

**Due: Nov 24, 2025**

## **Energy: Science, Technology, and Society**

### **Project 2**

#### **Prospects of a Northwestern NY 100-MW<sub>e</sub> Dispatchable Wind Farm**

The main goal of the project is to evaluate and illustrate the utility of dispatchable wind power generation in the NW New York area based on historical data. Motivation for the wind farm project is provided by stated U.S. state and federal energy policies to replace dispatchable conventional power generation based mainly on coal, gas, and nuclear plants by renewable energy technologies.

#### **Farm design criteria are**

1. Favorable wind patterns and soil consistency at site location,
2. Efficiency of turbine electricity generation,
3. Minimum land footprint,
4. Minimum length of cable connections and maintenance access pathways to all turbines.

**Research and complete all tasks** (1-12) defined below, collect and analyze relevant data, and write a detailed (typewritten) publication-ready technical report on the results of your study (MSWord or similar), provide the data base analyzed. Specifically,

- Show and discuss samples of original data in tables and graphs.
- Show and explain examples of pertinent calculations.
- Justify, based on your own study, your specific conclusions and recommendations for energy policy makers.

The project tasks defined below contain some suggestions of the costs of certain wind farm components. For your own estimates, obtain more relevant, recent data, as provided by publications of the wind research community and/or the wind industry. Always provide citations and links to the sources of the information used in your estimates.

#### **Project Tasks:**

- 1. Wind Technology Background Brief:** Explain briefly the functions and operating principles of the main components of a wind tower (foundation/base, tower, nacelle, rotor/hub, gearbox, generator, control). For example, explain how the generator power output can be controlled by pitch of the rotor blades and within what power range. How fast do the blades rotate (rpm=rotations per minute), what are typical tip speeds in mph?
- 2. Data Collection and Analysis:** Assess the data base for *surface wind* patterns in upstate New York, Ontario Lake on-shore, for the installation of a major wind farm.
  - a)** Retrieve the NOAA mean daily surface windspeed ( $v$ ) data at the **airport ROC** in Rochester (NY) for the **year 2024** as representative for the larger area.
  - b)** Generate an XLS data table for the probability distribution  $P(v) = \Delta N(v) / N \Delta v$  from the observed data. Sort the  $N$  data points and appropriately chosen speed intervals ( $\Delta v$ ).

c) Correct the distribution for the systematic increase of windspeed from ground level to a 95-m turbine hub height.

### 3. Wind Speed Distribution:

a) Fit the measured wind speed data in terms of the Weibull distribution (consult <https://wind-data.ch/tools/weibull.php?lng=en> or <https://real-statistics.com/distribution-fitting/fitting-weibull-regression/> ) and determine the characteristic Weibull parameters.

b) Produce graphs of relevant raw and fit data.

### 4. Calculate Single-Turbine Output:

Assume the popular wind turbine model **Vestas V100- 1.8 MW** for the large wind farm to be designed. Given the **daily wind data** obtained in 2) and the design power curve  $Output_e(v)$  specified below for the turbine, deduce the **daily mean** (and capacity factor) of the fluctuating **electrical power** generated by a single turbine.

a) Digitize the 60-Hz power curve given in the provided graph.

b) Produce sample graphs of the daily power generated by one turbine during a winter and a summer period during 2024, with each period 2-weeks long.

c) Present and discuss tabulated power data month by month.

d) Deduce the mean generated power, averaged over the entire year 2024.

e) Identify days in 2024 when the turbine rotor blades would have to be feathered because of high winds/storms?

f) Which days had mean wind speeds insufficient to generate power larger than 10% of rated (nominal)?

g) Which months had periods with lull days, what were the typical and what the maximum durations of lull wind periods?

### 5. Single Wind Tower Construction Cost:

a) Estimate the cost of materials for the conical 95-m tall tower proper for the Vestas V100, which is typically constructed of tubular steel (S355, 3-cm wall thickness), mounted on a massive foundation (base).

b) Estimate the cost for the solid, reinforced concrete base of the tower. (Given the soft soil properties of the NW-NY area, assume a 20-m  $\phi$ , circular base mat on 20-m long steel H-piles for the tower.)

c) From recent installations, obtain an estimate for the total man-hours, erection times and cost of one tower.

**Notes for reality checks:** The mean of the current total cost for one generic wind tower, i.e., turbine, rotor, and nacelle enclosures, is of the order of \$1/W. Adding current (2025) mean *balance of system* (BOS) and *soft costs* brings the total installed single-tower cost to app. \$1.5/W of nominal power. Typical crews have 6-8 construction workers. Alternative constructions are towers made of concrete or hybrid combinations, see enclosed tables and the papers, e.g., by *Singh and Huang*.

## 6. Farm Site Parameters for 100-MW Mean Generation

- a) Calculate the capacity factor of one Vestas V100 turbine for the year of 2024.
- b) Calculate the number  $N_t$  of turbines needed for a windfarm to generate a **mean electrical** power of 100 MW, given the 2024 wind speed distribution.
- c) Estimate the required total installed (nominal) wind capacity for the wind farm with 100-MW average output.
- d) Estimate the required total capital to realize that (bare) wind farm.

## 7. Site Layout: Based on the results obtained in Tasks 4 & 6, design a wind farm with $N_t$ wind towers in NW New York. The farm should be an array of $N_t$ individual towers with 100 MW of **average delivered total power** at the wind conditions prevailing during the surveyed time period. A cluster of 10 wind towers can be served by one collector/converter substation. Preferred location of a station is at the periphery of the wind farm.

- a) What are two areas in New York State most suitable for on-shore windfarms and why?
- b) Propose and argue for an optimal onshore farm design and sketch it schematically as simple geometrical pattern ( $\square$ ) on a Cartesian grid. Assume wake-safe distances between turbines ( $10 \times D_{\text{rotor}}$ , Betz Law). Provide a technical drawing to scale.
- c) Suggest and argue for an optimum placement of the substation for each cluster, minimizing access pathways and cable runs.
- d) Calculate the land area needed for the foundations of the bases of the wind towers (allow  $\frac{1}{4}$  acre ( $\square$ ) each), the access/service pathways (25' width, 2' deep foundation) to and between turbines, one 5'-wide strip of land along the maintenance pathways for underground power cables connecting each turbine to its transformer/inverter substation.
- e) Allow one 5'-wide strip of land along the maintenance pathways for underground power cables connecting each turbine to its transformer/inverter substation.

## 8. Converter Substations & Connections: A cluster of 10 wind towers can be served by one substation (construction cost app. \$4M) which collects the turbine 3-phase, AC power outputs and converts the sum to high-voltage DC (12kV-69kV).

- a) Estimate the total capital cost of all substations of the proposed farm.
- b) What specific cable types are needed for the collection of power from the turbine?
- c) Calculate the total length of the turbine AC power cables and the associated cable cost.
- d) Calculate the amount and cost of the gravel (app. \$20/cyard) needed to pave access/service pathways (25' width, 2' deep foundation) to and between turbines.

## 9. Capital Investment and O&M Cost: Estimate the installation capital required for the wind towers and the environmental (land) footprint of the farm with access pathways. According to the U.S. Department of Agriculture's Land Values 2020 Summary, an acre of land in NY costs \$3,100 on average. As an alternative to purchase, lease of farm land is available at local interest (annuity) rates of \$125/acre per year for a 25-year lease. The wind farm costs for operation and maintenance (typically 1-2 technicians per 10 towers) amount to approximately \$40/kW per year.

**10. Bare and Levelized Cost Estimate:** Assume similar operational conditions (as in 2024) to prevail over the 25-year lifetime of the farm and a fixed capital annuity rate (capital interest, app. 6.5%).

- d) Estimate the direct cost (\$/kWh) of electrical power delivered by the windfarm.
- e) Estimate the corresponding levelized cost (\$/kWh) of electricity.

**11. Emissions:** Base your calculations on the amount of concrete and steel used for the construction of the wind towers of the rest of the farm. Obtain recent estimates estimates for specific costs.

- a) Estimate the CO<sub>2</sub> amount generated in the construction of the wind towers from these two sources.
- b) Estimate the CO<sub>2</sub> amount avoided by the wind generated electrical energy over the lifetime of the farm.

Emissions: 1.85 t of CO<sub>2</sub> per ton of steel, 80.9 kg of CO<sub>2</sub> per t of structural concrete.

**12. Upgrade to Dispatchable Power:** To guarantee an always available (dispatchable) total power level of  $P_{\text{total}} = 100$  MW, the wind farm power output has occasionally to be supplemented by standby power. Evaluate the cost differential electrical power for the two options:

- a) The required power differential is provided by a local nat-gas-powered plant (0.1-GW<sub>e</sub> nominal, base load). To guarantee 0.1 GW<sub>e</sub> spot demand, the backup plant must be running continuously at a minimum of 15% nominal power. Use local retail cost (10¢/kWh) for calculating the cost of backup electricity.
- b) In a hybrid 100-MW installation, intermittend wind power is supplemented by a co-located bank of 1-MW power Li-Ion batteries, covering (fully charged) up to a 4-hr lull. The cost of electricity retrieved from a 4-hour, 1-MW battery bank is of the order of \$(3-4)/MWh. Calculate the power cost of this combination (wind farm plus on-site battery backup)

**Report:** Present a summary of the main results from your study in the publication-ready form of a technical report/research paper, like suggested by a provided template. Organize data in tables, illustrate them by figures/graphs of good (readable) quality, describe trends. Define data reduction procedures and present examples of relevant calculations and derivations.

**Project 2, Task 2 (Explanations/Hints):**

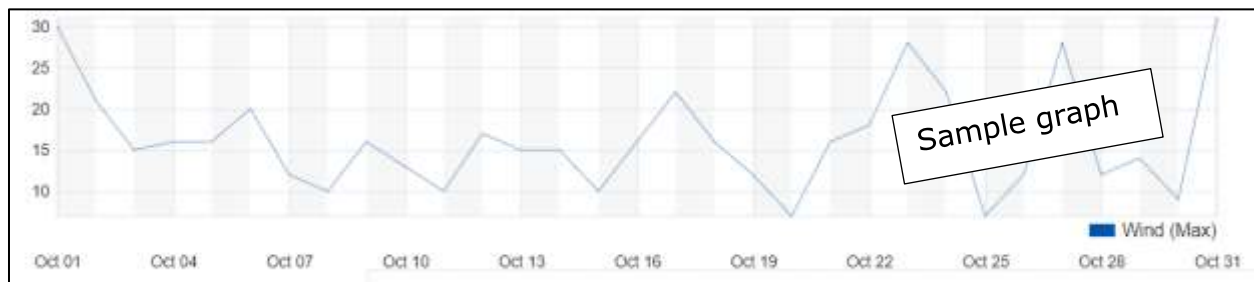
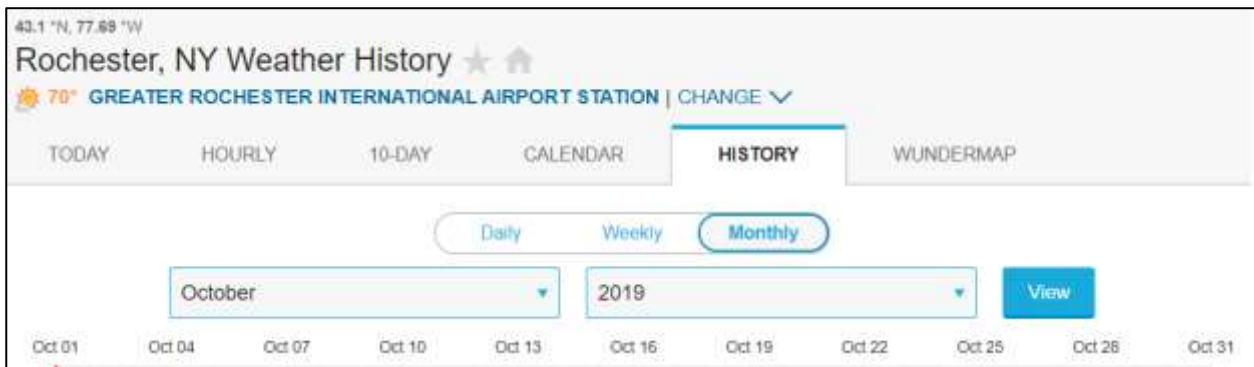
In preparation for the execution of Project 2, locate the web site below (or another official site) that posts hourly, daily, etc. numerical data for observations of wind speeds at the Rochester International Airport (ROC). Download numerical wind data from the site and insert them into a spreadsheet. Below are some screenshots from using the site.

<https://www.wunderground.com/history/monthly/us/ny/rochester/KROC/date/2019-10>

### Daily Observations

Time	Temperature (° F)			Dew Point (° F)			Humidity (%)			Wind Speed (mph)		
	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
Oct 1	88	75.1	68	71	66.3	63	93	76.0	48	3	11.2	6
Oct 2	70	60.8	53	68	57.4	45	100	88.8	72	21	11.2	0
Oct 3	57	53.6	50	56	50.3	43	100	88.6	71	15	8.6	0
Oct 4	57	49.9	45	54	43.6	38	97	79.9	61	16	8.7	0
Oct 5	59	50.2	40	43	38.1	35	90	65.8	44	16	7.9	0
Oct 6	75	63.6	55	60	52.2	41	80	66.9	53	20	9.9	5
Oct 7	64	58.4	53	59	53.9	49	97	85.7	65	12	5.2	0

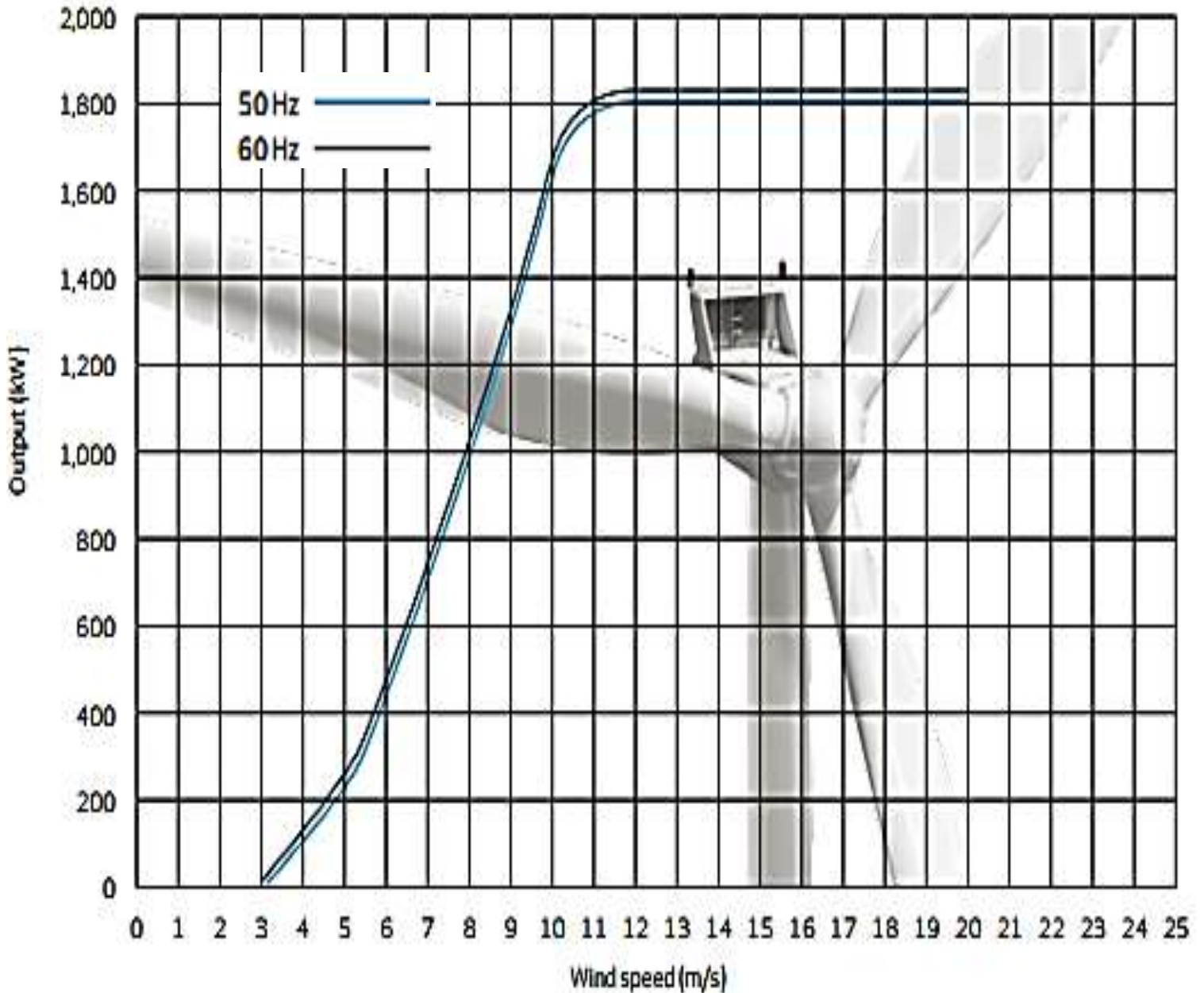
Sample data



Sample graph

### Project 2, Task 4: Turbine performance:

The figure and graphs below show the power curve for the Vestas V100-1.8MW turbine. It depicts the electrical output power in kW as a function of wind speed (m/s). Use the 60-Hz curve for the present application. The turbine operates between a cut in speed of 3m/s and a cut out speed at 20m/s.



# Vestas

## V100-1.8 MW

### Facts and figures

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**POWER REGULATION** pitch regulated with variable speed

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**OPERATING DATA**

Rated power	1,800 kW (50 Hz)
	1,815 kW (60 Hz)
Cut-in wind speed	3 m/s
Rated wind speed	12 m/s
Cut-out wind speed	20 m/s
Wind class	IEC S (IEC IIIA average wind/ IEC IIA extreme wind)
Operating temperature range	standard turbine: -20 °C to 40 °C low temperature turbine: -30 °C to 40 °C

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**SOUND POWER MODES**

Mode 0: Max sound power level:	105.0 dB (A)
Mode 1: Max sound power level:	105.0 dB (A)*
Mode 2: Max sound power level:	103.0 dB (A)
*) low noise at low wind	

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**ROTOR**

Rotor diameter	100 m
Swept area	7,850 m <sup>2</sup>
Nominal revolutions	14.5 rpm
Operational interval	9.3 – 16.6 rpm
Air brake	full blade feathering with 3 pitch cylinders

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**ELECTRICAL**

Frequency	50/60 Hz
Generator type	4-pole (50 Hz)/6-pole (60 Hz) doubly fed generator, slip rings

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**GEARBOX**

Type one planetary stage and two helical stages

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**TOWER**

Type tubular steel tower  
Hub heights 80 m and 95 m

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**BLADE DIMENSIONS**

Length 49 m  
Max. chord 3.9 m

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**NACELLE DIMENSIONS**

Height for transport 4 m  
Height installed (incl. CoolerTop\*) 5.4 m  
Length 10.4 m  
Width 3.4 m

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**HUB DIMENSIONS**

Max. diameter 3.3 m  
Max. width 4 m  
Length 4.2 m

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Max. weight per unit for transportation 70 metric tonnes

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The table below lists material amounts and costs of a single wind tower of 95-m hub height, made of tubular steel. The foundation for each tower is a concrete disk or rectangular (16.76 x 16.76 x 3.04 m<sup>3</sup>) plate, e.g., a design like the one given in the paper by A.N. Singh.

Quantities and costs of materials used in the construction of a wind tower of specified hub elevation.				
System Material	Proposed (240ft)	Tubular steel (240ft)	Proposed (320ft)	Unit Cost
Concrete (yd <sup>3</sup> )	600	---	880	\$ 400
Prestressing strands (lb)	28,500	---	34,000	\$ 1.50
Post-tensioning tendons (lb)	---	---	---	\$ 2.30
Threaded Bars (ft)	300	---	400	\$ 22.5
Reinforcement bars (lb)	50,800	---	73,500	\$ 1.00
Structural Steel (lb)	---	614,700	---	\$ 1.50
Material Cost	\$ 340,000	\$ 922,000	\$ 486,000	

**Note:** The above estimates for use of construction concrete do not include the service roads connecting the towers of the wind farm and the electrical power lines. Estimates of associated materials and costs should be based on the final geometrical design of the wind farm, requiring numbers and spacings estimates to be made first (Task 4).