Wind Resource Assessment and Mapping for Afghanistan and Pakistan

Dennis Elliott

National Renewable Energy Laboratory
Golden, Colorado USA
Benefits of Detailed, Regional Wind Mapping

• Accelerate identification of promising areas for wind prospecting and project development
• Facilitate investment in large-scale wind energy projects
• Support informed decision-making by public and private sectors
• Accelerate the wind project deployment process
NREL’s High-Resolution Wind Mapping Approach

- Computerized mapping approach using Geographical Information System (GIS) software (ArcInfo® and ArcView®)
- Designed for regional wind mapping (not micrositing)
- Combination of numerical, empirical and analytical methods
- Does not depend on high-quality surface wind data (but it helps)
- Produces 1 km² or finer wind power maps
NREL's wind mapping projects have been supported primarily by:

- U.S. Department of Energy
- U.S. Agency for International Development
- United Nations Environment Programme.
Afghanistan and Pakistan Wind Mapping
Project Responsibilities

• NREL
  – project coordination
  – data collection and analysis
  – review and validation of preliminary wind maps from numerical modeling
  – final map development and resource characterization
  – documentation

• 3TIER Environmental Forecast Group (subcontractor to NREL)
  – numerical modeling to produce preliminary wind map estimates

• Country Organizations
  – collection of data from in-country sources
  – data sent to NREL for review and use in the assessment

NREL’s SARI-Energy Activities
Major Global Data Sets used by NREL for Wind Resource Assessment

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Type of Information</th>
<th>Source</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Station Data</td>
<td>Surface observations more than 20000 stations</td>
<td>NOAA/NCDC</td>
<td>Variable up to 2006</td>
</tr>
<tr>
<td>Upper Air Station Data</td>
<td>Rawinsonde and pibal observations at 1800 stations</td>
<td>NCAR</td>
<td>1973-2005</td>
</tr>
<tr>
<td>Satellite -derived Ocean Wind Data</td>
<td>10-m ocean wind speeds gridded to 0.25 deg</td>
<td>NASA/JPL</td>
<td>1988-2006</td>
</tr>
<tr>
<td>Marine Climatic Atlas of the World</td>
<td>Gridded (1.0 deg) statistics of historical ship wind observations</td>
<td>NOAA/NCDC</td>
<td>1854-1969</td>
</tr>
<tr>
<td>Reanalysis Upper Air Data</td>
<td>Model-derived gridde d (~200km) upper air data</td>
<td>NCAR</td>
<td>1958-2005</td>
</tr>
<tr>
<td>Global Upper Air Climatic Atlas</td>
<td>Model -derived gridded (2.5 deg) upper air statistics</td>
<td>NOAA/NCDC</td>
<td>1980-1991</td>
</tr>
<tr>
<td>Digital Geographic Data</td>
<td>Political, hydrography, etc.</td>
<td>ESRI</td>
<td></td>
</tr>
<tr>
<td>Digital Terrain Data</td>
<td>Elevation – 1 km resolution</td>
<td>USGS/EROS</td>
<td></td>
</tr>
<tr>
<td>Digital Land Cover Data</td>
<td>Land use/cover and tree cover density – 0.5 km resolution</td>
<td>NASA/USGS</td>
<td></td>
</tr>
</tbody>
</table>

NREL’s SARI-Energy Activities
Numerical Modeling Method
Afghanistan and Pakistan Wind Mapping

• Model Design and Outputs
  – Modeling system created by 3TIER (U.S. company based in Seattle, WA)
  – A numerical weather model (WRF) coupled to a wind flow model (CALMET) and global weather, topographical, and land cover data
  – NCEP/NCAR Reanalysis (200-km grid) - most important global weather input for WRF
  – WRF simulates weather conditions (including winds) over 365 days selected from a 15-year period
  – WRF simulations to 2.5 km and CALMET simulations to 1 km
  – Model output grids provided to NREL for review and improvement with empirical and analytical methods
Data Analysis for Assessment and Validation – Surface, Upper-Air, Reanalysis, and Satellite Ocean Data

Afghanistan and Pakistan GTS Surface Meteorological Stations

Total Stations in Pakistan = 76
Total Stations in Afghanistan = 73

The Global Telecommunication System (GTS) surface meteorological stations are part of NREL’s global database.

Meteorological Stations
Total Observations

- 100,000 to 210,000
- 60,000 to 100,000
- 30,000 to 60,000
- 10,000 to 30,000
- 2,000 to 10,000
- 0 to 2,000
Recent Wind Measurements in Pakistan

- Wind measurement data from 47 towers in southern Pakistan are being analyzed for the assessment.

NREL’s SARI-Energy Activities
Key Deliverables
Afghanistan and Pakistan Wind Mapping

- High resolution annual wind power maps, with documentation, for distribution:
  - estimates for 50-m height above ground
  - horizontal spatial resolution: 1-km grid
- Electronic data sets, including
  - the modified and raw gridded map data in GIS format
  - other products including summaries of processed data from available wind measurement stations
- Presentation of project results to country partners and stakeholders from throughout the region

NREL’s SARI-Energy Activities
Afghanistan
50 m Wind Power

Wind Power Classification

<table>
<thead>
<tr>
<th>Wind Power Class</th>
<th>Resource Potential</th>
<th>Wind Power Density at 50m W/m²</th>
<th>Wind Speed at 50 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Poor</td>
<td>0 - 200</td>
<td>0.0 - 5.4</td>
<td></td>
</tr>
<tr>
<td>2 Marginal</td>
<td>200 - 300</td>
<td>5.4 - 6.1</td>
<td></td>
</tr>
<tr>
<td>3 Fair</td>
<td>300 - 400</td>
<td>6.1 - 6.8</td>
<td></td>
</tr>
<tr>
<td>4 Good</td>
<td>400 - 500</td>
<td>6.8 - 7.3</td>
<td></td>
</tr>
<tr>
<td>5 Excellent</td>
<td>500 - 600</td>
<td>7.3 - 7.7</td>
<td></td>
</tr>
<tr>
<td>6 Outstanding</td>
<td>600 - 800</td>
<td>7.7 - 8.5</td>
<td></td>
</tr>
<tr>
<td>7 Superb</td>
<td>&gt; 800</td>
<td>&gt; 8.5</td>
<td></td>
</tr>
</tbody>
</table>

*Wind speeds are based on an elevation of 1500 m and a Weibull k value of 1.6.
Afghanistan’s Wind Resources

Major Areas

• Major wind resource areas
  – Western Afghanistan especially
    • Northwestern Nimroz
    • Western Farah
    • Western Herat
  – Northeastern areas especially
    • Eastern Balkh
    • Northern Takhar
  – Wind corridor areas including
    • Near Jabalsaraj, Sarobi, and Tigrari in eastern Afghanistan
    • Near Qalat, Gadamsar, Walakhor, Golestan, and Gorzanak in central/southern Afghanistan
  – Elevated mountain summits and ridge crests especially in northern and eastern Afghanistan

NREL’s SARI-Energy Activities
## AFGHANISTAN - WIND ELECTRIC POTENTIAL
Good-to-Excellent Wind Resource at 50 m (Utility Scale)

<table>
<thead>
<tr>
<th>Wind Resource Utility Scale</th>
<th>Wind Class</th>
<th>Wind Power W/m²</th>
<th>Wind Speed m/s</th>
<th>Land Area km²</th>
<th>Percent Windy Land</th>
<th>Total Capacity Installed MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>4</td>
<td>400 - 500</td>
<td>6.8 – 7.3</td>
<td>15,193</td>
<td>2.4</td>
<td>75,970</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
<td>500 - 600</td>
<td>7.3 – 7.7</td>
<td>6,633</td>
<td>1.0</td>
<td>33,160</td>
</tr>
<tr>
<td>Excellent</td>
<td>6</td>
<td>600 - 800</td>
<td>7.7 – 8.5</td>
<td>6,615</td>
<td>1.0</td>
<td>33,100</td>
</tr>
<tr>
<td>Excellent</td>
<td>7</td>
<td>&gt; 800</td>
<td>&gt; 8.5</td>
<td>3,169</td>
<td>0.5</td>
<td>15,800</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>31,611</td>
<td>4.9</td>
<td>158,100</td>
</tr>
</tbody>
</table>

### Assumptions
- Installed capacity per km² = 5 MW
- Total land area of Afghanistan = 645,810 km²

NREL’s SARI-Energy Activities
Conclusions for Afghanistan Wind Mapping

- Advanced modeling and analysis techniques employed to produce detailed wind resource maps of Afghanistan
- High resolution wind maps and assessment information
  - Useful to identify best prospective areas and screen out less promising areas, minimizing cost and time of prospecting
  - Does not eliminate the need for on-site wind measurement
- Windy land area and theoretical wind potential estimates
  - Class 4+ (good-to-excellent for utility-scale applications)
    - 31,600 sq km, almost 5% of Afghanistan’s total land area (650,000 sq km)
    - 158,000 MW of potential installed wind capacity (assumes 5 MW/sq km)
  - Good potential for many wind/diesel and off-grid applications
    - Almost 12% of Afghanistan’s land area has Class 3 or better wind resource

NREL’s SARI-Energy Activities
Pakistan’s Wind Resources
Major Areas

• Major wind resource areas
  – Southeastern Pakistan especially
    • Hyderabad to Gharo region in southern Indus Valley
    • Coastal areas south of Karachi
    • Hills and ridges between Karachi and Hyderabad
  – Northern Indus Valley especially
    • Hills and ridges in northern Punjab
    • Ridges and wind corridors near Mardan and Islamabad
  – Southwestern Pakistan especially
    • Near Nokkundi and hills and ridges in the Chagai area
    • Makran area hills and ridges
  – Central Pakistan especially
    • Wind corridors and ridges near Quetta
    • Hills near Gendari
  – Elevated mountain summits and ridge crests especially in northern Pakistan

NREL’s SARI-Energy Activities
# PAKISTAN - WIND ELECTRIC POTENTIAL

Good-to-Excellent Wind Resource at 50 m (Utility Scale)

<table>
<thead>
<tr>
<th>Wind Resource Utility Scale</th>
<th>Wind Class</th>
<th>Wind Power W/m²</th>
<th>Wind Speed m/s</th>
<th>Land Area km²</th>
<th>Percent Windy Land</th>
<th>Total Capacity Installed MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>4</td>
<td>400 - 500</td>
<td>6.9 - 7.4</td>
<td>18,106</td>
<td>2.1</td>
<td>90,530</td>
</tr>
<tr>
<td>Excellent</td>
<td>5</td>
<td>500 - 600</td>
<td>7.4 - 7.8</td>
<td>5,218</td>
<td>0.6</td>
<td>26,090</td>
</tr>
<tr>
<td>Excellent</td>
<td>6</td>
<td>600 - 800</td>
<td>7.8 - 8.6</td>
<td>2,495</td>
<td>0.3</td>
<td>12,480</td>
</tr>
<tr>
<td>Excellent</td>
<td>7</td>
<td>&gt; 800</td>
<td>&gt; 8.6</td>
<td>543</td>
<td>0.1</td>
<td>2,720</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>26,362</td>
<td>3.0</td>
<td>131,800</td>
</tr>
</tbody>
</table>

**Assumptions**

- Installed capacity per km² = 5 MW
- Total land area of Pakistan = 877,525 km²
- Only land area included in calculations

NREL’s SARI-Energy Activities
Conclusions for Pakistan Wind Mapping

• Advanced modeling and analysis techniques employed to produce detailed wind resource maps of Pakistan
• High resolution wind maps and assessment information
  – Useful to identify best prospective areas and screen out less promising areas, minimizing cost and time of prospecting
  – Does not eliminate the need for on-site wind measurement
• Windy land area and theoretical wind potential estimates
  – Class 4+ (good-to-excellent for utility-scale applications)
    • 26,400 sq km, about 3% of Pakistan’s total land area (800,000 sq km)
    • 132,000 MW of potential installed wind capacity (assumes 5 MW/sq km)
  – Good potential for many wind/diesel and off-grid applications
    • Almost 9% of Pakistan’s land area has Class 3 or better wind resource