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The new worldwide microscale wind resource assessment data on IRENA’s Global Atlas

The EUDP Global Wind Atlas

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

DTU Wind Energy
Department of Wind Energy
Outline

• Project context

• Model chain

• Input data

• Output and verification

• Web user interface, walk through

• Future plans

• Global assessments of the technical potential
23 participating CEM governments account for 80 percent of global greenhouse gas emissions.
International collaboration

What is IRENA’s Global Atlas?

It is a high-level prospector for renewable energy opportunities

- builds on publicly available information
- information released by the private sector
- data released by institutions,
  - i.e. EUDP Global Wind Atlas
  - New European Wind Atlas

http://globalatlas.irena.org/
International collaboration
IRENA’s Global Atlas

It supports

• countries in prospecting their renewable energy opportunities
• companies to approach new markets
• the general public in gaining interest in renewable energy

http://globalatlas.irena.org/
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
- verify 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

Mesoscale

- 50 km
- 2.5 km
- 323 W/m²
- 410 W/m²

Mesoscale + microscale

- 100 m
- 50 km
- 505 W/m²
- 641 W/m²

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
Project context

Note:

This area exhibits large topography effects.

Even for Danish landscape effect can give 25 % boast in wind resource at the windiest 5 percentile.

Mean wind power density for windiest half of area
Model chain
Downscaling

GWA

main method stream
reanalysis data sets
generalization

large scale
(20 – 200 km)

medium scale
(1 – 20 km)

small scale
(0.1 – 1 km)

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
Model chain
What is Frogfoot?

Generalized wind climate datasets

Climate data manager

Climate Service

Terrain Service

Orography and roughness maps

Job management console

Job service

Results service

Results exporter

Output data

core Frogfoot-server components
ancillary components run on user PC
data that is input into the system
result outputs

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

Job Creation

Results Exporter

Job Management Console

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 \((z_0 = 2.0 \text{ m})\)
B. town \((z_0 = 0.5 \text{ m})\)
C. field \((z_0 = 0.05 \text{ m})\)
D. water \((z_0 = 0.0002 \text{ m})\)
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

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

Rule of thumb: 1:100
Datasets: atmospheric data

Reanalysis

<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>3-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>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 (&amp; updating)</td>
<td>hourly</td>
</tr>
</tbody>
</table>
Challenges in generalizing wind climatologies

- Roughness length among the various reanalysis varies
- The response of the simulated wind profile to the surface roughness varies from model to model
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 Shrubslands / Open Shrubslands</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></td>
</tr>
<tr>
<td>0.6</td>
<td>Closed (&gt;40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water</td>
<td>Savannas</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>
</tbody>
</table>
Example output
250 m calculation node spacing
Output and verification
Output and verification

Contingency map for a power density threshold of 600W/m$^2$ comparing WASA and GWA, **Tobias Ahsbahs, 2015**
Web user interface, walk through
Roughness length
Orography
WAsP Mesoroughness per sector
Orographic speed-up per sector
Annual mean wind climate
Selection of aggregation area
Wind rose
Windiest fractile plot
Wind speed distribution
Distribution of mean wind speed over area
Mean annual cycle over area
Still to complete

• Global runs with alternative reanalyses (1000 m)

• Complete verification

• Integration into IRENA global atlas

• Launch – IRENA-coordinated web event, September 2015
Future plans

• Following projects

  – Framework agreement led by ECN (NL) to supply renewable resource data to JRC TIMES-EU energy model.

  – Foundation for data inputs and concepts for server platform for the New European Wind Atlas
    • Roughness mapping improvements
    • Elevation data verification would be of value
    • Model chain development

  – Many possibilities for post processing of data
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/Economic (more constraints): 121,000 TWh/yr 440 Elyr</td>
</tr>
<tr>
<td>Lu et al. (2009)</td>
<td>Onshore and offshore</td>
<td>≥20% capacity factor (Class 1); 100 m hub height; 9 MW/km² spacing; based on coarse simulated met data set; exclusion for urban and developed areas, forests, internal water, permanent snow/snow ice; offshore assumes 100 m hub height, 6 MW/km², &lt;92.5 km from shore, ~200 m depth, no other exclusions</td>
<td>Technical (limited constraints): 840,000 TWh/yr 3,050 Elyr</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 Fellowes (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 (more constraints): 110,000 TWh/yr 400 Elyr</td>
</tr>
<tr>
<td>Archer and Jacobson (2005)</td>
<td>Onshore and near shore</td>
<td>≥Class 3; 80 m hub height; 9 MW/km² spacing; 48% average capacity factor; based on wind speeds from surface stations and ballon-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 Elyr</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 (more constraints): 278,000 TWh/yr 1,000 Elyr</td>
</tr>
</tbody>
</table>
Global assessments 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.

So far “back of the envelope” calculations suggest 2 – 300 PWh / year

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
Thank you for your attention

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