Turbine Cluster Simulation

Final Presentation

Team 7

Kwasi Darkwah

Scarlett Marzo

Aaron Seemungal

Ash Thomas

Team Introduction

Kwasi Darkwah

- Verification and Validation

Aaron Seemungal

- Data Analyst

Scarlett Marzo

- SE Manager

Ash Thomas

- Simulation Developer

SM

Agenda

1. Background
2. Problem Statement
3. Literature Review
4. Requirements Definition
5. Conceptual Model
6. Data Collection
7. Verification & Validation
8. Simulation Implementation
9. Experimentation
10. Conclusion

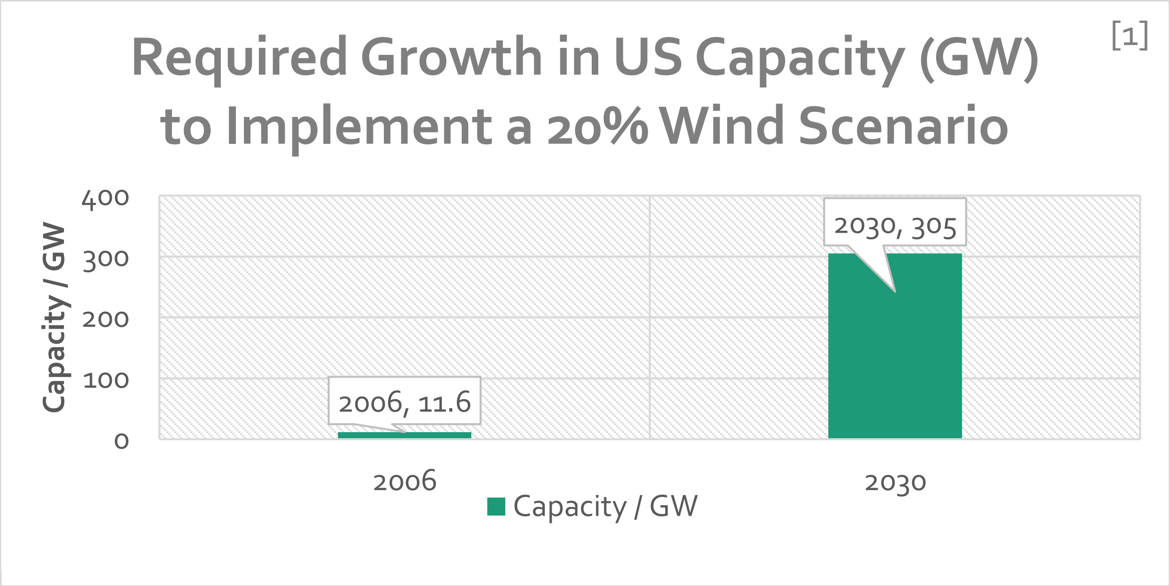
1. Background

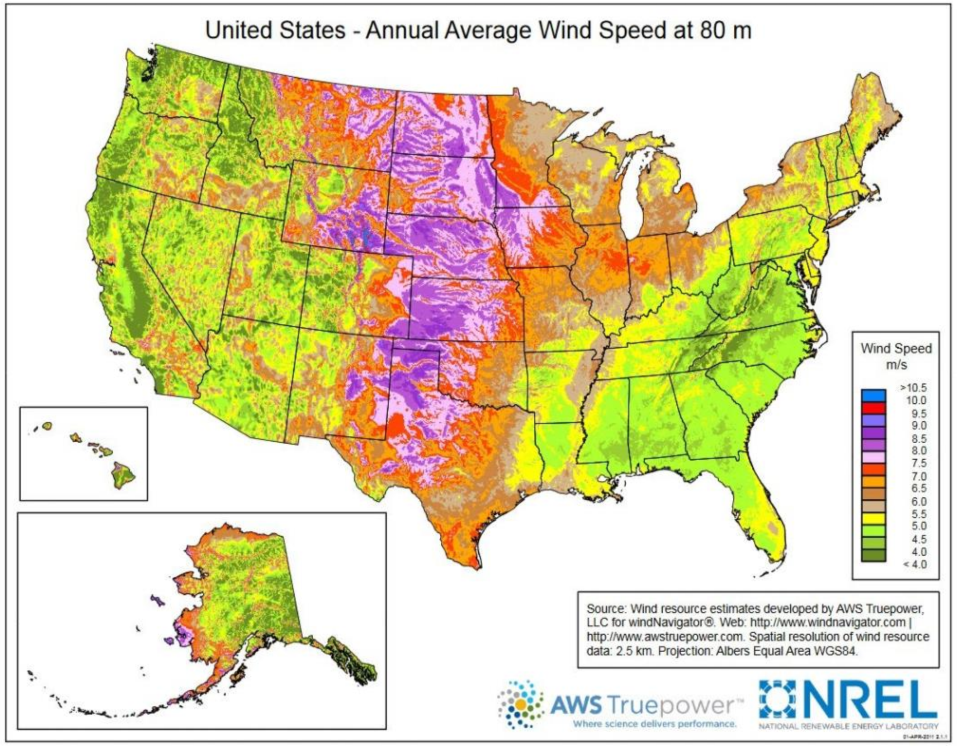
Background

United States is reconsidering its energy portfolio

- ✓ Increasing energy prices
- ✓ Supply uncertainties
- ✓ Growing environmental concerns

"In 2006, President Bush emphasized the nation's need for ***greater energy efficiency*** and a more ***diversified energy portfolio***. This led to a collaborative effort to explore a modeled energy scenario in which ***wind provides 20%*** of U.S. electricity by 2030."
– U.S. Department of Energy, July 2008 *[1]*





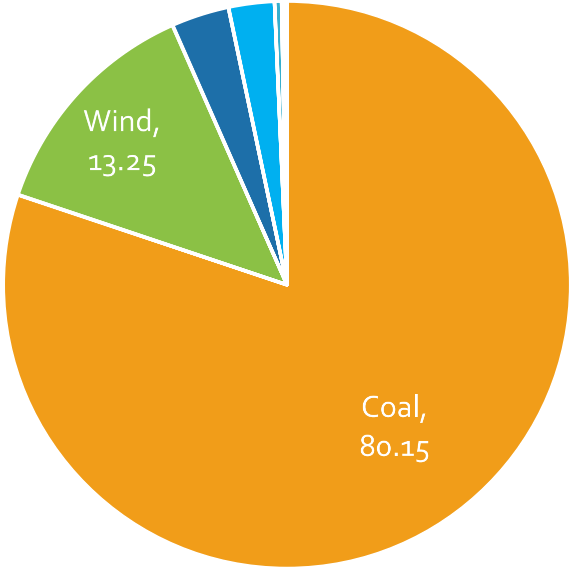
Source: US Energy Information Administration's Open Data API, Electricity Net Generation

SM

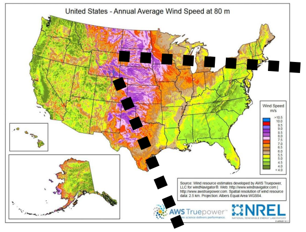
[1] https://www.energy.gov/sites/default/files/2013/12/f5/41869.pdf

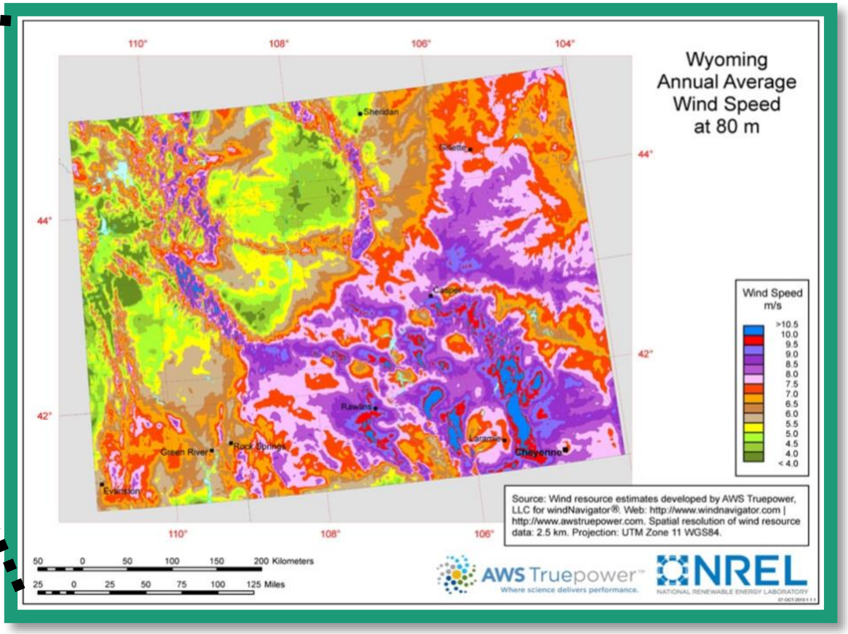
Background

Six proposed wind farms could add more than **1,600** megawatts of electricity generation capacity to Wyoming's grid by 2024, according to an announcement this week by utility Rocky Mountain Power's parent company, PacifiCorp."
– Sheridan Press: 6/28/2021



Energy Type	%
Coal	80.15%
Wind	13.25%
Natural Gas	3.3%
Hydro	2.61%
Solar	0.4%
Other Fossil Fuels	0.19%
Oil	0.11%





Scenario

PacifiCorp has reached out to us to help in the **selection of the wind turbine model** and the **number of turbines** that could produce the required power in a **single wind farm.**

***Problem Background**: https://www.thesheridanpress.com/news/regional-news/six-new-wind-farms-planned-for-wyoming/article_f247160e-d05c-11eb-a59f-37b3b8179372.html*

Source: US Energy Information Administration's Open Data API, Electricity Net Generation

2. Problem Statement

Problem Statement

"What is the minimum number of wind turbines (of a particular model) required for a wind farm of 6 square miles to produce an energy output of at least **700 GWh** over a year?"

By increasing wind energy, Casper would be able to use fossil fuels for downstream products and even sell off to other states.

Downstream O&G Products							
Gasoline	Jet Fuel	Diesel Oil	Plastics	Lubricants	Waxes	Asphalt	Natural Gas

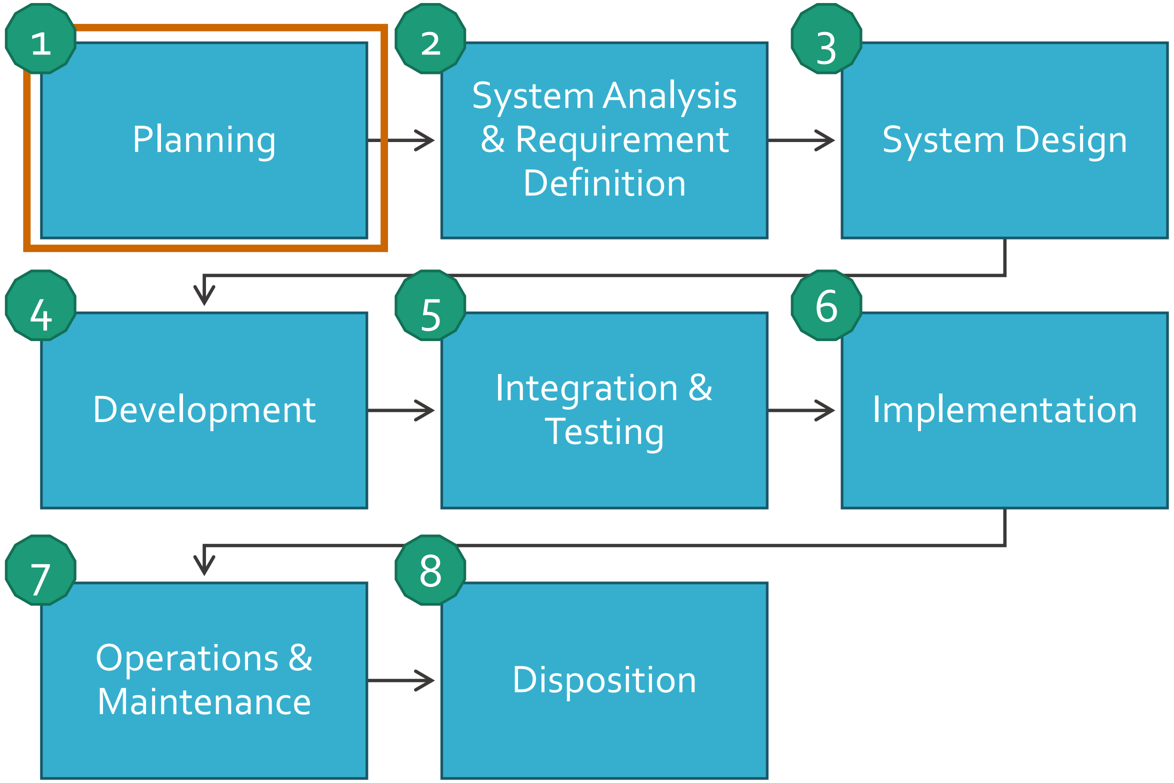
KD

Lifecycle Phase

Scenario

PacifiCorp has reached out to us to **help in the selection** of the **wind turbine model** and the **number of turbines** that could produce the required power in a **single wind farm**.

- This simulation aims to support the Planning phase of PacifiCorp's project.
- The simulation will help PacifiCorp make the decision about the model and quantity of wind turbines needed.



Project addresses step 1 of the systems life cycle phase

KD

3. Literature Review

Literature Review

Model Of A Wind Turbine Using Discrete Events

MATLAB

- Paper discusses **Colombia's challenges meeting energy demands**
- Strong dependence on hydroelectric power, whose efficiency is directly proportional reservoir levels
- Some representative **Latin American countries** already have a good installed **wind turbine base**
- The author's argument therefore is to **develop a model to evaluate wind potential** to determine **wind turbine feasibility**
- The paper describes the use of SimEvents, **MatLab's discrete-event simulator**
- **Time series** (wind dynamics) can be used to produce different **wind profiles**

An Agent-Based Multi-Scale Wind Generation Model

anylogic

- Paper discusses agent-based model for simulation of wind turbines using AnyLogic
- Goal is to develop a flexible model that allows the **simulation of power output of a wind farm**
- Model presents a **combination** of **agent-based modeling, discrete events and dynamic systems**
- Proposed model represents **power production** of wind turbines in aggregate time intervals taking fluctuating wind speeds and reliability factors into account
- The model **incorporates minimum wind speeds**, nominal wind speeds, and cut-off wind speeds to represent conditions where peak to no power is achieved
- The paper also introduces a **maintenance condition** where one or more units go into failure mode and its effect on **total power output**

Georgia Tech Library

Georgia Tech

References:
https://www.sciencedirect.com/science/article/pii/S1876610218312438
https://www.anylogic.com/resources/articles/an-agent-based-multi-scale-wind-generation-model/

4. Requirements Definition

Purpose & Scope of the Simulation

Modeling a population of wind turbines with **different specifications**

Simulating the weather over **a year** in **Casper, WY**

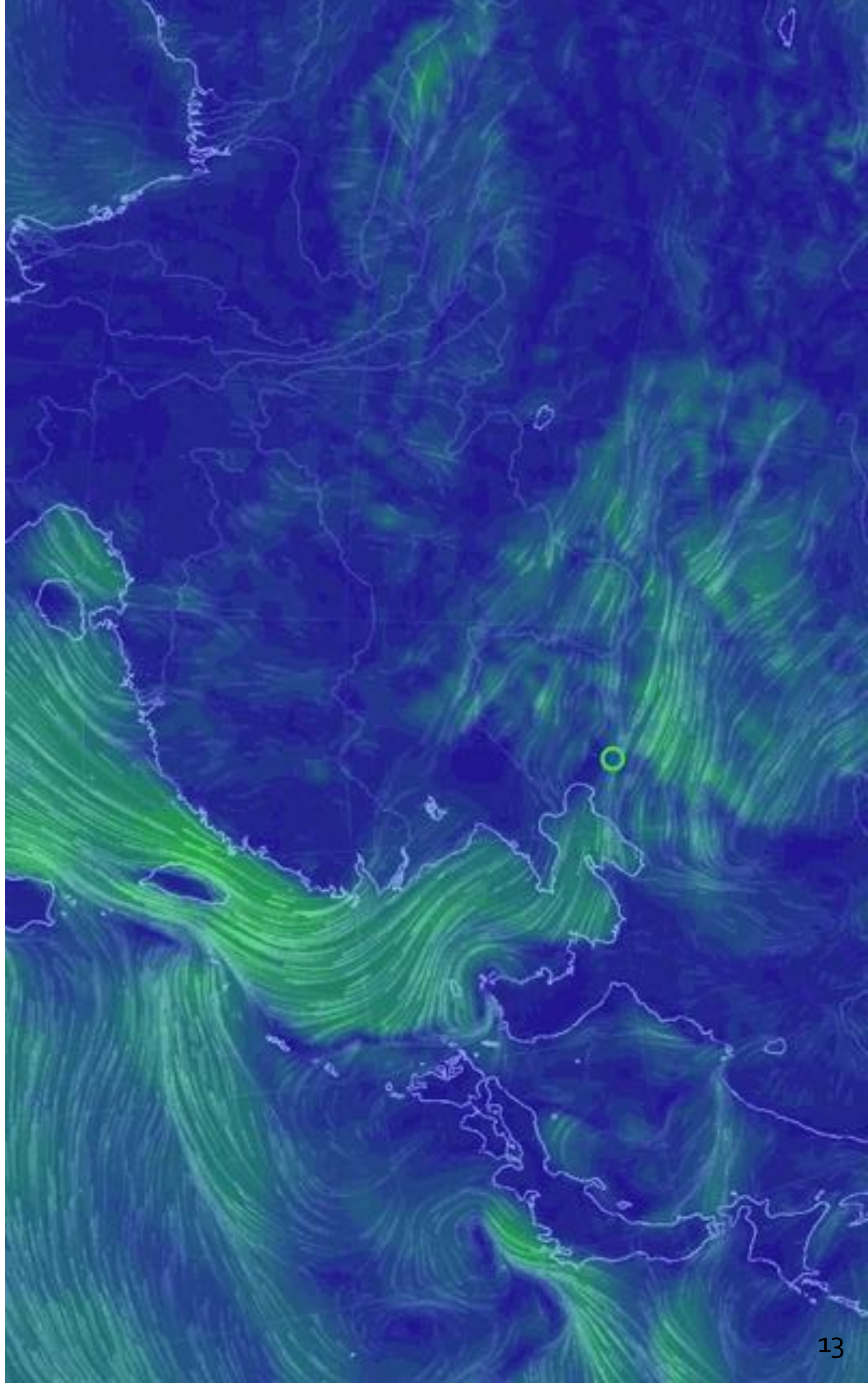
- **Model wind speed** from a data set

Simulating the **generation of electrical energy** from the power of wind

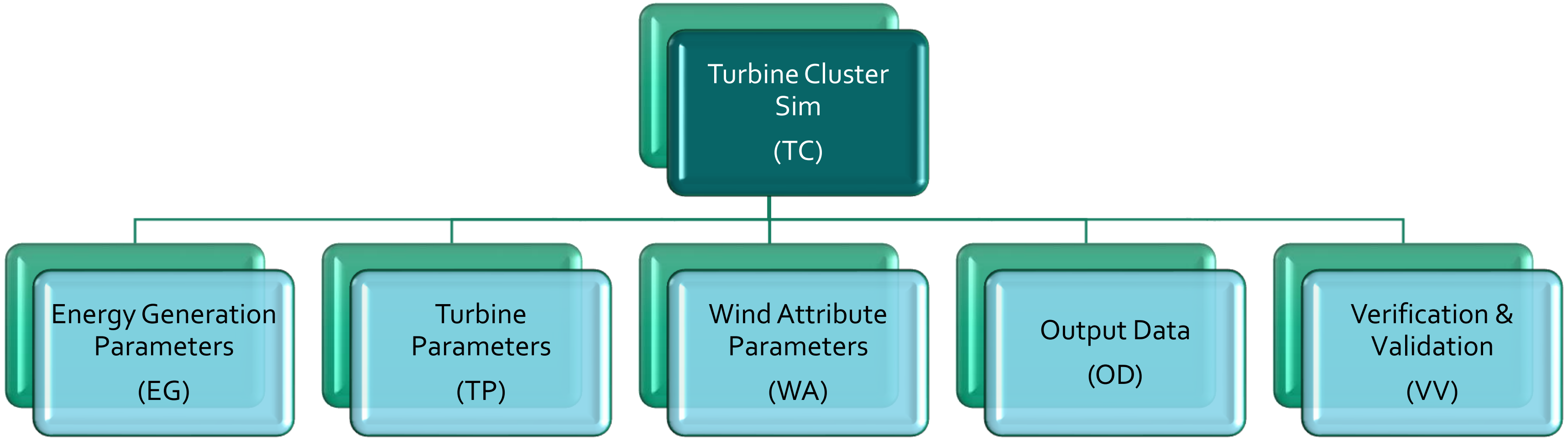
Determining **which turbine models** are compatible with the **limited land size**

Determining **how many wind turbines** are required to generate a minimum energy requirement

Providing quantitative results to the problem statement



Requirements Definition



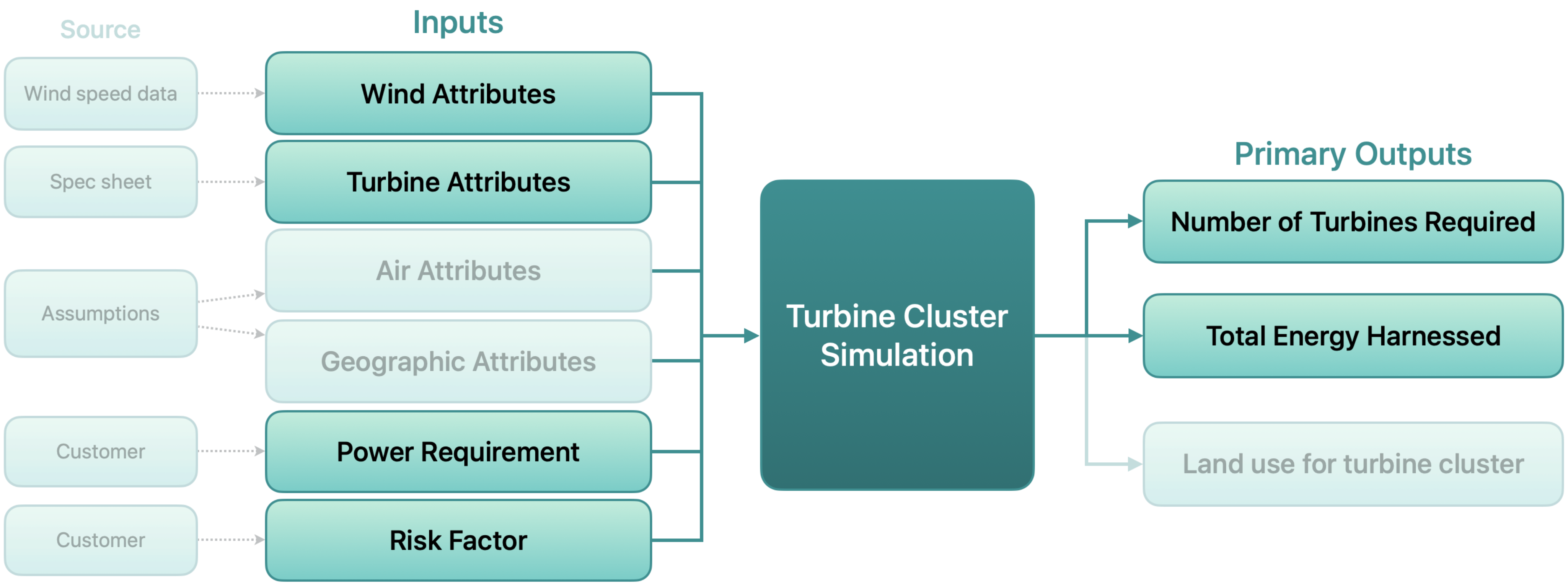
Energy Generation Parameters	**Input controls for Energy Generation (e.g., functional coefficients – Betz)**
Turbine Parameters	**Input controls related to the wind turbine (e.g., rotor diameter, cut-in velocity, rated velocity, efficiency factors)**
Wind Attribute Parameters	**Input controls related to the wind (e.g., wind speed)**
Output Data	**Output requirements from the simulation (e.g. total energy output calculated, total number of turbines)**
Verification & Validation	**Requirements to ensure that the model is coded correctly and accurately**

5. Conceptual Model

Conceptual Model

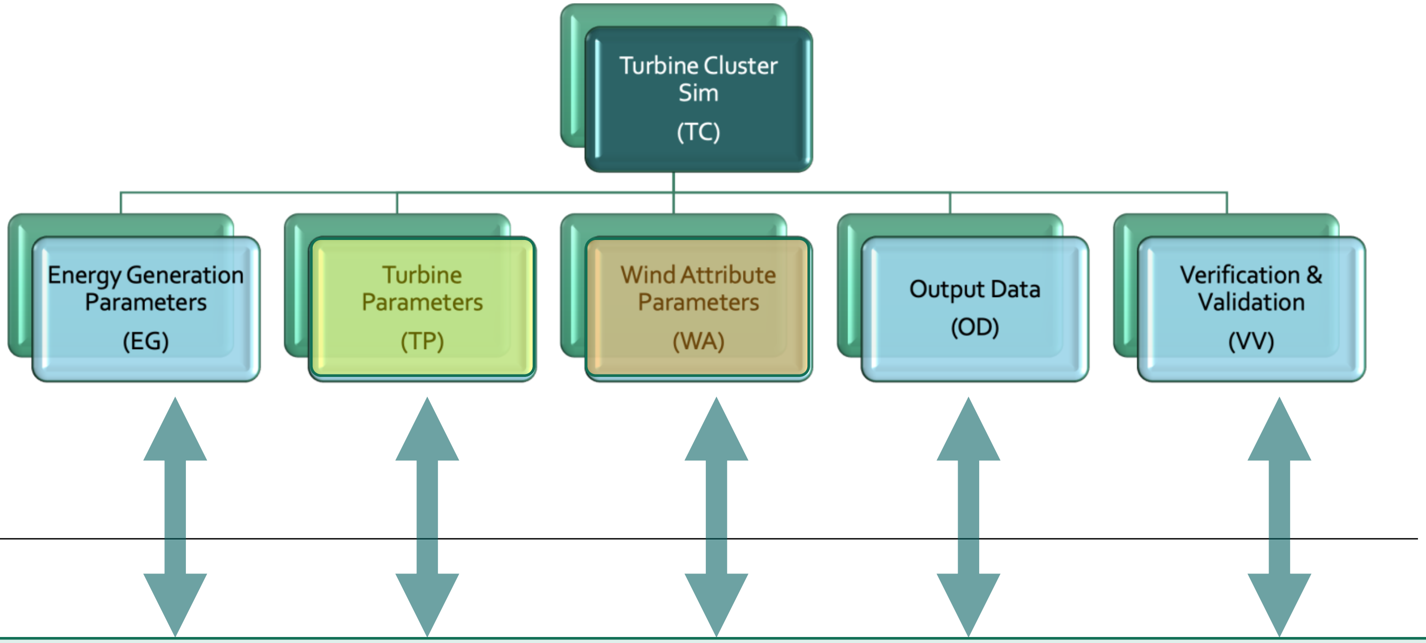
Problem Statement

*"What is the **minimum number of wind turbines** (of a particular model) required for a wind farm of 6 square miles to produce an **energy output** of **at least 700 GWh** over a year?"*

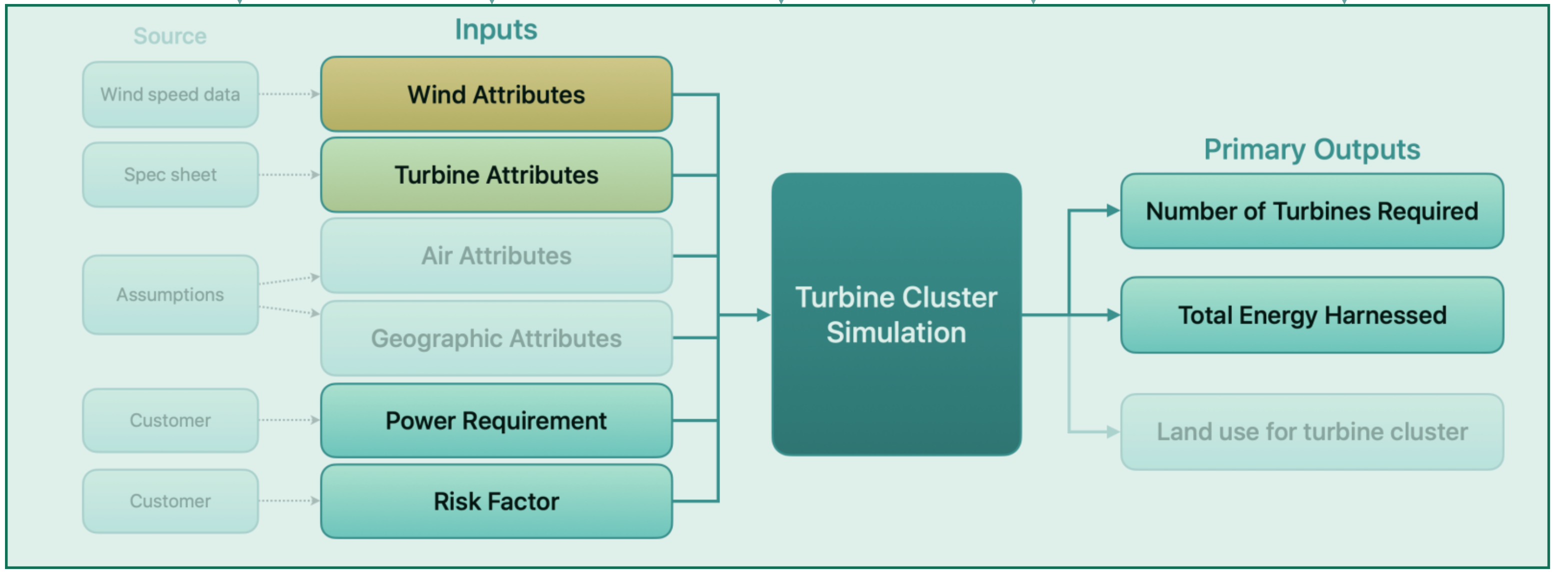


AT

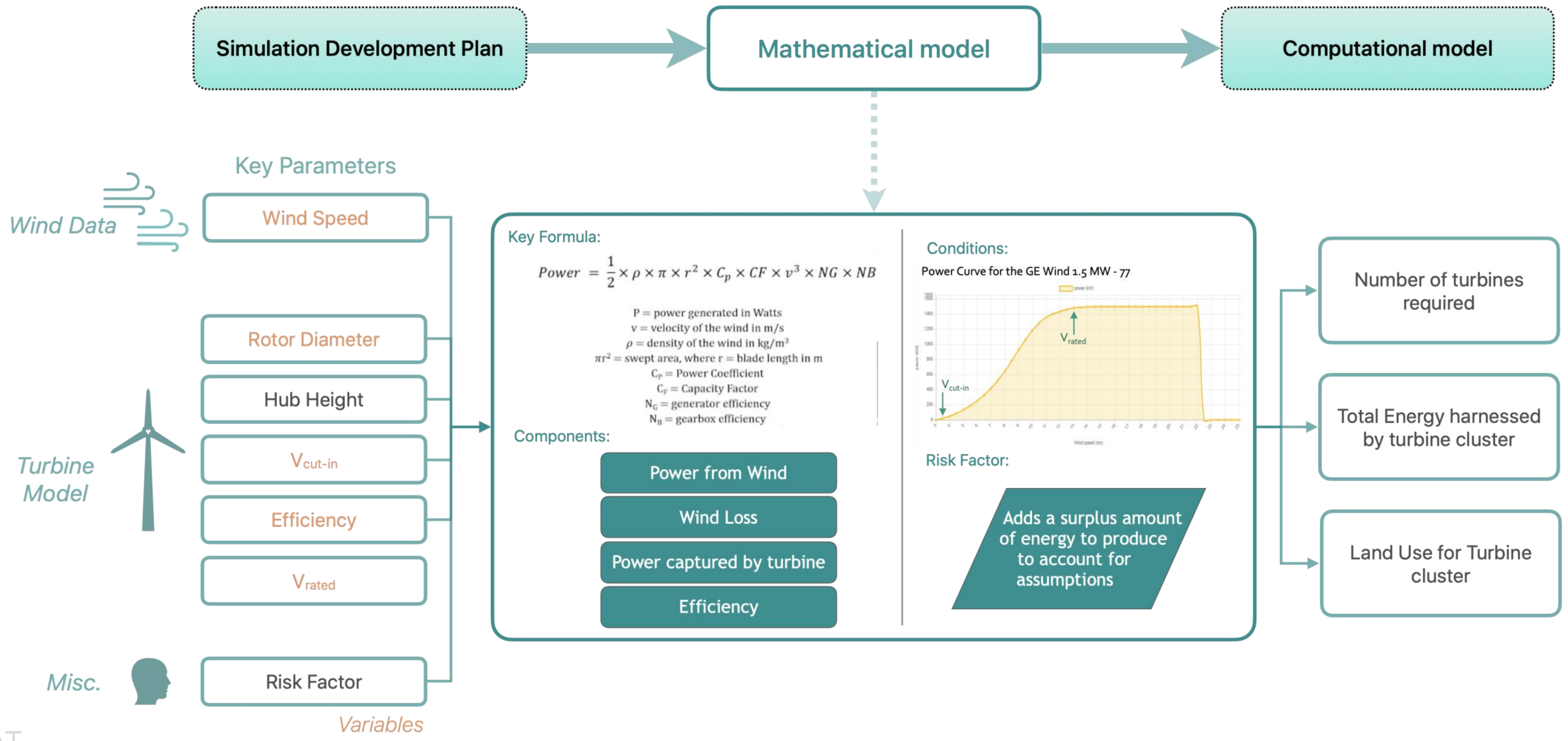
Requirements



Conceptual Model



Math Model



Simulation Development Plan
Mathematical model
Computational model
Key Parameters
Wind Data
Wind Speed
Rotor Diameter
Hub Height
V_{cut-in}
Efficiency
V_{rated}
Turbine Model
Misc.
Risk Factor
Variables
Key Formula:
$Power = \frac{1}{2} \times \rho \times \pi \times r^2 \times C_p \times CF \times v^3 \times NG \times NB$
P = power generated in Watts
v = velocity of the wind in m/s
ρ = density of the wind in kg/m^3
πr^2 = swept area, where r = blade length in m
C_p = Power Coefficient
C_F = Capacity Factor
N_G = generator efficiency
N_B = gearbox efficiency
Components:
Power from Wind
Wind Loss
Power captured by turbine
Efficiency
Conditions:
Power Curve for the GE Wind 1.5 MW - 77
V_{rated}
V_{cut-in}
Risk Factor:
Adds a surplus amount of energy to produce to account for assumptions
Number of turbines required
Total Energy harnessed by turbine cluster
Land Use for Turbine cluster

Overarching Assumptions

Land plot size is fixed and is the **primary constraint** over cost

The **topography** of the wind farm is considered **flat land**

Energy transmission, consumption and **storage** is **not considered** for the purposes of this simulation

The **overall efficiency** of a turbine **is the same** for all models regardless of manufacturer

The same **Separation factor** is applied across **all models** regardless of manufacturer

Wind speed is **constant** in an **hour**

Wind direction, air temperature, air density, geographic location & elevation are **constant**

Blade angle, blade design, material and weight considerations will be assumed to be of **negligible impact**

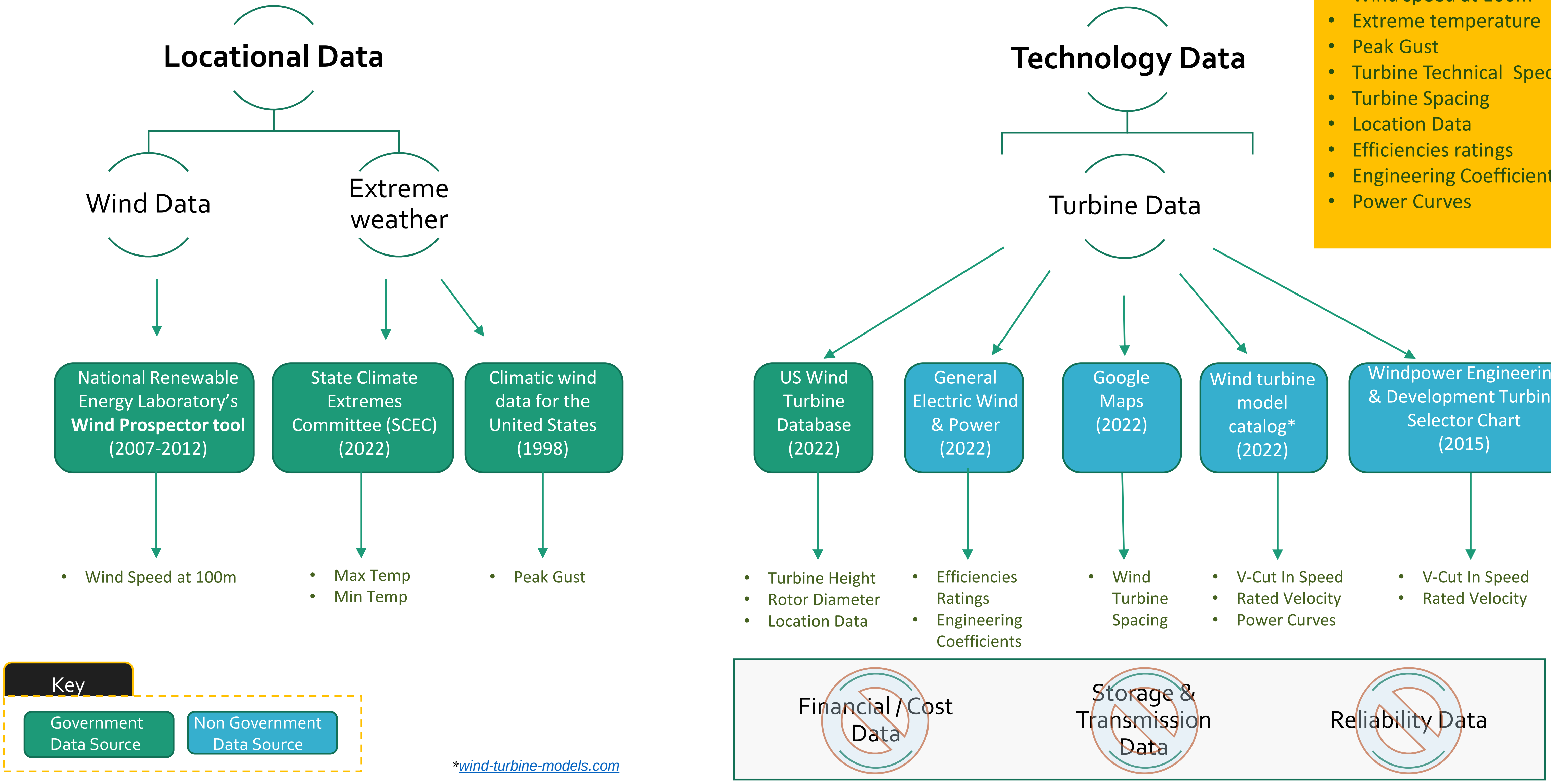
Model Parameter Assumptions

Key Inputs	Assumption List	
	Constants	**Variables**
Wind Attributes	Direction	Speed *(varied by time of year selected)*
Turbine Attributes	Down Time, Hub Height	Turbine *(Rotor Diameter, Cut-in Wind Speed, Efficiency, Rated Velocity)*
Air Attributes	Temperature, Density *(20°C @1 atm = 1.204kg/m^3)*	-
Geographic Attributes	Location, Elevation, Land Plot Size	-
Wind Farm Power Rating	270 MW	-

AS

6. Data Collection

Data Collection



Key data

- Wind speed at 100m
- Extreme temperature
- Peak Gust
- Turbine Technical Specifications
- Turbine Spacing
- Location Data
- Efficiencies ratings
- Engineering Coefficients
- Power Curves

*wind-turbine-models.com

AS

7. Verification & Validation

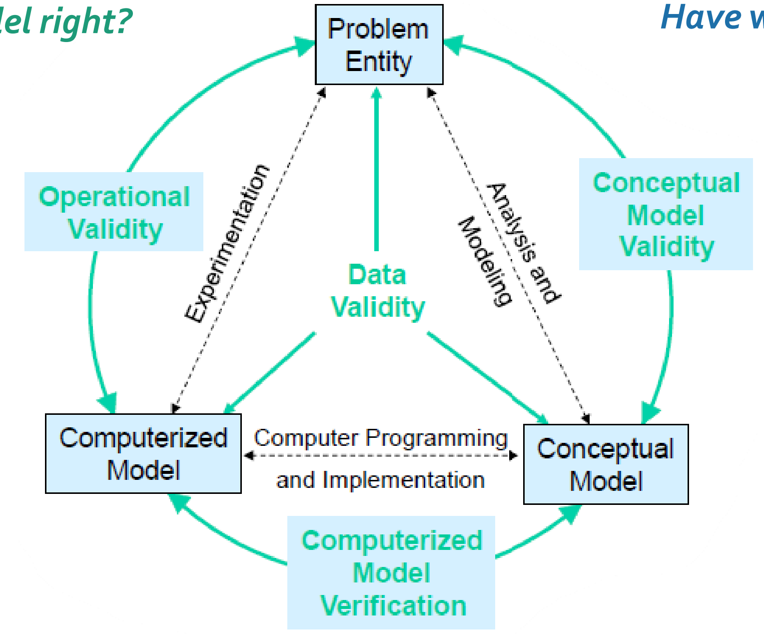
Verification & Validation Plan

Verification Plan

Transformational Accuracy

Have we built the model right?

- Verify simulation by ensuring traceability to the conceptual model and requirements
- Verify simulation with the conceptual model and requirements



Validation Plan

Behavioral or Representational Accuracy

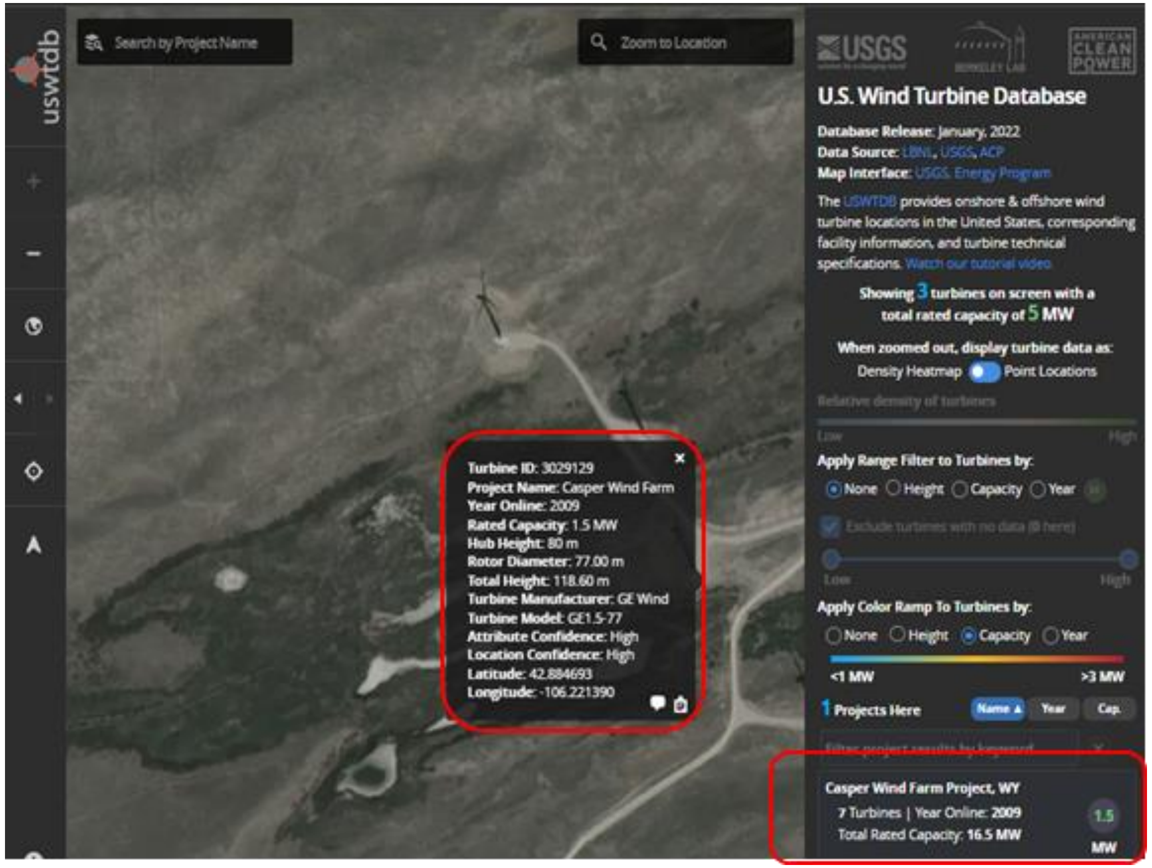
Have we built the right model?

- Validate conceptual model with the requirements
- Validate results of the simulation against real-world data

Verification Plan

- **Wind profile data** for a wind farm in **Casper, WY** collected from a credible database
- Systems requirements developed to create framework for logic of model
- **Requirements verified against objective** of the model to ensure they fall within scope
- Conceptual model developed showing independent variables and dependent variables
    - **Independent Variables**: Wind Data, Turbine Parameters, Risk Factor
    - **Dependent Variables:** Power Output, # of Turbines, Land Size
- **Conceptual model** verified to ensure synchronization with system requirements
- **MATLAB selected** as programming language and code verified to ensure logic was consistent with conceptual model setup

US Wind Turbine Database – Casper Wind Farm



KD

Validation Plan

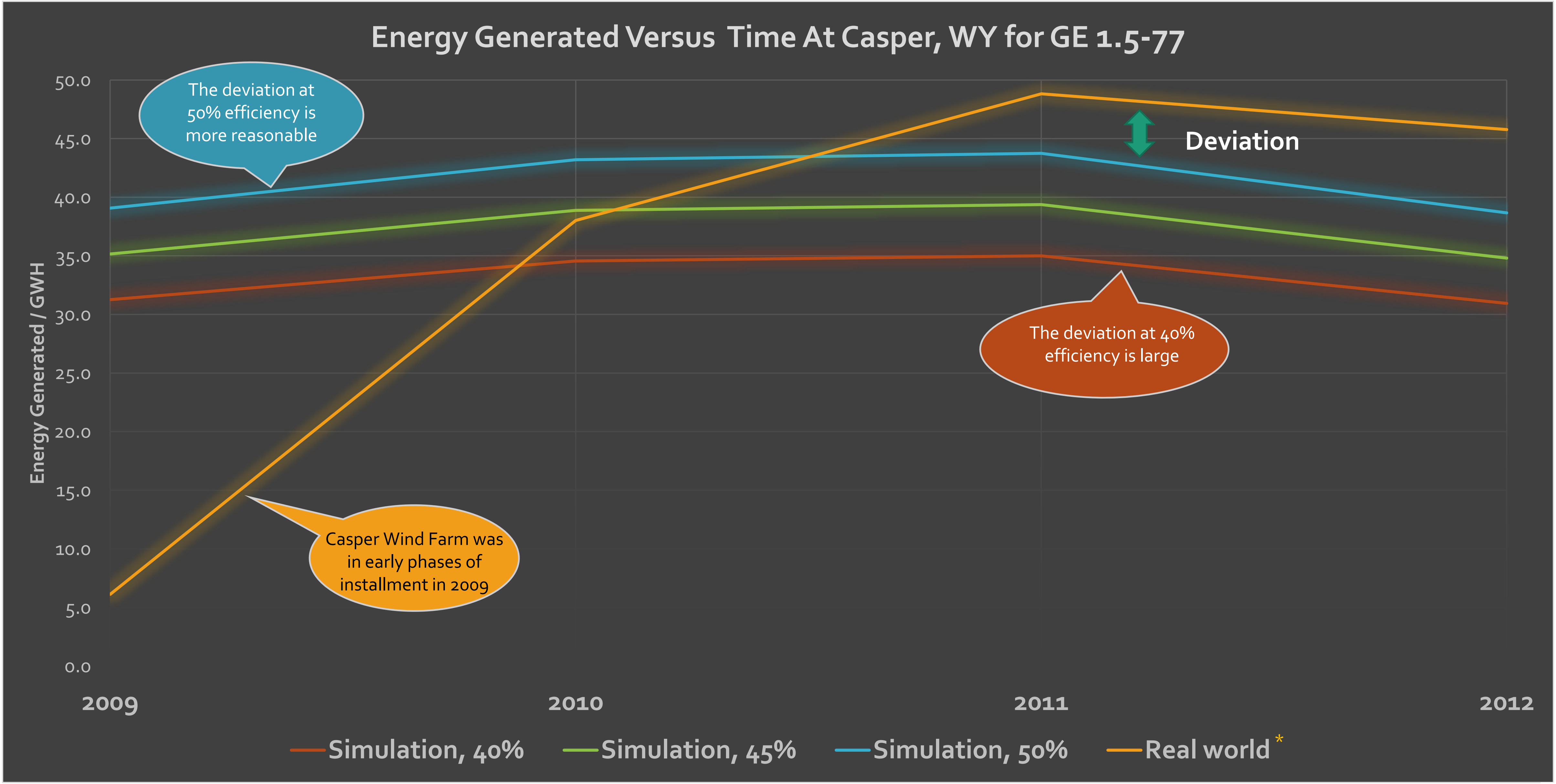
Simulation of model implemented using a quantity of **11 GE Wind 1.5 MW-77** to match the same quantity and model in the existing Casper Wind Farm

Simulation executed using US Energy Information Administration data from **2009 to 2012**

Model was run at **three** wind turbine efficiency ratings **(40%, 45%, and 50%)** within the real-world efficiency range

The GE 1.5 MW-77 served as validation for the simulation model as this model in installed in the existing Casper Wind Farm for comparative analysis

The effect of varying efficiency on the model…

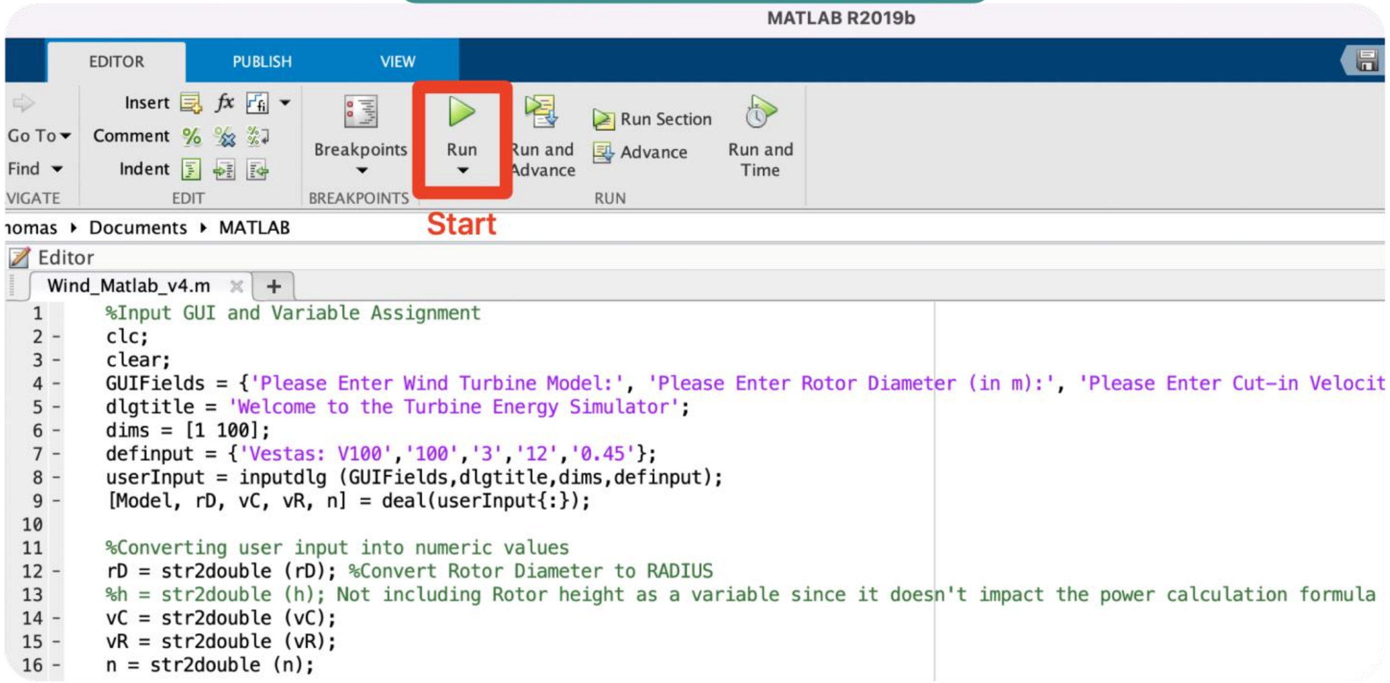


* Casper Windfarm project – [EIA Electricity Data Browser]

8. Simulation Implementation

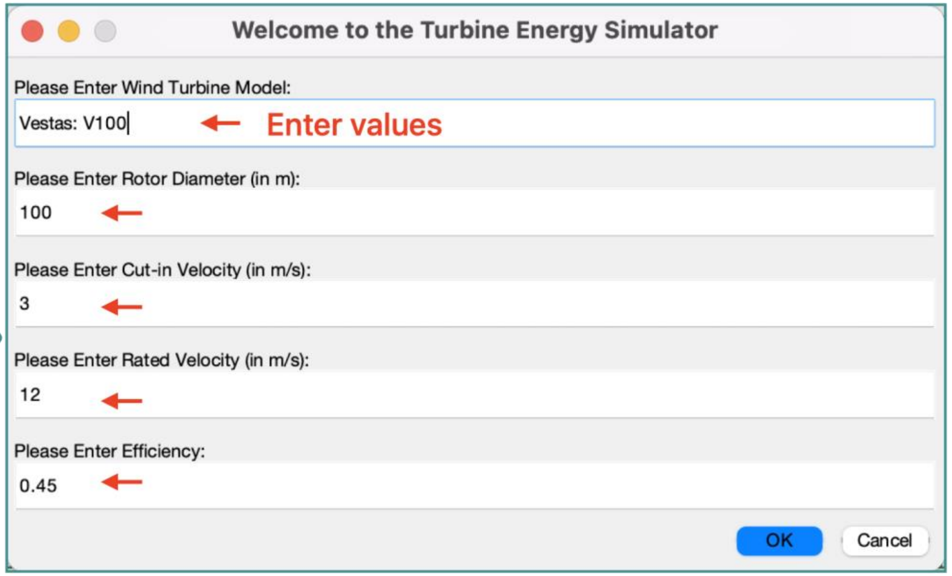
Simulation Implementation

Step 1) Start Program



Matlab Code

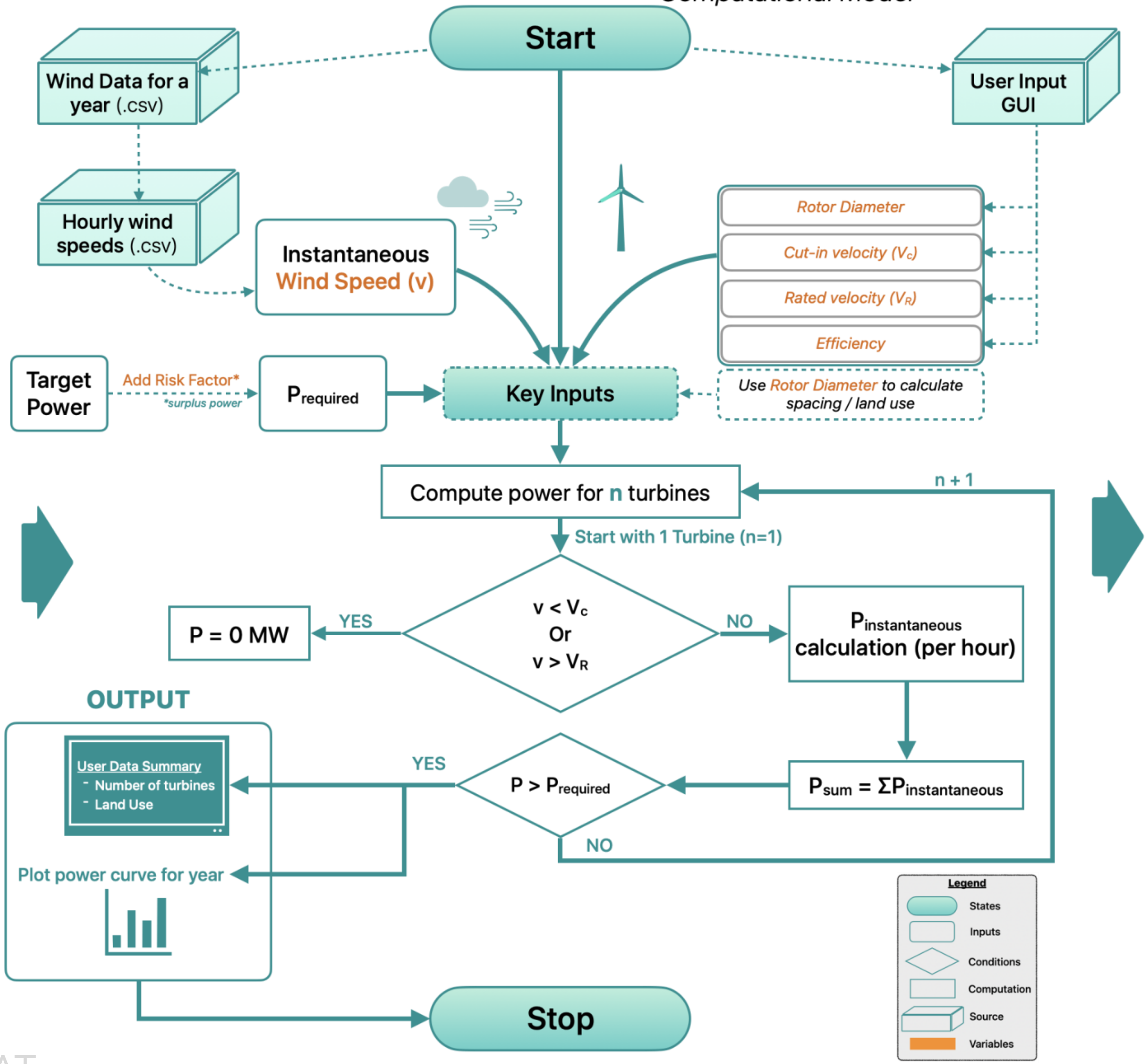
Step 2) Input Turbine Model Information



Graphical User Interface for the User

Step 3) Simulation Computation

Computational Model



Step 4) Sample Output

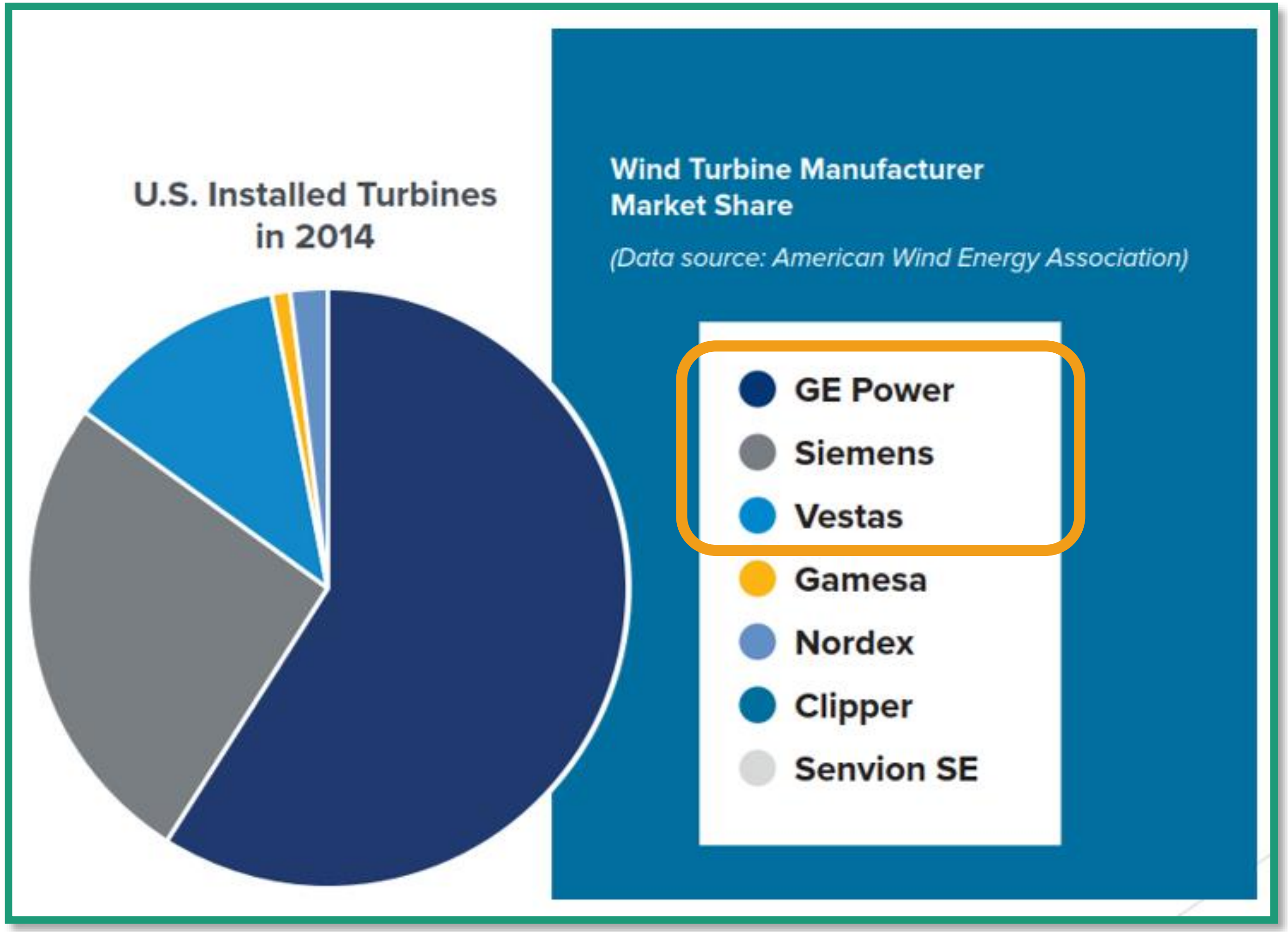
Visual Output for the User once the code converges on the result

```
User Data Summary
-------------------
159 turbine(s) would be required to meet the required energy output of 851 GWh.
The net energy produced by 159 turbine(s) is 851.47 GWh.
Each turbine of this model takes up 0.027 sq miles (17.47 acres) of land area
(including inter-turbine spacing).
Overall land use is 72.32%
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
The model Vestas: V100 may be used to achieve required energy output.
```

AT

9. Experimentation

Manufacturer Selection



"Three wind turbine manufacturers have largely dominated the wind industry in the U.S.—General Electric (GE), Siemens, and Vestas."

New York State Energy Research and Development Authority (NYSERDA)* -2014

Business Support

Greater availability of operators	Greater availability of spares

SM

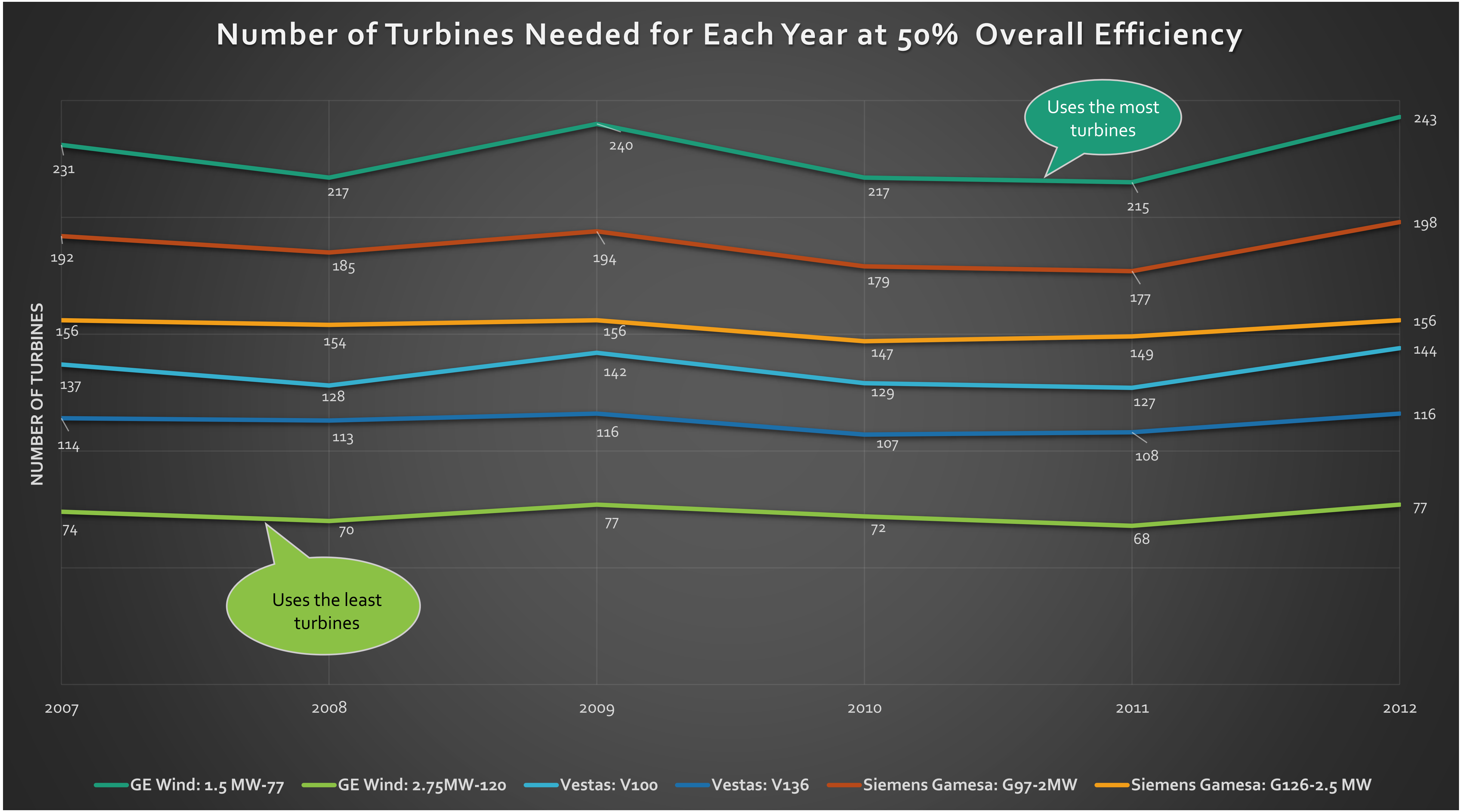
* *New York Wind Energy Guide for Local Decision Makers: Wind Energy Basics*

Experimentation

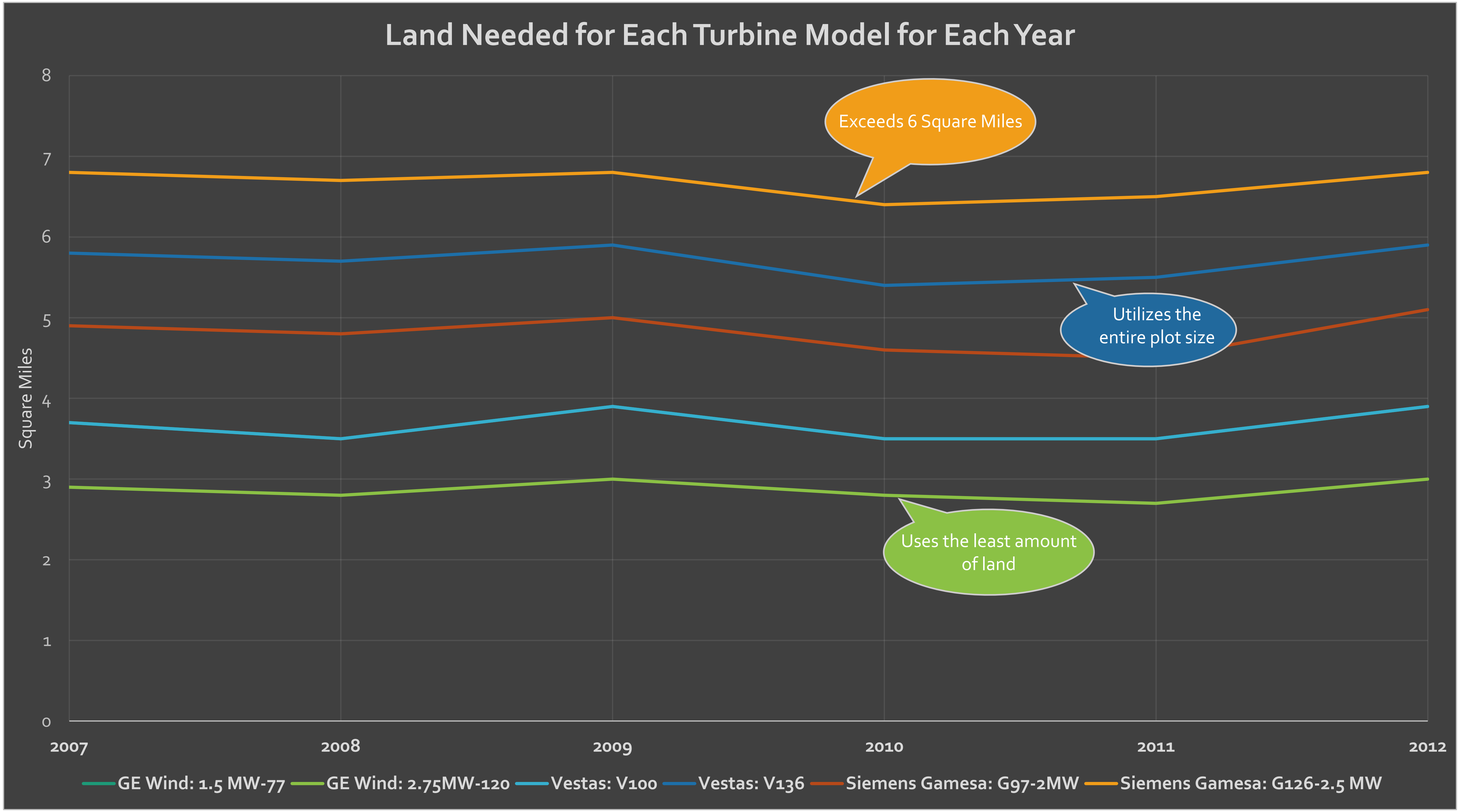
- Series of **6** experiments for different wind turbine models
- Each wind turbine model is tested across **6** years of real-world wind data **(2007 – 2012)**
- Efficiency maintained constant at **50%** *(determined from verification)*

Turbine Model	Rotor Diameter (m)	Cut-In Velocity (m/s)	Rated Velocity (m/s)
GE Wind 1.5 MW-77	77.0	3.5	12.0
GE Wind 2.75 MW-120	120.0	3.0	13.0
Vestas V100-1.8	100.0	3.0	12.0
Vestas V136-3.45	136.0	3.0	10.5
Siemens Gamesa G97-2 MW	97.0	3.0	11.0
Siemens Gamesa G126-2.5 MW	126.0	2.0	10.0

Results

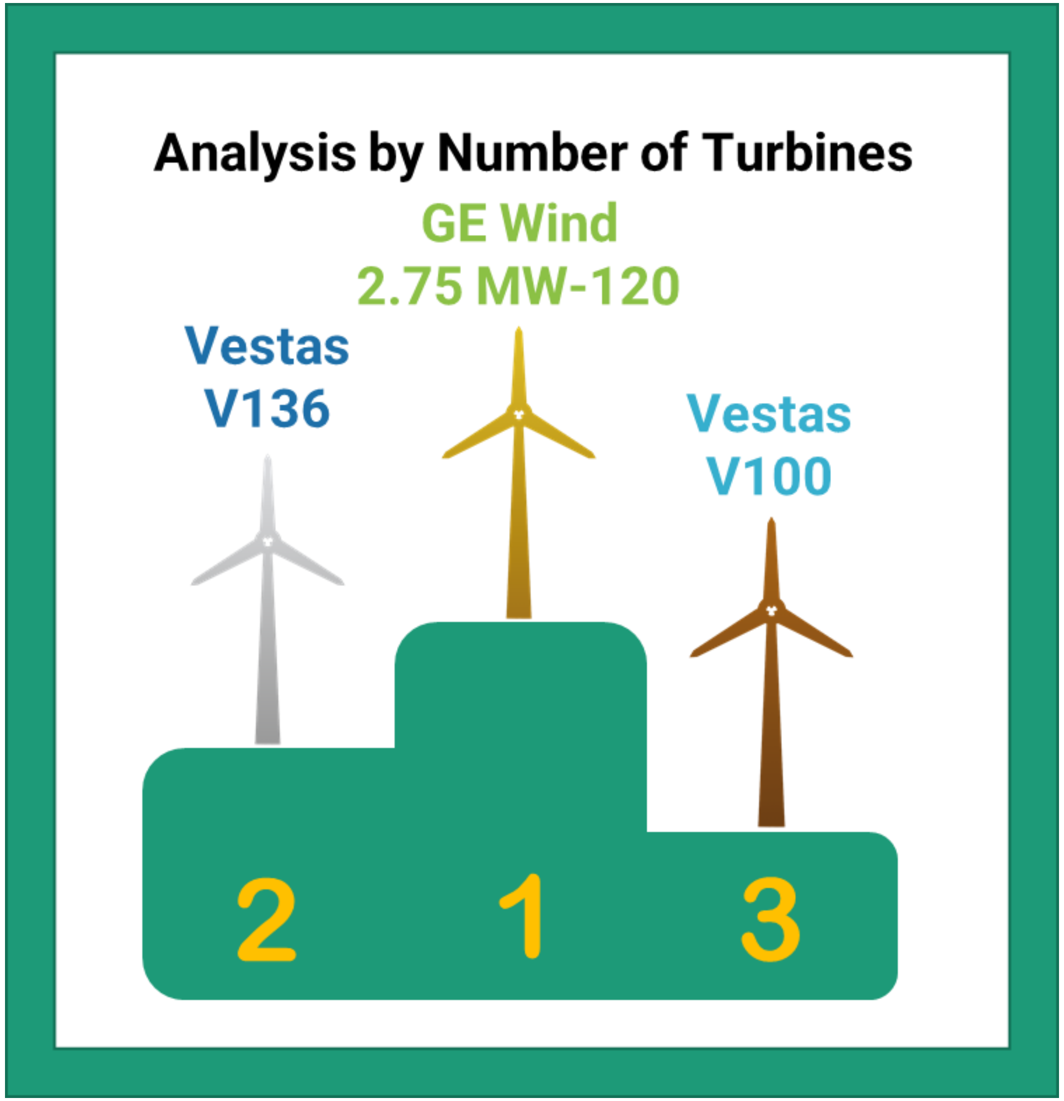

Number of Turbines Needed for Each Year at 50% Overall Efficiency
NUMBER OF TURBINES
Uses the most turbines
Uses the least turbines
231
217
240
217
215
243
192
185
194
179
177
198
156
154
156
147
149
156
137
128
142
129
127
144
114
113
116
107
108
116
74
70
77
72
68
77
2007
2008
2009
2010
2011
2012
GE Wind: 1.5 MW-77
GE Wind: 2.75MW-120
Vestas: V100
Vestas: V136
Siemens Gamesa: G97-2MW
Siemens Gamesa: G126-2.5 MW

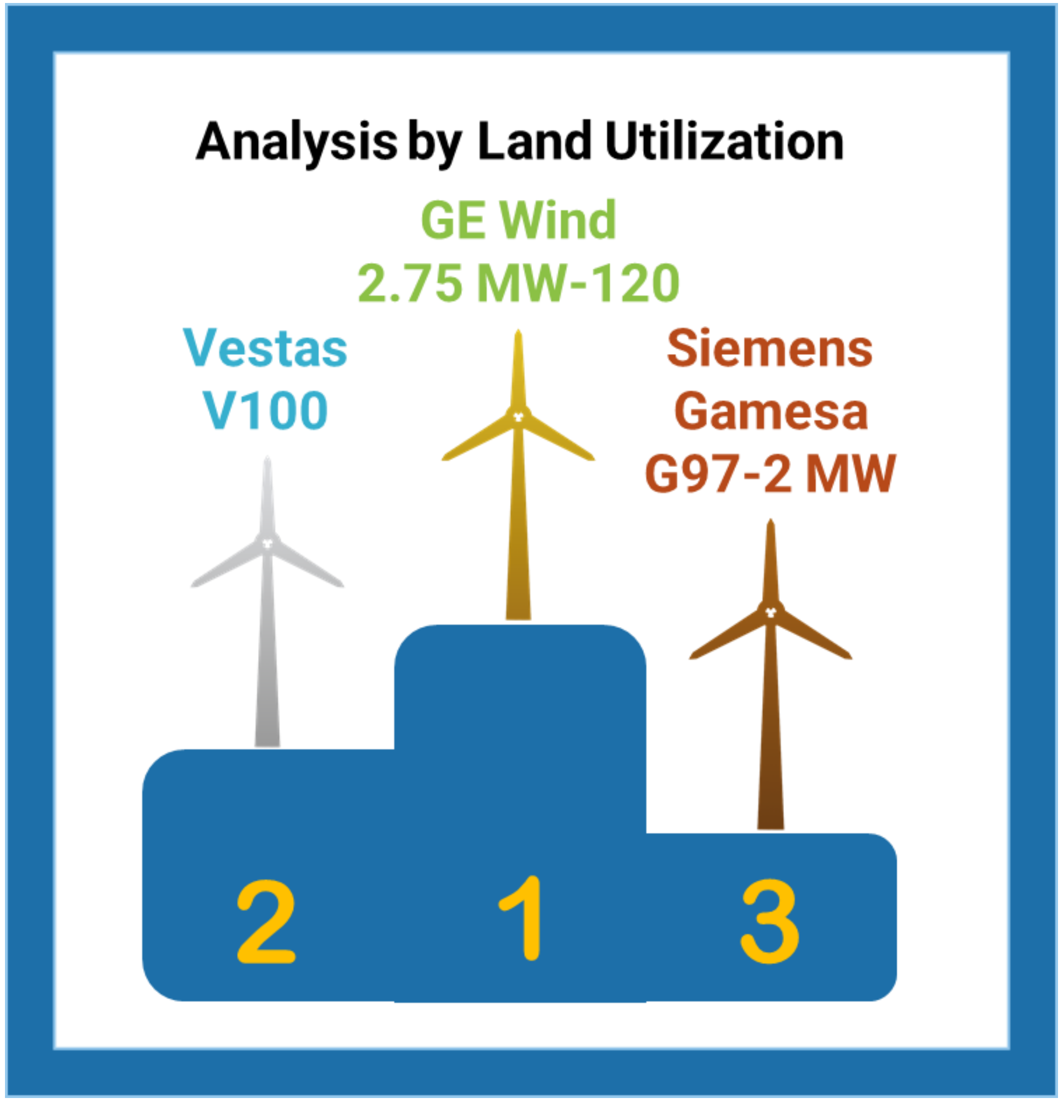
SM


Land Needed for Each Turbine Model for Each Year
Square Miles
0
1
2
3
4
5
6
7
8
2007
2008
2009
2010
2011
2012
Exceeds 6 Square Miles
Utilizes the entire plot size
Uses the least amount of land
GE Wind: 1.5 MW-77
GE Wind: 2.75MW-120
Vestas: V100
Vestas: V136
Siemens Gamesa: G97-2MW
Siemens Gamesa: G126-2.5 MW

SM

10. Conclusion


Analysis by Number of Turbines
GE Wind
2.75 MW-120
Vestas
V136
Vestas
V100
2
1
3


Analysis by Land Utilization
GE Wind
2.75 MW-120
Vestas
V100
Siemens
Gamesa
G97-2 MW
2
1
3

Stretch Goals for Future M&S Needs

- Which turbine option would be the most cost-effective solution?
- What is the land size required to set up a wind turbine cluster of a particular model?
- What is the maximum achievable power output in this location?
- Is the simulation scalable for a larger project?

In Summary…

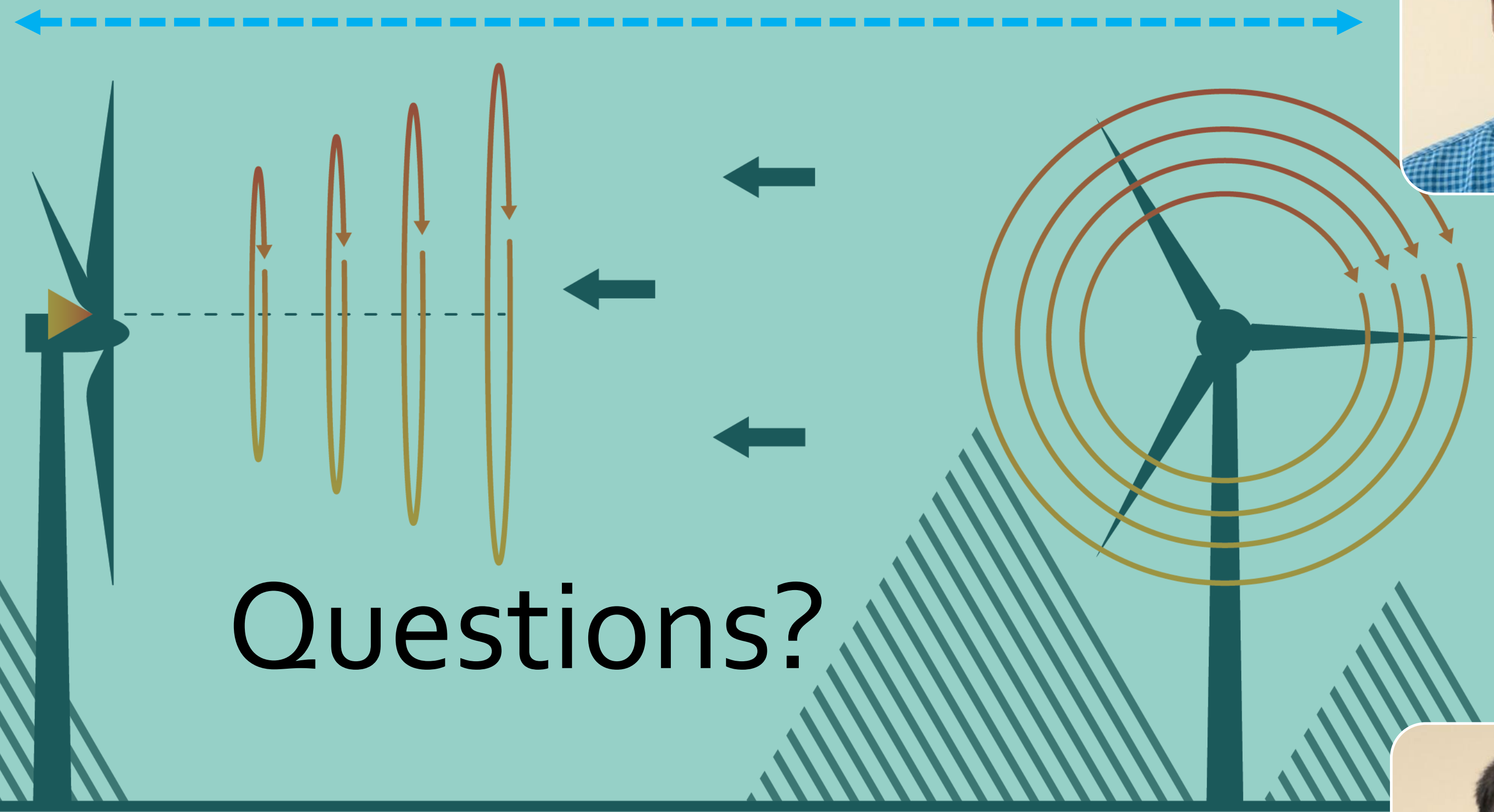
Was the output of the model validated against the need?

Why should you believe the answer?

What does the experimentation and results tell the customer?

What are the limitation of your simulation and experimentation?





Questions?


Thanks to Kayla, Marshall, Dr. Loper and GE Wind !