEA for the Western Gulf of Gdansk (PL)

Technical reports

- 19 - Modelling for MSP – Tools, concepts, applications
- 20 - Data exchange structure for MSP
- 21 - Effects of underwater noise on harbour porpoises around major shipping lanes
- 22 - Remote sensing methods for detecting small fishing vessels and fishing gear
- 23 - Legal and planning options for integrating fisheries into Maritime Spatial Planning
- 24 - Stakeholder Involvement in MSP
- 25 - SEA in MSP: Recommendations from the German and Polish experience
- 26 - Fisheries in the MSP context
- 27 - Seabed and habitat mapping in the Hatter Barn area
- 28 - BaltSeaPlan Web-advanced tool in support of MSP
- 29 - Case Study: Systematic site selection for offshore windpower with Marxan in the pilot area Pomeranian Bight
- 30 - Case Study: Site selection of fisheries areas for MSP
- 31 - Recommendations for legislative action regarding the MSP in Europe

Maritime Spatial Planning (MSP) has become a widely acknowledged and necessary tool for co-ordinating spatial use and balancing of interests in the sea. In view of expanding activities such as offshore wind energy parks and growing shipping traffic and at the same time increasing needs to protect the marine environment a systematic, integrative and forward-looking planning is required in order to safeguard the sustainable development of the seas. Currently, however, this tool is far from being established practice.

The 3.7 million € INTERREG IVB project “**BaltSeaPlan**” (2009–2012) has been the largest project in recent years dealing with maritime spatial planning throughout the Baltic Sea Region. Under the lead of the German Federal Maritime and Hydrographic Agency (BSH) and covering partners from all Baltic Sea countries (except Finland) the project has not only developed pilots in 8 demonstration areas, but also advanced methods, instruments & tools as well as data exchange necessary for an effective maritime spatial planning.

The results of BaltSeaPlan are published in a series of reports all available for free download under www.baltseaplan.eu.

The development of offshore wind energy is a driving force for looking at sea uses in a more integrated way and to develop Maritime Spatial Planning. The modelling tool MARXAN is a tool known to be used for selection of sites for nature protection. The **BaltSeaPlan Report № 29 “Case Study: Systematic site selection for offshore windpower”** shows how this tool was adapted during BaltSeaPlan to identify suitable sites for offshore wind energy production taking into account the targets of the wind sector and the limitations to it set by nature conservation demands, tourism or shipping. The model was used in the pilot area Pomeranian Bight / Arcona Sea to identify locations for offshore wind energy.
