Advanced Energy Partnership for Asia

Wind Energy Fundamentals for the Bangladesh Financial Sector

Prateek Joshi

National Renewable Energy Laboratory (NREL)

Training for the Bangladesh Bank

April 2024

Image: Prateek Joshi (NREL)

Introduction to NREL

NREL at a Glance

3,675 workforce, including:

- 2,732 regular/limited term
- 490 contingent workers
- 211 postdoctoral researchers
- 152 graduate student interns
- 90 undergraduate student interns

—as of 9/30/2023

World-class research expertise in:

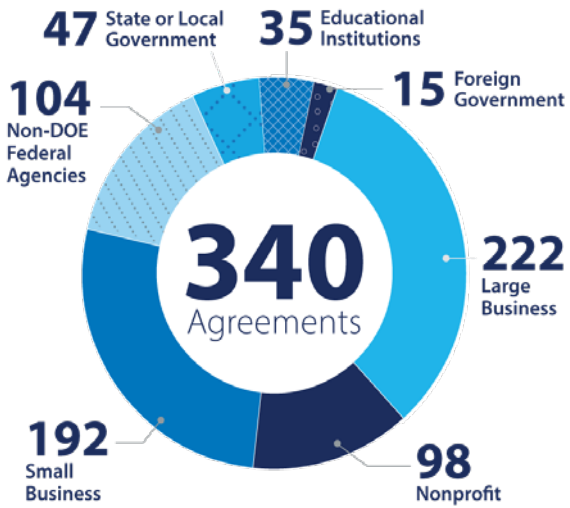
- Renewable Energy
- Sustainable Transportation & Fuels
- Buildings and Industry
- Energy Systems Integration

Partnerships with:

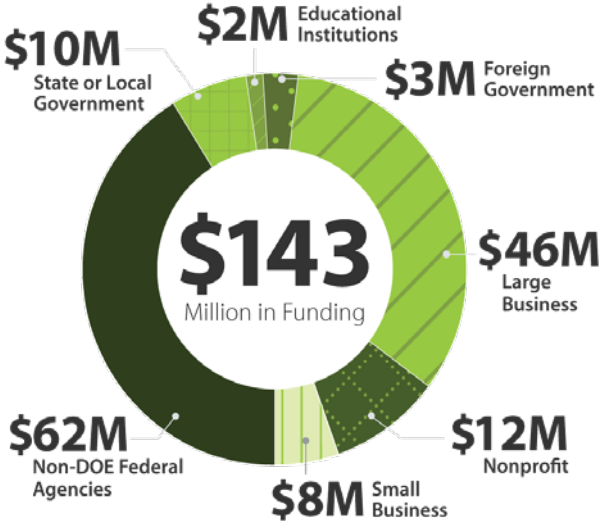
- Industry
- Academia
- Government

4 campuses operate as living laboratories

More Than 1,000 Active Partnerships in FY 2023



Agreements by Business Type



Funding by Business Type

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Global Technical Platforms

The USAID-NREL Partnership's global technical platforms provide free, state-of-the-art support on common and critical challenges to scaling up advanced energy systems.

REexplorer
MAPPING OUR ENERGY FUTURE

www.re-explorer.org

Greening the Grid

www.greeningthegrid.org

I-JEDI

www.i-jedi.org

Resilient Energy Platform

www.resilient-energy.org

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Global Development Trends and Wind Technology

Global Development Trends

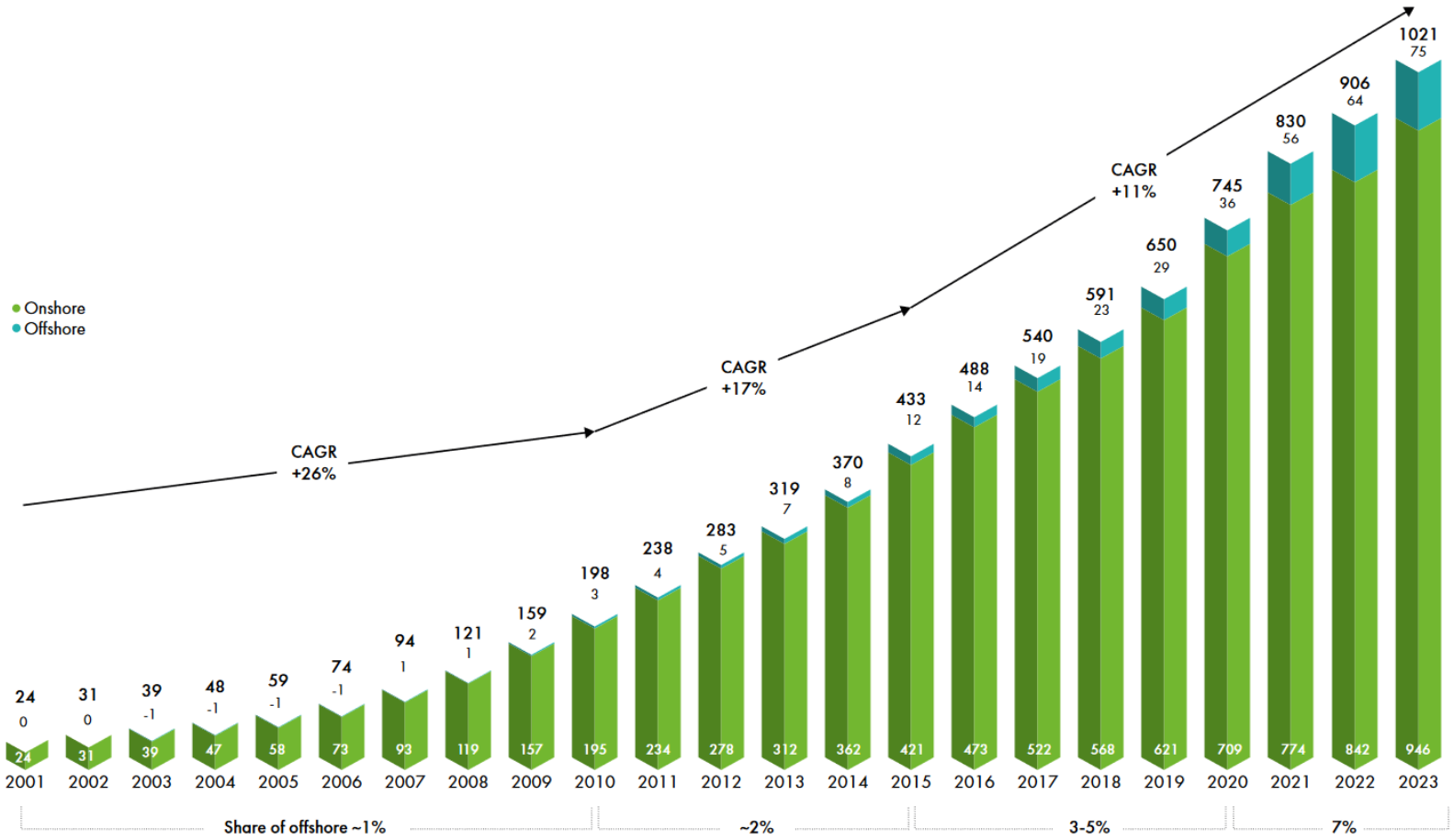

Figure 1. Global installed capacity of wind (GW), 2001-2023

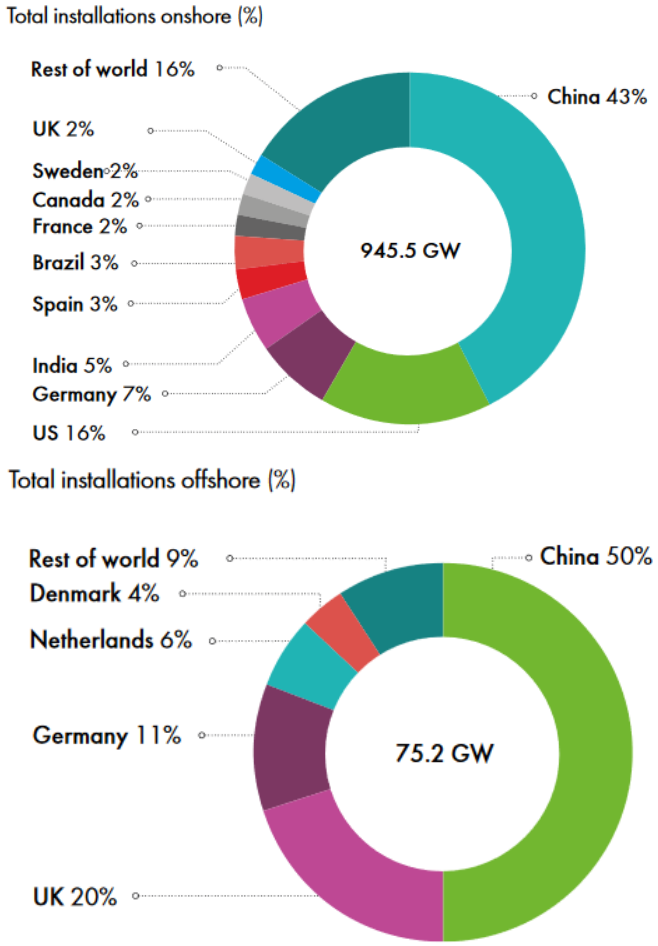

Figure 2. Percentage of total onshore and offshore installations by country (2023)

Source: Global Wind Energy Council (2024)

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Onshore vs. Offshore Wind

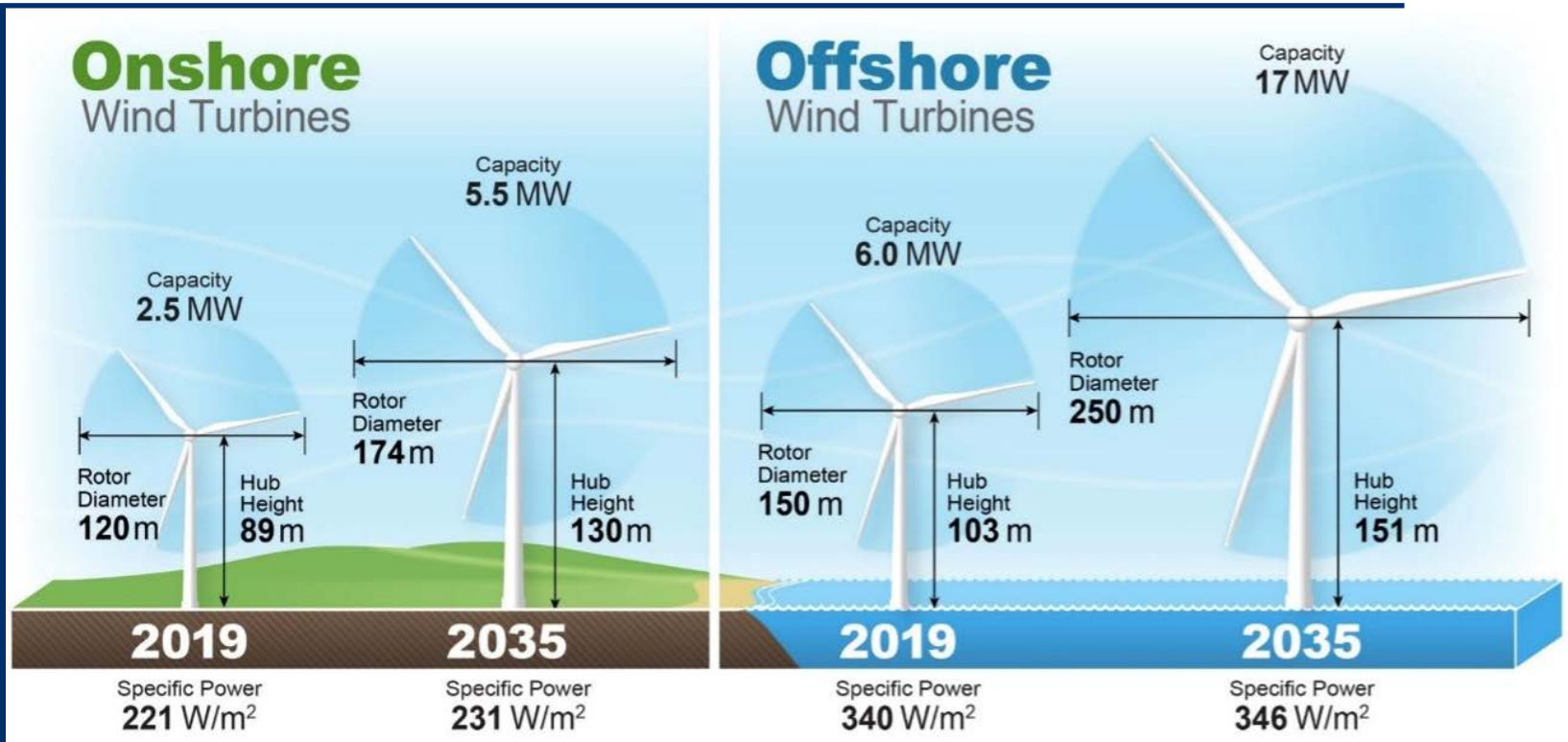

Figure 3. Current and projected characteristics for onshore and offshore wind turbines

Image: Lawrence Berkeley National Lab

Figure 4. Offshore wind project in the United States

Image: Dennis Schroeder (NREL)

- Offshore wind turbines have higher hub heights and larger rotor diameters.
- Wind speeds are typically higher, more consistent, and less turbulent offshore.
- Offshore wind farms are not constrained by land availability but have separate permitting considerations.
- Barriers to offshore wind include a lack of supporting infrastructure (vessels, cranes, ports, etc.), difficult construction conditions, and higher costs.

Source: Beiter et al. (2021)

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Wind Turbine Types

Horizontal Axis Wind Turbines

Figure 5. Horizontal axis wind turbines

- Most common design in use globally, particularly for large scale applications, due to higher efficiency.
- Blades must face the direction of the wind for optimal performance, requiring complex yawing and pitching systems.
- Able to access higher wind speeds at higher hub heights.

Vertical Axis Wind Turbines

Figure 6. Vertical axis wind turbines

- Not very common and less efficient due to increased drag on the blades.
- Turbines are omnidirectional, thus using wind coming from any direction.
- Take up less space and have advantages in urban environments with more turbulent wind conditions.

Images: Prateek Joshi (NREL), David Jager (NREL)
Sources: Winslow (2017)

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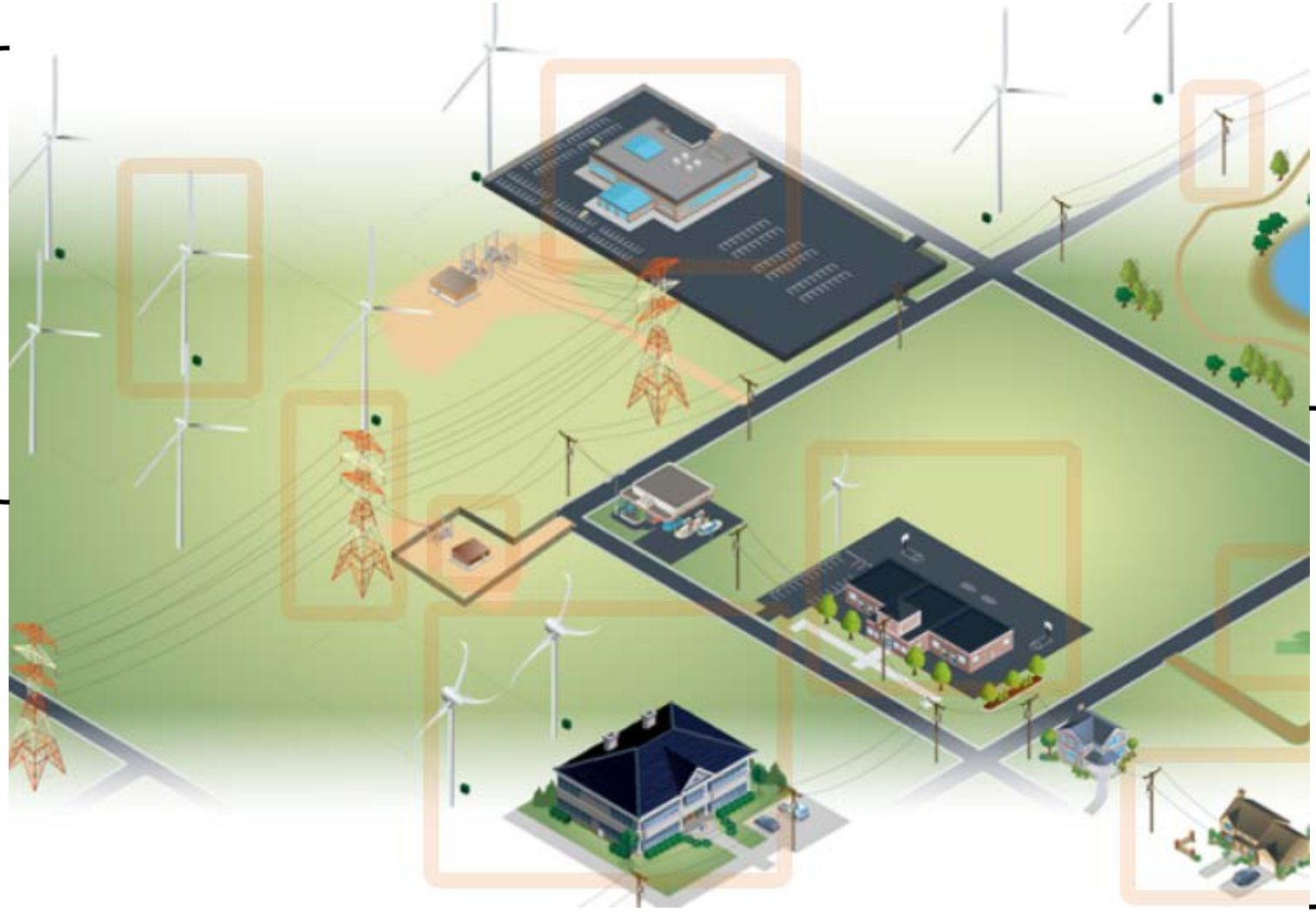
Utility-Scale vs. Distributed Wind

Utility-scale: "Dozens or hundreds of large-scale (>1 MW) wind turbines in the same location and connected to the transmission system, with a total capacity typically over 20 MW."



Distributed: "One or several wind turbines in the same location and connected to the distribution system or off-grid to serve specific or local loads."

Figure 7. System with utility-scale and distributed wind

Image: U.S. Department of Energy

Distributed Wind

Figure 8. Distributed wind turbine size classifications

Small
(≤ 100 kW)

Mid-size
(101 kW – 1 MW)

Large-scale
(> 1 MW)

Images: Prateek Joshi (NREL)

Applications

- Isolated grids (e.g., villages, island communities, military bases, etc.).
- Backup power for normally grid-connected systems (e.g., cell towers).
- Microgrids that can connect and disconnect from the main distribution system.
- Industrial facilities.
- Academic and commercial campuses.
- Residences and farms.

Source: Reilly et al. (2021)

Wind Turbine Components

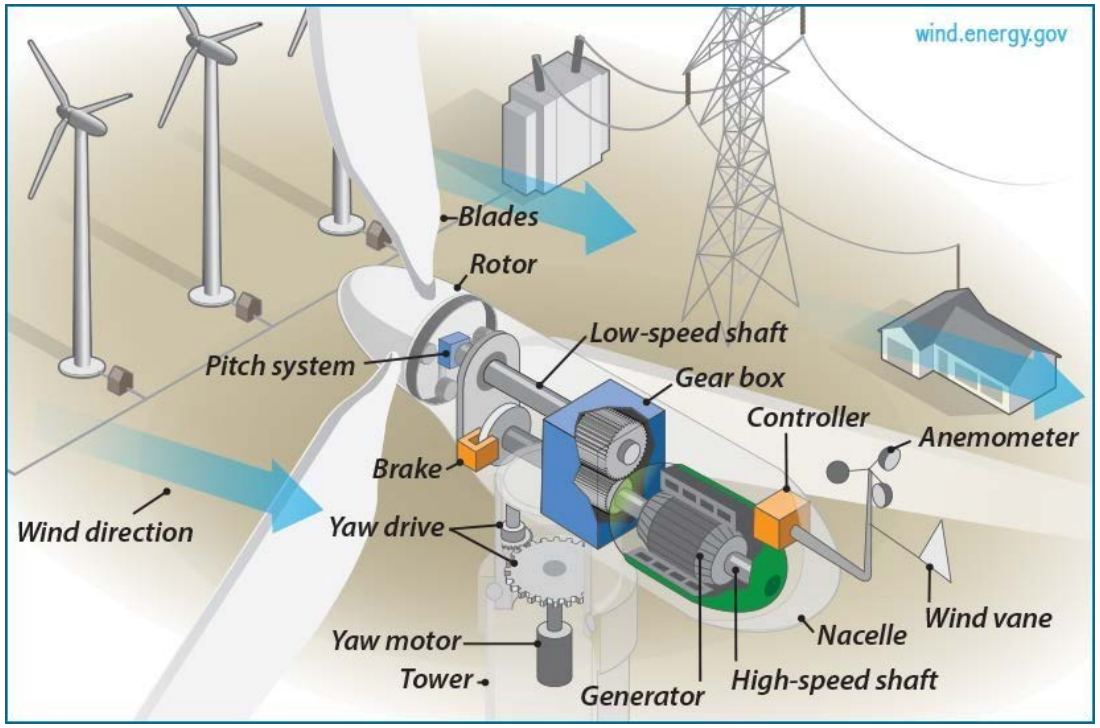


Figure 9. Wind turbine components

Image: U.S. Department of Energy

Figure 10. Wind turbine blade manufacturing and testing facility tour for Bangladesh government officials during visit to NREL

Image: Werner Slocum (NREL)

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Wind Potential Assessment and Generation Forecasting

Wind Resource Characteristics

Mean Wind Speed: "Average annual (or longer term) wind speed"

Wind Speed Distribution: "How many hours per year does the wind blow at (x) m/s?"

Wind Direction*: "*How often and how strong are the winds from particular directions?"

Diurnal Wind Distribution: "What time of day has the most wind energy?"

Seasonal Wind Distribution: "What time of year has the strongest wind resource?"

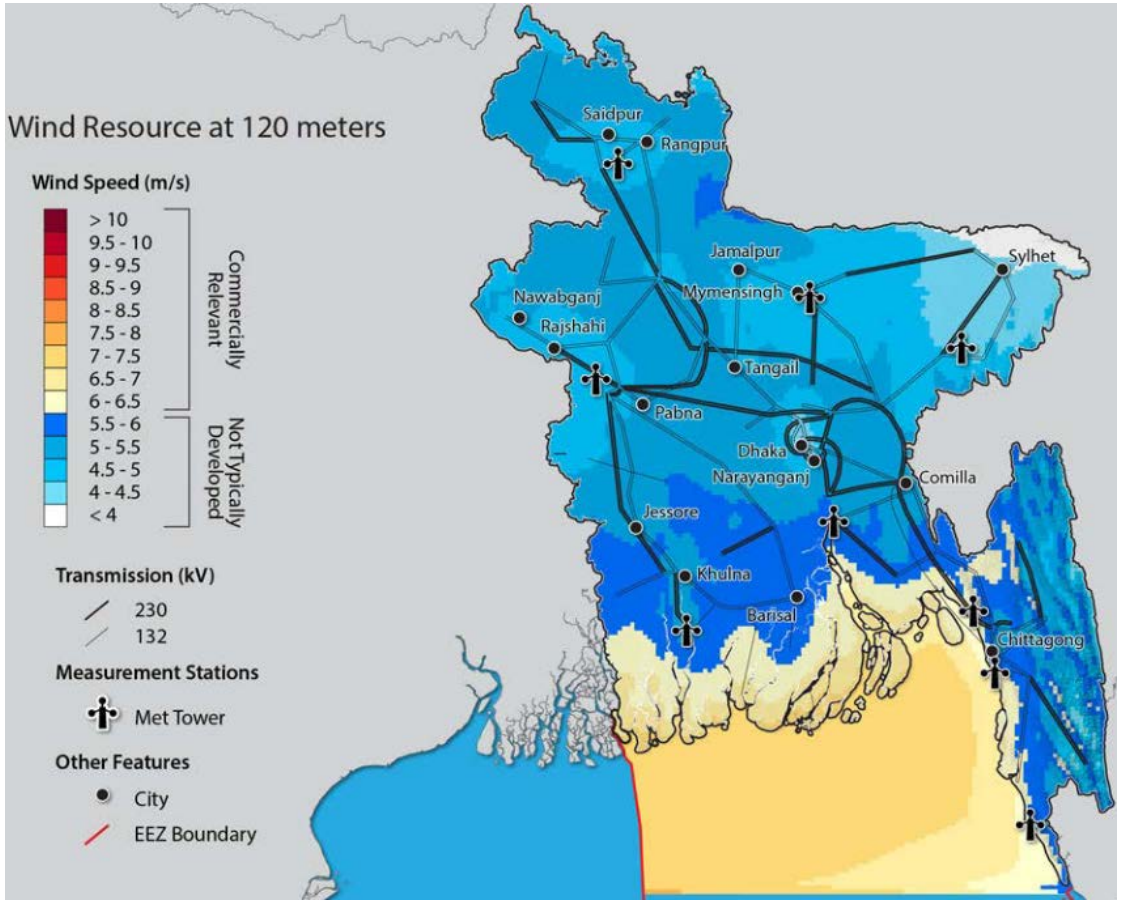

Figure 11. Modeled and measured wind speeds at 120m in Bangladesh

Image: Jacobson et al. (2018)

Source: Robichaud (2018)

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Wind Data

Wind Data for Prospecting

Available from governments, research organizations, etc.

Identifies locations for potential development.

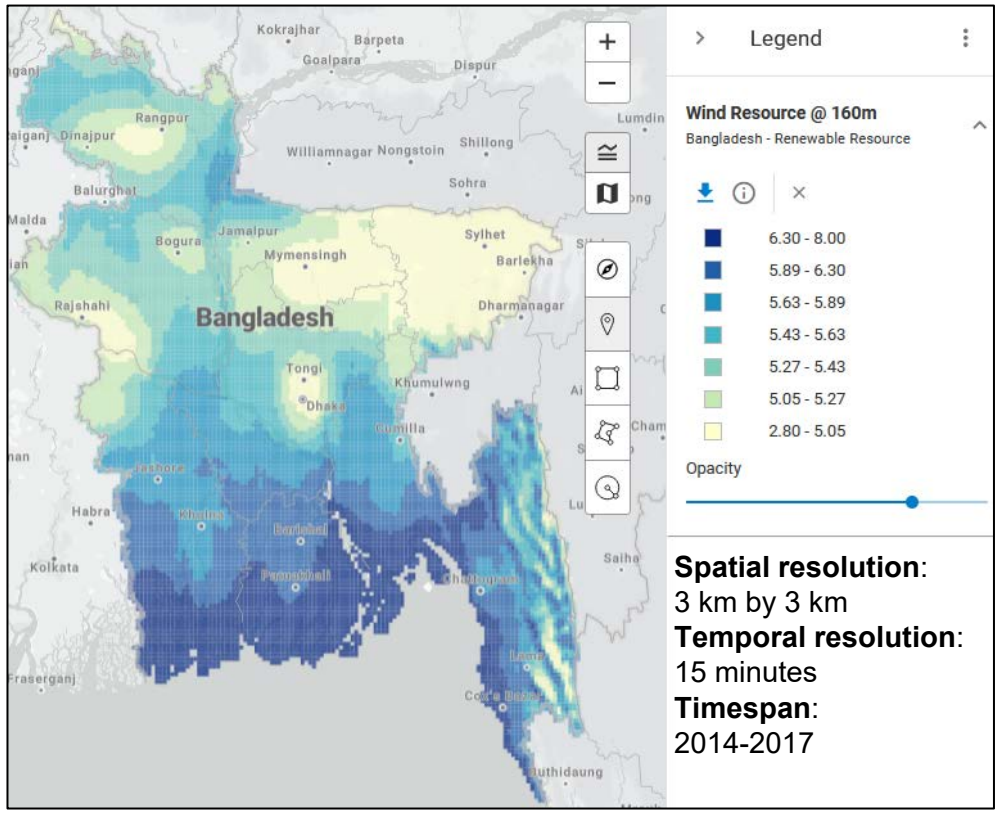

Figure 12. Wind resource data for Bangladesh

Image: Joshi et al. (2023)

Wind Data for Development

Responsibility of developer to obtain site-specific data.

MET towers installed to validate the resource.

Land contract can have an option period that will allow for wind measurement and permitting activities.

Figure 13. Meteorological (MET) towers

Image: Prateek Joshi (NREL)

Bangladesh Wind Data: REZ Case Study

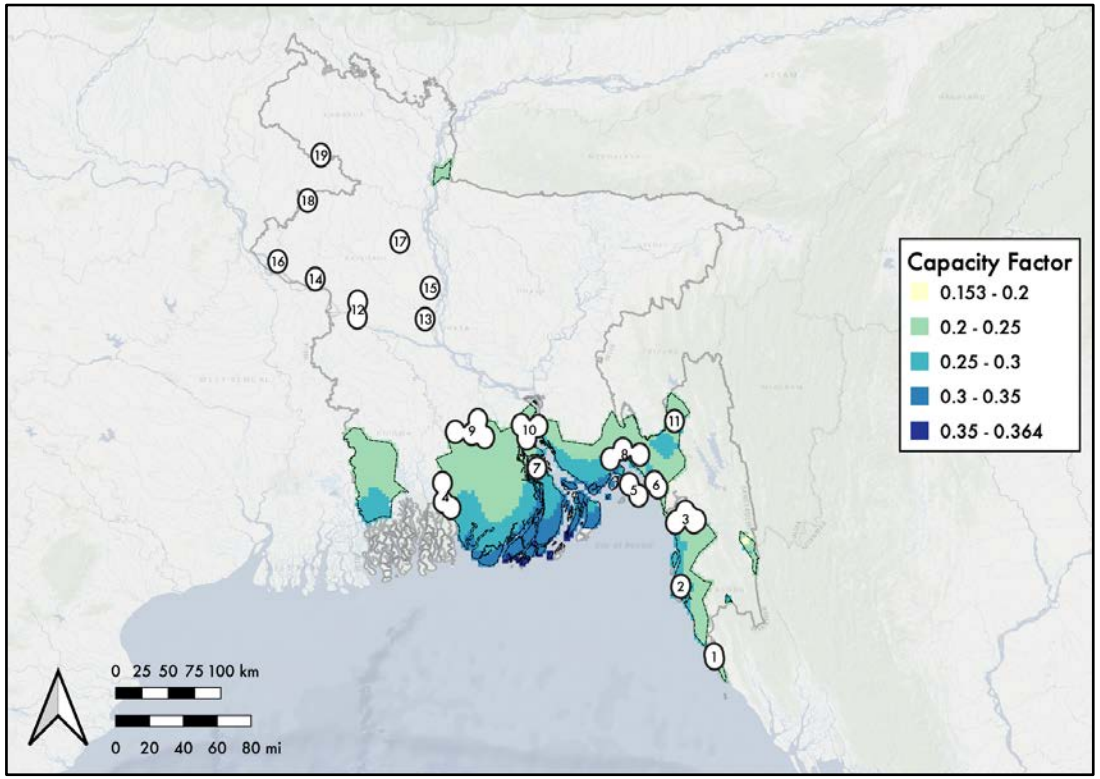

Figure 14. Potential candidates for REZs in Bangladesh compared to wind study areas

High-fidelity wind resource data, along with other geospatial data, was used to determine potential renewable energy zones (REZ) in Bangladesh, corresponding to BEZA economic zones.

Source: Joshi et al. (2023)

Renewable Energy (RE) Data Explorer

- The RE Data Explorer web platform provides free renewable energy data, analytical tools, and technical assistance to developers, policymakers, and decision makers throughout the world.
- Users can access renewable energy data and related geospatial data sets to guide development of domestic energy resources.
- Performs visualization and analysis of renewable energy potential that can be customized for different scenarios.
- Supports prospecting, integrated planning, policymaking, and other decision-making activities to accelerate renewable energy deployment.

Figure 15. RE Data Explorer home page

www.re-explorer.org/

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Turbine Power Curves

Cut-In Speed: Speed below which power is not generated.

Rated Wind Speed: Speed at which power is 100% of rated power.

Cut-Out Speed: Speed at which turbine shuts down to protect rotor and drive train from damage.

This is an example power curve from a wind turbine in 2014. Not all turbines will have these exact power curve characteristics.

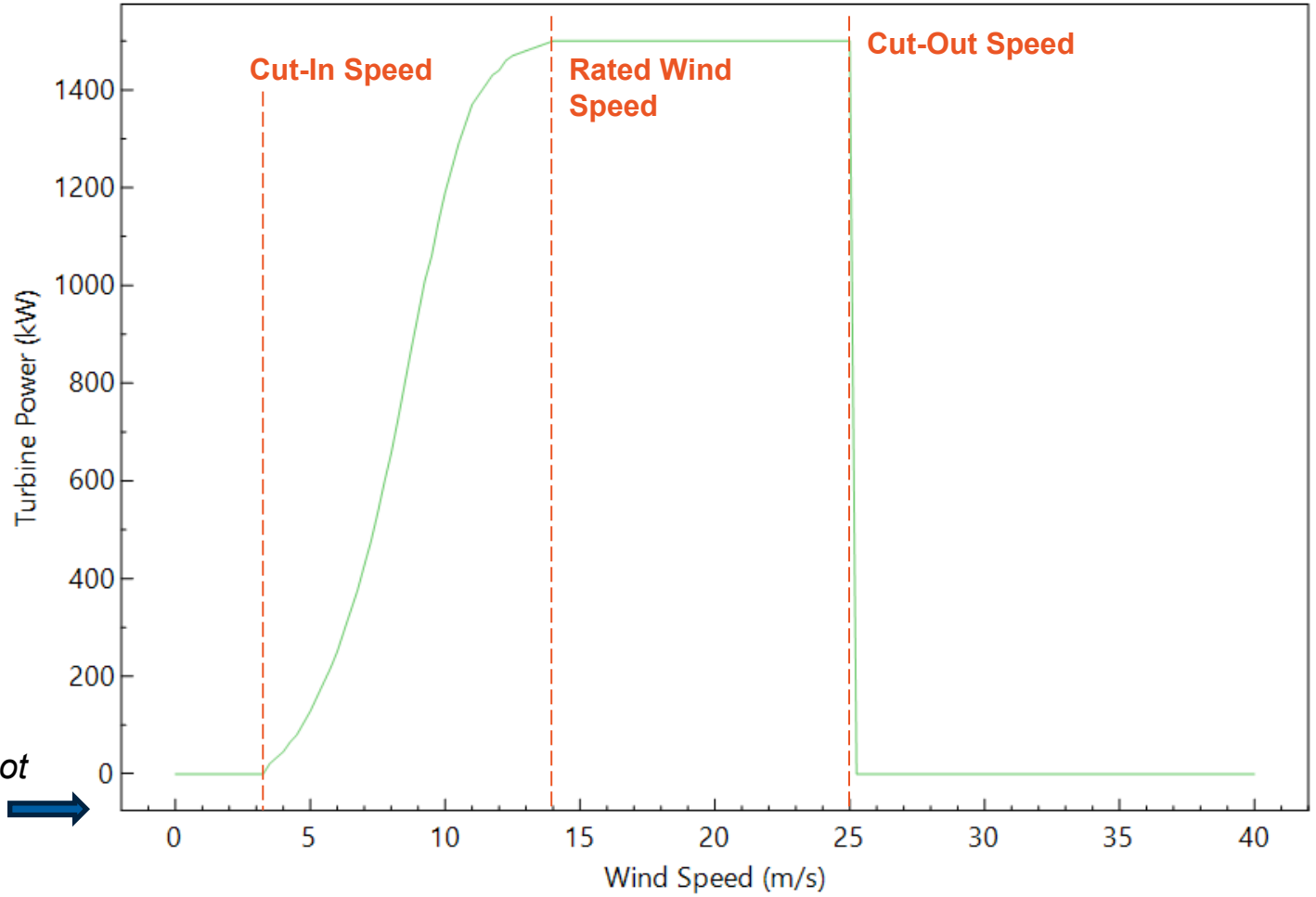

Figure 16. Example power curve for a wind turbine

Source: Freeman et al. (2014)

Power from Wind

$$P_{wind} = E\frac{1}{2}\rho A v^3$$

P_{wind} = power extracted from wind

E = efficiency of the turbine

ρ = density of the air

A = swept area of the turbine = πr^2

r = radius of the rotor

v = wind speed

Greater power extraction:

Increase in rotor radius (r) results in larger swept area (A)

Increase in turbine height allows access to lower density air (ρ) and higher wind speeds (v)

Source: Joshi and Gokhale-Welch (2022)

Resource Data Informs Energy Planning

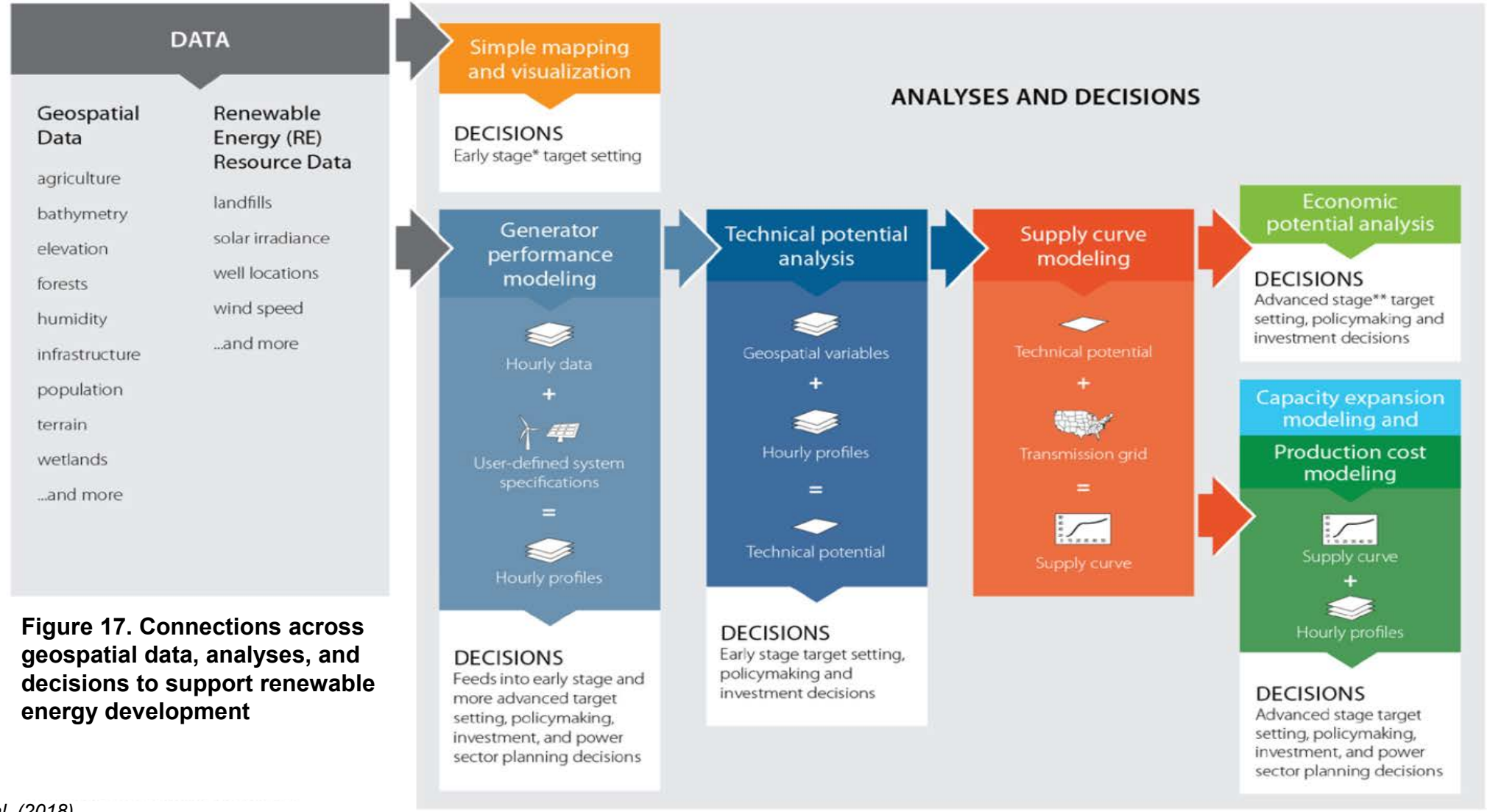

Figure 17. Connections across geospatial data, analyses, and decisions to support renewable energy development

Image: Cox et al. (2018)

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Wind Project Development

Wind Development Process

Desktop Analysis:

Assess market, wind resource, land use, transmission, etc.

Site Selection:

Site visits, landowner meetings, install MET towers for data collection, etc.

Permitting:

Aviation, wildlife, energy modeling, environmental studies, economic impact studies, etc.

Power Contracts:

Respond to request for proposals, negotiate contracts or PPAs, etc.

Construction:

Workforce development, site logistics, interconnection agreement, O&M, etc.

Figure 18. MET tower installation in Bangladesh

Image: Jacobson et al. (2018)

Figure 19. Wind turbine being transported on highway to construction site

Image: Prateek Joshi (NREL)

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Technology Trends

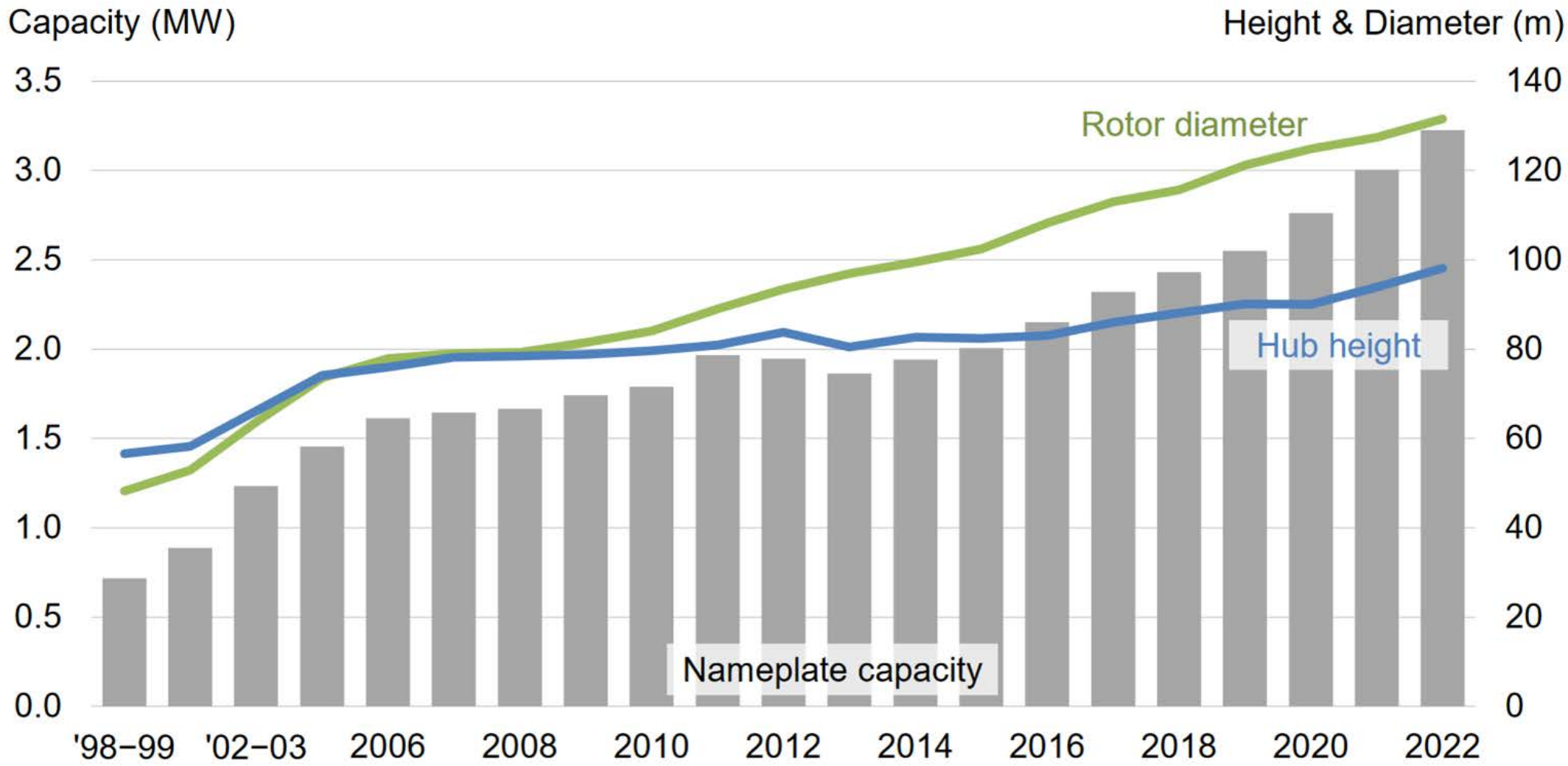

Figure 20. Trends in wind turbine technology for onshore utility-scale projects, 1998-2022

Source: Wiser et al. (2023)

Land Considerations

Land ownership profile:

- Private
- Public

Environmental factors:

- Wildlife habitat
- Protected environmental areas
- Slope and topography

Permitting requirements:

- National and local permits
- Zoning ordinances
- Application requirements and schedule
- Public hearings

Legal Contracts

Figure 21. Wind farm co-located with agricultural land

Image: Prateek Joshi (NREL)

- Wind turbine spacing is important to reduce wake effects.
- Wind turbines can be co-located with agricultural land, and the actual footprint of the turbines is a small fraction of the total area.

Source: Joshi and Gokhale-Welch (2022)

Interconnection Agreement

- Signed between developer (project owner) and utility (transmission line owner):
  - Needed for power purchase agreement (PPA) and project financing
- Steps:
  - Developer selects a site (completes preliminary due diligence)
  - Signs land lease(s) at interconnection point
  - Signs study agreement with utility:
    - Feasibility Study & System Impact Study
    - Facility Study
  - Execute Interconnection Agreement
  - Designates amount (MWs) of power that can be connected to system at a specific location:
    - Designates all equipment needed to interconnect (X-MWs) and who is responsible for which equipment (network vs. developer)
    - Designates construction schedule
    - Designates payment schedule and cost

Source: Joshi and Gokhale-Welch (2022)

Figure 22. High-voltage transmission lines

Image: Prateek Joshi (NREL)

Benefits and Challenges

Cost Trends and Projections

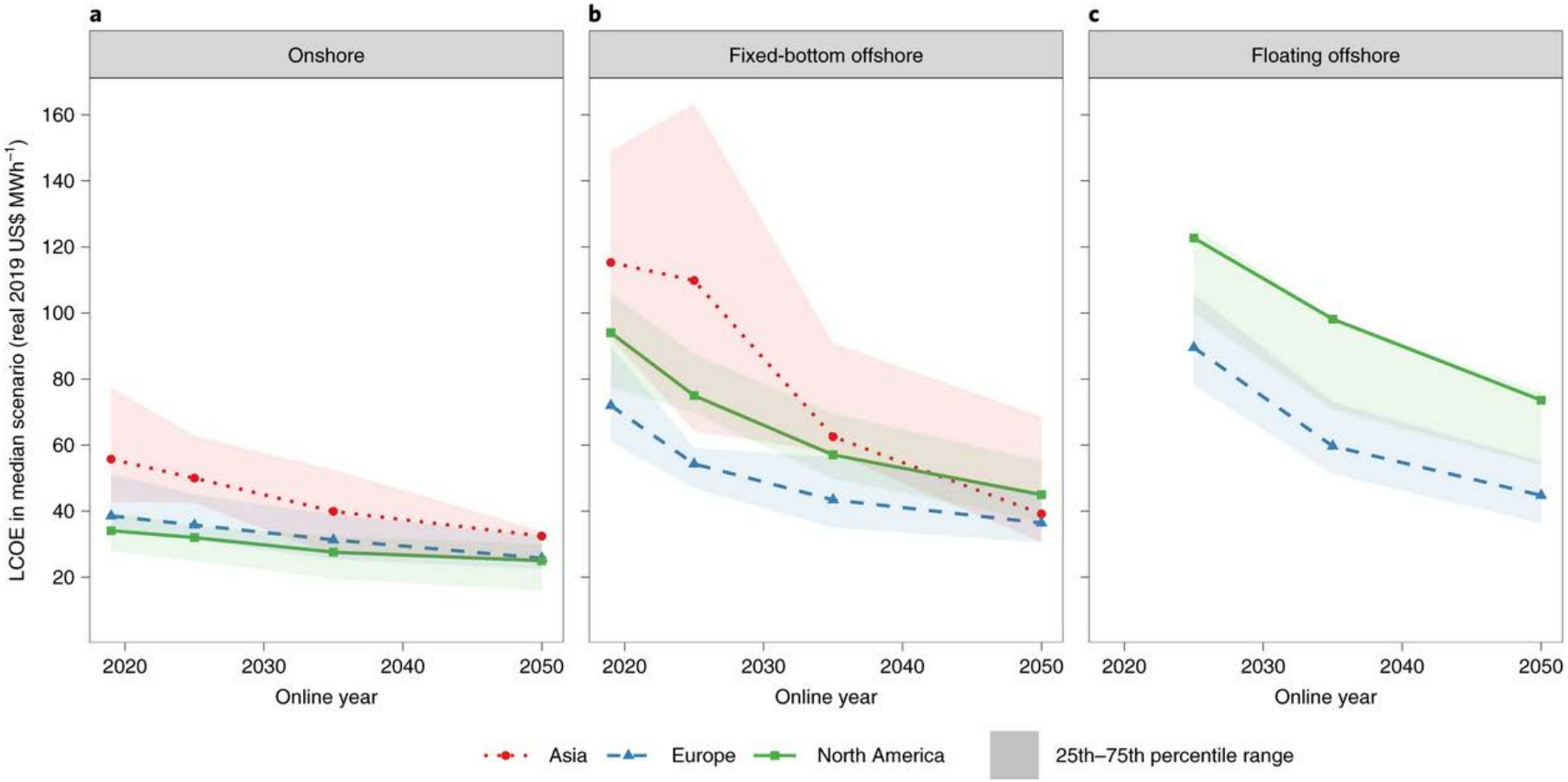

Figure 23. Median-scenario wind LCOE projections from 2020 survey of experts, 2021-2050

Source: Wiser et al. (2021)

Wind Turbine Noise

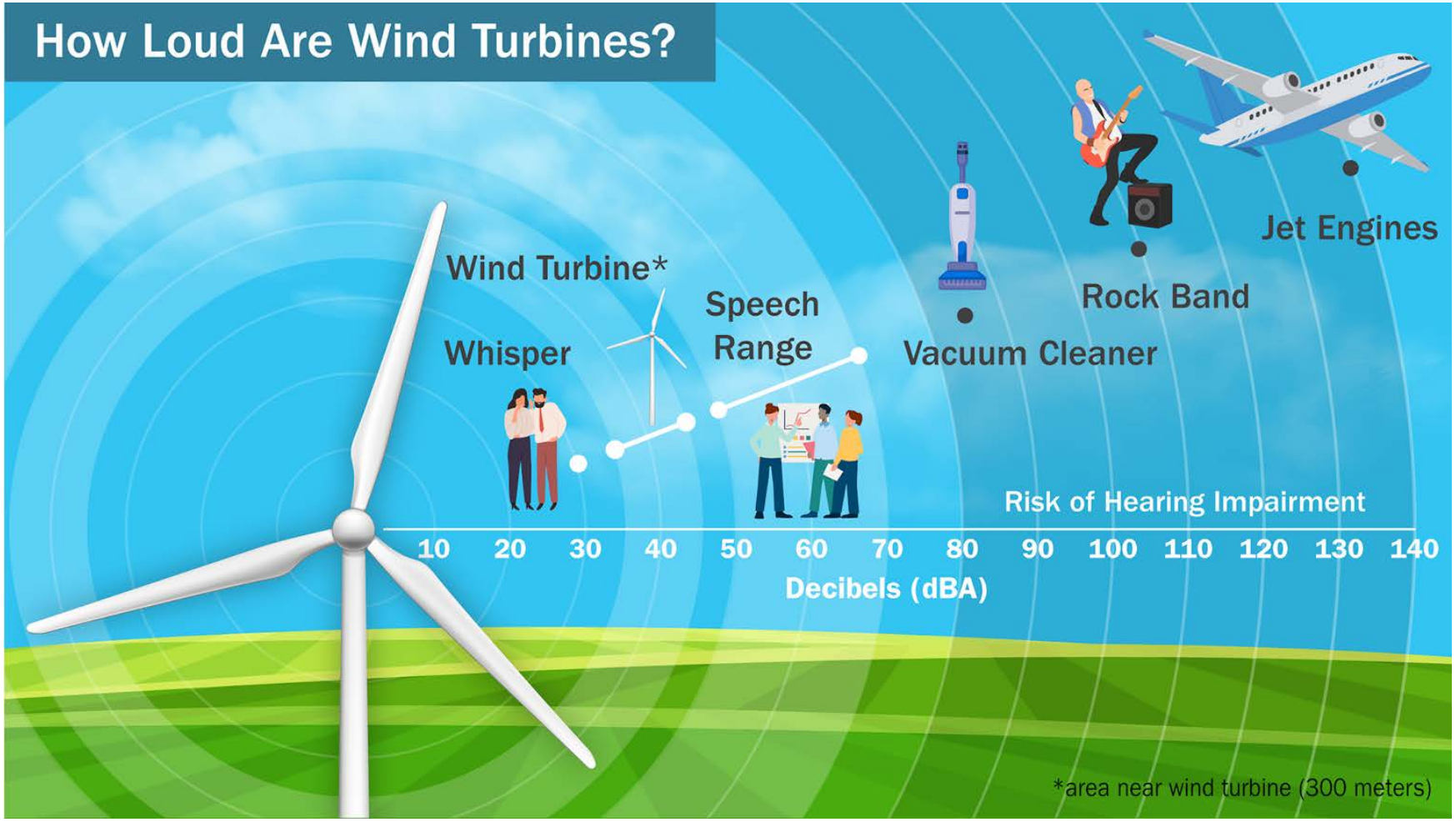

Figure 24. Sound levels of wind turbines compared to other noise sources

Image: Al Hicks (NREL)

Benefits and Challenges of Wind Energy

Benefits for Bangladesh

- ✓ No greenhouse gas emissions
- ✓ No air pollution
- ✓ Job creation and economic development
- ✓ Co-location with agriculture

Challenges for Bangladesh

- ❖ Workforce development
- ❖ Developing a supply chain
- ❖ Grid integration of variable renewable energy
- ❖ Access to low-cost finance

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