Wind resource, turbulence and electricity production in forests

Mattias Mohr, Johan Arnqvist, Hans Bergström
Uppsala University (Sweden)
Project: Wind Power in Forests II - Forestwind

- Continuation of Wind Power in Forests project
- Better estimation of wind resource
- Better estimation of turbine loads (wind shear/veer, turbulence, inhomogeneous forests)
- Quantify effects on energy production

→ Use and develop models for these purposes
Problems

- What is the wind resource over Swedish forests at 150 m height above ground?

- What about the loads?

- Is energy production affected?

Forest height depends on mainly latitude and altitude. New laser scans give very detailed picture of Swedish forest. Swedish forest is inhomogeneous ("patchwork")!!!
Old mast: Ryningsnäs

- 140m high mast
- 18m high mast
- T1, T2 = wind turbines
New mast: "Mossen", Småland

180 m mast with turbulence instruments

One important question: Can Sodar & Lidar replace masts in forests?
Wind resource assessment

- Better estimations of roughness \((z_0)\), displacement height \((d)\) and leaf area density improves models (mesoscale and CFD)

- 42 sites in Wind power in forests I (final report) :
  \(d = 16\) m; \(z_0 = 1.4\) m (median values)
Wind profile over forest

- Correct input parameters crucial for models!

- Especially: How does inhomogeneous influence parameters?
Modelling of forest: Different approaches

1. Mesoscale models simulate flow down to displacement height (with drag = f(z₀))
2. CFD models simulate flow all the way down (with drag = f(leaf area density))

Can CFD-type forest parameterisations improve mesoscale models? → Maybe

Can mesoscale models be used instead of CFD models for micro siting → Maybe

For small clearings/forests approach 1 does not work!
Drag parameterisations

\[
\frac{\partial u}{\partial t} = \ldots - C_d \cdot LAD \cdot |\vec{u}_{\text{horizontal}}| \cdot u
\]

(same for v-component)

\[
\vec{u} = \text{horizontal wind vector, } u = \text{wind component W-E}
\]

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag coefficient for forest</td>
<td>(C_d)</td>
<td>0.2</td>
</tr>
<tr>
<td>Forest canopy height</td>
<td>(h_c)</td>
<td>20 m</td>
</tr>
<tr>
<td>Leaf area index</td>
<td>(LAI = \int_{0}^{h_c} LAD(z) , dz)</td>
<td>5</td>
</tr>
<tr>
<td>Height of max. leaf area density</td>
<td>(z_m = 0.6 h_c) (pine forest)</td>
<td>12 m (e.g. Halldin, 1985)</td>
</tr>
<tr>
<td>Leaf area density</td>
<td>(LAD(z)) (pine forest)</td>
<td>Lalic and Mihailovic (2004)</td>
</tr>
<tr>
<td>Maximum leaf area density</td>
<td>(L_m = LAI / h_c \cdot 1.70)</td>
<td>0.425</td>
</tr>
</tbody>
</table>
Example results: WRF mesoscale model

Wind Speed Reduction over Forest

Forest edge

x [km] z [m]
Forest leaf area density problematic

How should we average data from all pixels?

Theoretical profile (for mature homogeneous forest)

Forest leaf area density profile different to theoretical profile!
Better input parameters for models

- Nationwide maps of
  - Surface roughness
  - Displacement height
  - Leaf area density = f(height)

from airborne laser scans

Suggestions of averaging methods

Figur: Johan Arnqvist
• IEC standard exceeded, but does it matter???
Turbulence simulations

- LES = Large Eddy Simulation model (simulates largest turbulent vortices)

- Forced by data from WRF mesoscale model

- Methods have to be developed for this

Figure: Bastian Nebenführ (Chalmers)
Power Curve Working Group identified four main factors:

1. Air density
2. Vertical wind shear
3. Vertical wind veer
4. Turbulence intensity
5. (Directional variation)
6. (Vertical inflow angle)

Especially high above forests and in Sweden!!

Factors 2 - 4 probably most important in South.
Factor 3 probably most important in North.
Wind shear effects on power curve

- As turbines get bigger and bigger, important to consider shear and veer! → Ekman layer

- Rotor equivalent wind speed with wind veer:

\[ U_{\text{equiv}} = \left( \sum_i \left( \bar{U}_i \cos(\phi_i) \right)^3 \cdot \frac{A_i}{A} \right)^{1/3} \]
Turbulence effects on power curve

- Energy gain/loss depending on curvature of power curve

\[ \bar{P} = P(\bar{u}) + \frac{1}{2} \frac{d^2 P(\bar{u})}{d\bar{u}^2} \sigma_u^2 \]

Power curve valid for 10 minute averages, but wind speed variations due to turbulence

Vestas V90-3.0 MW
THANK YOU FOR YOUR ATTENTION!


