Regional wind resource mapping in non-mountainous terrain

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SYNOPSIS

A methodology for wind resource mapping has been developed and employed to establish a detailed and reliable Wind Resource Atlas for Denmark. Wind atlas analysis, interpolation of wind atlas data sets, automated generation of digital terrain descriptions and WAsP modelling are elements of the method. The atlas contains wind speed and direction distributions for 12 sectors and four heights: 25, 45, 70 and 100 m a.g.l. The spatial resolution is 200 metres. The atlas has been verified by comparison with actual wind turbine power productions from over 1200 turbines. More than 80% of these turbines were predicted to within 10%.

INTRODUCTION

Detailed information on the actual wind resource of a region or an entire country is a prerequisite for the optimal utilisation of wind energy on a large scale. In the past, this information was often given as the wind resource potential, i.e. in the form of a *wind atlas* (9). The wind atlas, however, does not provide directly the detailed information required for planning purposes and siting of large wind farms; it only forms the necessary basis for more detailed resource assessments.

WIND RESOURCE MAPPING

A methodology has been established whereby a detailed and reliable *wind resource atlas* can be constructed for non-mountainous regions. The wind resource atlas contains estimates of the actual wind resource over the region, i.e. wind speed and wind direction distributions for several heights over the actual terrain and with high spatial resolution in the horizontal. The *wind resource map* is but one representation of the wind resource atlas. The approach is illustrated and verified by a new Wind Resource Atlas for Denmark (43,093 km^2).

THE METHODOLOGY

The methodology is based on the wind atlas methodology (9, 3) with several novel extensions. There are two main steps to the method: determination of the regional wind climate of the region or country and estimation of the actual wind climates over the same region.

The *regional wind climate* is determined by wind atlas analysis of existing meteorological stations (5). These wind atlas estimates are then verified by comparison of WAsP predictions (3) with measured wind turbine productions. The variation of the wind power potential may be derived from the variation of power productions from standard wind turbines or by spatial interpolation of the wind atlas data sets.

The *actual wind resource* in grid points with a regular spacing of, say, 100 m are then calculated by the WAsP program for several heights above the ground surface. Inputs are the interpolated wind atlas climatologies and WAsP terrain descriptions (3) derived from existing databases of terrain orography and land-use. At present, sheltering obstacles are not consid-

ered in the modelling. Some characteristics of the methodology are outlined below.

Inputs and Tools

The regional wind climate of Denmark was determined by standard WAsP analysis (3, 5) of about 25 met. stations, i.e. one station per ~1750 km^2. In addition, a number of Swedish (2) and German (8) stations were used. The detailed variation of the wind power potential between stations is derived from the variation of actual power production of a large number of wind turbines, or by spatial interpolation of the wind atlas data sets (6).

The actual wind climate and resource are calculated in a regular grid with a cell size of 200 m, using the WAsP program. Inputs are the regional wind climates and descriptions of the elevation and roughness characteristics of Denmark. The orography is given by a digital height contour map with 5-m contours. The roughness maps were derived by vectorisation of scanned topographical map sheets of scale 1:50,000. Six classes/layers of land use were used: water areas, forests, towns, tree groups, shelter belts and single houses. Large water bodies, forests and towns are described directly as polygons with a specific roughness length, z_0, whereas the 'background roughness' is determined by the occurrence and density of dwellings, tree groups, shelter belts and single houses; these were counted in sub-areas of 1 by 1 km^2 and each sub-area assigned a z_0.

Verification

The methodology has been verified by a wind resource atlas for Denmark. More than 1200 wind turbines of 75 kW rated power or larger were selected based on the availability and quality of production data and documentation of their history and performance. The power curves were further checked extensively.

Comparisons of actual power productions with power production estimates based on the wind resource atlas show that more than 80% of the turbines are predicted to within ±10% of their actual production.

SUMMARY AND PERSPECTIVES

A methodology for regional wind resource mapping has been developed and tested for the land area of Denmark (4). The method is particularly well suited for regions with simple topography and climatology – where reliable wind and topographical data exist.

The *Wind Resource Atlas for Denmark 1999* provides a detailed and reliable picture of the Danish wind resource. It can be used as a tool for planning on all levels of society, as a tool for macro-siting of wind turbines and wind farms and as a tool for information on Danish wind climate in general. Final siting, layout considerations and project feasibility, however, should not be based solely on the atlas. The methodology is described in more detail by Mortensen *et al.* (4). A wind resource map for Denmark can be downloaded from www.emd.dk

The method and tools can be applied in other regions where the topography and climatology are not too complex. In mountainous regions, or regions with a more complex wind climatology, the regional wind climate should be determined using meso-scale models (1, 7).

ACKNOWLEDGEMENTS

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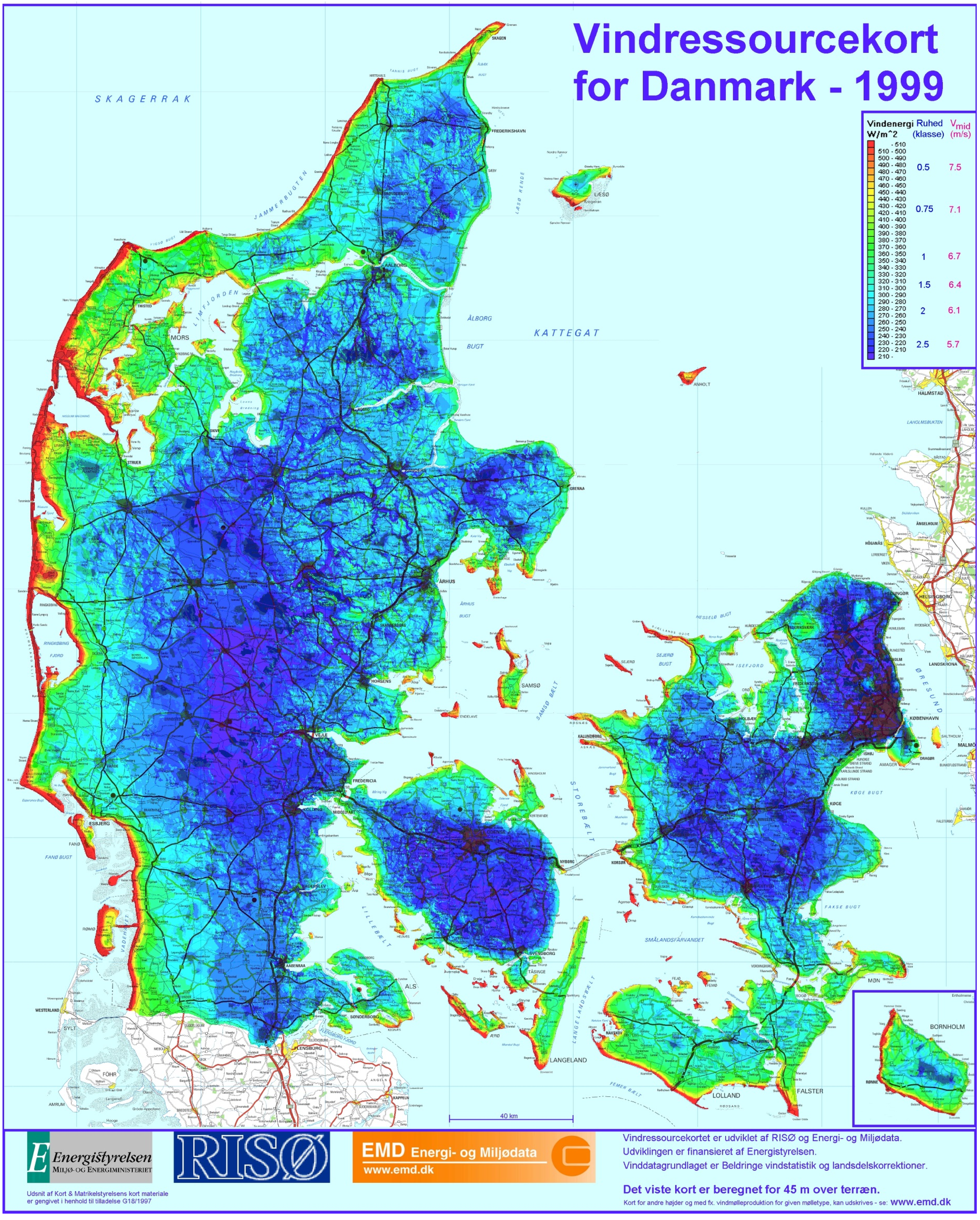

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The WAsP program can be used to map the actual wind resource over large regions: The wind resource of Denmark (43,093 km^2) is shown above – as the energy density [Wm^{-2}] at a height of 45 m a.g.l. The methodology/verification is outlined in the paper and the wind resource map of Denmark can be downloaded from www.emd.dk.