Alpine Windharvest

ALPINE WINDHARVEST

Development of information base regarding potentials and the necessary technical, legal and socio-economic conditions for expanding wind energy in the Alpine Space*

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GIS Analysis 'Franches Montagnes', Switzerland

(Documentation of GIS Concepts, Methods and Results)

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…is an interdisciplinary research project funded by the EU Interreg IIIB "Alpine Space Programme" (Project No. A/I-2/3.1/5) and by national and regional co-financing bodies of the project partners. The project started in May 2002 and will end at the end of April 2005.

Background of the project:

Wind power became a leading renewable energy technology in flat terrain, especially near shore. While the alpine space also promises some excellent wind locations, much of the knowledge and experience accumulated about wind power so far cannot simply be transferred to the alpine setting.

The lack of experience concerns all levels of government confronted with problems of siting, spatial planning, nature protection/environmental impact analyses, road and electric grid requirements, appropriate tariff regulation etc. The project aims at remedying these deficiencies.

This lack of experience also regards entrepreneurs, investors and even producers of equipment given the special climatic and geological conditions. This increases economic risks, inhibits site exploration and planning activities even for attractive locations. The small number of existing projects in the alpine space impedes standard procedures.

Lack of experience also affects the acceptance of wind power by nature protection organisations and local residents. There is much need for additional knowledge and information; standard models for the resolution/mediation of conflicts will be useful.

For this reason, it is essential to pool the limited experience with wind power in the alpine space for synergy effects, cross-fertilisation and greater efficiency in developing data sets, methods, approaches and solutions for public and private actors, particularly since many of the underlying phenomena are trans-national while most research so far was primarily national (e.g. meteorology).

A common approach will facilitate a harmonised European approach to the problems under consideration, particularly with regard to government policy.

Main activities:

Develop knowledge basis for deploying wind energy:

a) Methods and instruments for identifying wind energy potential in complex terrain more efficiently (meteorologists, geographers, digital relief analyses and actual wind measurements; includes pilot measurements on specific locations).

b) Deal with problems peculiar to wind turbines in alpine conditions (blade icing; access - need for special mounting equipment); standardise technologies, estimates of access requirements (roads and grid). Common approaches for entire alpine space will create bigger market for improvements and induce responses from equipment manufacturers.

c) Analyse ecological impact of turbines in different alpine settings on fauna and flora according to altitude, soil/rock and meteorological conditions; establish check list of factors for whole alpine space. Develop strategies to minimise impact. Improve information for local/ regional authorities.

d) Analyse and compare legal, social, political and economic framework conditions for deployment of wind power in alpine space and their impact on its competitiveness. Formulate regulatory proposals.

e) Prepare methods of resolving conflicts between wind power and other interests (environmental organisations, local residents, hunting). Improve visualisations (more difficult in alpine terrain), standardise participation in administrative procedures and mediation. Facilitate work of local and regional authorities.

f) Measure potential contribution of this energy source to regional development, particularly when joined with hydro storage and electricity generation from biomass.

Alpine Windharvest Report Series:

The Alpine Windharvest Report Series is published by the Alpine Windharvest partnership network in order to disseminate the results of the project to the interested public and to experts in the field. Reports are edited by the responsible project partner(s) who commissioned and approved the report according to our internal division of labour. Reports can be downloaded from our homepage. Printed versions can be directly ordered from the project coordinator by e-mail: dieter.pesendorfer@sbg.ac.at.

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Documentation of GIS Concepts, Methods and Results

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Abstract

In work package 7 of the Interreg III b project "Alpine Windharvest", a test area called "Franches Montagnes" was examined with a Geographical Information System (GIS) in order to find the most suitable sites for wind power installations. The main principles of GIS modeling are described in the Workbook for Wind Energy GIS Analysis (Alpine Windharvest Report No. 7-3), this report covers the specific aspects of the model built for the Franches Montagnes test area.

The aim of the analysis was to find the most interesting sites within the test area, where wind power projects are most promising. It was set up as a decision support system, and the result should not be perceived as a wind power potential inventory.

The GIS model covers an area of 30x30 km in the north-western part of the Swiss Jura mountains. Seven layers were used as input data. For each of them, criteria were set up to define the suitable parts of the area. The most significant layer is wind velocity (threshold set to 5.5 m/s at 70m a.g.l.), followed by forests and slopes, settlements and protected areas. Almost no restriction comes from unstable grounds and water surfaces in the area.

With the given criteria, a portion of 1.2% of the test area can be considered to be suitable for wind power projects, which is a good result because it leads to the most interesting sites.

If a wind velocity threshold of 4.5 m/s was applied instead, an area of 5.8% would be considered to be suitable, which is close to the result of a Swiss national study of 2004 that covered the Franches Montagnes as well, but followed the lines of a wind potential inventory model.

The model depends on adequate, accurate and reliable input data, otherwise the concept is quite simple. It can be transferred to other areas and adapted to different conditions.

Table of Contents

1. Introduction

This report covers the methods and results of the GIS analysis for the Franches Montagnes test area in work package 7 of the Interreg III b project "Alpine Windharvest". The aim of this GIS analysis is to identify the most suitable areas for wind turbine installation according to a defined set of criteria.

As a base principle and according to the guidelines in the "Workbook for Wind Energy GIS Analysis"[1], the GIS methods for wind power site identification developed in Windharvest WP7 should be applicable even if only few GIS data are available, and even with little time and finance resources.

In 2003/2004, in the course of a nation-wide study "Wind Energy Concept for Switzerland"[2], a methodology was developed and applied that met much wider goals. It was set up as an inventory of possible wind power sites in Switzerland, out of which the best sites were to be identified. Thus, a basis was to be created for introducing wind power into land use regulation plans, along with a discussion forum for the exchange of diverging opinions among experts. That GIS model used many GIS data layers and a series of quite complicated criteria that included some political aspects of wind power development in Switzerland. For example, the wind power sites identified by the model were re-drawn by hand in order to better fit into the landscape chambers.

The Alpine Windharvest GIS model for the Franches Montagnes takes most input data from that study and benefits largely from the inherent conceptual work. The big exception is the wind velocity layer that was extracted from the Alpine-wide model output, whereas for the Swiss study a different wind model based on an finer DTM was used.

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1 Dällenbach et al., 2005: Workbook for Wind Energy GIS Analysis. Alpine Windharvest Report No. 7-3.

2 Swiss Federal Office of Energy, 2004: Konzept Windenergie Schweiz.

2. GIS Data Specifications

2.1. Extent, projection, resolution

The Franches Montagnes test area (fig. 1) is approx. 30x30 km wide and covers a part of the Jura mountains with areas of fairly good wind conditions and some existing as well as planned wind power plants. The area is situated across the French-Swiss border. Since data were available only for Switzerland, the French part of the test area (22%) was not examined. The remaining part covers an area of 700 km^2.

Area extent: Lower left: 554'975/219'975 – upper right: 585'025/250'025 m [3]

All the input layers, including the wind model data from the Alpine region, were present in a raster format, therefore the operational format in the Franches Montagnes test area was raster as well.

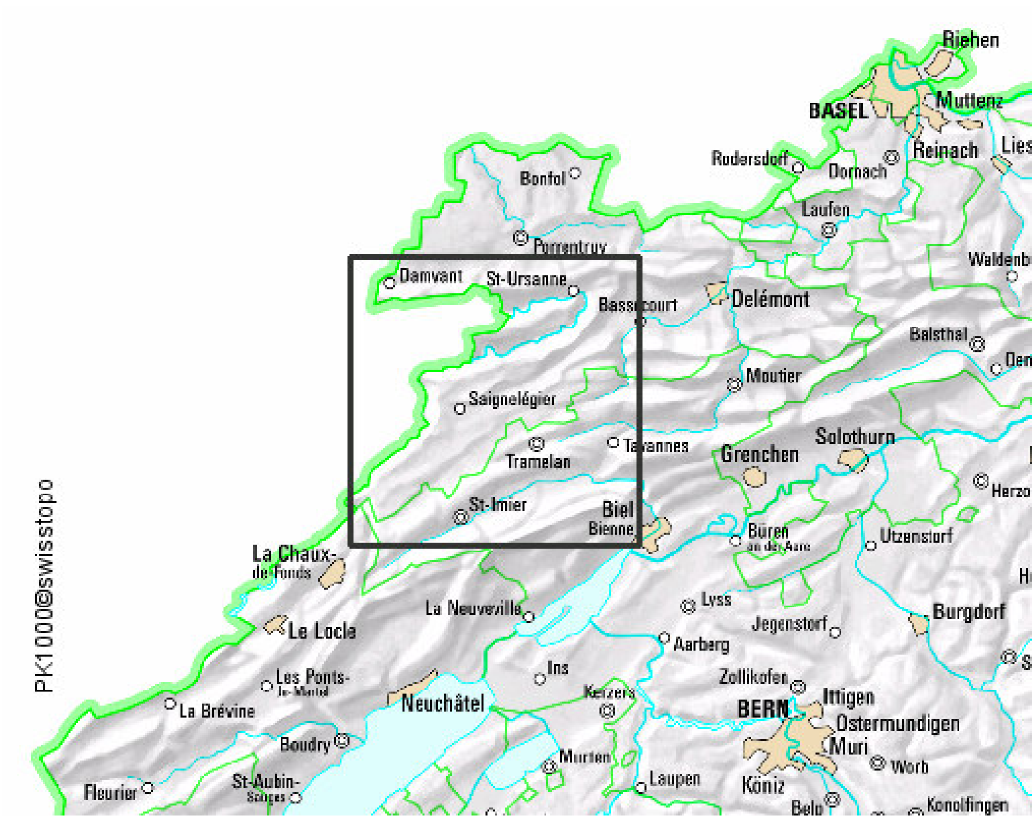

Fig. 1: Extent of the Franches Montagnes test area in NW Switzerland.

[3] Co-ordinates are based on the Swiss Grid, details are available on http://www.swisstopo.ch/de/geo/projektion.htm (in German)

Model resolution was set to 50x50m, the same as for the Wind Energy Concept for Switzerland mentioned in the introduction.

The edge co-ordinates are set in a way that the centre of each 50x50m raster cell is at a multiple of 50m (model resolution), and in a way that the cells fit into the raster with the data from the Wind Energy Concept for Switzerland.

2.2. Included layers and criteria

The input layers and exclusion criteria listed in table 1 were used to construct the GIS model for the Franches Montagnes test area. No rule was defined for street access, since all of the test area was considered accessible with an economically acceptable effort.

Tab. 1: Layers and criteria used in the Franches Montagnes test area GIS model.

Layer	Description
Wind veloc-ity	Mean annual wind velocity at 70m a.g.l. (hub height), model output. Areas with < 5.5. m/s are excluded. Data source: Alpine wind model, 250m resolution, *METEOTEST*
Forests	Forests and open forests, excluded due to strict Swiss legal protection, with a surrounding buffer of 50m. Data source: Swiss dataset VECTOR 25, by Federal Office of Topography [4]
Slopes	Slopes with >20% are excluded because construction of access tracks or foundations is considered too expensive. Data source: Swiss DHM 25m resolution, by Federal Office of Topography
Settlement	Hectares considered inhabited with >= 1 permanent inhabitant, excluded due to various possible impacts from wind power plants, with a buffer of 300m. Data source: Swiss national census 1990, hectares
Protected areas	Zones excluded because of wildlife and/or landscape protection on a na-tional level, with a buffer of 200m. Data source: Several layers, mostly from Swiss Agency for the Environment, Forests and Landscape [5]
Grounds	Areas with unstable grounds where costs for foundations are considered too expensive. Data source: Swiss dataset VECTOR 25, by Federal Office of Topography
Lakes	Lake surfaces, excluded due to high legal and technical requirements (no buffer). Data source: Swiss dataset VECTOR 25, by Federal Office of Topography

[4] www.swisstopo.ch

[5] www.umwelt-schweiz.ch/buwal/eng/index.html

3. GIS Methods

3.1. Software

With a few exceptions, GIS data processing was done under ArcGIS® 8.3[6] using ArcCatalog®, ArcToolbox® and SpatialAnalyst® Raster Calculator.

3.2. Data preprocessing

1. Data projection

Only the wind velocity layer had to be projected, since it arrived from model output in UTM co-ordinates. All other layers were already represented in the Swiss national co-ordinate system.

For the projection in ArcInfo® the following parameter file was used:

```
input
projection UTM
datum WGS84
units METERS
zone 33
parameters
output
projection OBLIQUE_MERCATOR
datum USER_DEFINED 674.000 14.000 405.000 0.0000 0.0000 0.0000 0.0000
units METERS
spheroid BESSEL
parameter
2
1.00000
7 26 22.500
46 57  8.660
90.00000
-9419820.5907
200000.00000
end
```

2. Clipping input data to test area extent, resampling

Except for the wind data, the original datasets were simply clipped to the test area.

The wind velocity layer arrived from modeling output and projection with a cell size of 250x250m, and with a different raster origin than all the other data. By resampling the layer to the 50m cell size with a bilinear interpolation, data was transferred into the project's spatial definition (fig. 2).

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[6] ArcGIS, ArcInfo, ArcCatalog, ArcToolbox and SpatialAnalyst are registered trade marks by ESRI, Environmental Systems Research Institute, Redlands, CA, USA

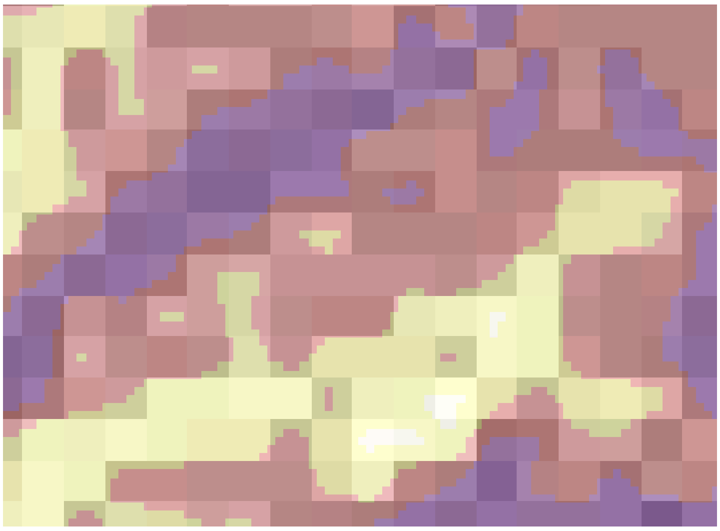

Fig. 2: Overlay of wind velocity layers before (gray) and after resampling (colored) from 250 to 50 cell size, using a bilinear interpolation.

3.3. GIS analysis

GIS analysis mainly consisted in reclassifying the input layers according to the criteria in table 1. The resulting layers contain purely 1/0 values, indicating whether a cell may be used for wind power installation (1) or not (0). They are displayed in the figures on the following pages. Each layer has a specific effect of exclusion, which indicates its relevance in the model:

In each layer, all suitable grid cells, according to the layer's criteria, were assigned a value of 1, all unsuitable cells a value of 0.

Tab. 2: Input layers and their rate of exclusion.

Layer	**Exclusion rate**
Wind velocity	90.5%
Forests	59.1%
Slope	42.2%
Settlement	41.4%
Protected areas	26.8%
Grounds	0.4%
Lakes	0.1%

Of course, areas happen to be excluded by more than one layer, therefore the sum of exclusion amounts to more than 100%.

Wind velocity

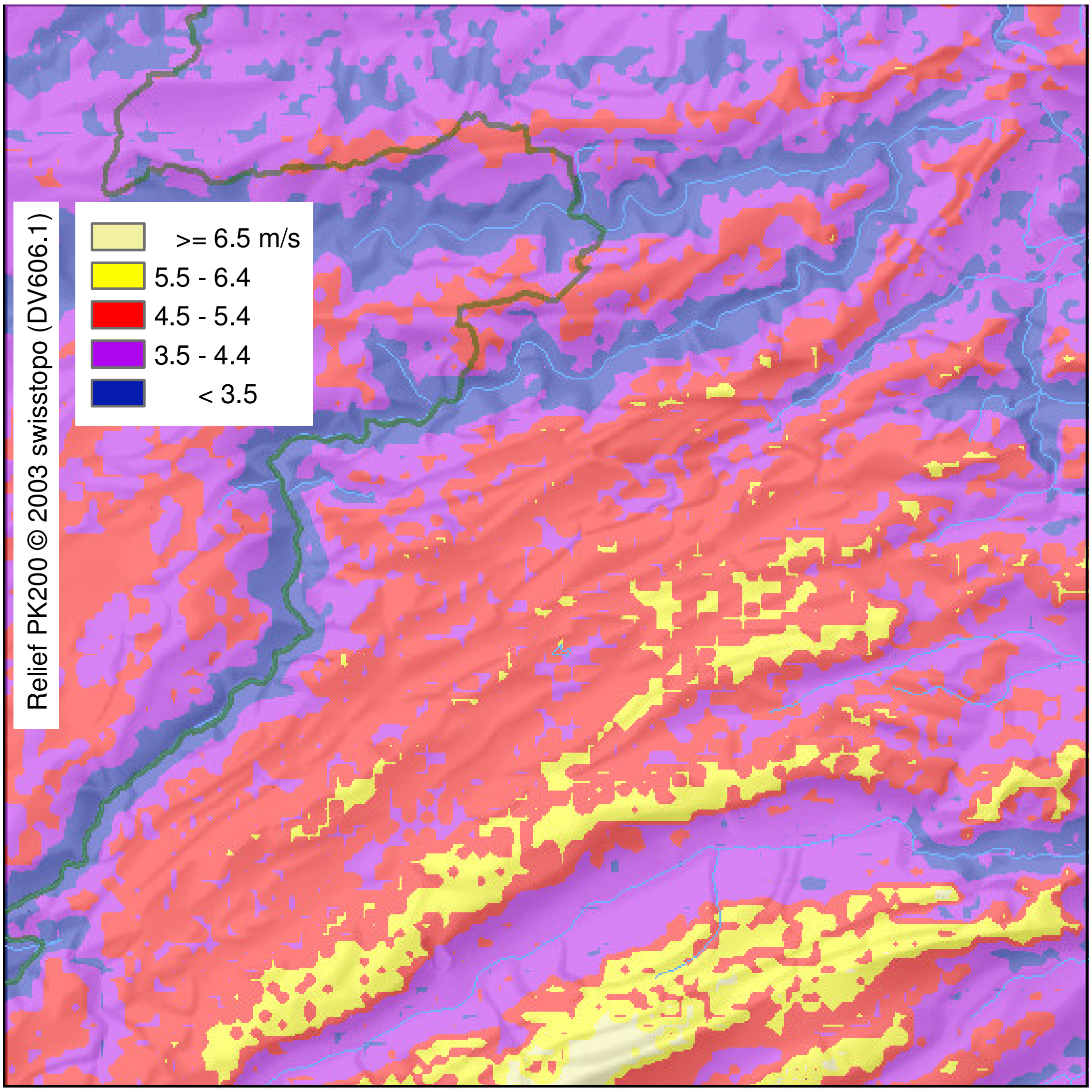

Fig. 3: Mean annual wind velocity at 70m a.g.l.

Highest values (> 7 m/s) are reached in the south of the test area, on a ridge that will largely be excluded due to landscape protection. The limit of suitability for wind power exploitation was set to 5.5 m/s, including the yellow and bright yellow surfaces.

Forests

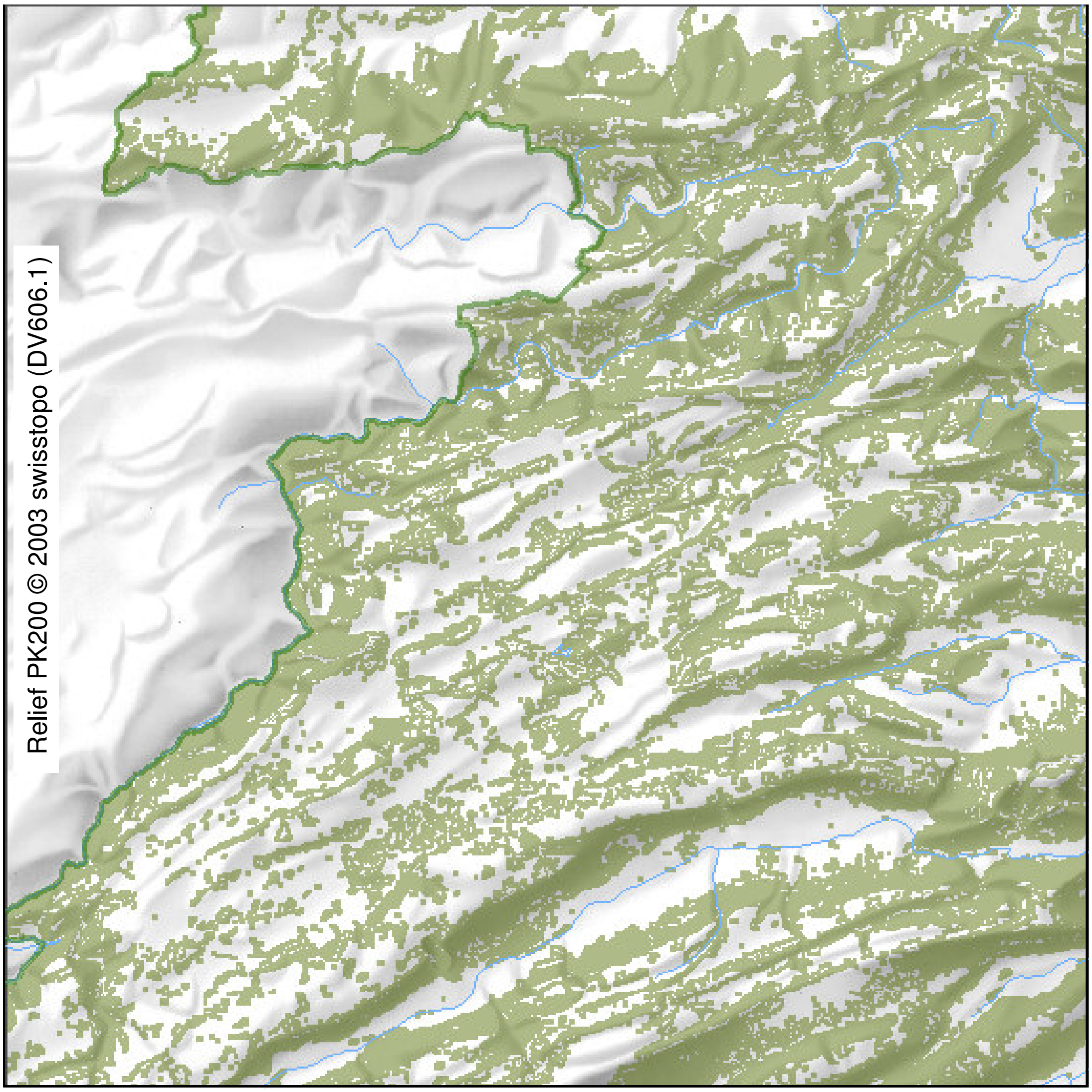

Fig. 4: Areas excluded from wind power exploitation due to forest cover.

In Switzerland, forests are submitted to an almost absolute protection by laws on a national level. In a statement in the course of the work on the Wind Energy Concept for Switzerland, the national forest authorities considered the installation of wind turbines in forests virtually impossible, even in the areas of open forests that are quite common in the test area perimeter.

Wildlife and landscape protection

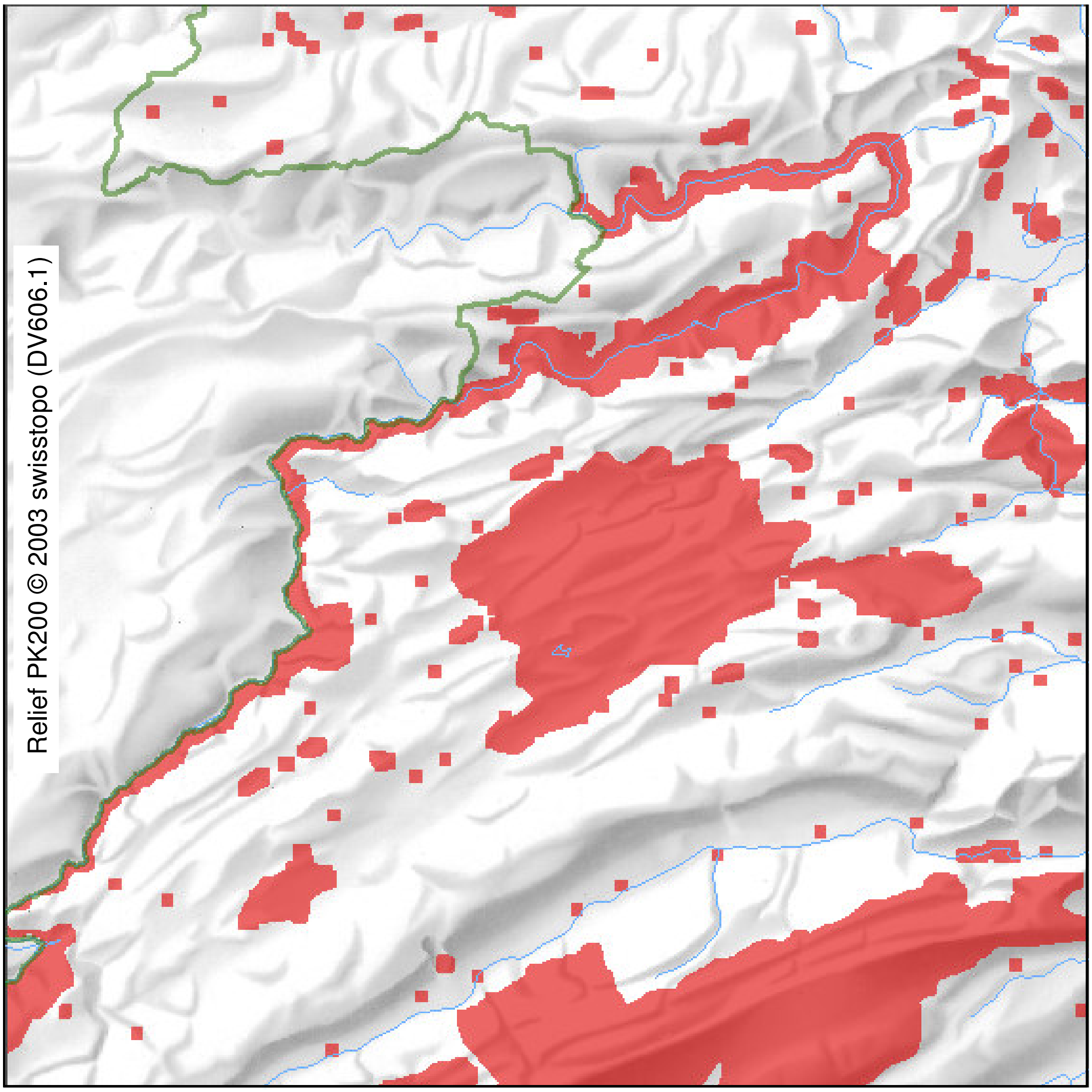

Fig. 5: Areas protected for wildlife or landscape reasons.

Only national inventories have been used for this analysis. Additional areas may be protected on a regional or local level. The large protected areas are landscapes of national interest and protected marshlands. The small single squares cover centers of villages and towns listed in the Inventory of Swiss Heritage Sites [7].

[7] refer to www.isos.ch

Settlements

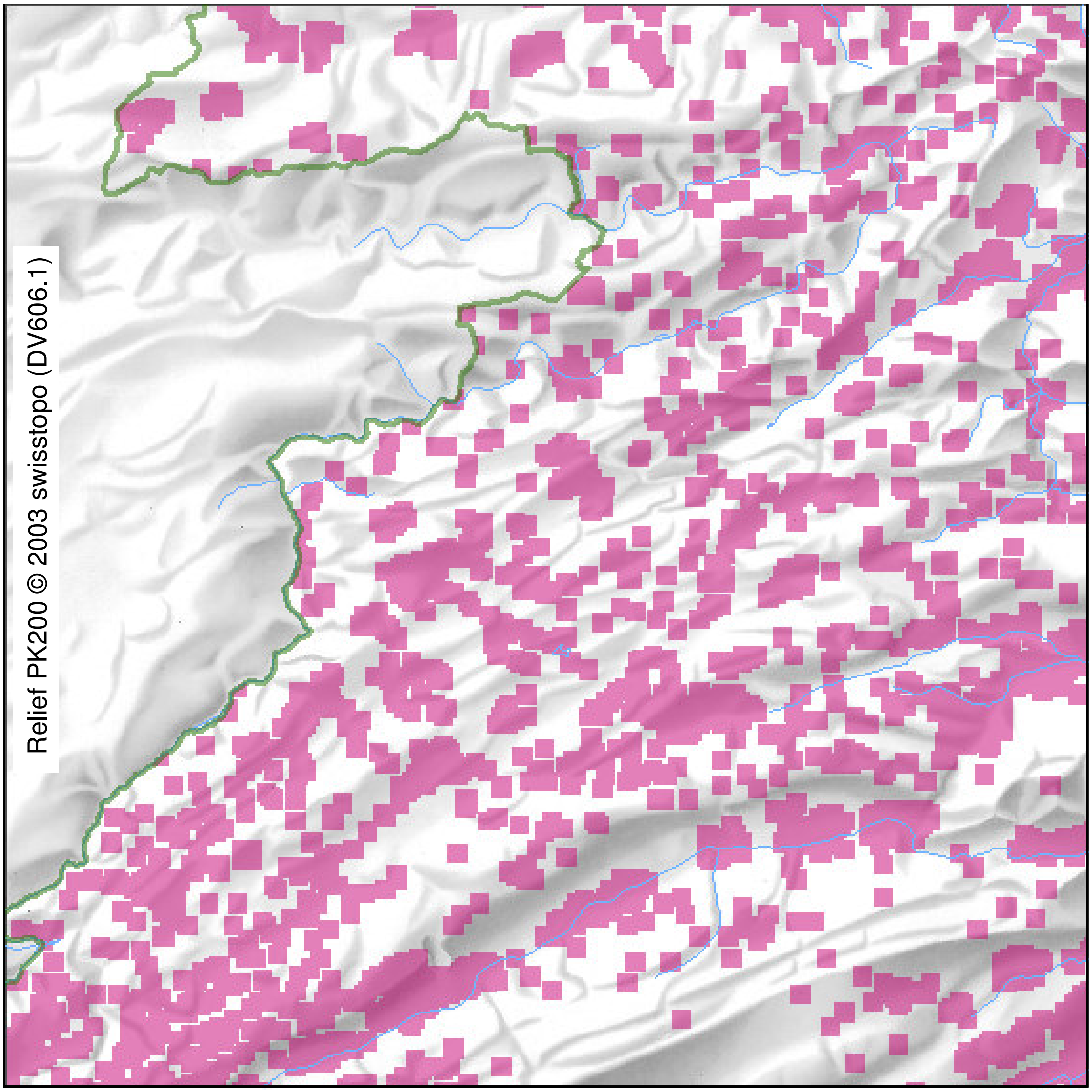

Fig. 6: Excluded Inhabited areas, with a square buffer of 300m.

Inhabited areas are excluded for wind power plants because of the possibility of noise immission, light flickering or ice fall. Hectares are considered inhabited with at least 1 permanent inhabitant, according to the 1999-census. A buffer of 300m was defined around inhabited areas according to discussions with a number of experts.

Slope

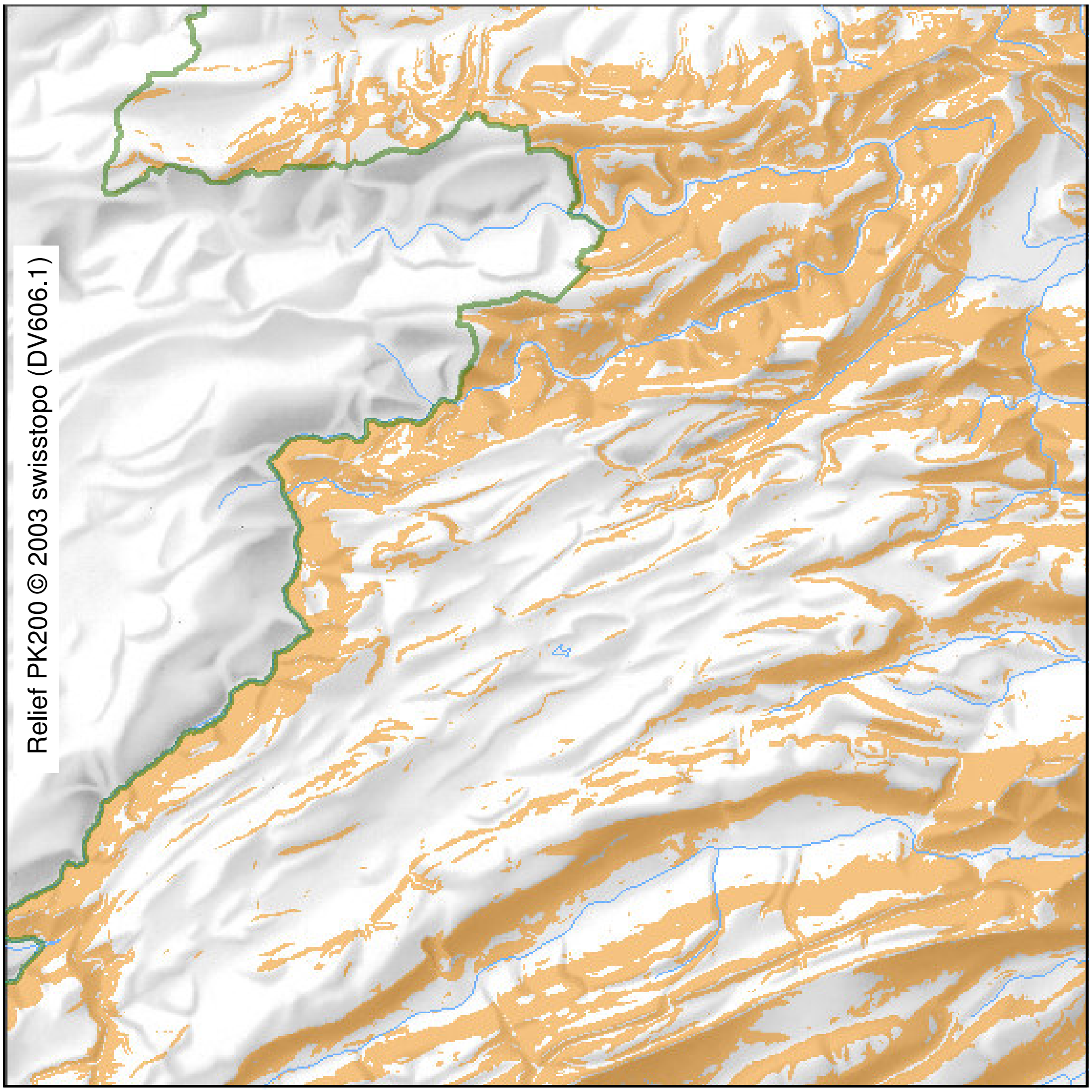

Fig. 7: Areas with slopes of > 20% considered unsuitable.

Basically, it is assumed that every part of the test area can be reached with heavy lorries, e.g. by means of temporary tracks that can be constructed with a reasonable economical effort.

With the steepness, the costs for building such access tracks and foundations increase and may at some point exceed the economic revenue of the wind turbine to be installed. This threshold was established at 20% slope after discussions with engineers.

Unstable grounds, lakes, swamps

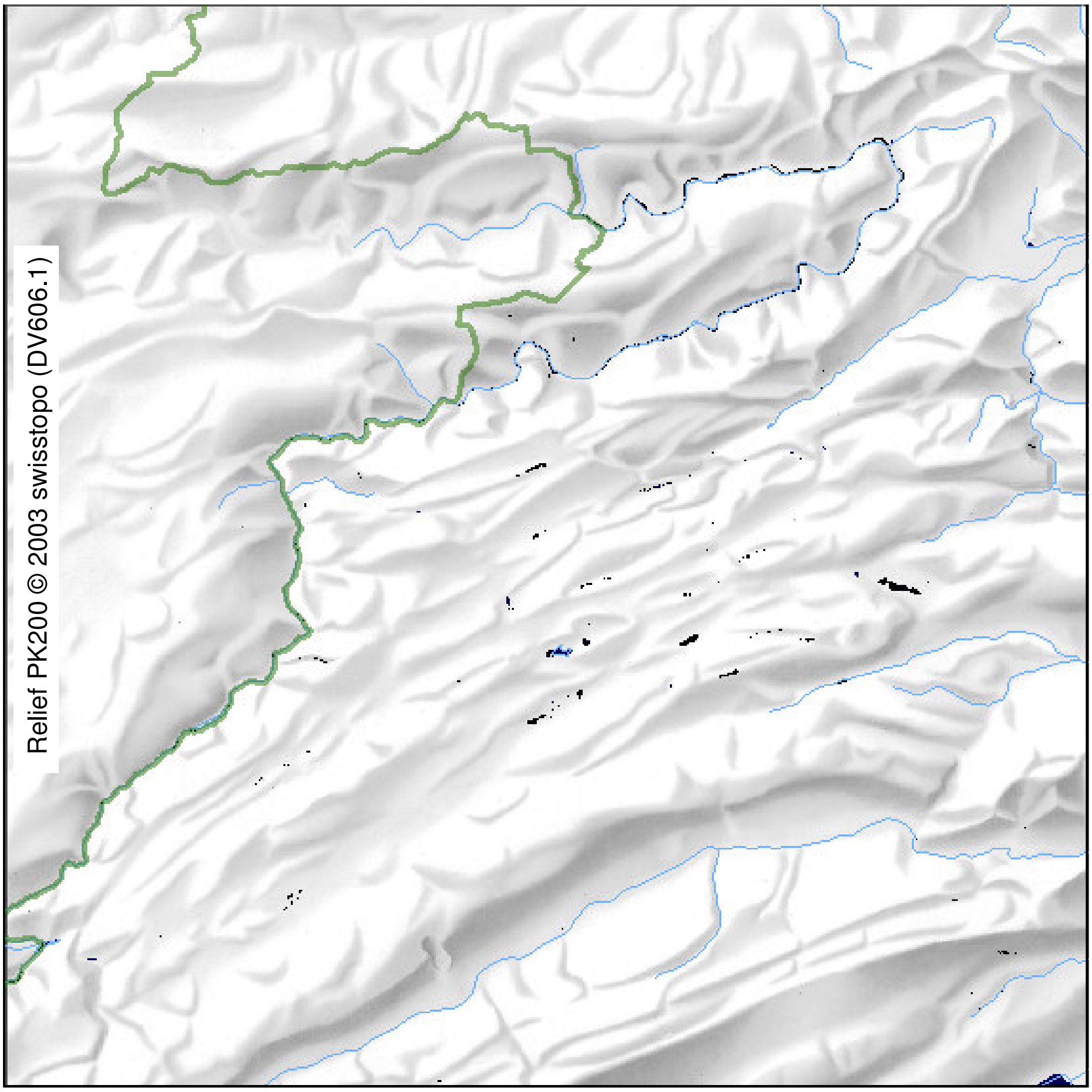

Fig. 8: Unstable grounds and water surfaces, unsuitable for wind turbine installation.

Marshlands, river beds and small lakes together cover only a very small part of the test area surface.

4. Results

4.1. Evaluation of model results

The resulting, so-called preferred areas for wind power installations (fig. 9) are those that are not covered by any restriction from one of the input layers used in the model (i.e. grid cells with value 1 in each input layer).

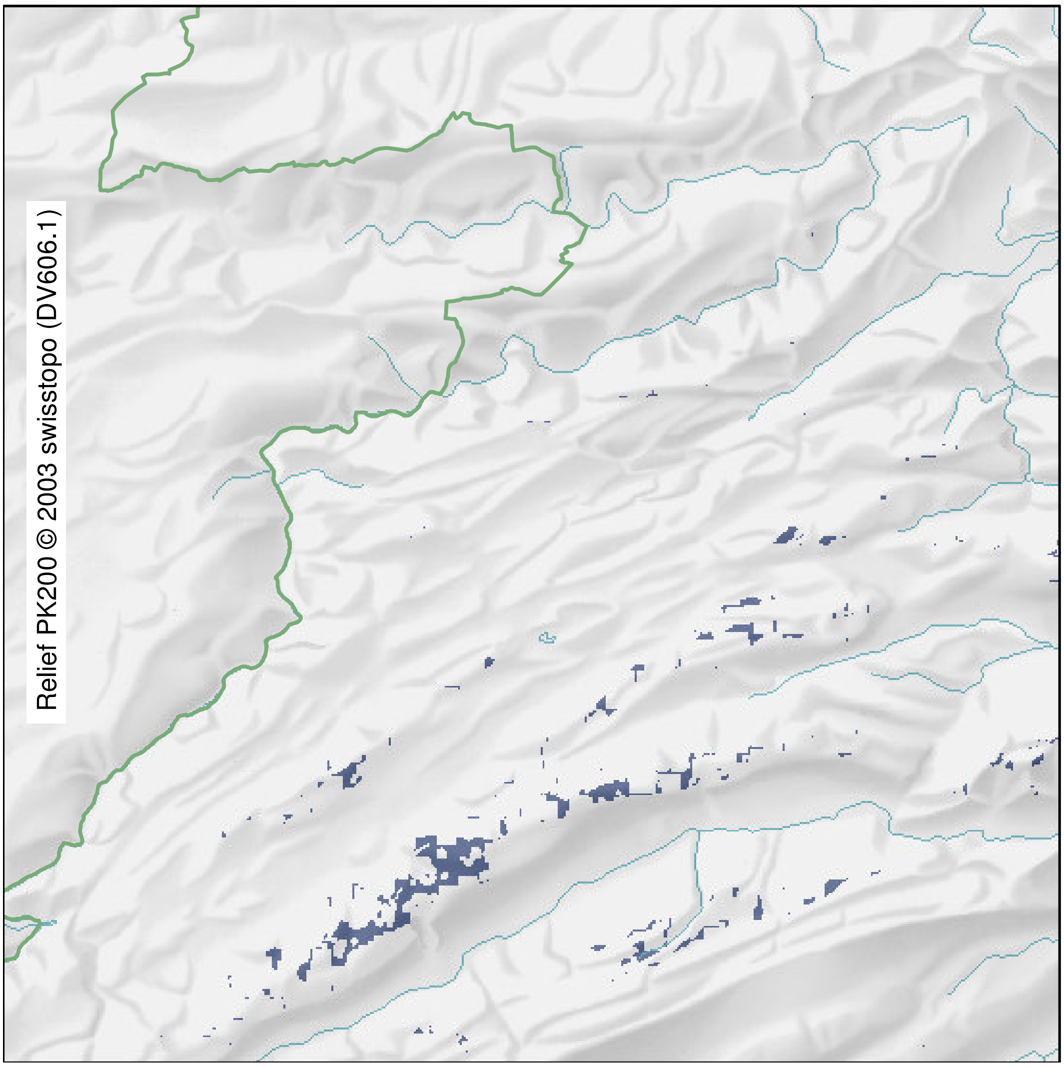

Fig. 9: Preferred areas without restrictions in any of the input layers.

In the test area, the preferred area covers a surface of 8.5 km^2 or only slightly more than 1%. All the rest is covered by at least one restriction layer. Roughly 2/3 of the area are excluded by 2 or 3 criteria, however no cell is excluded in all 7 layers.

Tab. 3: Parts of the test area per number of restricting layers.

No. of restrictions	% of Test Area
0	1.2
1	12.6
2	31.7
3	35.7
4	16.5
5	2.3
6	< 0.1
7	0.0

The geographical interpretation shows that the preferred areas lie on the flat ridges with the highest wind speeds in the test area, in the open spaces mostly used as pastures and outside the inhabited areas (fig 10).

It is a nice confirmation of the model concept and parameters that the site with existing wind power plants appears among the unrestricted, preferred areas (fig. 10).

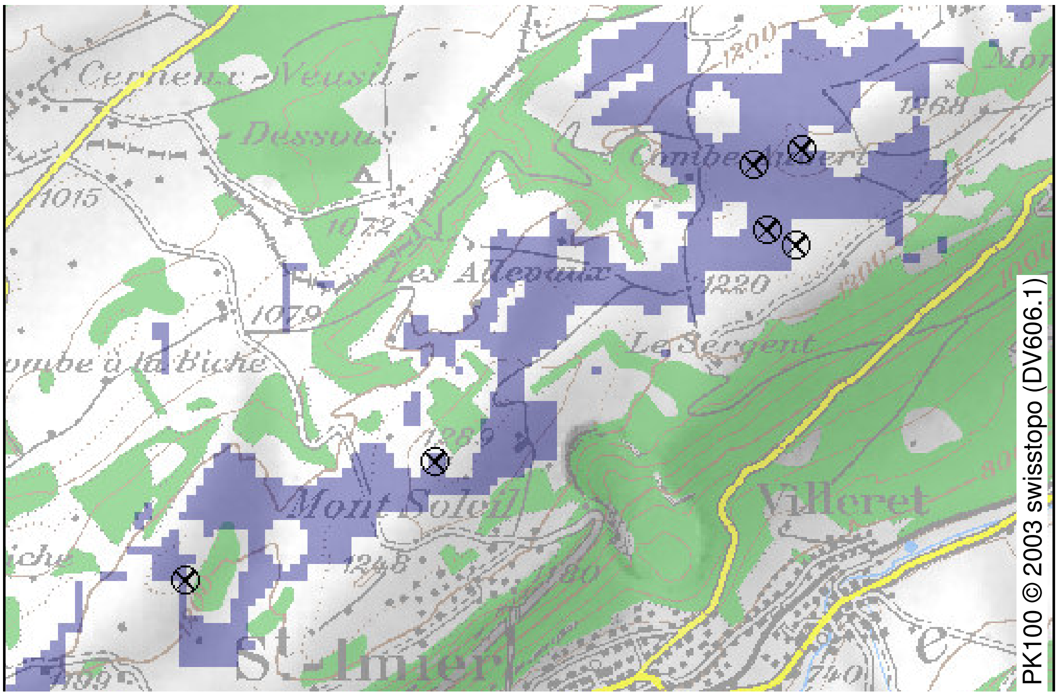

Fig. 10: Preferred areas according to model output (blue) and existing wind power plants in the Mt. Crosin/Mt. Soleil area.

4.2. Scenario: 4.5 m/s wind velocity threshold

In order to evaluate model sensitivity, we examined a scenario with a lower suitability limit of 4.5 instead of 5.5 m/s annual average wind velocity, which is the most distinguishing input layer.

Wind velocity distribution in the test area shows the characteristics illustrated in fig. 11, with absolute minimum/maximum values of 1.9 m/s and 7.3 m/s respectively.

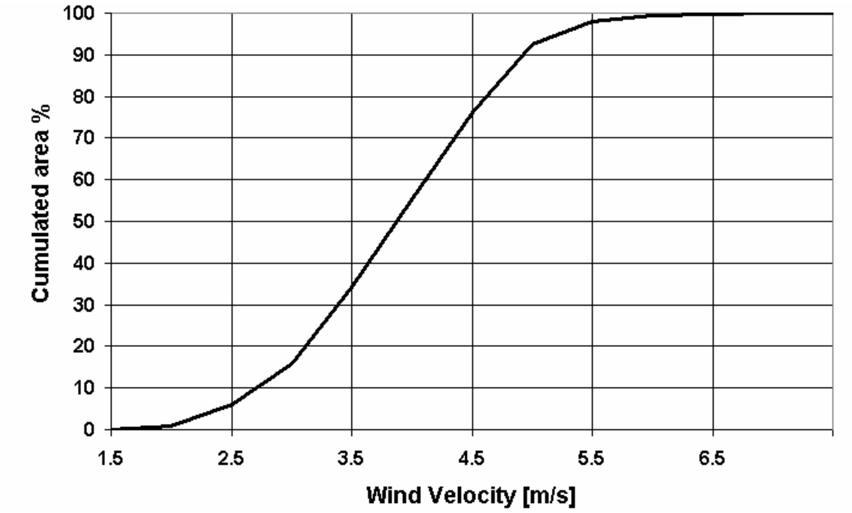

Fig. 11: Area distribution of wind velocity in the Franches Montagnes test area.

It is clear that with a lower wind velocity threshold of 4.5 instead of 5.5 m/s , a significantly larger portion of the test area will be considered suitable (roughly 25% instead of 2.5% of the wind velocity layer).

Large parts of the high plateaus in the test area are in a wind regime of approx. 5 m/s annual average. The map in fig. 12 shows that most of them would be included at a threshold of 4.5 m/s, but only the higher ridges appear as suitable with a threshold of 5.5 m/s (fig. 3).

In the resulting layer, a lower limit of 4.5 instead of 5.5 m/s leads to a noticeable increase of the preferred area (5.8% instead of 1.2%, see fig. 13). A threshold of 4.5 m/s is therefore less suitable for finding the really best sites in the area, but would provide a more general inventory of wind power potential.

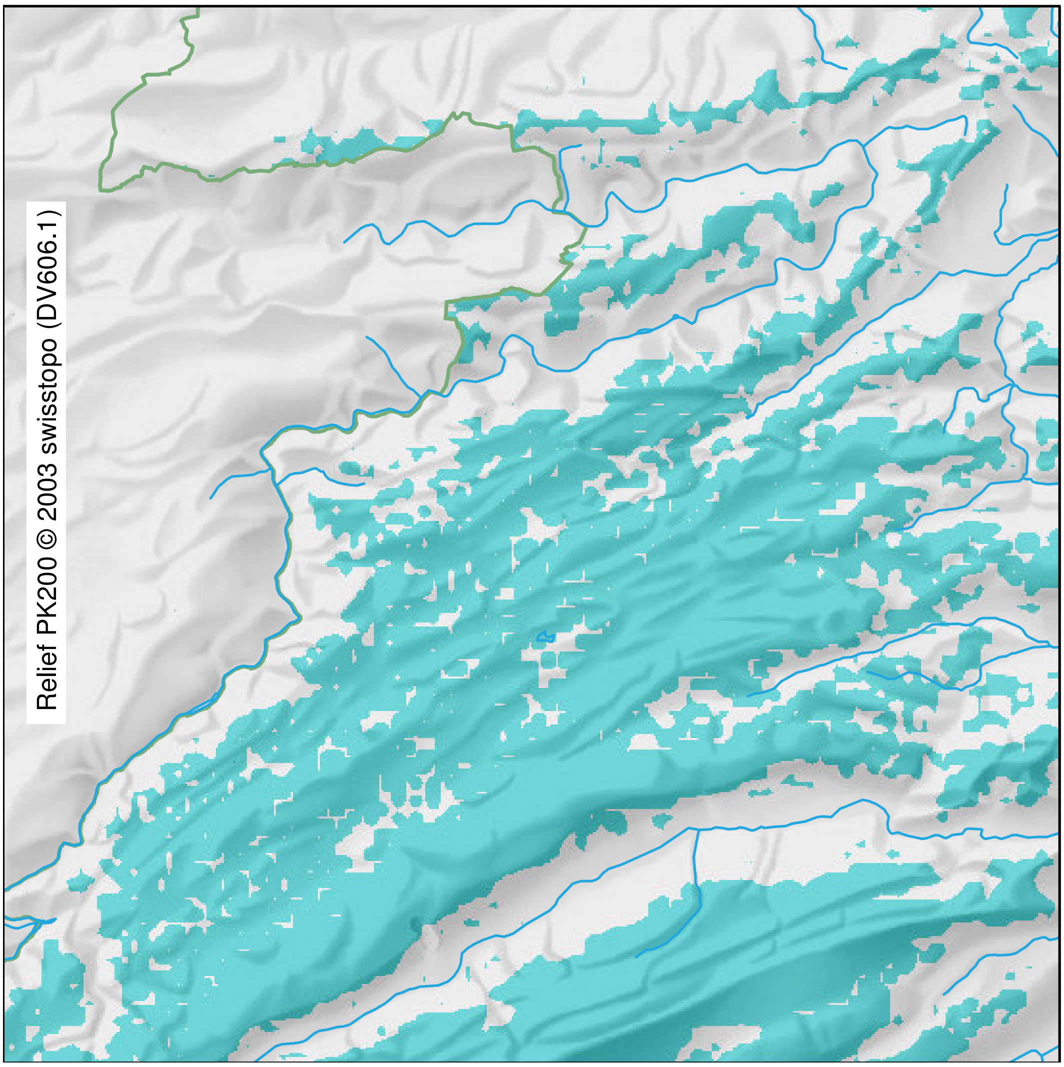

Fig. 12: Areas above a wind velocity threshold of 4.5 m/s (blue).

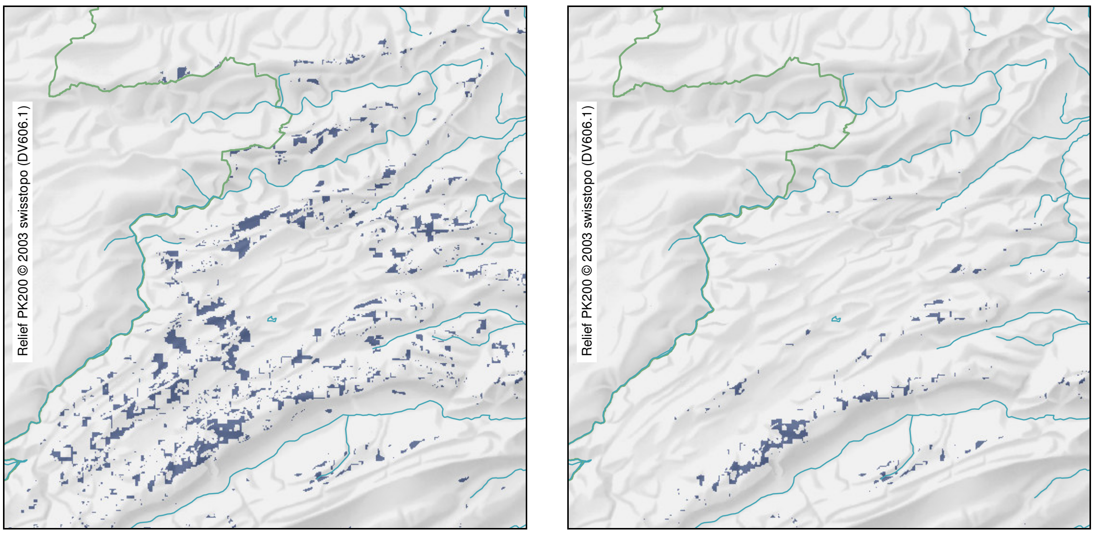

Fig. 13: Preferred areas at a wind velocity threshold of 4.5 m/s (scenario, left) and 5.5 m/s (model output, right).

4.3. Comparison to the Wind Energy Concept for Switzerland

In the course of the Wind Energy Concept for Switzerland project, a layer similar to the preferred areas was produced as an intermediate result, based on which the most interesting sites were identified and re-designed manually.

Most of the criteria and input data are the same as those used for the Franches Montagnes test area, but the model results cannot be compared directly for 2 reasons:

- The most important difference is that the new wind speed layer for the Wind Energy Concept for Switzerland was taken from a more precise model with a smaller target scale and resolution. To compare the results means therefore basically to compare the two wind velocity layers.
- The second difference is that in the Wind Energy Concept for Switzerland, forest areas were not yet excluded at this stage of the modeling process. Instead, a higher threshold of 5.5. m/s of wind velocity was applied to forested areas, according to the principle that the promised energy yield has to be more interesting in areas with stronger restrictions. Only very few forested areas in the test area reach 5.5 m/s.

Tab. 4: Preferred areas for wind power exploitation in the extent of the Franches Montagnes test area, comparison of different model outputs.

	Preferred area	
Model	**km^2**	**% of test area**
Wind Energy Concept for Switzerland	30.7	4.4 %
Current GIS analysis, scenario with 4.5 m/s threshold	40.6	5.8 %
Current GIS analysis, results with 5.5 m/s threshold	8.5	1.2 %

5. Conclusions

The model concept applied to the Franches Montagnes test area was designed in order to find the most interesting sites for wind power projects. Criteria thresholds were set to quite strict levels, in order to identify the most promising parts in an area that is already known as suitable for wind power exploitation, in fact it holds the largest wind park in Switzerland today.

The model was built as a decision support system in the service of a hypothetical wind power promoter who needs high precision information. The aim was not to produce an inventory with a rather statistical aspiration, where even terrains with medium suitability might be listed in a first approach to get the general characteristics of the region, but to show the most interesting sites.

The input data used for the current analysis cover most of the criteria that are relevant for a wind power project in Switzerland on a national level, although there might be additional information available on a regional and local scale. Data and criteria were mostly taken from the Wind Energy Concept for Switzerland without much further reflexion, except for the definition of the wind velocity threshold.

The wind velocity layer proved to be the most significant level in the model. Using a threshold of 5.5 m/s for mean annual wind velocity, the result is slightly more than 1% of the examined area that is considered unrestricted and therefore preferred. Lowering the criteria thresholds especially for wind velocity would result in an increase of the unrestricted area, increasing the requirements would soon lead to the exclusion of the entire surface.

Even though the results match the existing wind park in the area, the limitations of the model must not be neglected. The wind velocity model output for the entire Alpine region carries a statistical error of up to +/-1.5 m/s, with a tendency to lower errors in areas with good measurement data, which is the case in the current test area. In general, criteria thresholds were set in a conservative way in order for the model to provide a reliable result.

Even in the areas now identified as unrestricted, it is crucial that at the beginning of a new wind power project a detailed study be established to examine the local situation, especially concerning the following aspects:

- Wind conditions
- Ecology / environment
- Legal framework
- Political acceptance