

EUDP 11-II, Globalt Vind Atlas, 64011-0347

DTU Wind Energy
Department of Wind Energy
Outline

• Model chain
• Input data
• Output
• Global assessments of the technical potential
The global wind atlas objective

- provide wind resource data accounting for high resolution effects

- use microscale modelling to capture small scale wind speed variability (crucial for better estimates of total wind resource)

- use a unified methodology

- ensure transparency about the methodology

- validate the results in representative selected areas

For:
- Aggregation, upscaling analysis and energy integration modelling for energy planners and policy makers

Not for:
- Not for wind farm siting
Project context

Wind resource (power density) calculated at different resolutions

Mean power density of total area

Mean power density for windiest 50\% of area

Wind farms are not randomly located but are built on favourable areas.
Model chain
Downscaling

GWA

- large scale
  (20 – 200 km)

- medium scale
  (1 – 20 km)

- small scale
  (0.1 – 1 km)

main method stream

reanalysis data sets

generalization

hi-res. topography

microscale modelling

wind resource: hi-res.
Model chain
Global Wind Atlas implementation

• Military Grid Reference System (MGRS) form basis of the job structure

• MRGS zones are divided into 4 pieces (total 4903)

• 2439 jobs required to cover land and 30 km offshore

• Frogfoot system runs WAsP-like microscale modelling. Inputs
  – Generalized reanalysis winds
  – High resolution elevation and surface roughness data
What is Frogfoot?

- Generalized wind climate datasets
- Climate data manager
  - Climate Service
  - Terrain Service
    - Orography and roughness maps
- Job management console
  - Job service
    - WAsP worker
    - WAsP worker
    - WAsP worker
    - WAsP worker
- Results service
  - Results exporter
- Output data

Like WAsP this is developed in partnership with World In A Box based in Finland.
Frogfoot components

Job Creation

Job Management Console

Results Exporter

WAsP Worker
Model chain
How to work with Frogfoot?

WAsP Worker(s)
Microscale
Orographic speed-up

Streamlines closer together means faster flow

Winds speed up on hills
Winds slow down in valleys

Modification of the wind profile
Microscale
Surface roughness length

Geostrophic wind speed = 10 ms$^{-1}$

A. forest ($z_0 = 2.0$ m)
B. town ($z_0 = 0.5$ m)
C. field ($z_0 = 0.05$ m)
D. water ($z_0 = 0.0002$ m)
Microscale
Surface roughness change

Roughness change from 0.02cm to 20cm

- IBL: upper
- IBL: lower
- Rule of thumb

Unchanged profile
Transition profile
New log-profile

Rule of thumb: 1:100

Accounted for by roughness speed-up and meso roughness parameters from WAsP flow model

Microscale
Surface roughness change

Roughness change from 0.02cm to 20cm

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- Rule of thumb

Unchanged profile
Transition profile
New log-profile

Rule of thumb: 1:100

Accounted for by roughness speed-up and meso roughness parameters from WAsP flow model
Datasets: atmospheric data

<table>
<thead>
<tr>
<th>Product</th>
<th>Model system</th>
<th>Horizontal resolution</th>
<th>Period covered</th>
<th>Temporal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA Interim reanalysis</td>
<td>T255, 60 vertical levels, 4DVar</td>
<td>~0.7° × 0.7°</td>
<td>1979-present</td>
<td>6-hourly</td>
</tr>
<tr>
<td>NASA – GAO/MERRA</td>
<td>GEOS5 data assimilation system (Incremental Analysis Updates), 72 levels</td>
<td>0.5° × 0.67°</td>
<td>1979-present</td>
<td>6-hourly</td>
</tr>
<tr>
<td>NCAR CFDDA</td>
<td>MM5 (regional model)+ FDDA</td>
<td>~40 km</td>
<td>1985-2005</td>
<td>hourly</td>
</tr>
<tr>
<td>CFSR</td>
<td>NCEP GFS (global forecast system)</td>
<td>~38 km</td>
<td>1979-2009 (updating)</td>
<td>6-hourly</td>
</tr>
</tbody>
</table>
Datasets terrain: elevation and roughness

Topography: surface description

Elevation

Shuttle Radar Topography Mission (SRTM) resolution 90 - 30 m

Viewfinder, compiles SRTM and other datasets resolution 90 - 30 m

ASTER Global Digital Elevation Model (ASTER GDEM) resolution 30 m

Land cover

ESA GlobCover resolution 300 m

Modis, land cover classification resolution 500 m
Challenges in determining surface roughness

GLOBCOVER

- European Space Agency initiative
- January – December 2009
- Global 300m resolution
- 22 Classes
- Data gaps near poles
  - Limited number of overpasses
  - Large number of cloudy images

<table>
<thead>
<tr>
<th>Value</th>
<th>GlobCover global legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Post-flooding or irrigated croplands</td>
</tr>
<tr>
<td>14</td>
<td>Rainfed croplands</td>
</tr>
<tr>
<td>20</td>
<td>Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)</td>
</tr>
<tr>
<td>30</td>
<td>Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)</td>
</tr>
<tr>
<td>40</td>
<td>Closed to open (&gt;15%) broadleaved evergreen and/or semi-deciduous forest (&gt;5m)</td>
</tr>
<tr>
<td>50</td>
<td>Closed (&gt;40%) broadleaved deciduous forest (&gt;5m)</td>
</tr>
<tr>
<td>60</td>
<td>Open (15-40%) broadleaved deciduous forest (&gt;5m)</td>
</tr>
<tr>
<td>70</td>
<td>Closed (&gt;40%) needleleaved evergreen forest (&gt;5m)</td>
</tr>
<tr>
<td>90</td>
<td>Open (15-40%) needleleaved deciduous or evergreen forest (&gt;5m)</td>
</tr>
<tr>
<td>100</td>
<td>Closed to open (&gt;15%) mixed broadleaved and needleleaved forest (&gt;5m)</td>
</tr>
<tr>
<td>110</td>
<td>Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)</td>
</tr>
<tr>
<td>120</td>
<td>Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)</td>
</tr>
<tr>
<td>130</td>
<td>Closed to open (&gt;15%) shrubland (&lt;5m)</td>
</tr>
<tr>
<td>140</td>
<td>Closed to open (&gt;15%) grassland</td>
</tr>
<tr>
<td>150</td>
<td>Sparse (&gt;15%) vegetation (woody vegetation, shrubs, grassland)</td>
</tr>
<tr>
<td>160</td>
<td>Closed (&gt;40%) broadleaved forest regularly flooded - Fresh water</td>
</tr>
<tr>
<td>170</td>
<td>Closed (&gt;40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water</td>
</tr>
<tr>
<td>180</td>
<td>Closed to open (&gt;15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water</td>
</tr>
<tr>
<td>190</td>
<td>Artificial surfaces and associated areas (urban areas &gt;50%)</td>
</tr>
</tbody>
</table>
### Challenges in determining surface roughness

**Roughness lengths used in the GWA**

<table>
<thead>
<tr>
<th>Roughness</th>
<th>GLOBCOVER_Class</th>
<th>Modis_Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Water bodies</td>
<td>Water</td>
</tr>
<tr>
<td>0.0004</td>
<td>Permanent snow and ice</td>
<td>Snow / Ice</td>
</tr>
<tr>
<td>0.005</td>
<td>Bare areas</td>
<td>Baren or sparsely vegetated</td>
</tr>
<tr>
<td>0.03</td>
<td>Closed to open (&gt;15%) herbaceous vegetation (grassland, savannas or lichens/mosses)</td>
<td>Grasslands</td>
</tr>
<tr>
<td>0.05</td>
<td>Sparse (&lt;15%) vegetation</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>Post-flooding or irrigated croplands (or aquatic)</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>Rainfed croplands</td>
<td>Croplands</td>
</tr>
<tr>
<td>0.1</td>
<td>Closed to open (&gt;15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (&lt;5m)</td>
<td>Closed Shrublands / Open Shrublands</td>
</tr>
<tr>
<td>0.2</td>
<td>Closed to open (&gt;15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water</td>
<td>Permanent Wetland</td>
</tr>
<tr>
<td>0.3</td>
<td>Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)</td>
<td>Cropland / Natural Vegetation Mosaic</td>
</tr>
<tr>
<td>0.5</td>
<td>Closed to open (&gt;15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Mosaic grassland (50-70%) / forest or shrubland (20-50%)</td>
<td>Savannas</td>
</tr>
<tr>
<td>0.6</td>
<td>Closed (&gt;40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Closed to open (&gt;15%) broadleaved evergreen or semi-deciduous forest (&gt;5m)</td>
<td>Evergreen Broadleaf Forest</td>
</tr>
<tr>
<td>1.5</td>
<td>Closed (&gt;40%) broadleaved deciduous forest (&gt;5m)</td>
<td>Deciduous Broadleaf Forest</td>
</tr>
<tr>
<td>1.5</td>
<td>Open (15-40%) broadleaved deciduous forest/woodland (&gt;5m)</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Closed (&gt;40%) needleleaved evergreen forest (&gt;5m)</td>
<td>Evergreen Needle Leaf Forest</td>
</tr>
<tr>
<td>1.5</td>
<td>Open (15-40%) needleleaved deciduous or evergreen forest (&gt;5m)</td>
<td>Deciduous Needle leaf Forest</td>
</tr>
<tr>
<td>1.5</td>
<td>Closed to open (&gt;15%) mixed broadleaved and needleleaved forest (&gt;5m)</td>
<td>Mixed Forest</td>
</tr>
<tr>
<td>1.5</td>
<td>Mosaic forest or shrubland (50-70%) / grassland (20-50%)</td>
<td>Woody Savannas</td>
</tr>
<tr>
<td>1.0</td>
<td>Artificial surfaces and associated areas (Urban areas &gt;50%)</td>
<td>Urban and Built-Up</td>
</tr>
<tr>
<td></td>
<td>No data (burnt areas, clouds,...)</td>
<td></td>
</tr>
</tbody>
</table>
Validation

Synthetic Aperture Radar

The limitations of this method include
• that only onshore areas can be mapped
• the extrapolation of wind speeds to Global Wind Atlas heights introduces uncertainty.
Validation

Against high resolution resource maps generated from measurement based generalized winds.

A limitation is the comparison is being made against, in part, results of modelling.

Global Wind Atlas
Validation

Against validated numerical wind atlas results

Advantage is that the validation can be done over land
The limitation is a comparison is being made against results of modelling, so it is not a comparison against measurements.

Numerical wind atlas
KAMM / WAsP

Global Wind Atlas
Validation

Against validated numerical wind atlas results

An advantage is that the validation can be done over land. A limitation is that a comparison is being made against results of modelling, so it is not a comparison against measurements.

National Validated Numerical Wind Atlas
WASA project
http://www.wasaproject.info/
Global Wind Atlas at DTU
globalwindatlas.com
Surface roughness length
Global Wind Atlas at DTU
globalwindatlas.com
Orography
Global Wind Atlas at DTU
globalwindatlas.com
Orographic speed up for westerly winds at 100 m
Global Wind Atlas at DTU
globalwindatlas.com
Mean wind speed at 100 m
Global Wind Atlas at DTU
globalwindatlas.com
Top-quartile mean wind speed at 100 m
Global Wind Atlas at DTU
globalwindatlas.com
Tools, e.g. power density for windiest areas at 100 m
Global Wind Atlas at DTU
globalwindatlas.com
Mean wind speed at 100 m
Global Wind Atlas at DTU
globalwindatlas.com
mean wind speed high ruggedness masked out (RIX)
Future application  
Global assessment of the technical potential

We can use the EUDP Global Wind Atlas to determine global potential accounting for high resolution effects and get a better spatial breakdown.

The challenge is to create a consistent approach, with range of tested assumptions, available for the community to scrutinize.

The Global Wind Atlas makes this easier via

- Transparency of methodology
- Providing data to allow annual energy production calculation
- GIS integration of datasets
Global assessments of the technical potential

IPCC Special Report on Renewable Energy Sources and Climate Change: range tech. pot. 19 – 125 PWh / year (onshore and near shore)

<table>
<thead>
<tr>
<th>Study</th>
<th>Scope</th>
<th>Methods and Assumptions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krewitt et al. (2009)</td>
<td>Onshore and offshore</td>
<td>Updated Hoogwijk and Graus (2008), itself based on Hoogwijk et al. (2004), by revising offshore wind power plant spacing by 2050 to 16 MW/km²</td>
<td>Technical (more constraints): 121,000 TWh/yr 440 EJ/yr</td>
</tr>
<tr>
<td>Lu et al. (2009)</td>
<td>Onshore and offshore</td>
<td>&gt;20% capacity factor (Class 1); 100 m hub height; 9 MW/km² spacing based on coarse simulated model data set; exclusions for urban and developed areas, forests, inland water, permanent snow/ice; offshore assumes 100 m hub height, 6 MW/km², &lt;92.5 km from shore, &lt;200 m depth, no other exclusions</td>
<td>Technical (limited constraints): 840,000 TWh/yr 3,050 EJ/yr</td>
</tr>
<tr>
<td>Hoogwijk and Graus (2008)</td>
<td>Onshore and offshore</td>
<td>Updated Hoogwijk et al. (2004) by incorporating offshore wind energy, assuming 100 m hub height for onshore, and altering cost assumptions; for offshore, study updates and adds to earlier analysis by Fellows (2000); other assumptions as listed below under Hoogwijk et al. (2004); constrained technical potential defined here in economic terms separately for onshore and offshore</td>
<td>Technical/Economic (more constraints): 110,000 TWh/yr 490 EJ/yr</td>
</tr>
<tr>
<td>Archer and Jacobson (2005)</td>
<td>Onshore and near shore</td>
<td>&gt;Class 3; 80 m hub height; 9 MW/km² spacing; 48% average capacity factor; based on wind speeds from surface stations and balloon-launch monitoring stations; near-shore wind energy effectively included because resource data includes buoys (see study for details); constrained technical potential = 20% of total technical potential</td>
<td>Technical (limited constraints): 627,000 TWh/yr 2,260 EJ/yr</td>
</tr>
<tr>
<td>WBGU (2004)</td>
<td>Onshore and offshore</td>
<td>Multi-MW turbines; based on interpolation of wind speeds from meteorological towers; exclusions for urban areas, forest areas, wetlands, nature reserves, glaciers, and sand dunes; local exclusions accounted for through corrections related to population density; offshore to 40 m depth, with sea ice and minimum distance to shore considered regionally; constrained technical potential (authors define as ‘sustainable’ potential) = 14% of total technical potential</td>
<td>Technical (limited constraints): 278,000 TWh/yr 1,000 EJ/yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Technical (more constraints): 39,000 TWh/yr 140 EJ/yr</td>
</tr>
</tbody>
</table>
Assumption:
5 MW per km$^2$ capacity density
Annual production from wind.

- all: 581 PWh
- low ruggedness: 528 PWh
- low ruggedness onshore: 344 PWh

Note: 1 PWh = $1 \times 10^{15}$ Wh
Thank you for your attention

http://globalwindatlas.com/map.html
http://globalwindatlas.com/methods.html
http://globalwindatlas.com/datasets.html
http://globalwindatlas.com/tutorials.html

Contact:
jabab@dtu.dk

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