



Improving the Representation of Renewable Energy Technologies in Global Climate Stabilization Scenarios: Status Update



CCI/IA
Snowmass
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Outline

1. Offshore Wind Potential Estimates, Globally
2. Improving the accuracy of onshore wind supply estimates via downscaling
3. Accounting for other geospatial issues: Transmission
4. Initial Scenario results—GCAM/PNNL team.
5. Next Steps

Motivations...

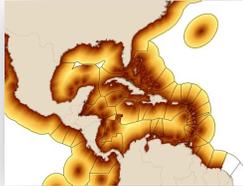
1. Goal: Improve the representation of RE technologies for climate stabilization analysis and apply to:
 - IPCC SRREN, AR5 RCP, NAS/NRC Analysis
 - EMF 24 and IAMC
 - Domestic, International and Global Energy Economic Analysis
2. Improve state of modeling & knowledge
3. Create global community of EE/RE modeling experts & link with IAM/CGE community

Offshore Wind Supply Curves

Database creation and processing

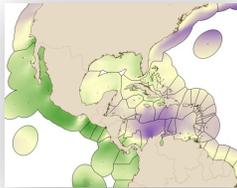
Offshore Wind Database

Distance to Shore (meters)



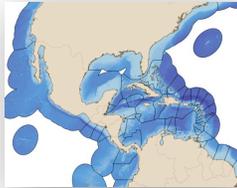
- Distance to shoreline
- Shoreline specific to EEZ

Wind Resource (meters/second)



- NOAA Blended Sea Winds
- Monthly wind speed
- 30km resolution
- 0.11 wind sheer used to extrapolate 10m-90m

Bathymetry (meters)



- NOAA ETOPO1
- 1.9km resolution

Protected Areas (status)

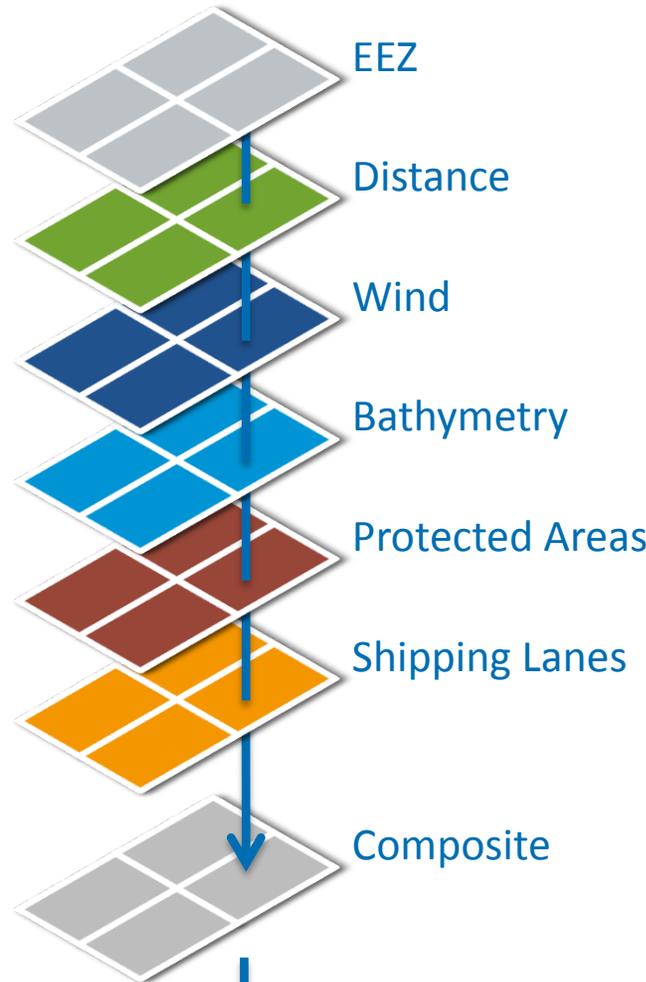


- Protected Planet

Shipping Lanes (ship tracks per km²)



- National Center for Ecological Analysis and Synthesis



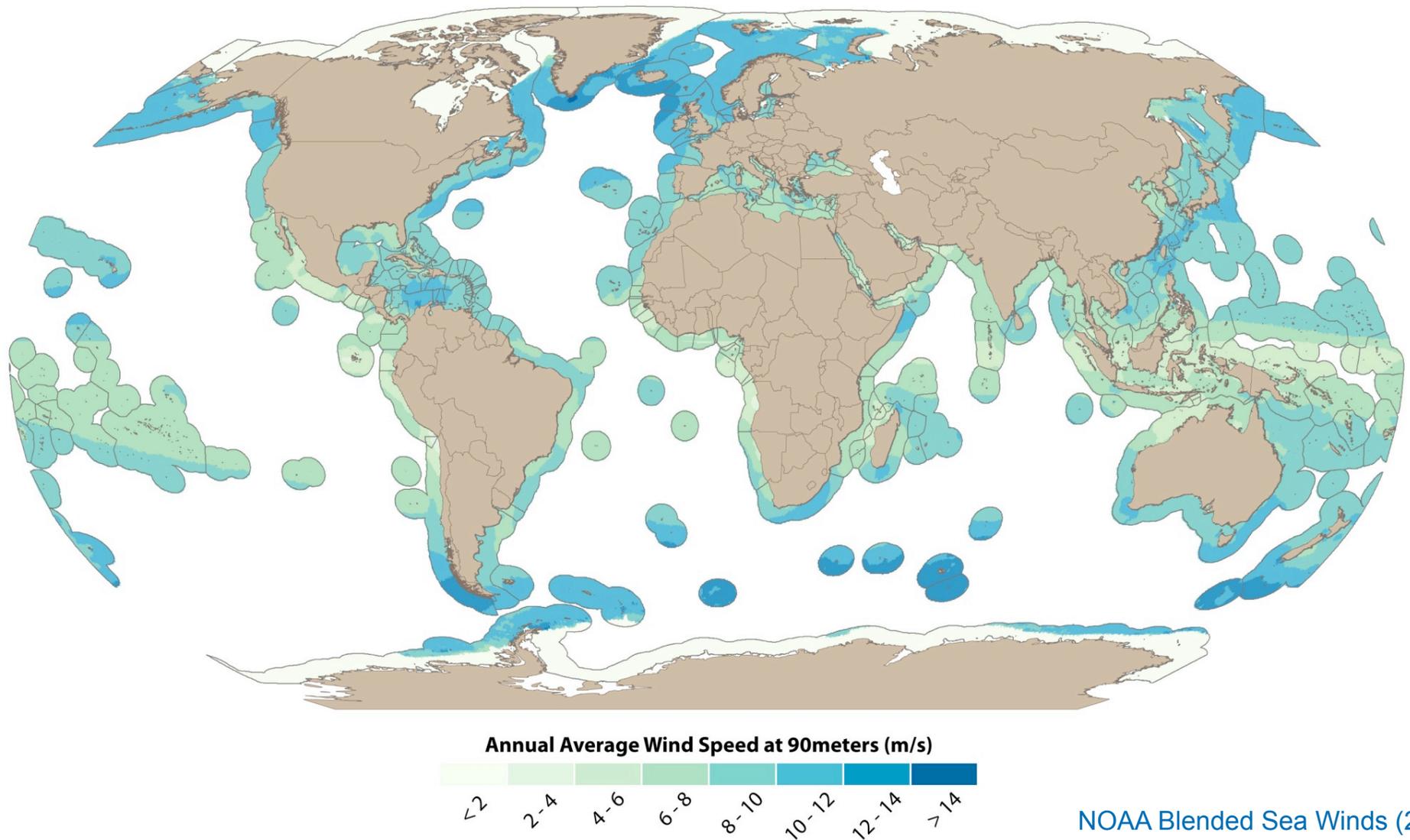
41 million records



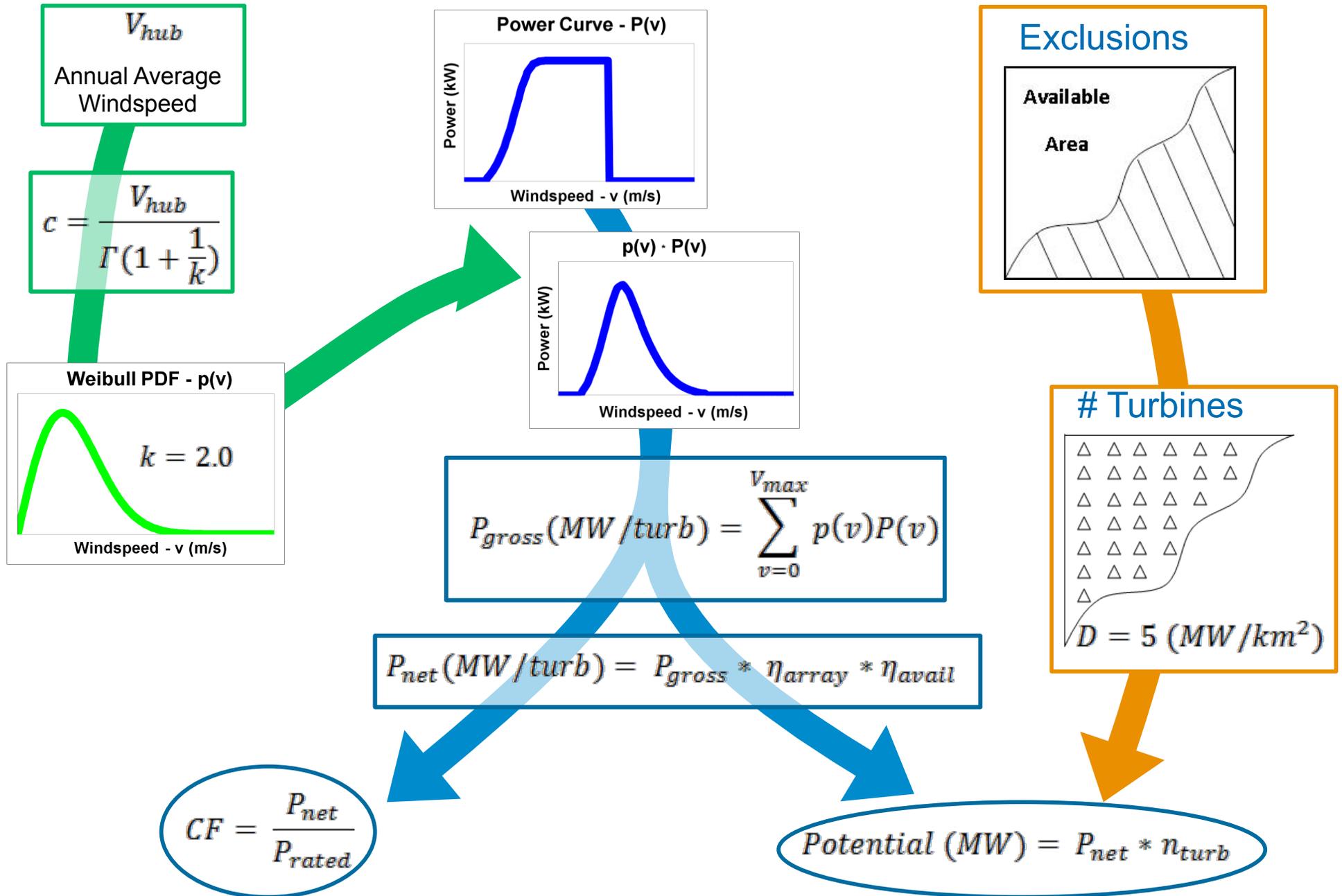
- PostgreSQL Database
- EEZ Country
 - EEZ Sovereign
 - Jan-w/s-10m
 - Jan-w/s-90m
 - Feb-w/s-10m
 - Feb-w/s-90m
 - ...
 - Annual Average-w/s-10m
 - Annual Average-w/s-90m
 - Distance to shore
 - Bathymetry
 - Protected Area (PA)
 - PA – Name
 - PA – Designation
 - PA – Type
 - PA – IUCN
 - PA – Status and Rank
 - 1. Formally Designated
 - 2. Designated
 - 3. Informally Designated
 - 4. Adopted
 - 5. Inscribed
 - 6. Proposed
 - 7. Recommended
 - 8. Voluntary – Recognized
 - 9. Voluntary – Unrecognized
 - 10. ""
 - Ship tracks per km²
 - 1. 0 – 5 linear km per km²
 - ...

Wind Speed Map

Annual average wind speed by Exclusive Economic Zone (EEZ), within 200 nautical miles of shore.



Supply Curve Algorithm



Comparison to Previous Assessment

For a check on the wind speed database and summarization algorithm, we aligned assumptions with those of a wind resource assessment completed at Harvard.

The Harvard study used the Goddard Earth Observing System Data Assimilation System, version 5 (GEOS-5) for its wind speed data and assessed both onshore and offshore resource. Here we compare only offshore assessments.

Characteristic	Assumption Set	
	NREL	Harvard
Hub height	100m	100m
Min-resource cut-off	20% CF	20% CF
Representative turbine	3.5 MW IEC Class I	3.6 MW GE
Array density	5 MW/km ²	5.84 MW/km ²
Depth classes	0-20m, 20-50m, 50-200m	0-20m, 20-50m, 50-200m
Distance from shore	0-50 nautical miles	0-50 nautical miles
Exclusions	None	None

Lu, X; McElroy, M; Kiviluoma, J. (2009). *Global potential for wind-generated electricity*. Proc. Natl. Acad. Sci. 106, 10933.

Comparison to Previous Assessment

Potentials are comparable across the two studies. Some of the largest differences are for Canada and Russia, where the NREL assessment has markedly less resource. We believe the long northern borders—resourceless in the NREL study—to be the root of the disparity.

	Potential wind energy (TWh)	
	NREL	Harvard
United States	9017	14000
China	4897	4600
Russia	9809	23000
Japan	2695	2700
India	1746	1100
Germany	159	940
Canada	5553	21000
United Kingdom	4679	6200
South Korea	1230	990
Italy	596	160
Global (PWh)	120	157

	Potential wind energy (TWh)			
	NREL		Harvard	
	Global	Global	US48	US48
Shallow (0-20m)	27391	42000	1039	1200
Transitional (20-50m)	33264	40000	824	2100
Deep (50-200m)	59742	75000	962	2200
Total	120396	157000	2825	5500

Lu, X; McElroy, M; Kiviluouma, J. (2009). *Global potential for wind-generated electricity*. Proc. Natl. Acad. Sci. 106, 10933.

Updated Offshore Assessment

Using the same Blended Sea Winds dataset but different assumptions, the NREL team developed a set of country-level supply curves. Some of the assumptions match those of Musial and Ram (2010) in their U.S. offshore wind assessment.

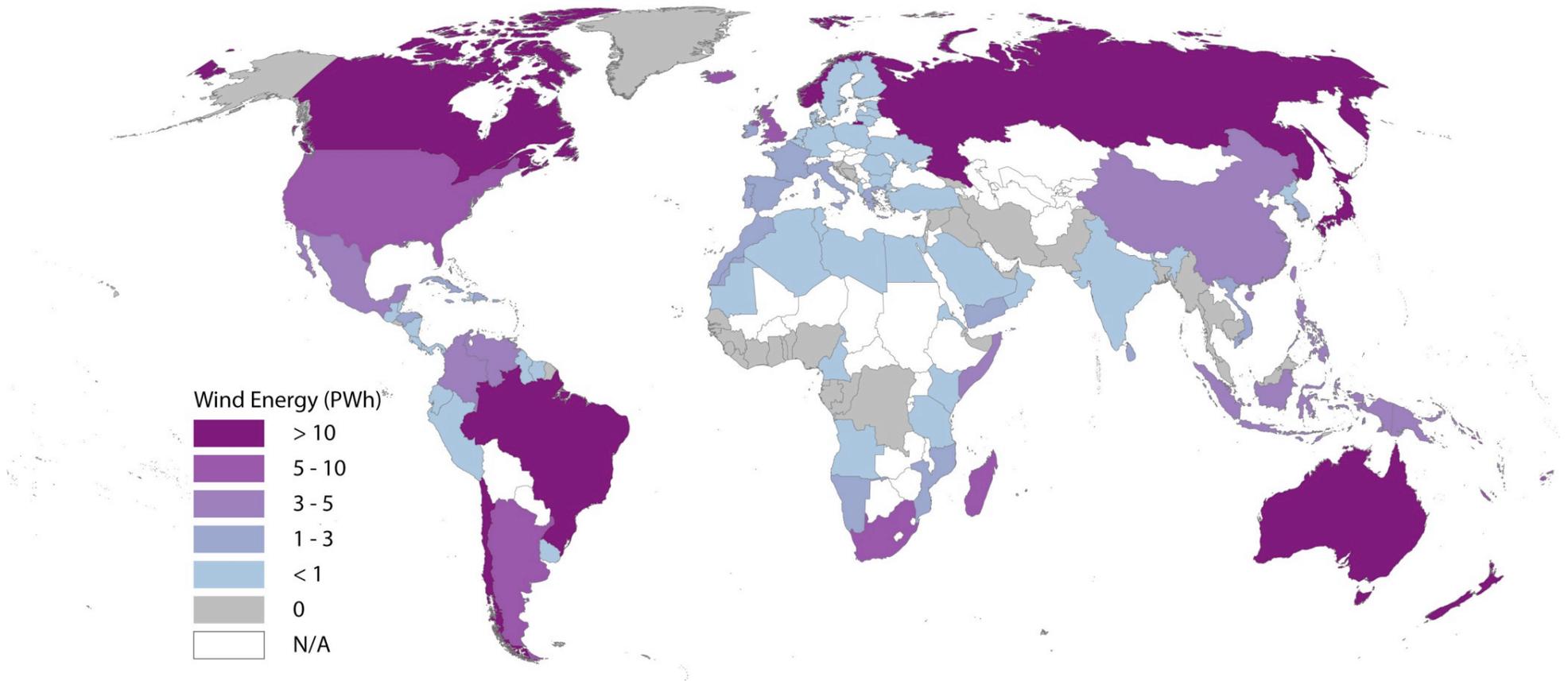
The NREL supply curves are reported by wind- and depth-class in terms of nameplate capacity of potential resource.

Characteristic	Assumption
Hub height	90m
Min-resource cut-off	8.0 m/s
Representative turbine	3.5 MW IEC Class I
Array density	5 MW/km ²
Depth classes	0-30m, 30-60m, 60-1000m
Distance from shore	0-100 nautical miles
Exclusions	Protected Planet IUCN I-III

Musial, W; Ram, B. (2010). *Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers*. NREL/TP-500-40745.

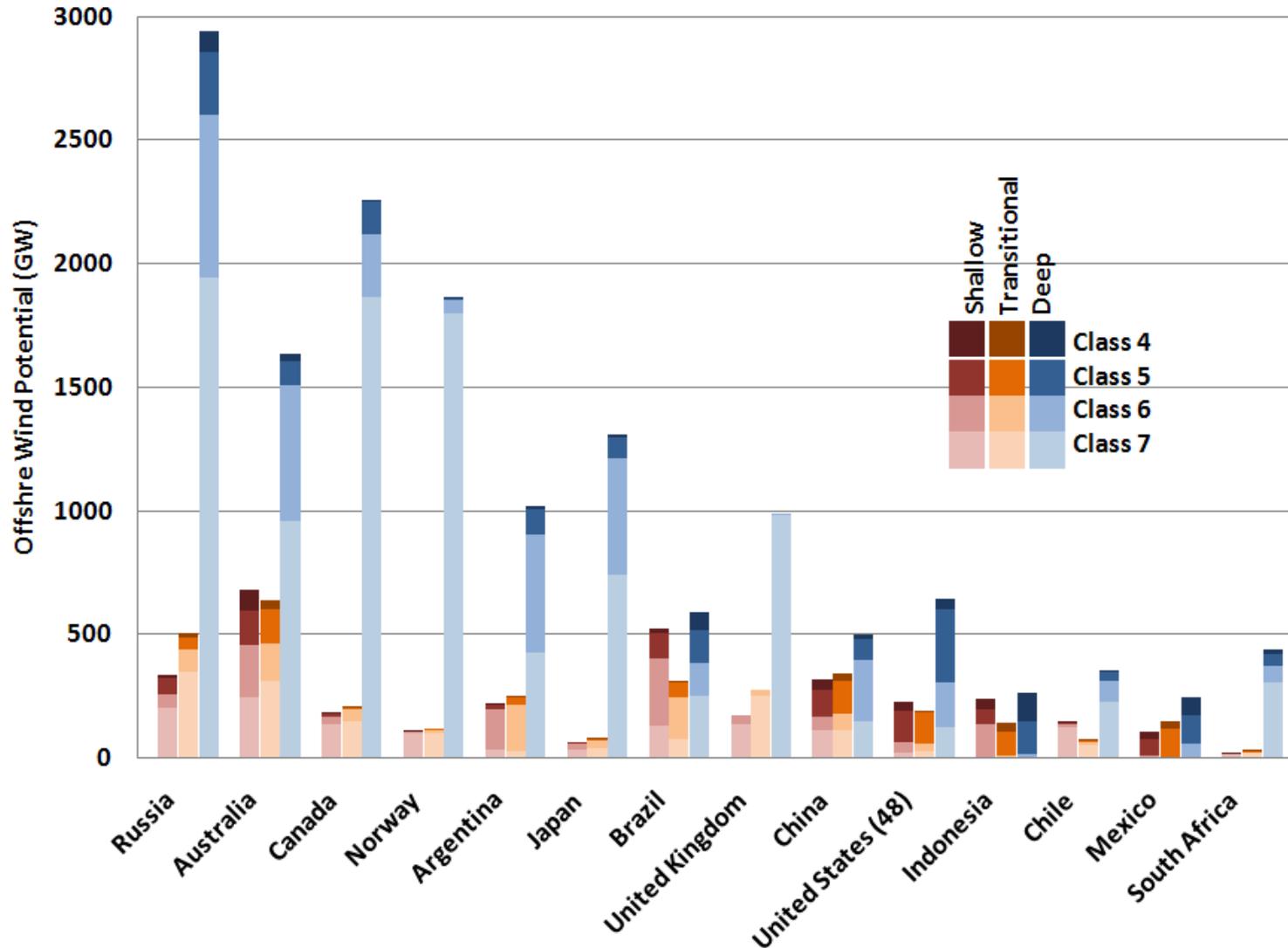
Gross Offshore Wind Potential

Annual PWh of offshore wind potential, by country.



Offshore Wind Supply Curve

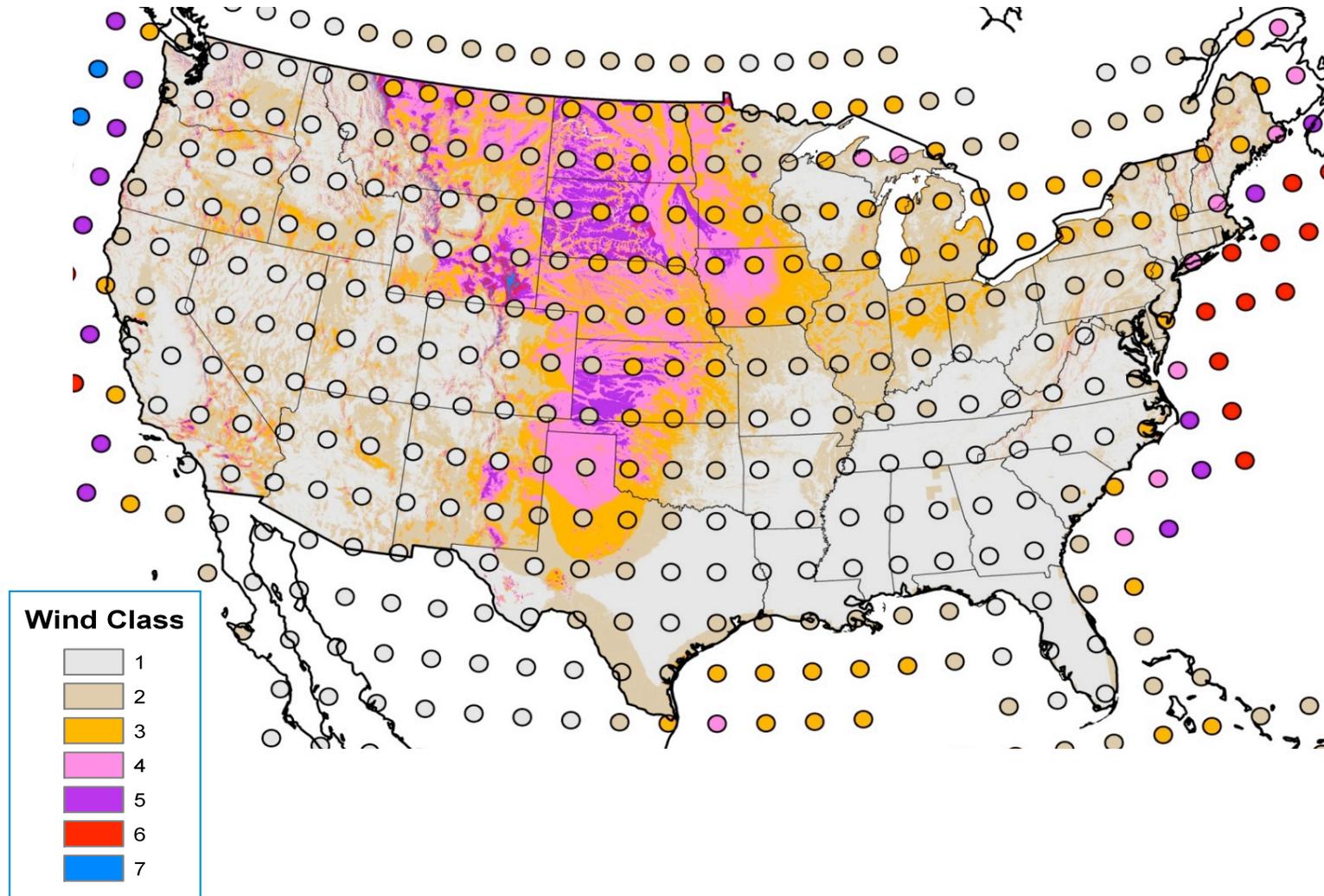
Offshore wind potential, by resource class and depth class, for selected countries



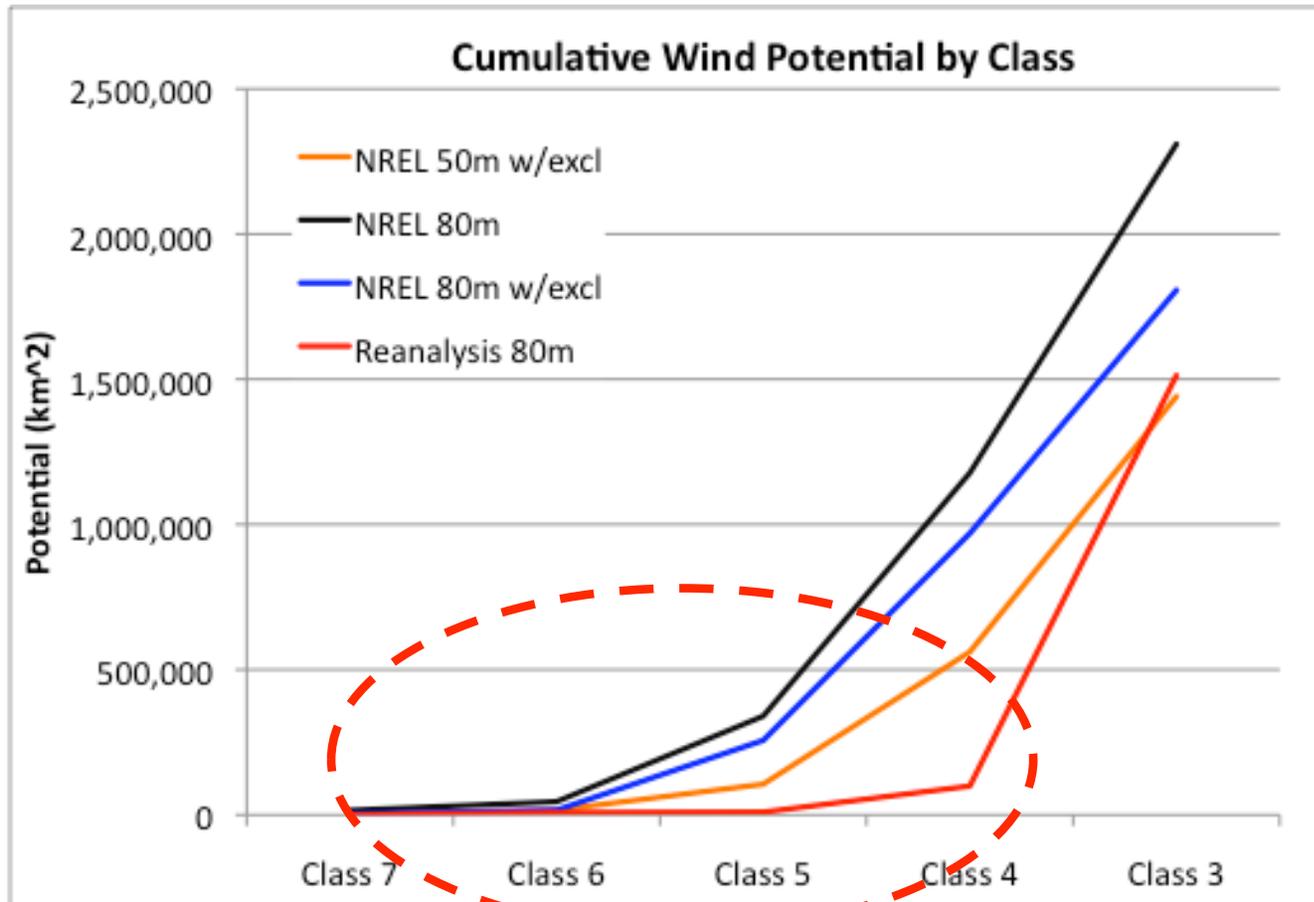
Onshore Wind Resource Downscaling

Accounting for terrain-induced wind regimes

Local-to-Global Impacts

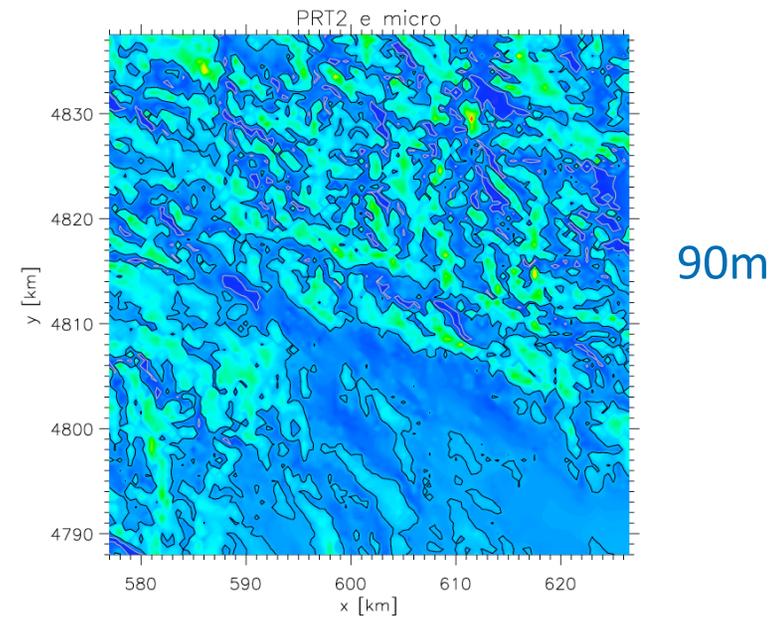
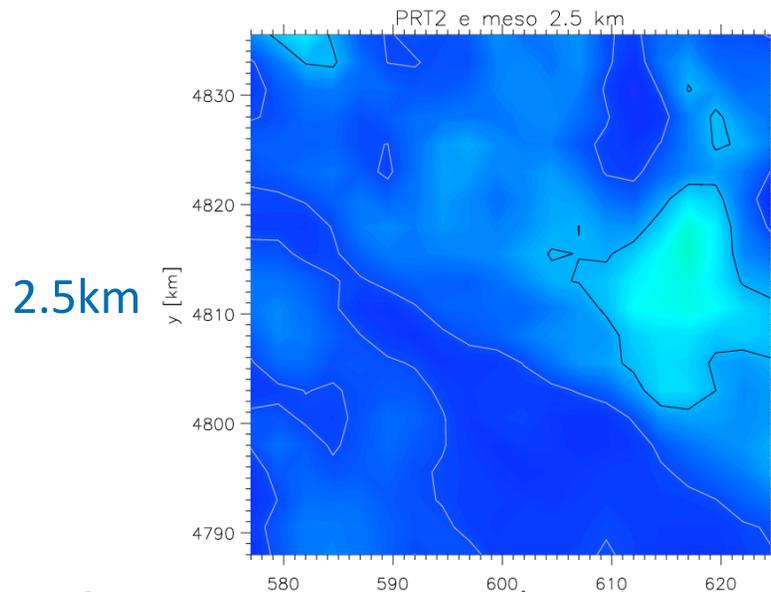
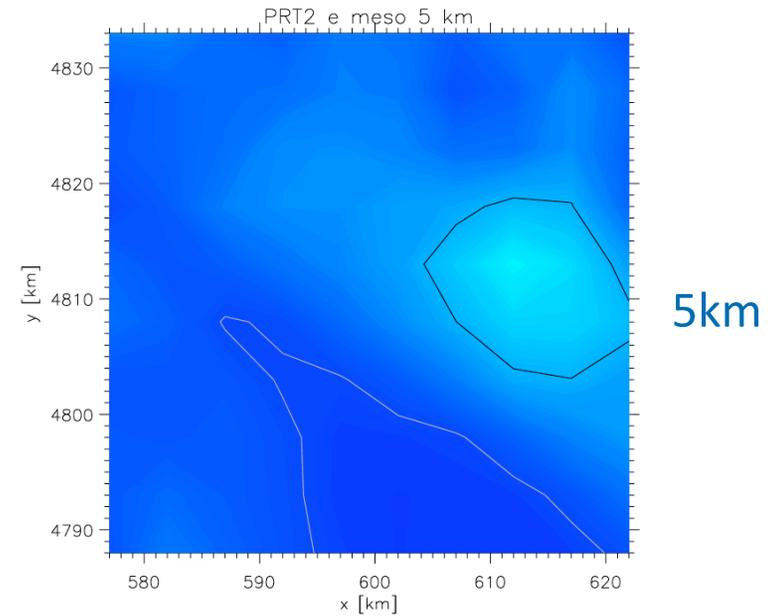
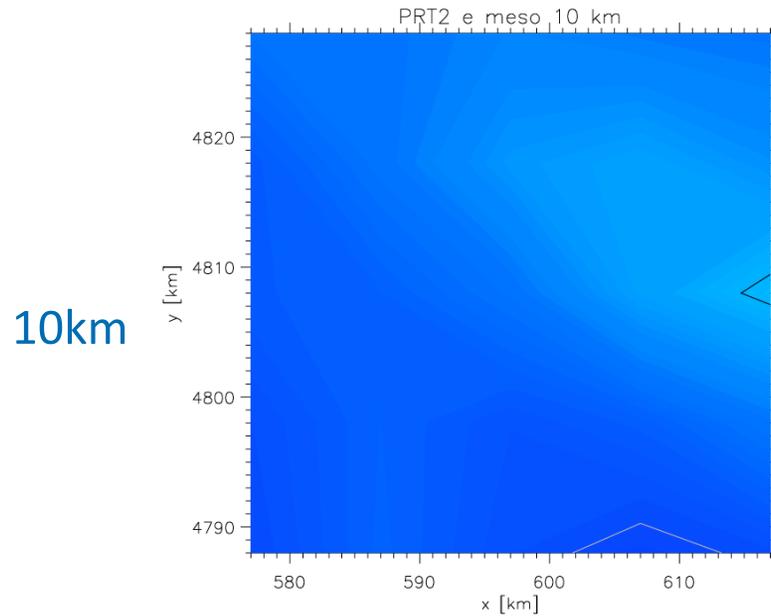


Coarse Scale Data Underestimates High Wind Class Resource



~ 250,000 km² missing.
Up to 750GW of highest
quality, least cost, resource.

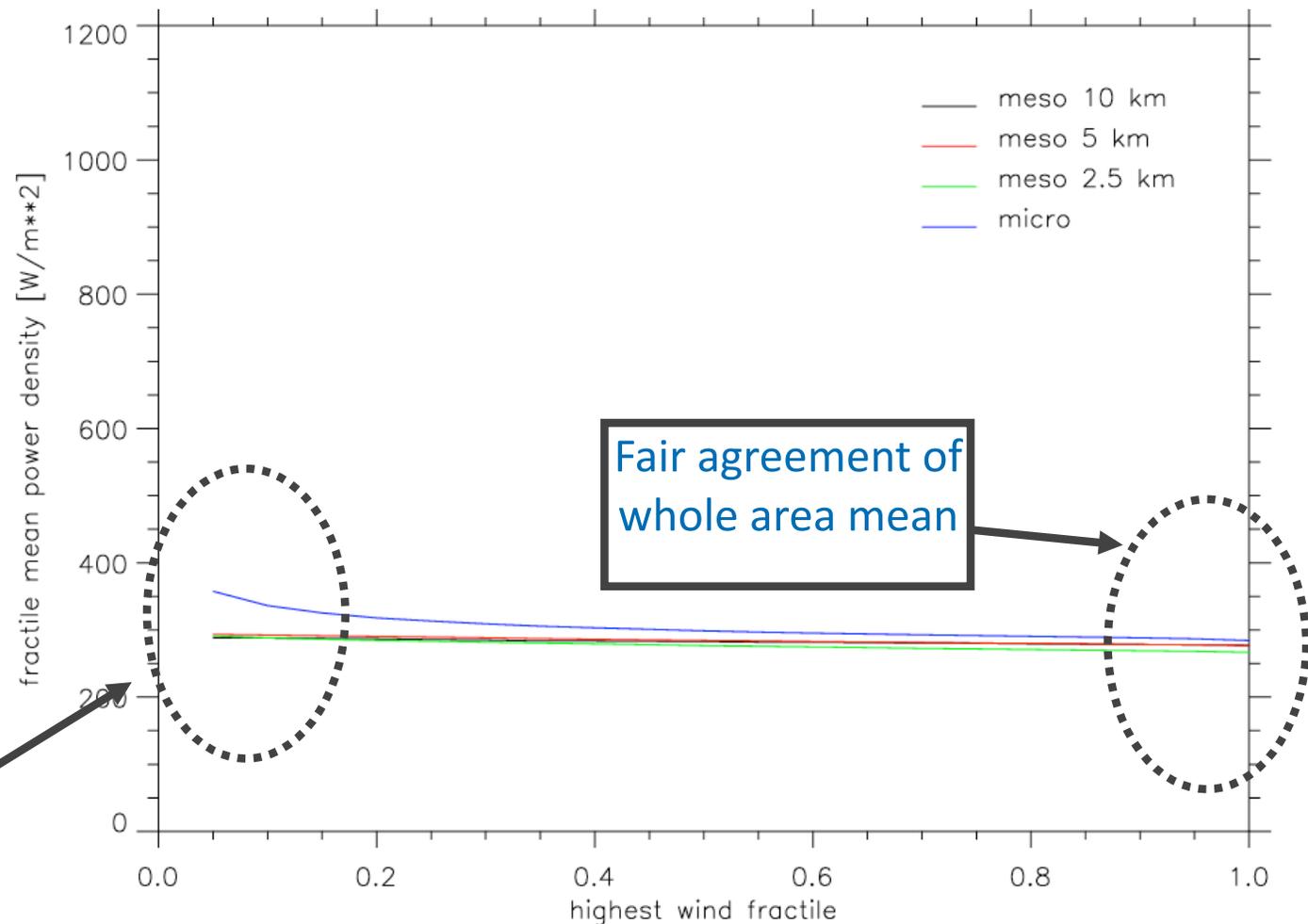
Geospatial Scale is Important



Source: H. Jorgensen, J. Badger, Risoe

Denmark test area

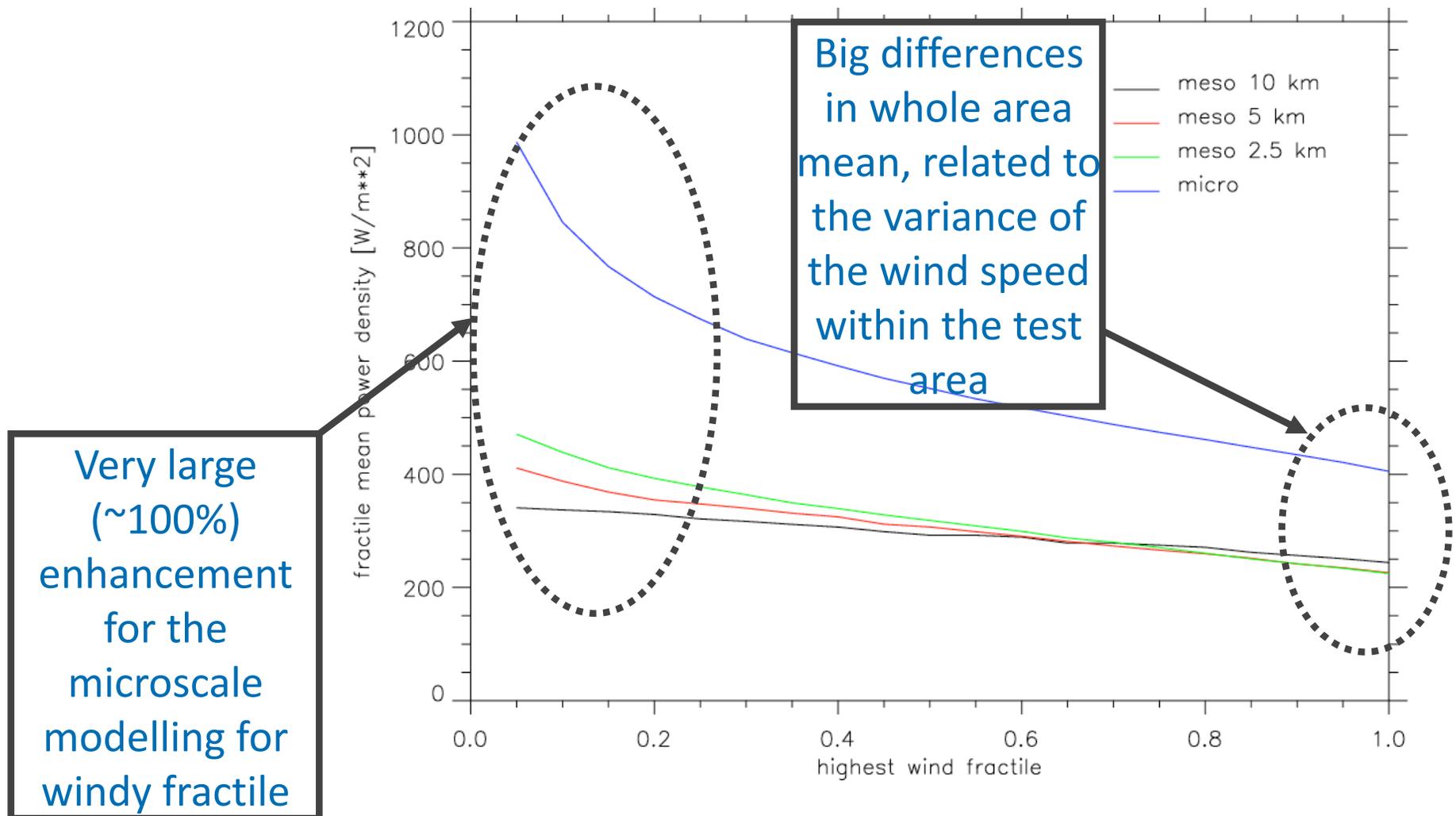
fractile mean wind power density at 50m above ground level



25 % power enhancement of mean power density for windy fractile

Portugal test area

fractile mean wind power density at 50m above ground level



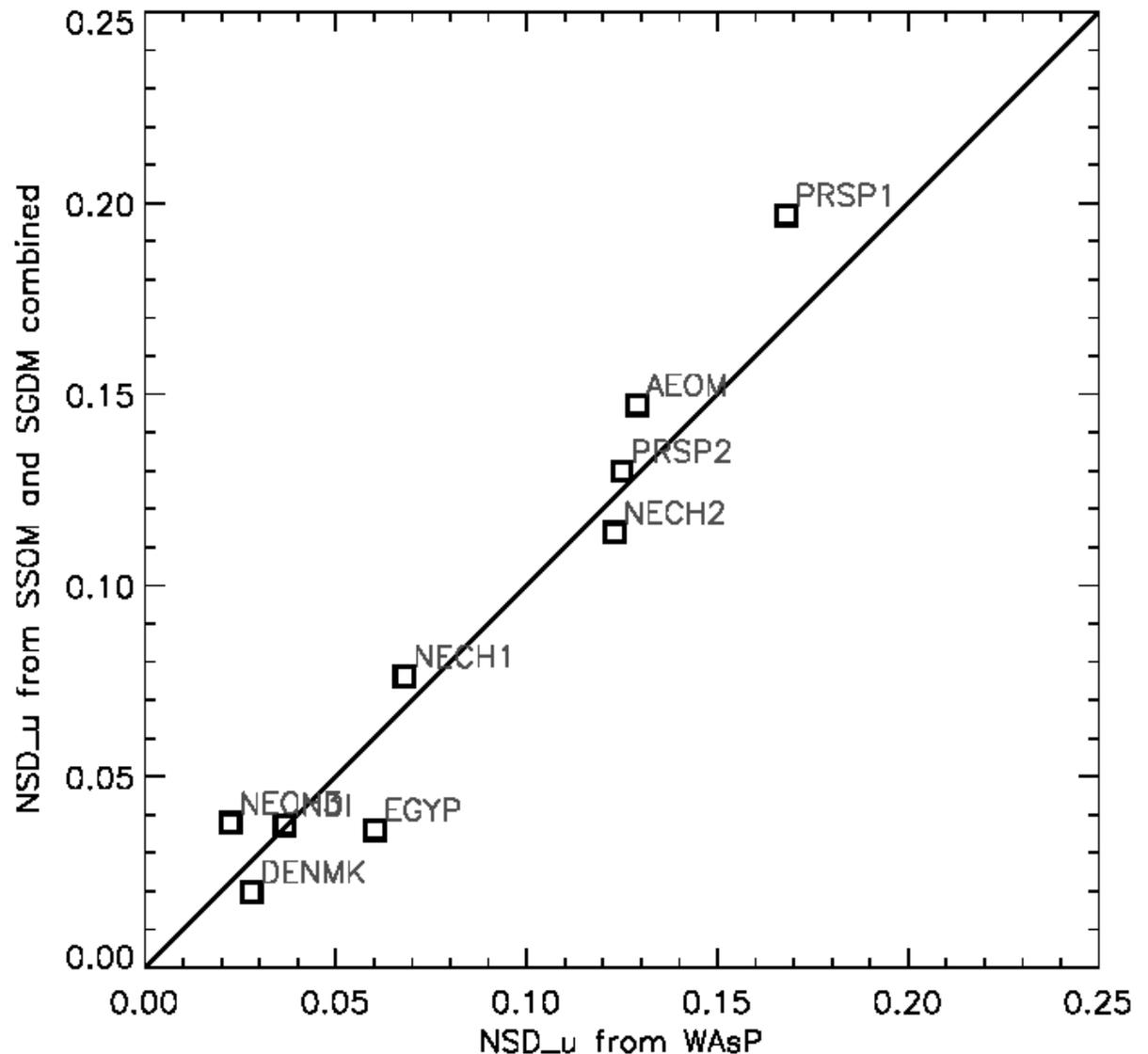
Orography and Roughness Contribution

...to Normalized Standard Deviation of Wind Speed

The orography and roughness standard contributions deviations can be combined by the following:

$$\sigma_A = \sqrt{\sigma_{oro}^2 + \sigma_{rou}^2}$$

The result of the combination plotted against the standard deviation from WAsP shows reasonable agreement



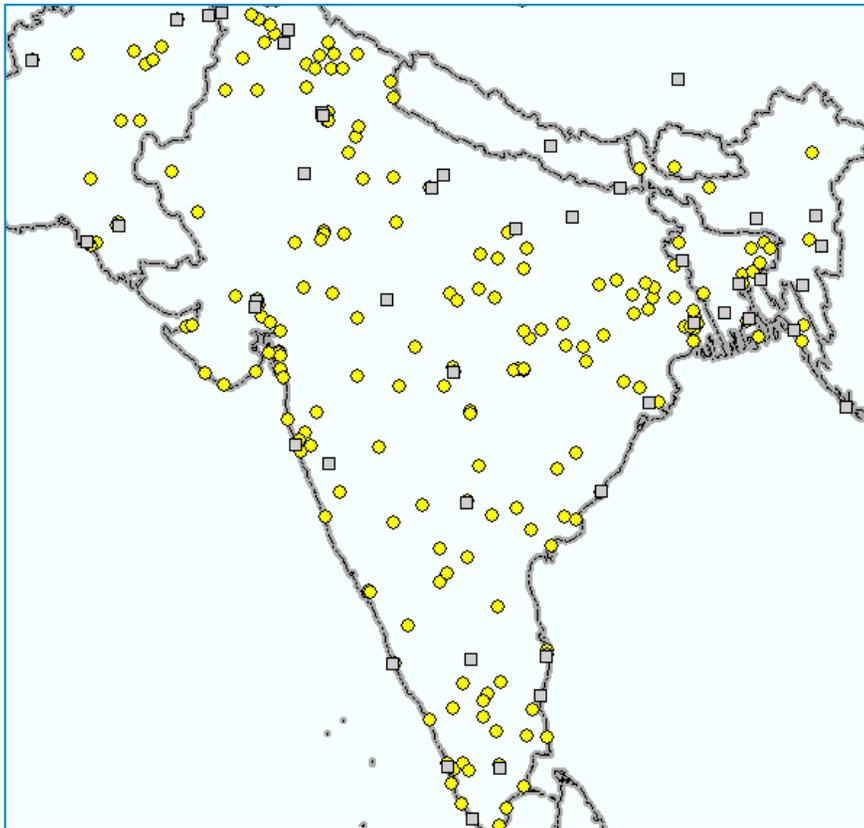
Integration and Transmission

Accounting for spatial heterogeneity of resource and load

Synthetic Transmission Network

Problem: How to estimate costs associated with getting electricity to grid. No global transmission dataset was located.

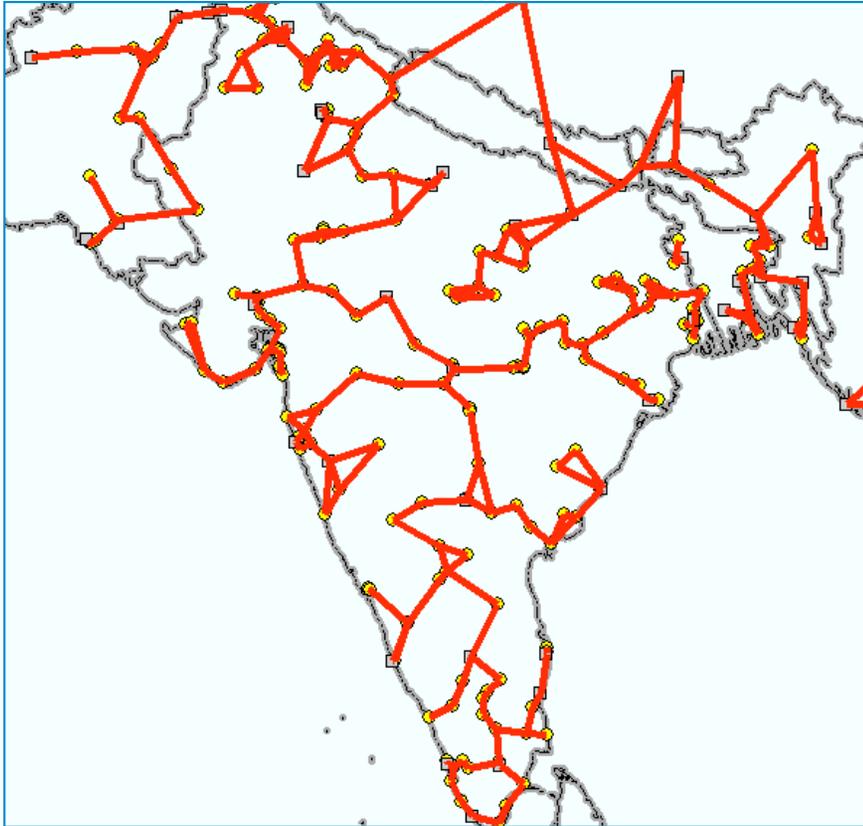
Synthetic grid based on a global database of large energy output power plants (Carbon Monitoring for Action, www.carma.org) and a global dataset of large urban areas.



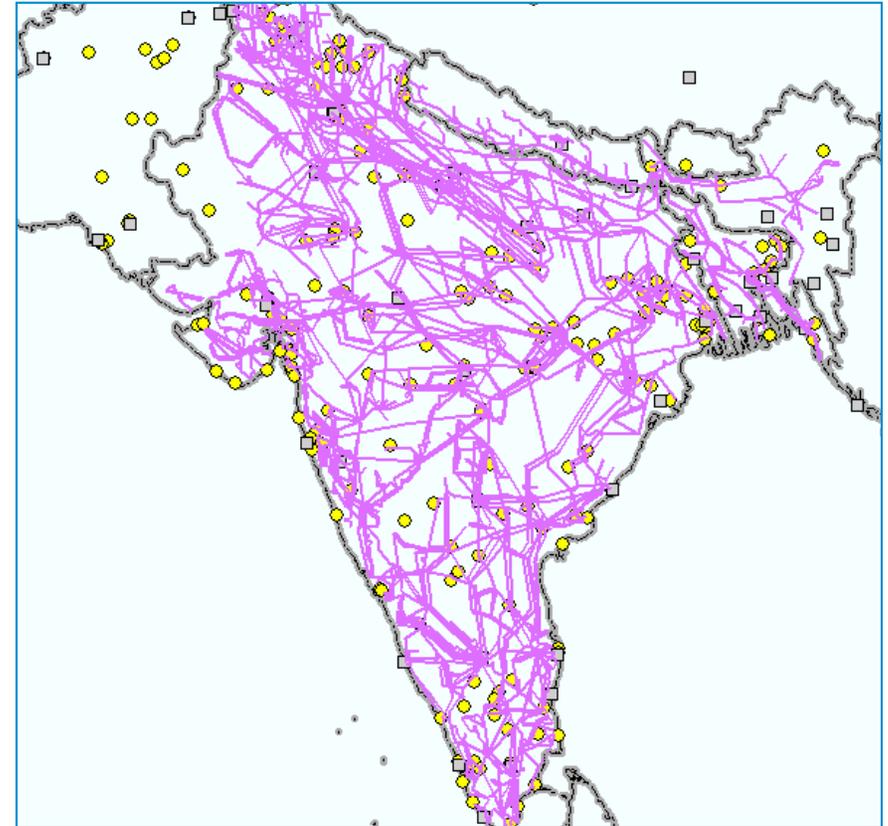
- Power plants and urban areas are linked based on minimum distance
- Each plant or city links to the two closest other points in the synthetic network (will apply maximum distance)
- Isolated clusters within 200 km are linked together by minimum distance
- Comparison with available transmission line data

Synthetic Transmission Network

Initial network results



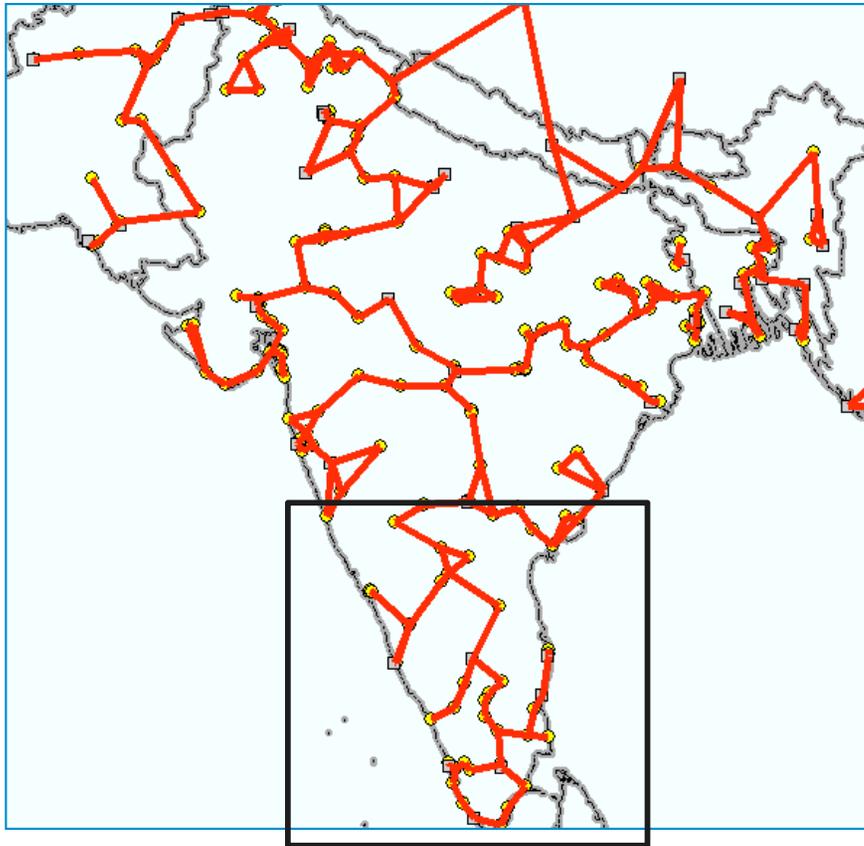
Available transmission data
(India, Nepal and Bangladesh)



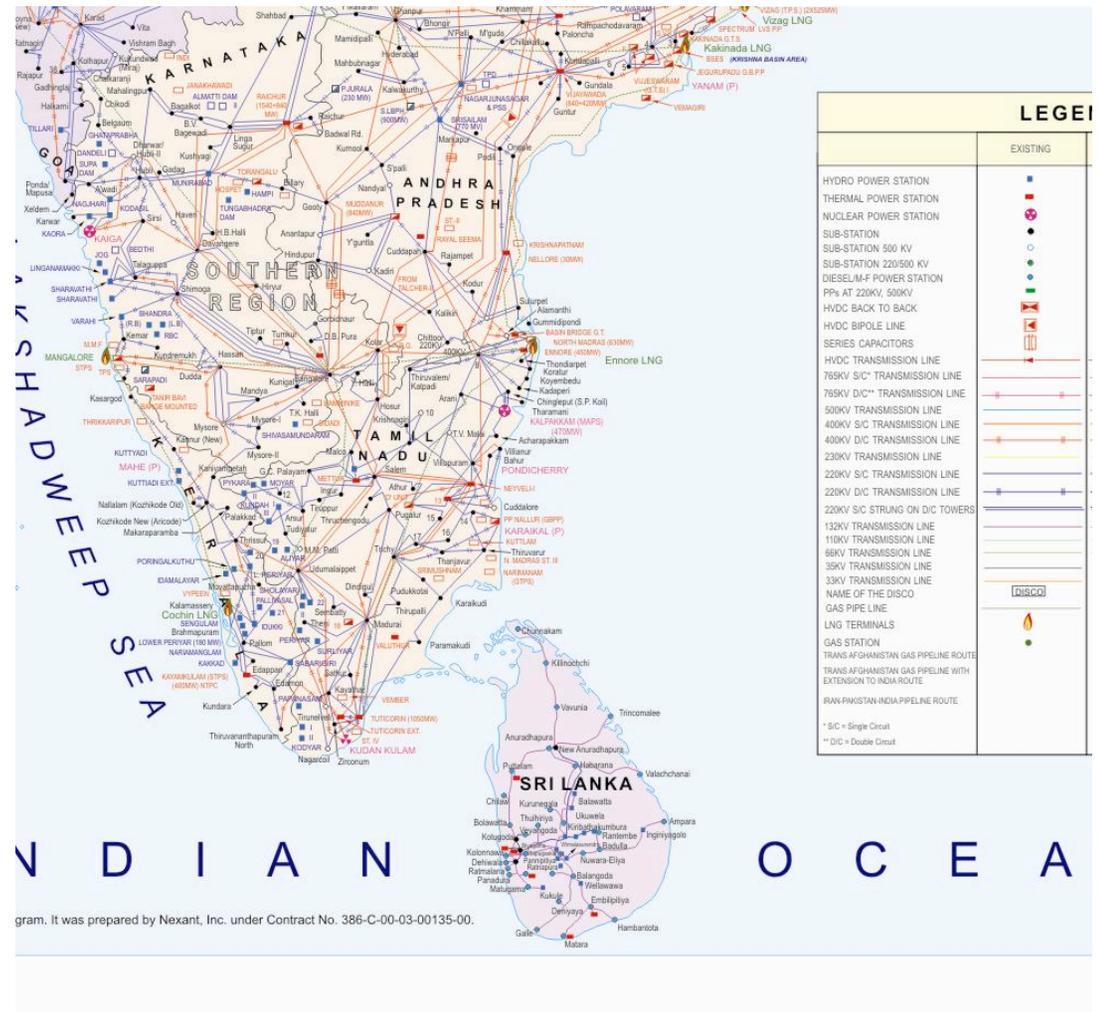
Network not as dense, but can major arteries approximated. May increase line representation by including more cities, adding more links, etc.

Synthetic Transmission Network

Initial network results



SE Asia map used to digitize



Digitized layer doesn't include voltage – many lines in the overlay are smaller (220 kV and less)

GCAM Scenario Results

with new offshore wind supply curves



Pacific Northwest
NATIONAL LABORATORY

Wind Energy in GCAM

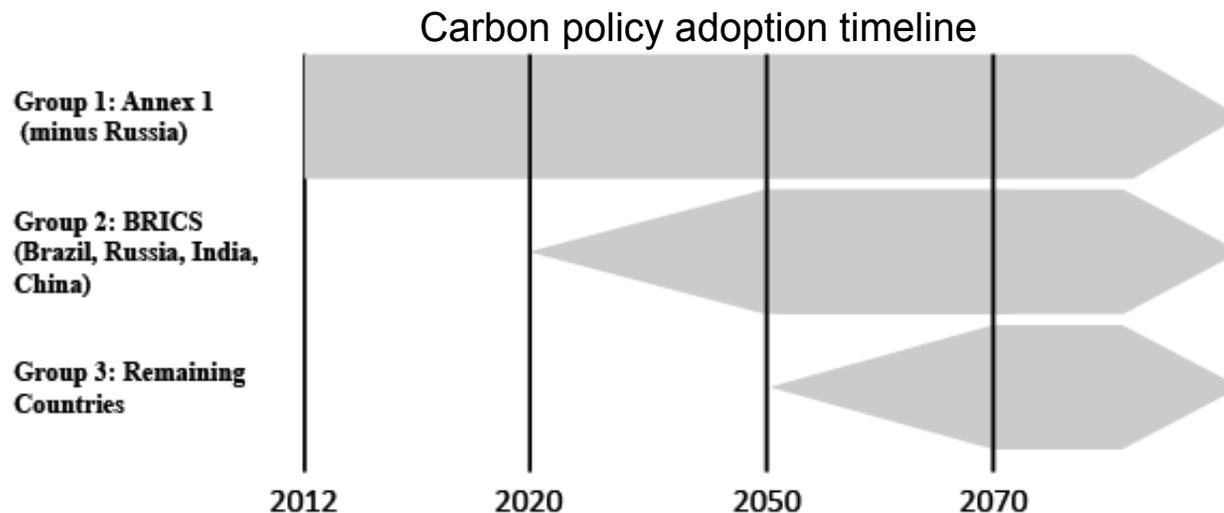
- Onshore and Offshore wind energy
- Split into two components
 - Resource – with cost and supply characteristics, also incorporates transmission costs
 - Technology – including capital, variable O&M, fixed O&M, and capacity factor
- Constraints
 - Backup requirements – increasing levels of backup (gas turbine) required with increasing penetration into the electric sector.

Offshore wind technology

- For onshore wind, core model assumes capital costs from EERE GPRA 2008, and O&M costs and improvement rates from 20% by 2030 report
- The costs for offshore are from the 20% by 2030 report, and include turbines, towers, foundations, installation, and interconnection fees.
 - 2005 costs were based on existing European offshore wind farms, and improvement factors assumed beyond that

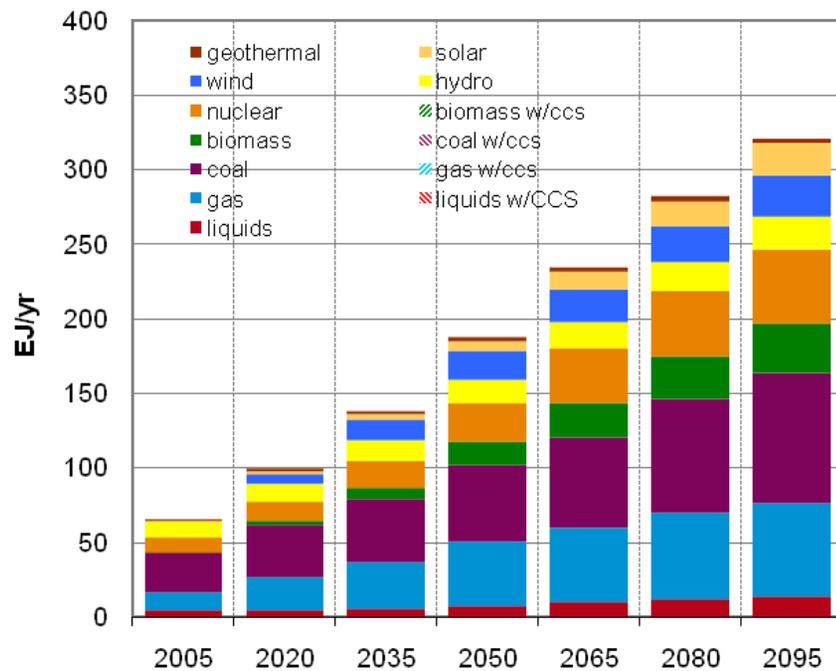
	2020 Wind Technology Costs	
	Onshore	Offshore
Capital (\$2007/kW)	1140	2181
Fixed O&M (\$2007/kW-year)	11.7	15.2
Var O&M (\$2007/MWh)	0.5	1.4
Capacity Factor	45%	47%

- Reference Case
 - Some technological improvements
- Representative policy case
 - Modified EMF22 Scenario: Delayed participation scenario in which majority of developed regions begin mitigation in 2012 and remaining regions enter at points in the future
 - 3.7 W/m² forcing target at the end of the century, roughly equivalent to 550 ppmv CO₂-e

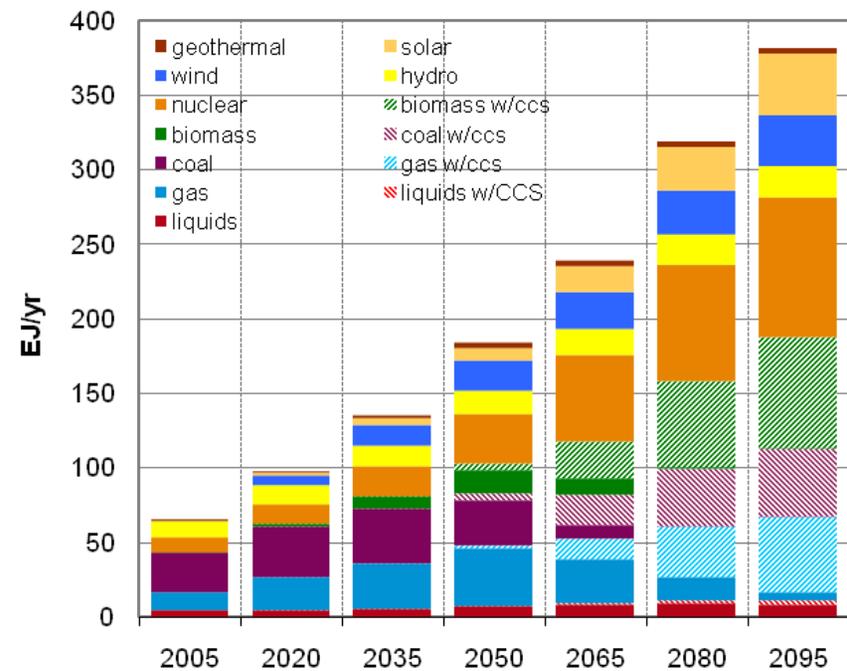


Global Electricity System Results

- Wind energy as a whole grows from 28EJ to nearly 36EJ under this policy.
- Electricity demand grows under the policy as electrification of end-use sectors becomes a viable way to reduce emissions.
- Wind is only one of several carbon-abatement options that include CCS, nuclear, and solar.



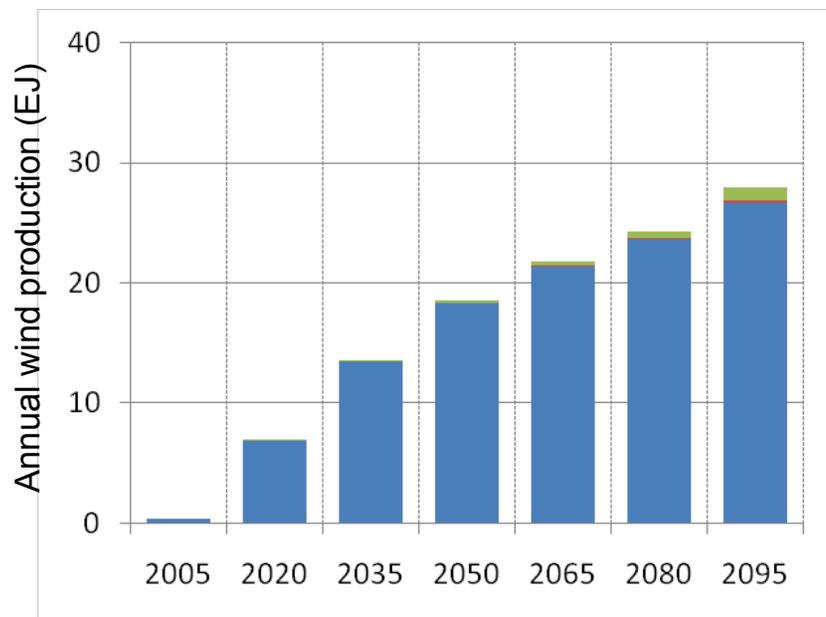
Reference



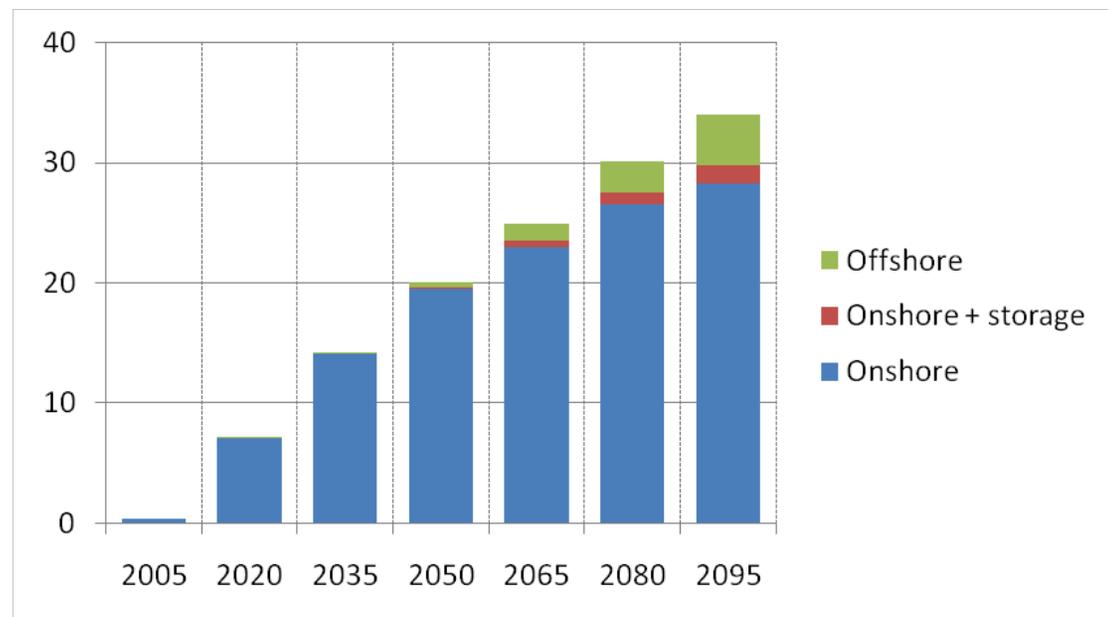
Policy

Impacts of Policy on Offshore Wind

- Vast majority of wind production is from land-based turbines
- Offshore contribution increases from 6% to 17% (2 new EJ from onshore wind, 4.5EJ from offshore)
- Much of the growth in wind under a policy comes from offshore generators.



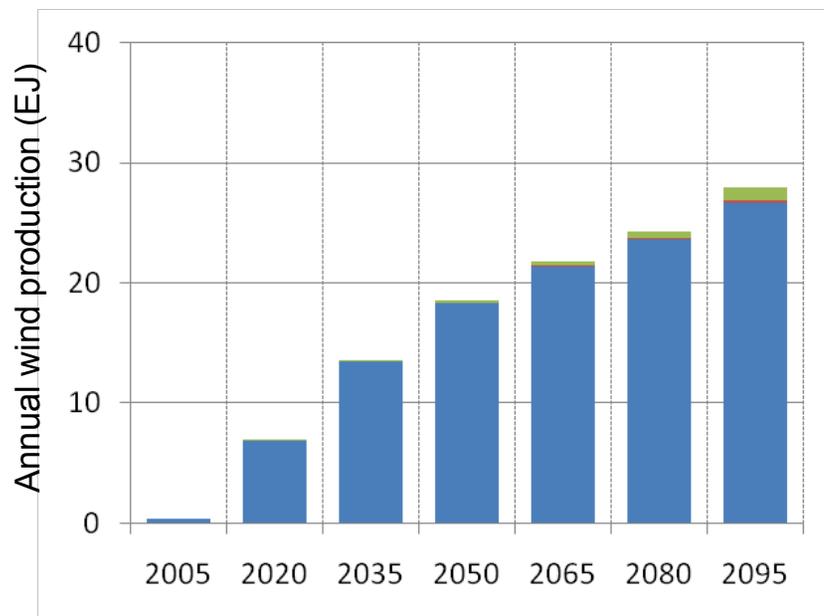
Reference



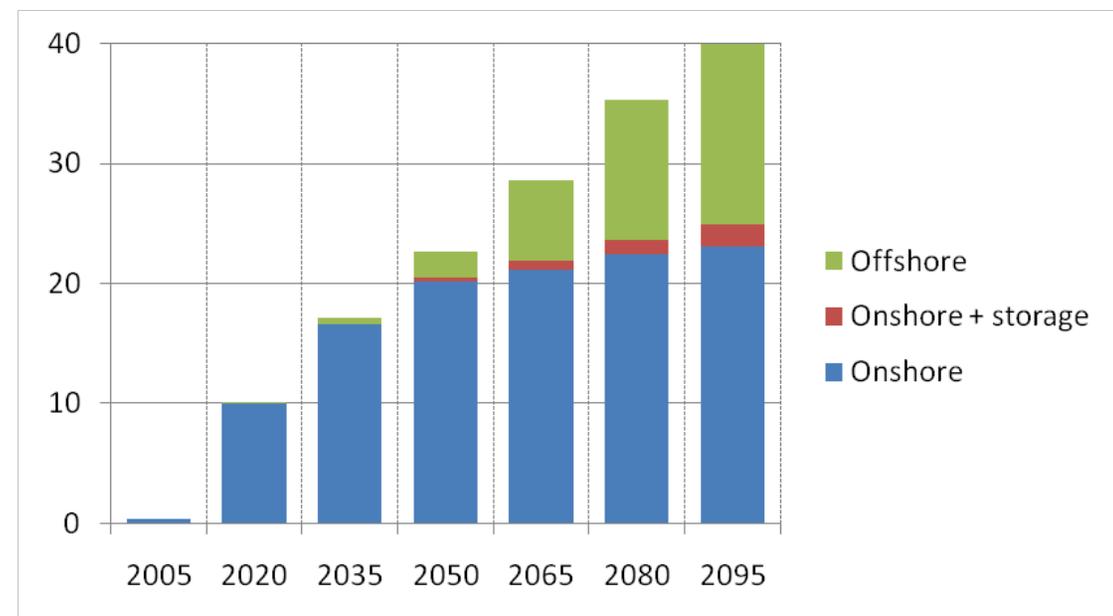
Policy

Technology Cost Sensitivity

- Decrease all wind technology costs by 20% in all future time periods.
- Total wind deployment increases.
 - Onshore decreases slightly, offset by large increase in offshore.



Reference



Policy+Tech

Conclusions and Further Research

1. New Offshore wind supply curves utilizing 0.25° data have been developed and may be utilized, along with appropriate cost information into global models.
2. Initial work indicates statistical downscaling may offer a relatively rapid approach to improved onshore resource estimation, but this requires further detailed validation and comparison to other approaches.
3. Initial work on synthetic grids provide a basis for initial approximation of the geospatial economics of incorporating spatially specific electricity generation resources.
4. Initial Scenario analysis indicates more wind contribution to climate stabilization scenarios.

Further Research Areas:

1. Create a new global supply curves for onshore wind utilizing newly available 40km resolution data.
2. Test and validate approaches to more accurately incorporate the fine scale features of wind for global data.
3. Incorporate improved data and cost analysis into IAM global data representation, followed by comparative evaluation of energy technology contributions to stabilization scenarios.