



Netherlands Environmental Assessment Agency



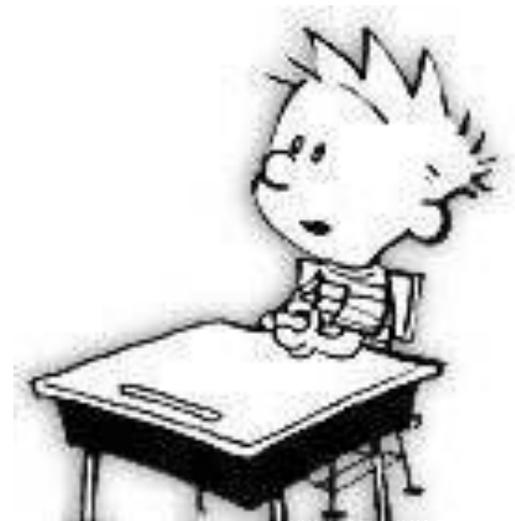
Global wind potential

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Overview of renewable energy potential IMAGE team

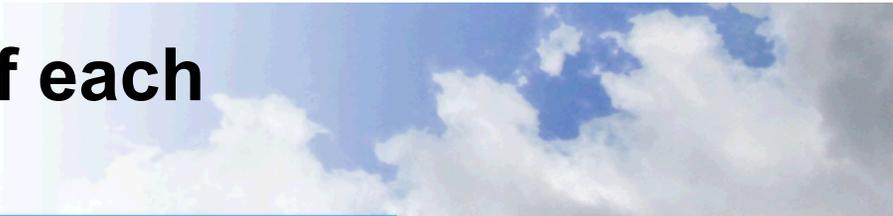
- Motivation (situation in 2000):
 - Little transparent information on renewable energy potential available, even less so on potentials with costs;
 - No work at all on potential for different renewables in one common framework; existing potentials for wind, solar and bio-energy were not comparable.



Overview of renewable energy potential IMAGE team

- Hoogwijk-thesis (2004)
 - 5 peer-reviewed publications for potential of wind, PV, bio-energy
 - *Hoogwijk M, de Vries B, Turkenburg W (2004) Assessment of the global and regional geographical, technical and economic potential of onshore wind energy. Energy Economics 26:889-919.*
 - 6th peer-reviewed publication on the comparison of different renewables
 - *de Vries, B. J. M., van Vuuren, D. P., and Hoogwijk, M. M. (2007). "Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach". Energy Policy, 35, (4): 2590-2610.*
 - Has become important input in assessments (IPCC, REN21, WEA) and models on renewable energy

Assessment of potential of each source (Hoogwijk, 2004)



Wind



PV



Bio-energy



0.5 x 0.5 degree

Geographic potential

Theoretically extractable output

Wind speed
Land cover

Irradiance
Land cover

Crop growth
Land cover

Technical potential

Taking into account extraction

Conversion factors
Operational factors (load hours)

Economic potential

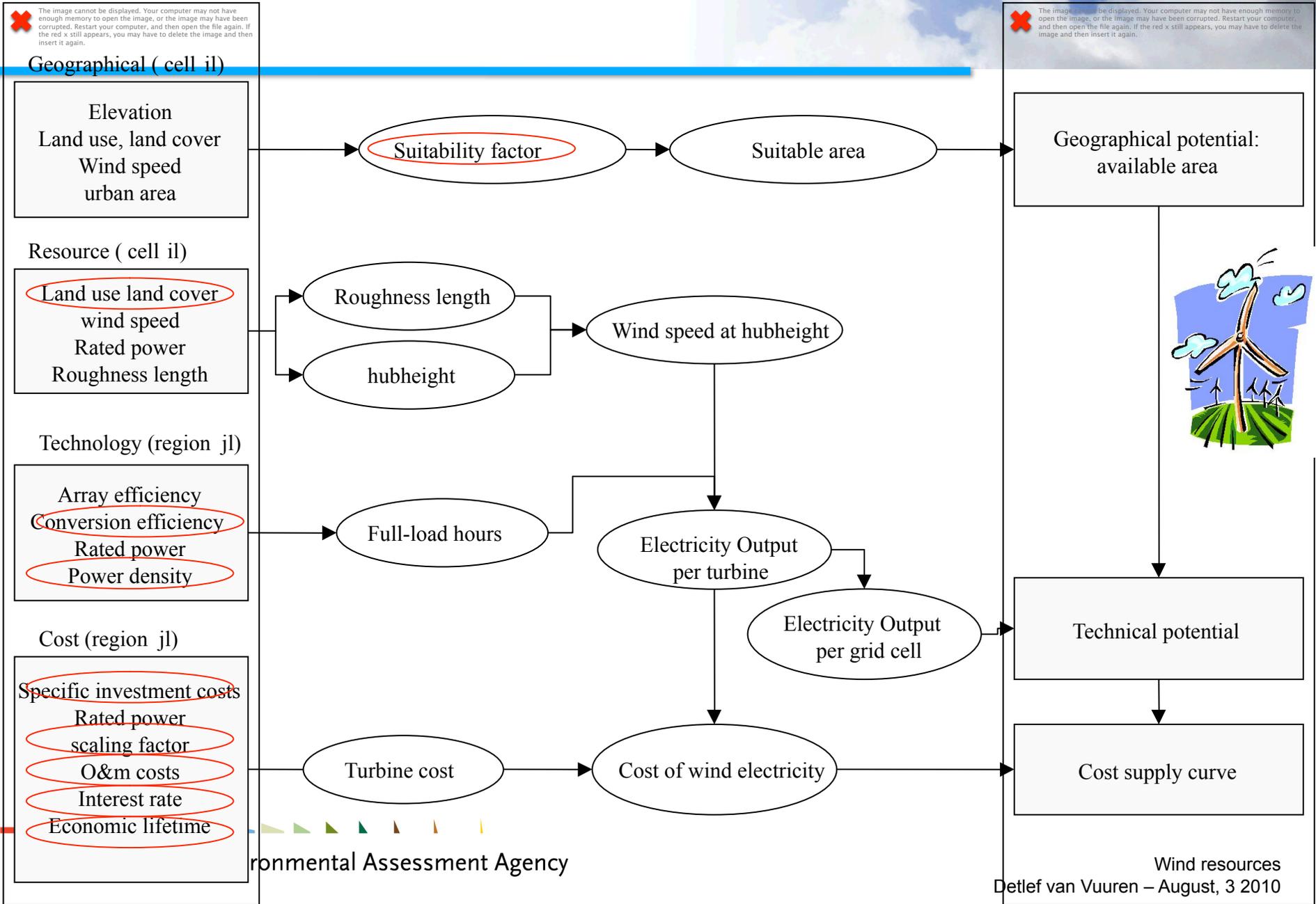
Technical potential below certain costs

Investment costs
OM costs
Discount rate
Lifetime

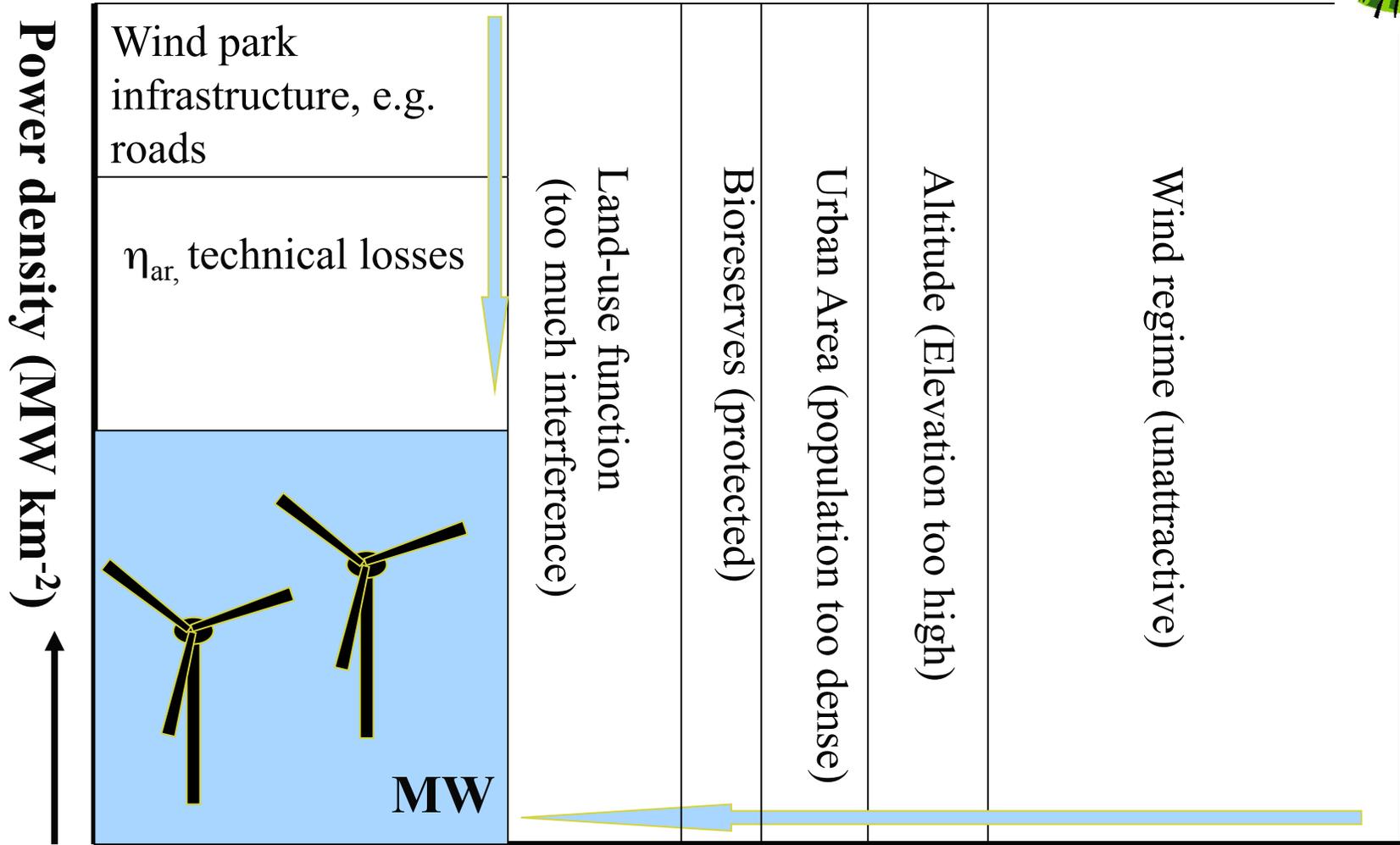
Input (cell i /region j)

Interim variables (cell i)

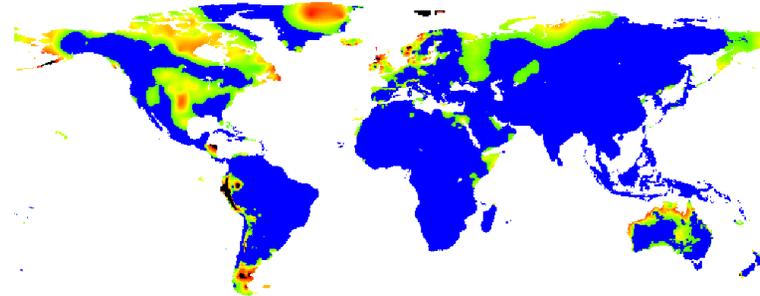
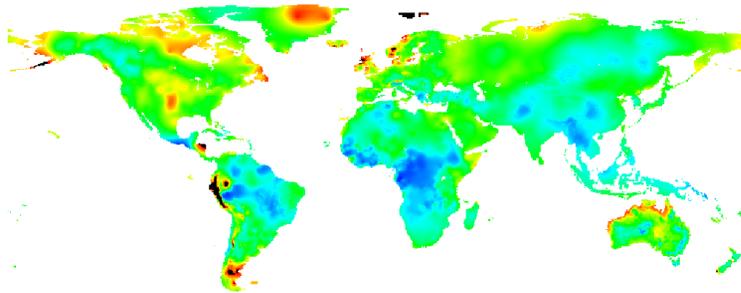
Output (Region j)



Land-use constraints; available area

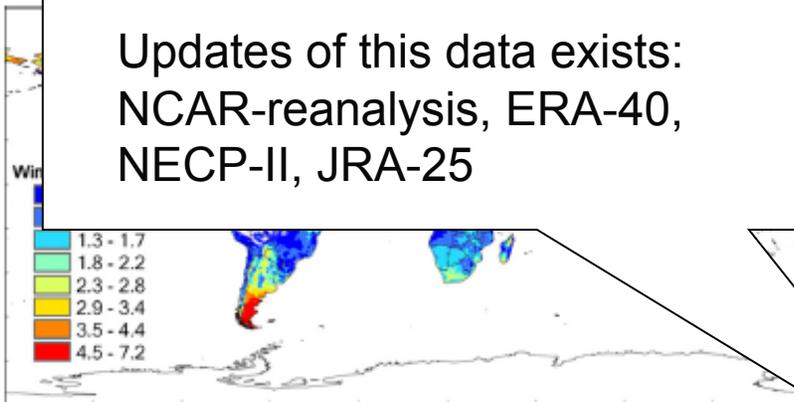


Step 1: Data on Wind speed



Excluding areas < 4 m/s

Updates of this data exists:
 NCAR-reanalysis, ERA-40,
 NECP-II, JRA-25



Xi Lu, Michael B. et al. (2009)

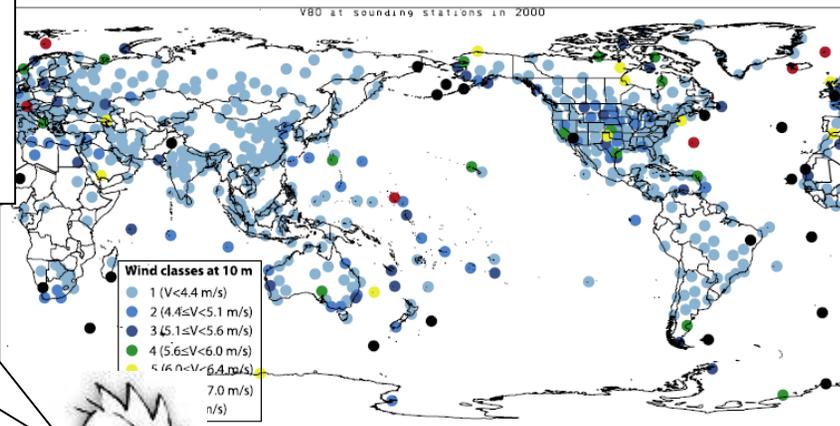
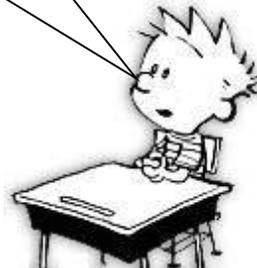


Figure 3. Same as Figure 2, but for observed wind speed at 10 m.

r and Jacobsen (2005)

Goddard Earth Observing System Data
 Assimilation System (GEOS-5 DAS).



Wind resources

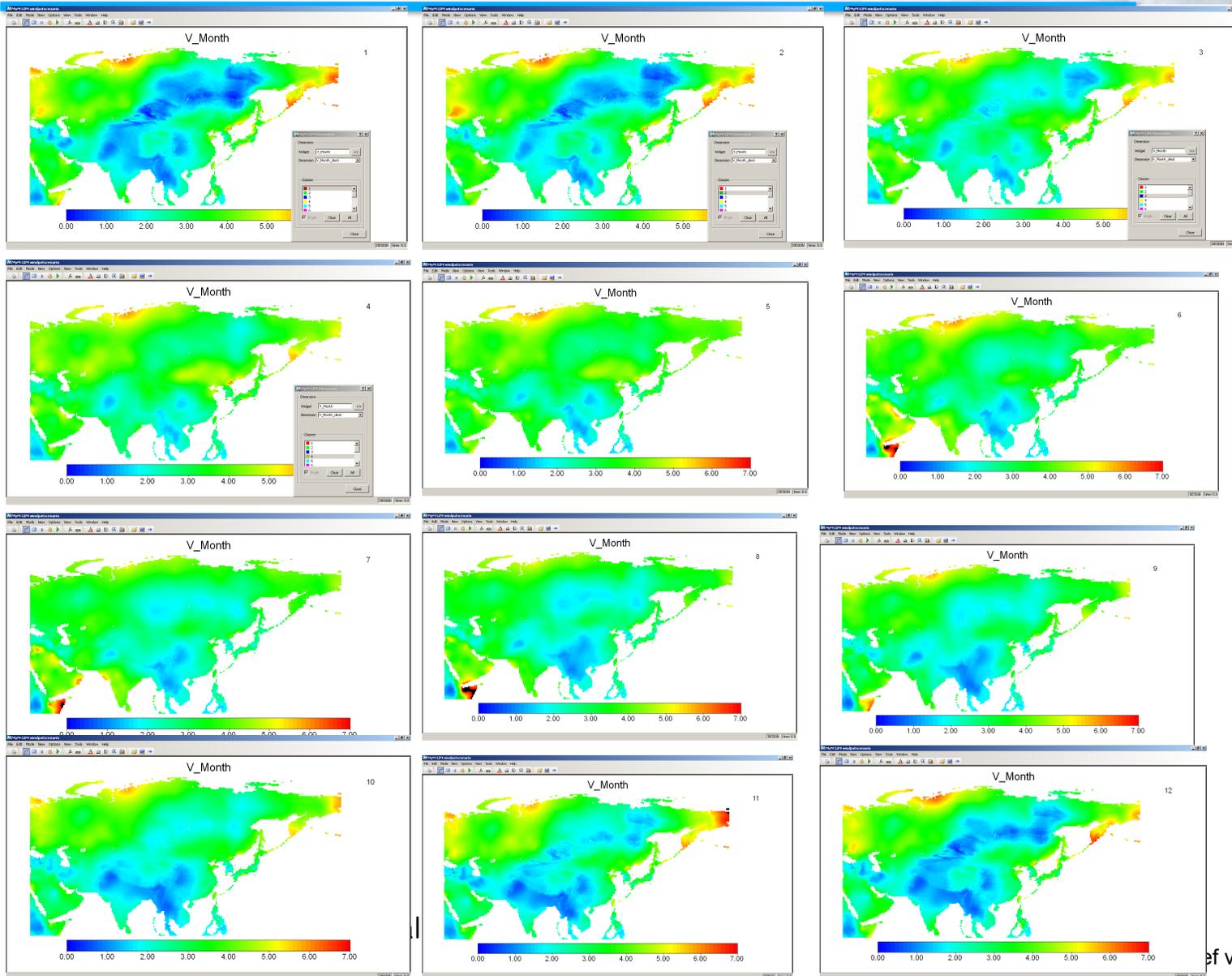
Detlef van Vuuren – August, 3 2010

Step 1: Data on Wind speed

No digital databases or atlases providing monthly or annual average wind speed values at grid cell level for the world have been published. Therefore a detailed comparison of our wind speed data with other studies could not be made. To explore the quality of the data we have done a visual comparison with maps from the European wind atlas (Petersen et al., 1981), the Wind Atlas for the U.S.A (Elliot et al., 1986), the wind atlas of India constructed by the Indian Institute of Tropical Meteorology (Rangarajan, 1998) and a wind atlas for South East Asia (TueWind Solutions, 2001). These comparisons show that the data are fairly consistent. Similar patterns are found and values are of the same order of magnitude, although the figures from the CRU database seem to be slightly lower than those in the wind atlases. In particular the comparison with the wind atlas of India (Rangarajan, 1998) showed that the wind speed data may regionally be rather low. While the CRU data give for India a regional annual average of 2.3 m s^{-1} at a height of 10 m, Rangarajan gives the lowest value as 2.5 m s^{-1} at 10 m. (Rangarajan, 1998).



Step 1: Data on Wind speed: Monthly variation



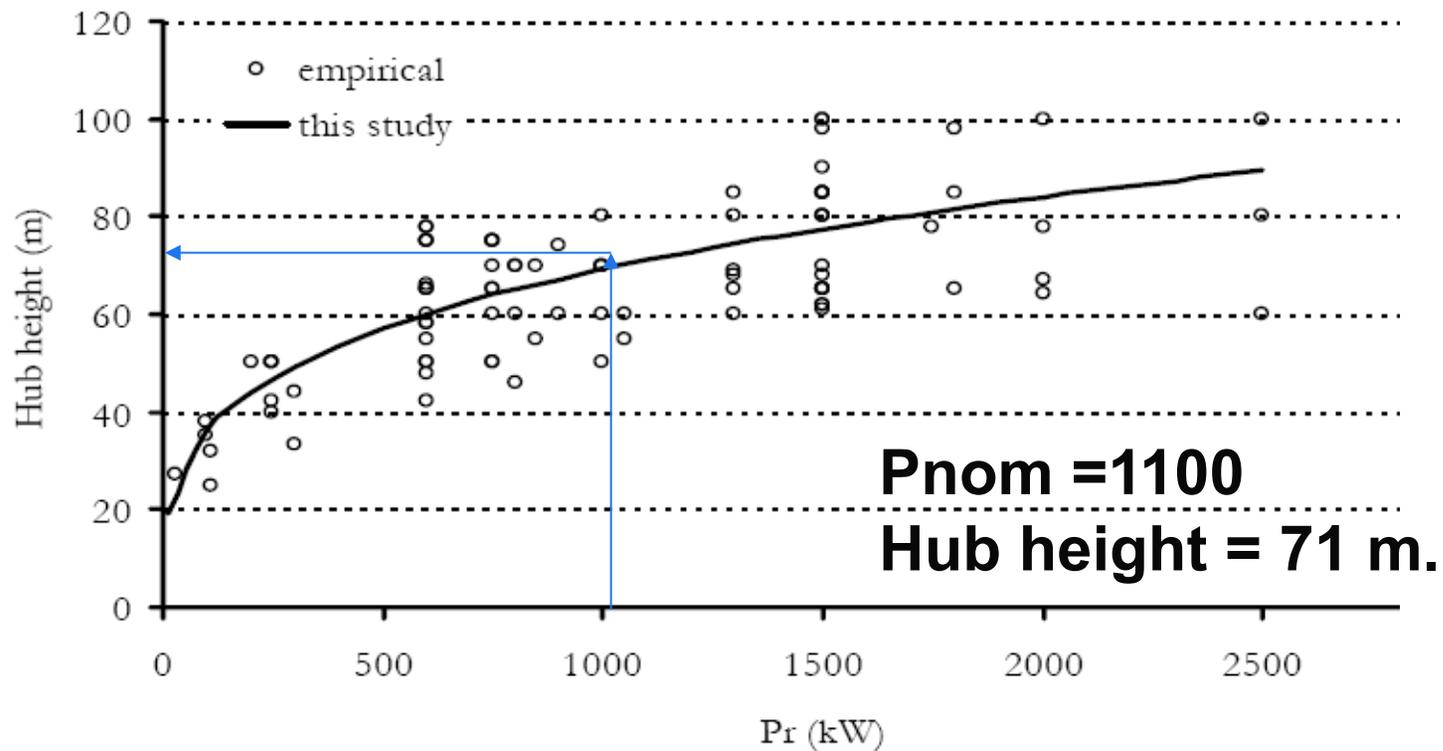
Jan-Mar

Apr-Jun

Jul-Sep

Okt.-Dec.

Step 2: Calculation of technical potential: Definition of standard turbine



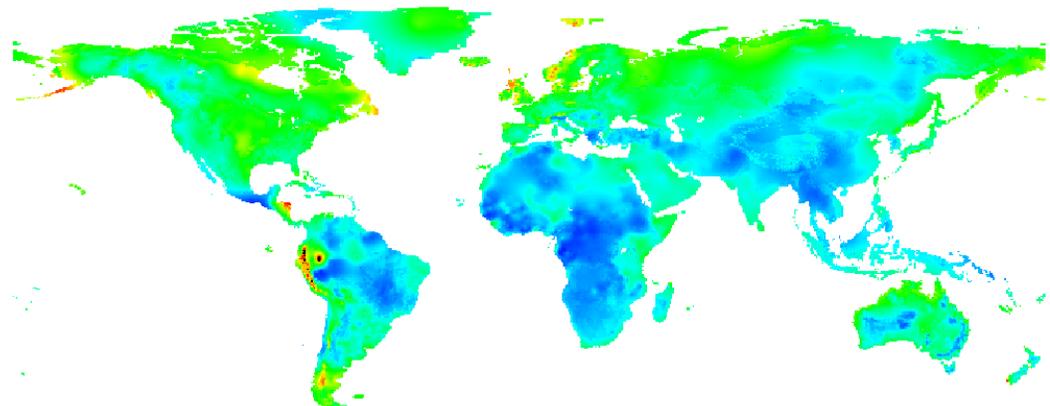
Step 2: Correction of wind data to standard hub-height

$$V_{hub} = V_{10} * \left(\frac{\ln(H / z_0)}{\ln(10 / z_0)} \right)$$

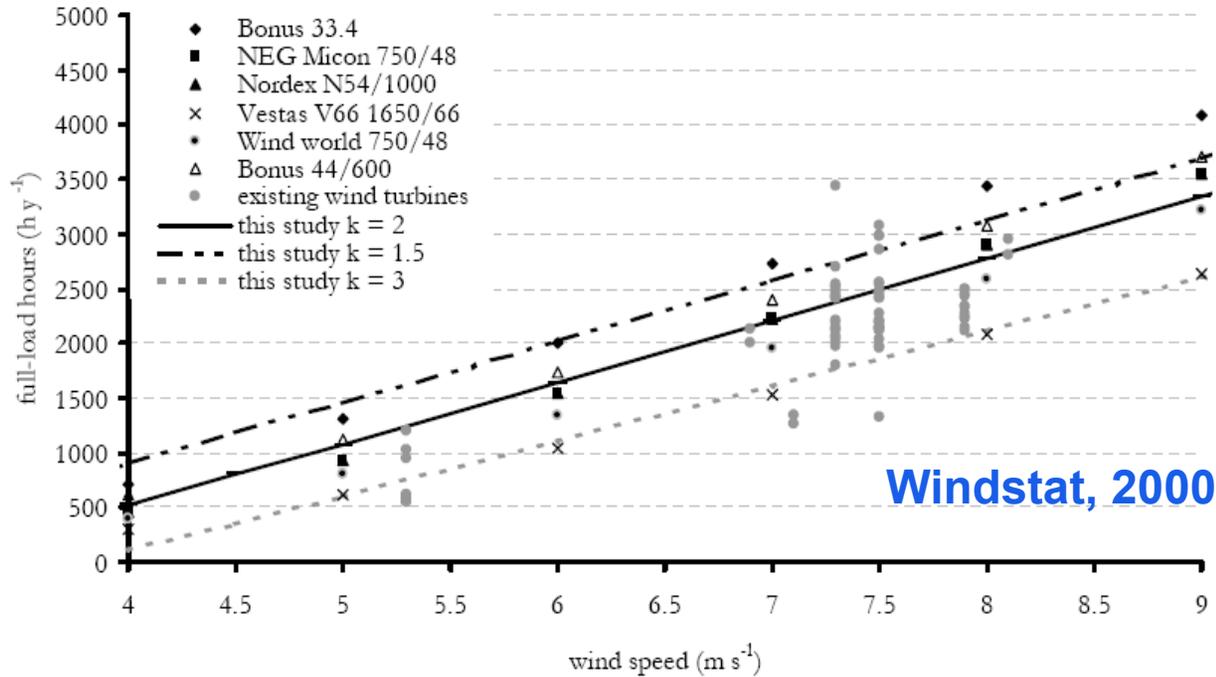
Lysen (1982)

	Roughness index (z_0)
Agr. Land	0.25
Forest	1
Ext. Grazing	0.03
Tundra	0.25
Grassland/steppe	0.03
Desert	0.005
Shrubland	0.1
Savanna	0.25

VHub_annual



Step 2: Full load hours as function of wind speed



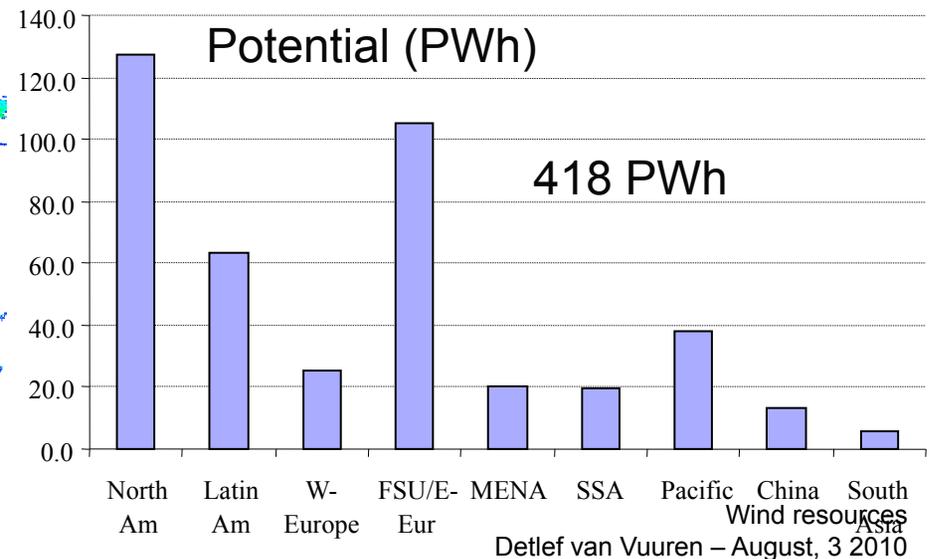
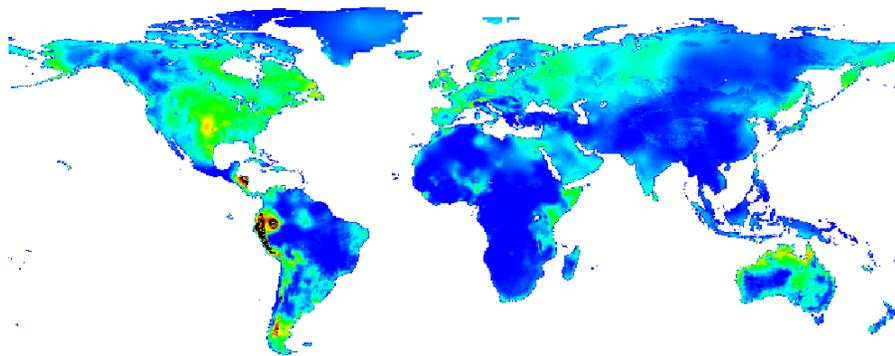
CF= Full Load hours/
hours per year

$$h_{H,i} = \alpha_1 * V_{H,i} + \alpha_2$$

Calibrated using an underlying Weibull function of k=2

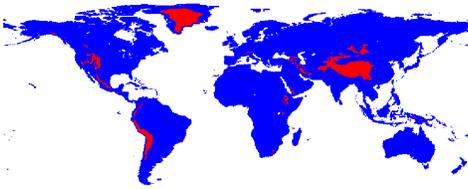
Step 2: Power density (per cell)

- $Pot_{theor} = N_{turb} \times P_{rated} \times CF(v) \times Eff_{maint} \times Eff_{array}$
 - N_{turb} based on a maximum 4 MW/km² of rated power
 - $Eff_{maint} = 0.97$ (most of the time during low wind period)
 - $Eff_{array} = 0.90$ (assuming 1000 kW, 2 x 2 matrix, 5 hub height spacing)

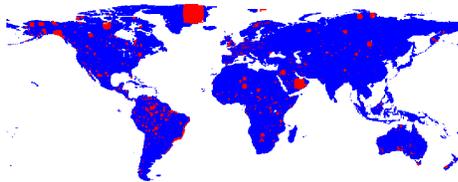


Step 3: Exclusion factors for land types

Height (<2km)



Reserves

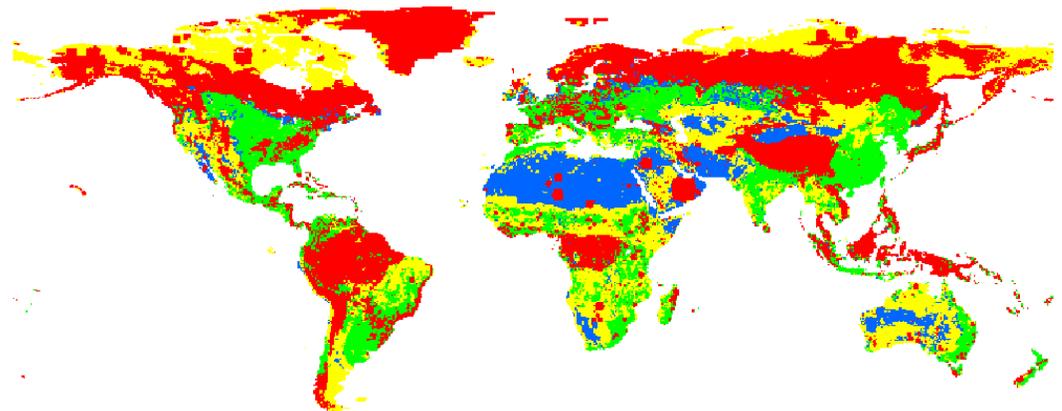
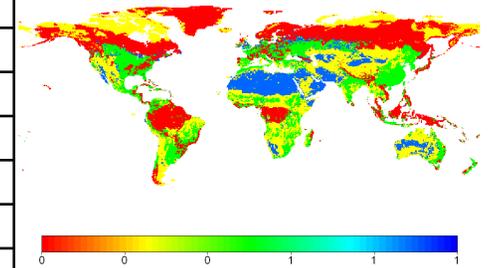


Urban area



	De Vries, 2007	Hoogwijk, 2004
Forests	0	0-0.1
Savannah	0.25	0.9
Steppe/grassland	0.25	0.8
Shrubland	0.25	0.5
Tundra	0.25	0.5-0.8
Desert	0.9	1
Agriculture	0.5	0.7
Ext. Grazing	0.25	0.8
Abon. Ag	0.9	0.7

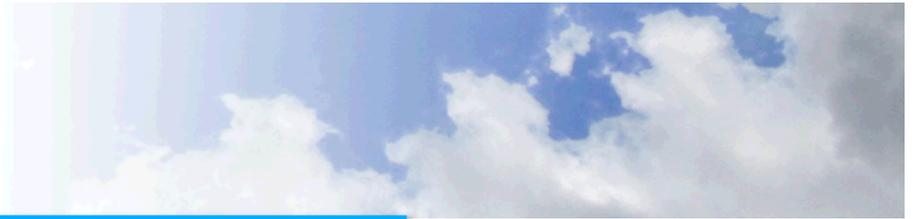
Land



Netherlands Environmental Assessment Age



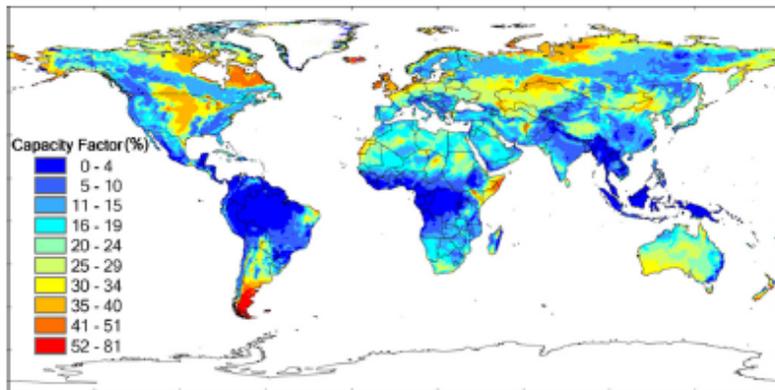
Step 4: Costs



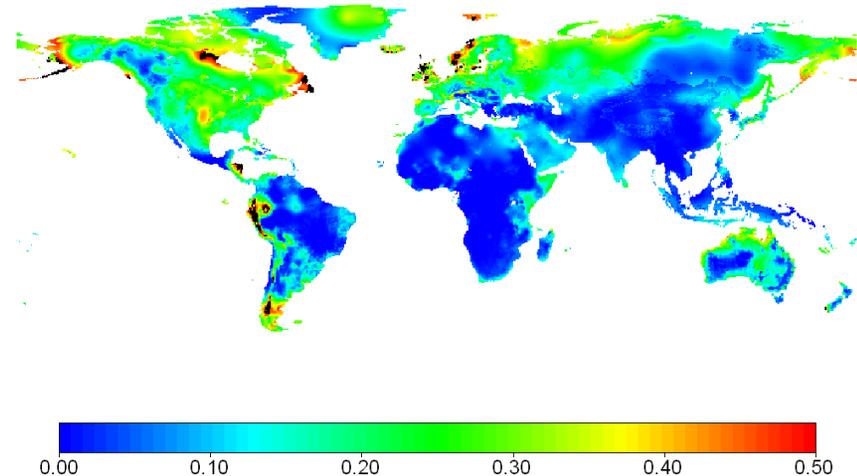
$$COE = \frac{(1 + \varepsilon)I\gamma}{E} + TC = \frac{A}{CF} + TC$$

Capacity factor

Xi Lu, Michael B. et al. (2009)

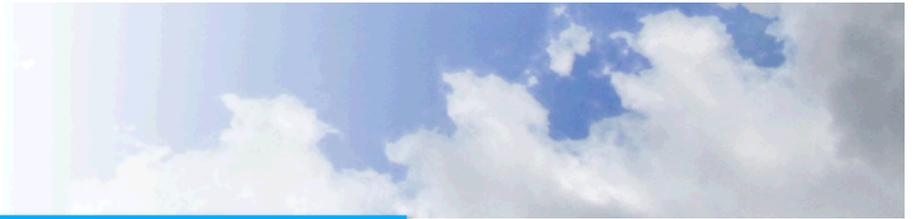


Ours



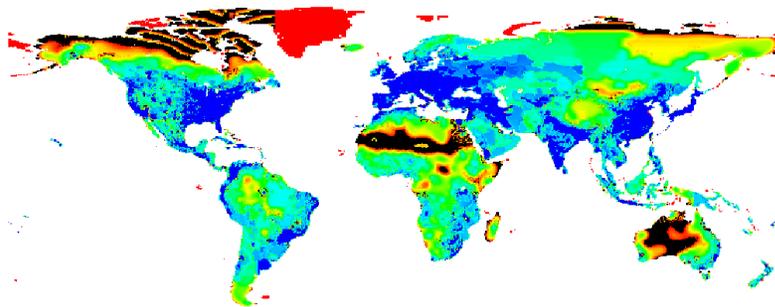
Capacity factor can function as the main costs indicators. It allows groups to set their own assumptions on progress on investment costs development (although there is some relationship with assumed hub height)

Distribution costs

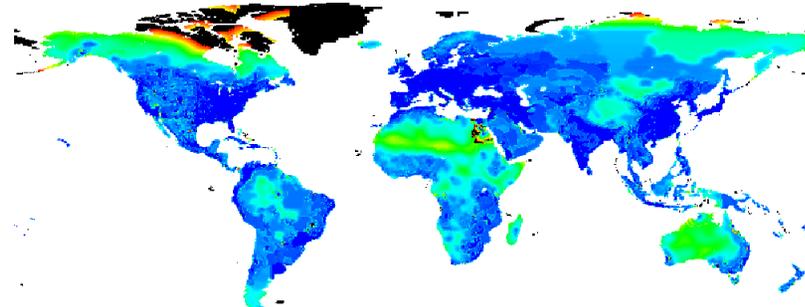


- Used population density map and country power use to determine power density map
- From each grid cell determined distance to a 40 MW load by drawing increasing size circles

Transport



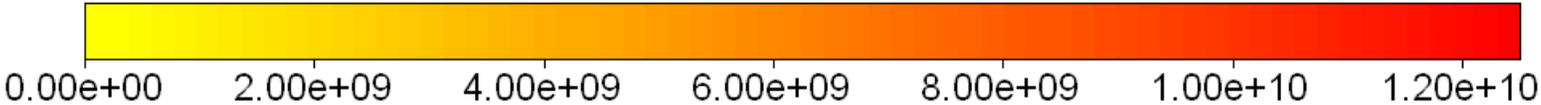
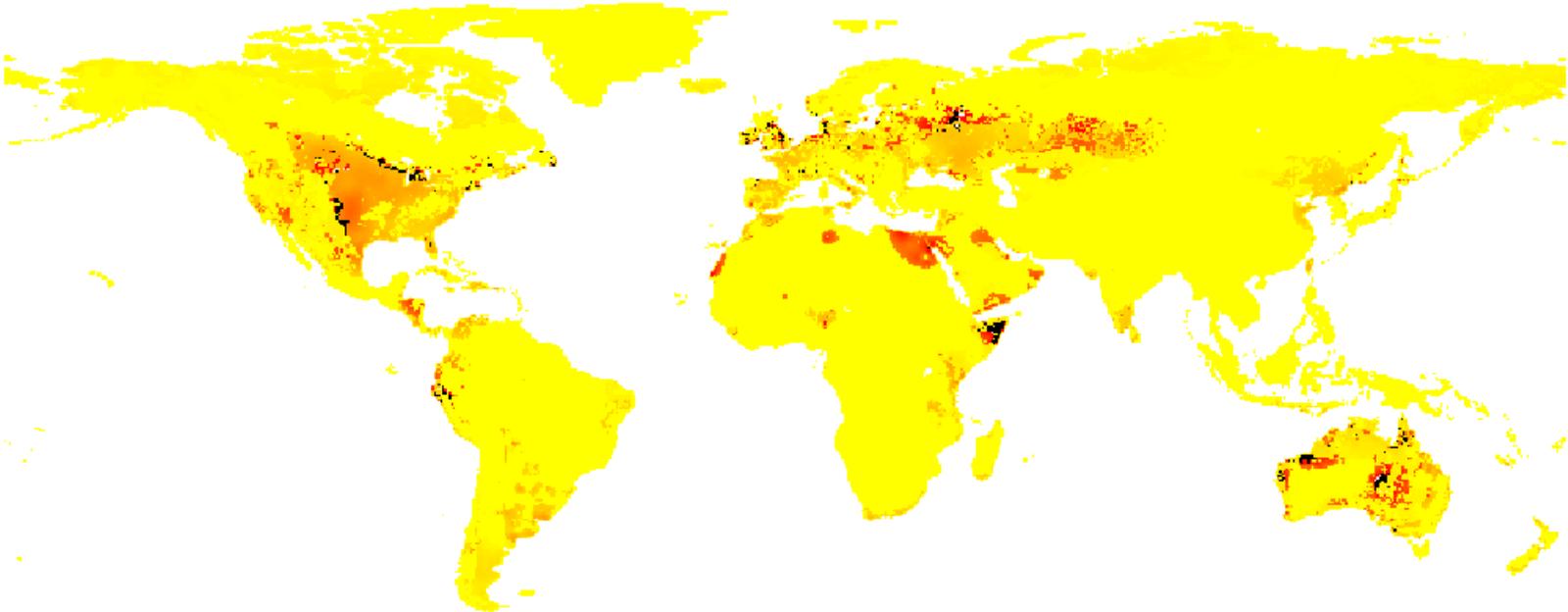
WindTransCost



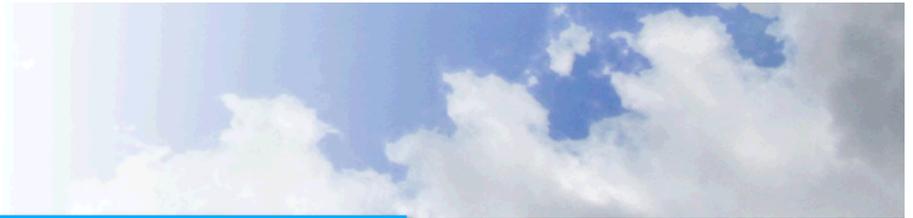
Available potential



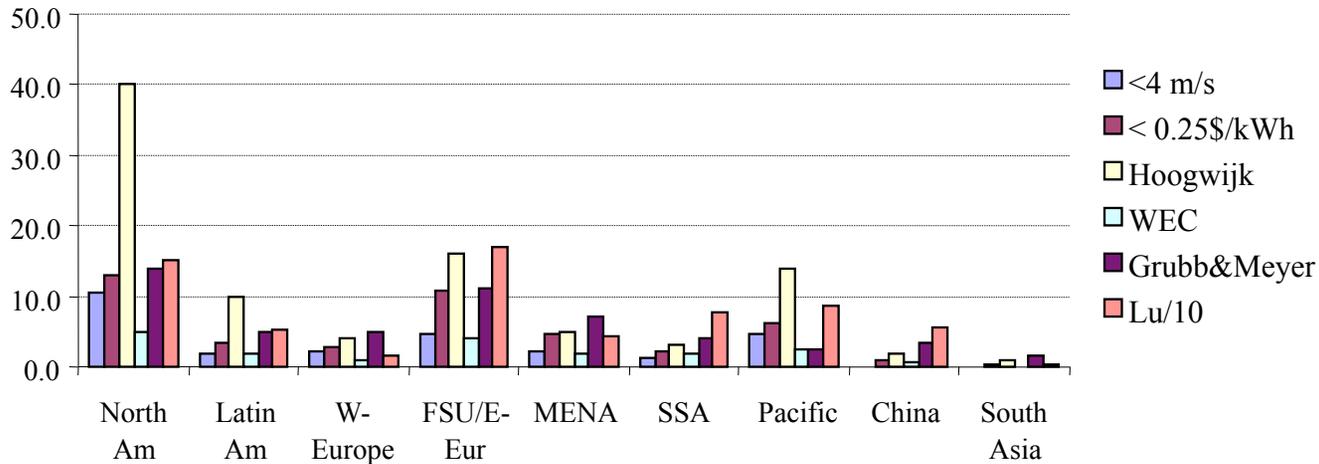
Potential at 0.25\$/kWh



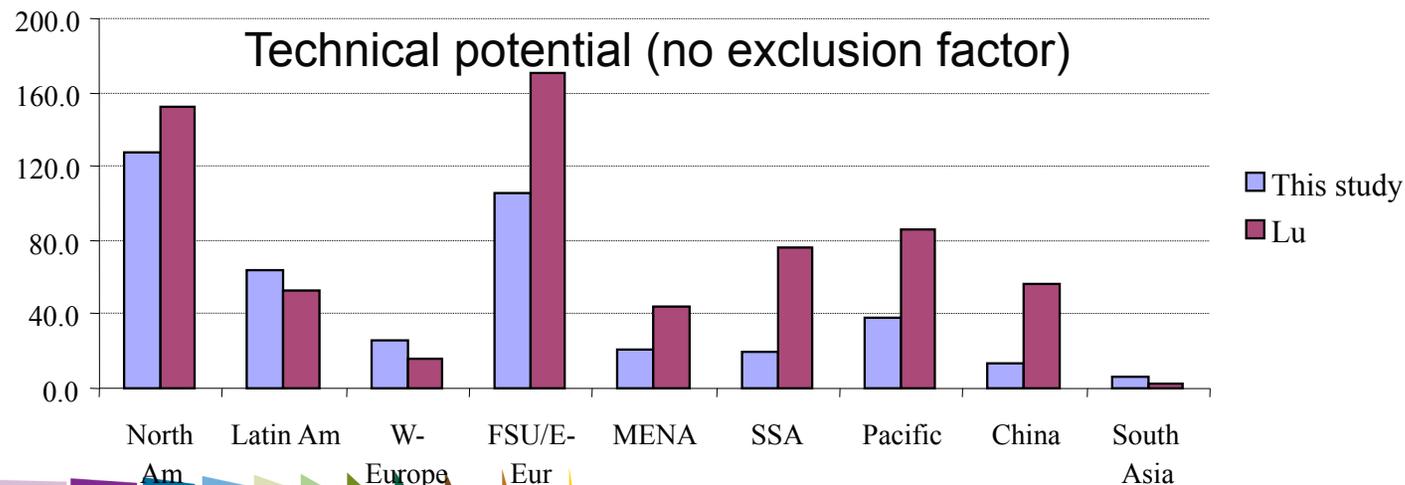
Regional potentials



Potential (with exclusion factors/cut off)



Technical potential (no exclusion factor)



Global potentials



- Global potential:
 - Lu: 840 PWh (no forest, no urban, $CF > 0.2$)
 - Archer/Jacobson: 630 PWh (> 7.2 m/s)
 - Here: 30-44 PWh (exclusion factors)
 - Or: 418 PWh (no exclusion factors or cut-off)
 - Original Hoogwijk: 95 PWh (much higher exclusion factors)
 - World electricity use: 15 PWh

Improvements (my wish list to NREL)

- Wind maps + aggregation issue
- Correction to 80m (and method ok?)
- Wind speed to full load hours (and method ok?)
- Power density calculations (and method ok?)
- Exclusion factors (IAMs together)
- Distribution costs

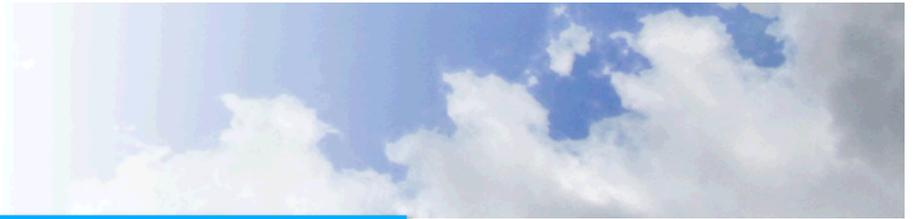


What would be the best way for the community?

- For some models wind potential is really exogenous input: Can we provide harmonised data set of potentials and CF (and do we use the IMAGE system as part of this?) ?
- Some other modelling groups seem to like deriving the data themselves: intermediate products?



Thank you!



*Hoogwijk M, de Vries B, Turkenburg W (2004) Assessment of the global and regional geographical, technical and economic potential of onshore wind energy. **Energy Economics 26:889-919.***

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