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# Week 2

# Wind Power

# Forecasting

# W2 Lesson 1

# Wind Power Forecasting:

# Explore Phase

# AI and Climate Change

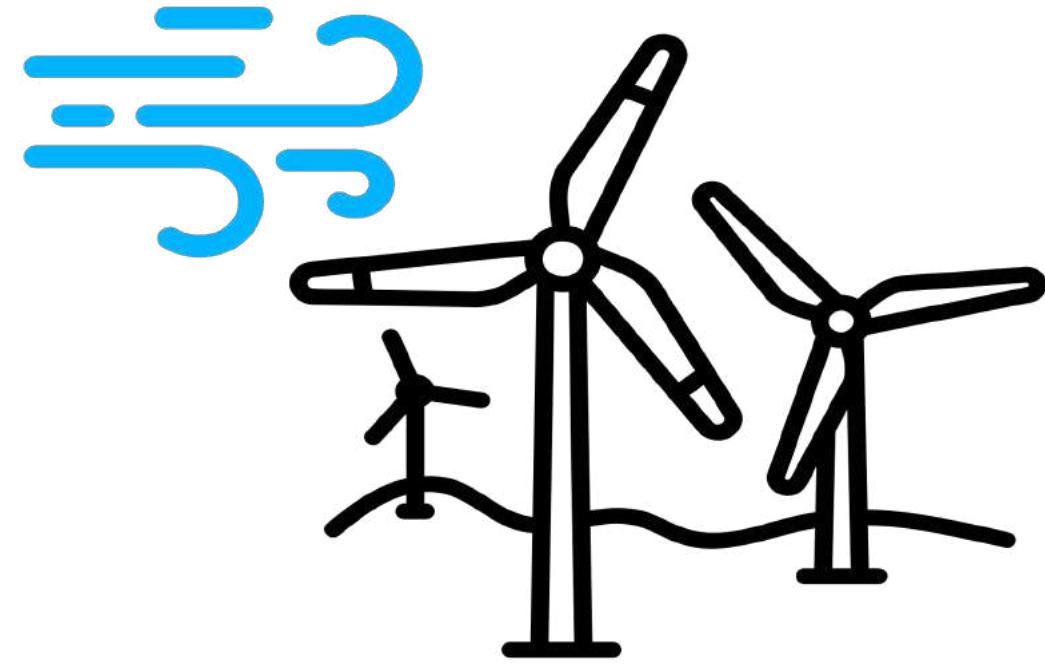
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DeepLearning.AI

## Introduction to Wind Power

# Wind power vs wind energy



## Wind Power Generation

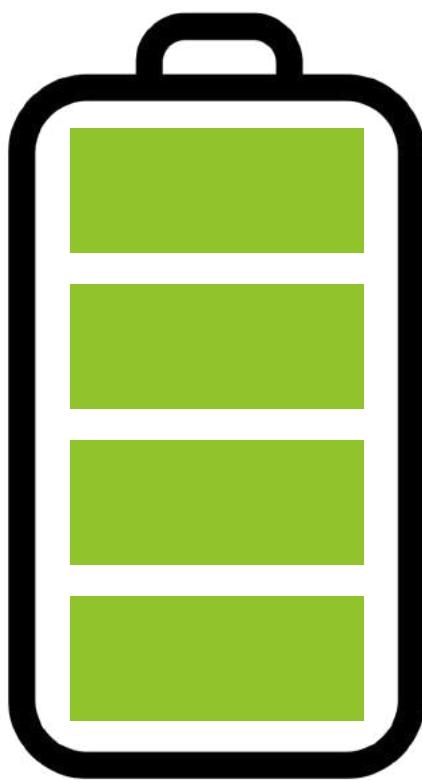
The **rate** at which  
**energy** is *generated*  
by a wind turbine

## Power Consumption

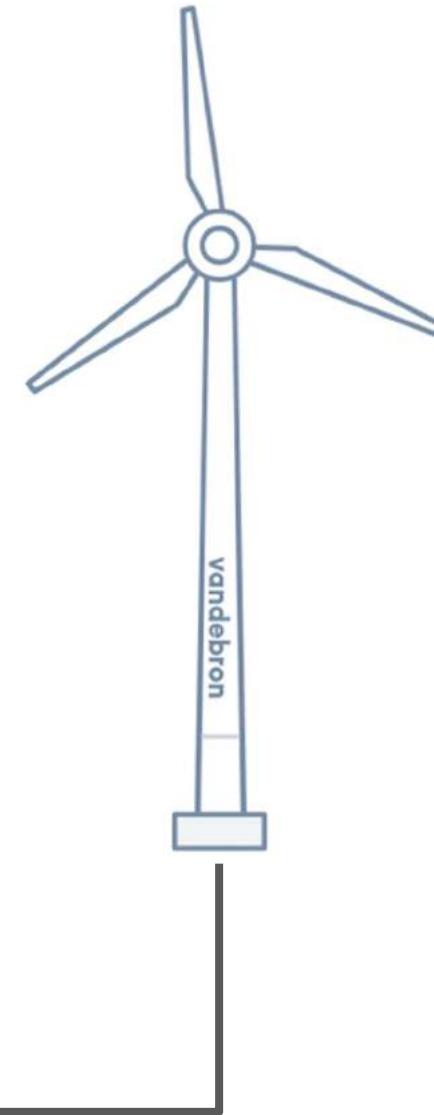
The **rate** at which  
**energy** is *consumed* by  
individuals, industry, etc.

# Wind power generation

The **rate** at which **energy** is *generated* by a wind turbine

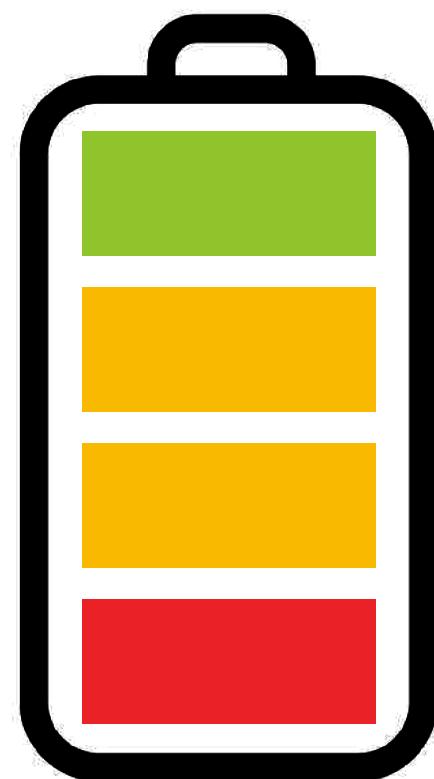


←



# Wind power consumption

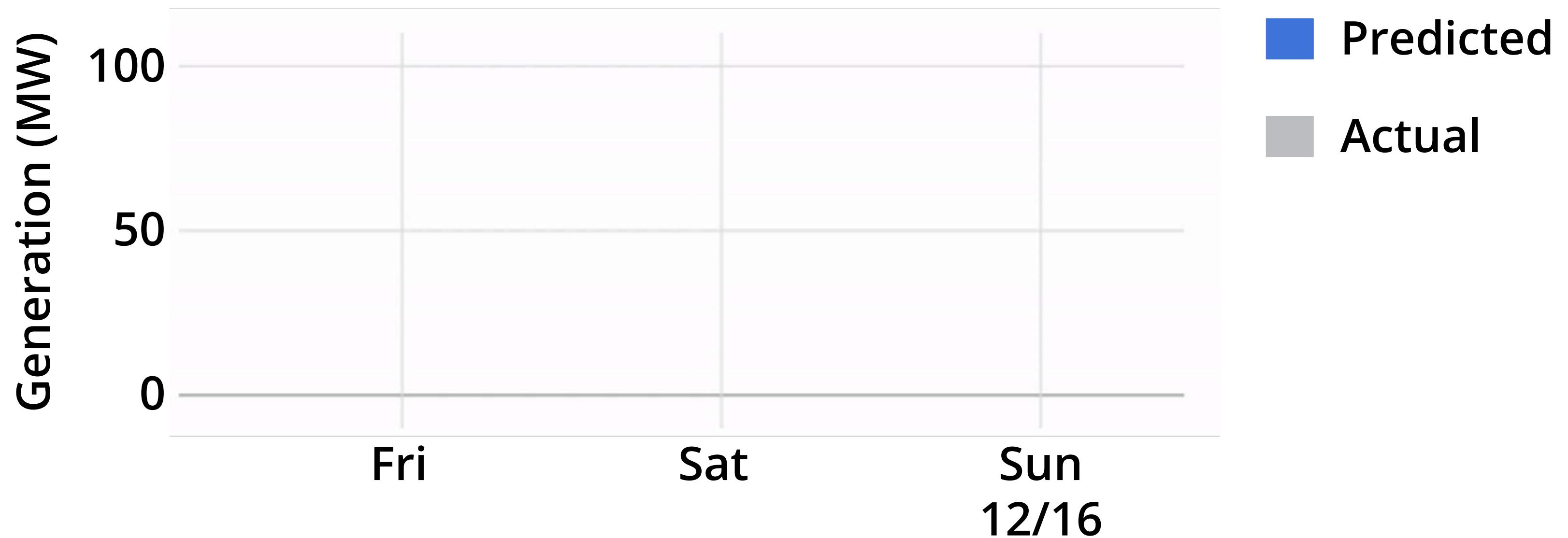
The **rate** at which **energy** is *consumed* by individuals, industry, etc.



40 watt  
light bulb

# DeepMind

**The DeepMind system predicts wind power output 36 hours ahead**



*Machine learning can boost the value of wind energy. Google DeepMind, 2019*



# AI and Climate Change

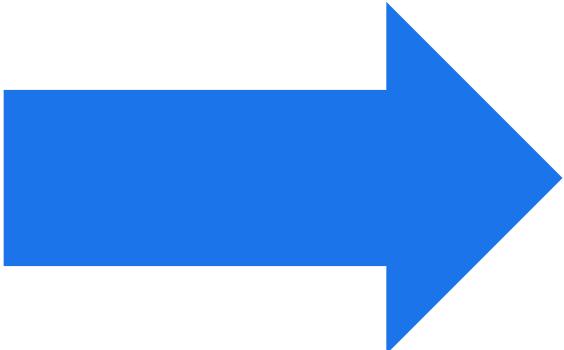
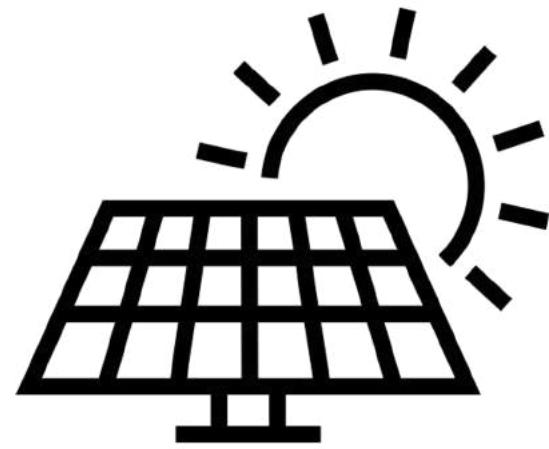
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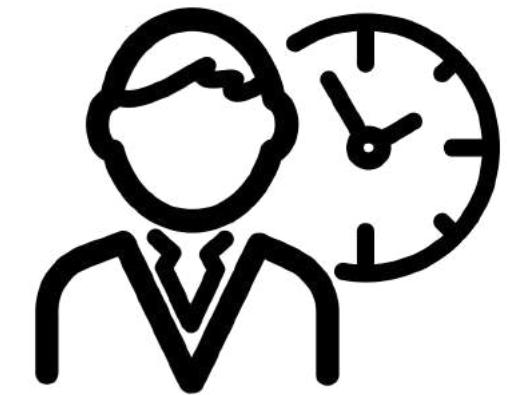
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**Project Spotlight: Predicting  
Solar Energy With Machine  
Learning - Jack Kelly**

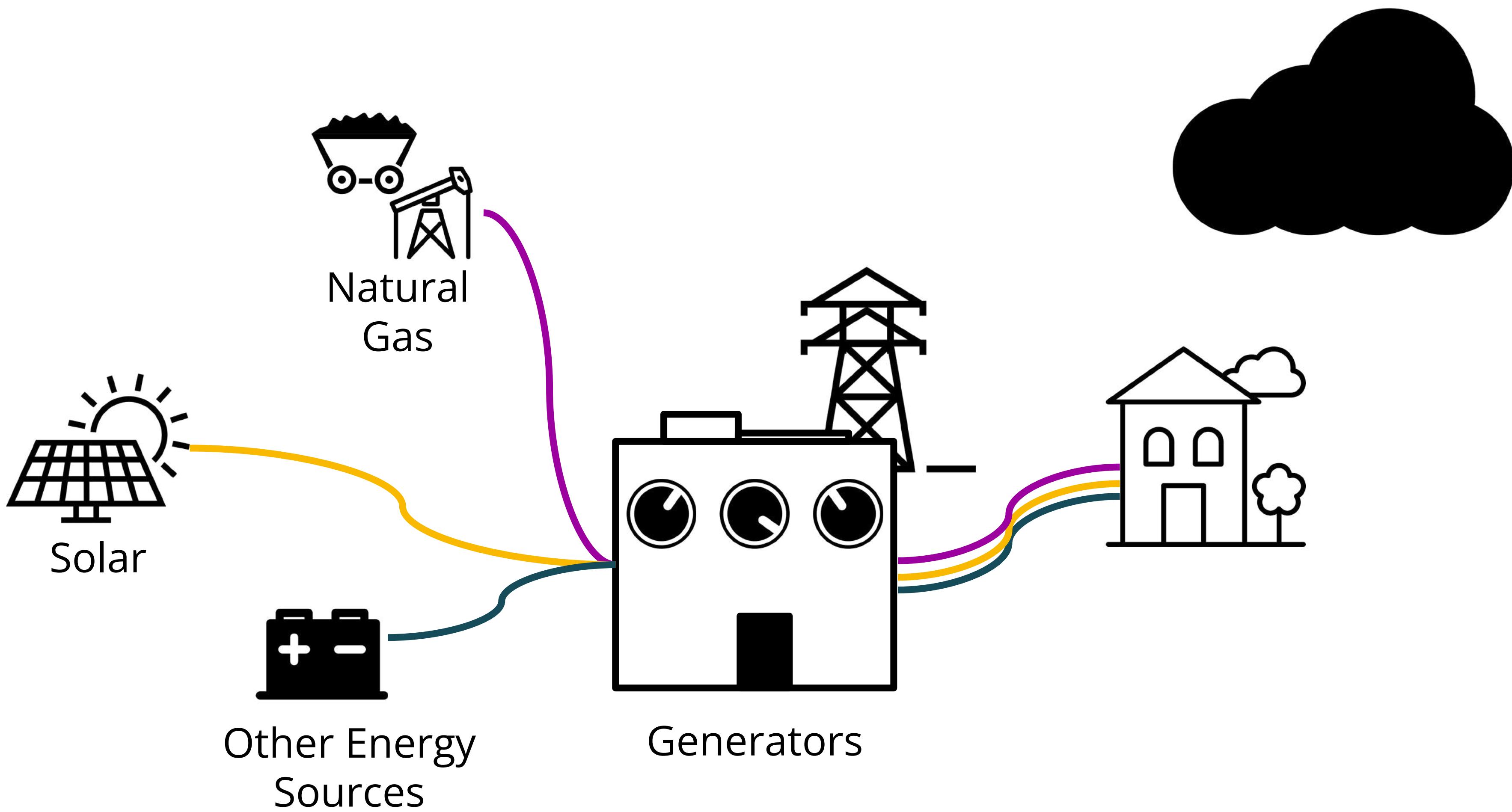
# Solar NOWCASTING

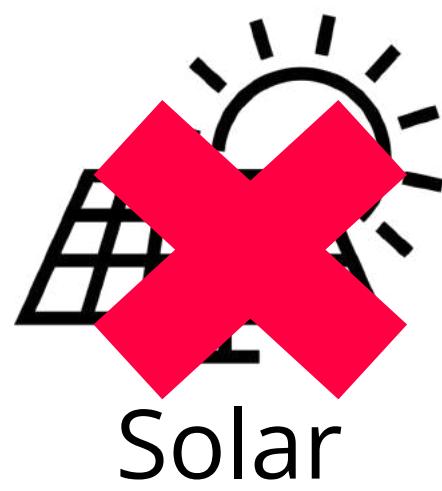


Forecasting  
solar electricity  
generation

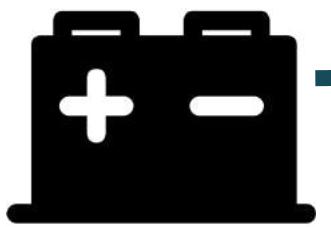


Dispatchable  
generation

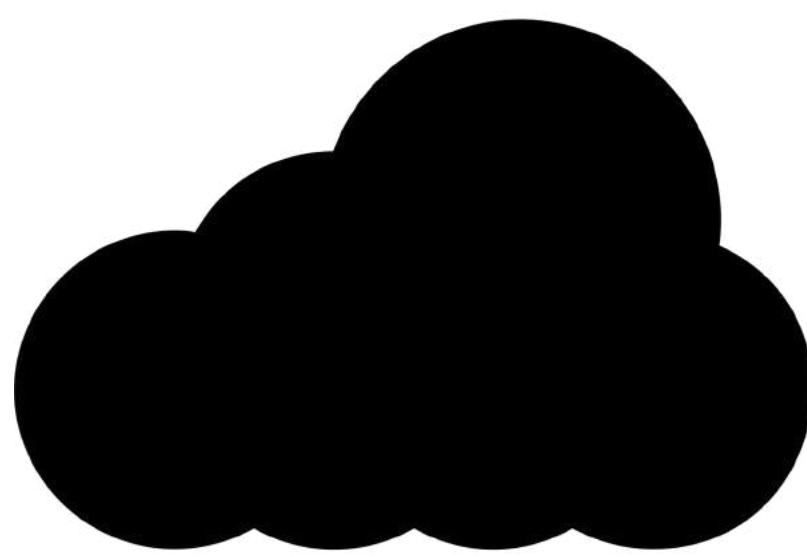
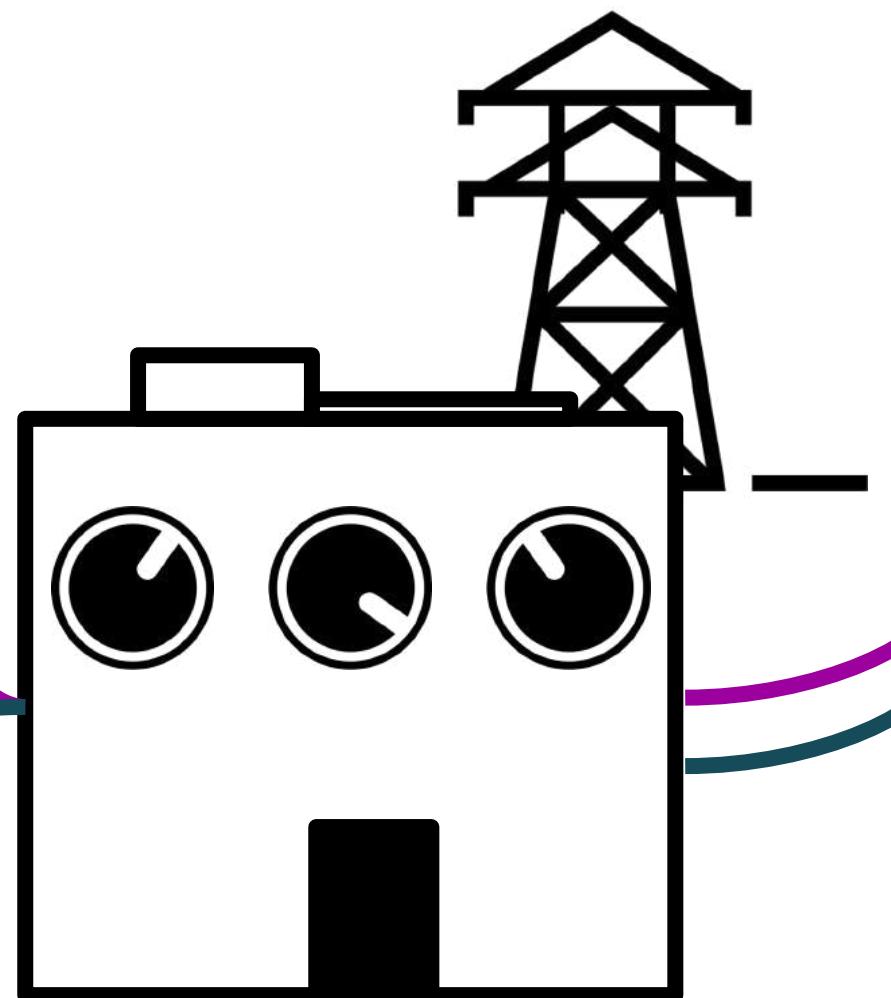


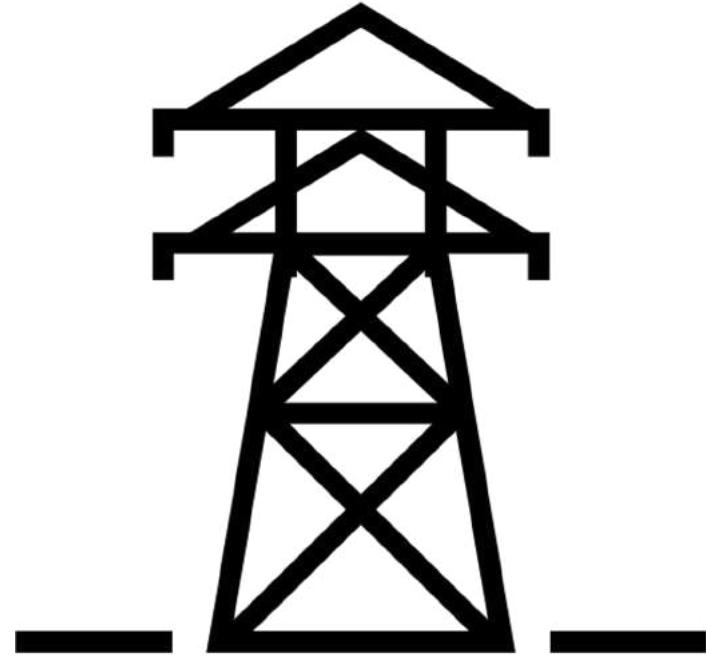


Natural Gas



Other Energy Sources





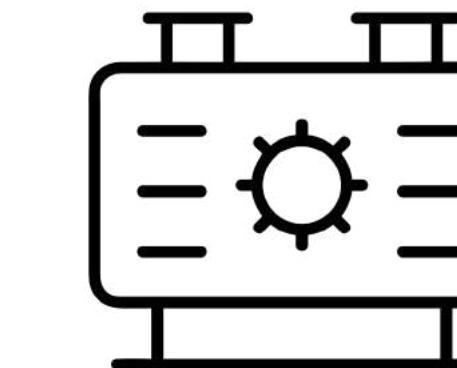
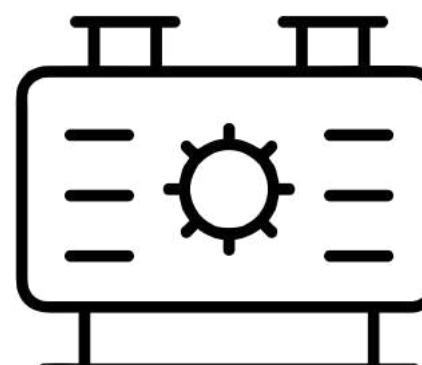
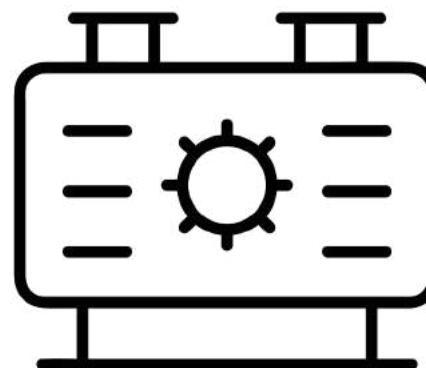
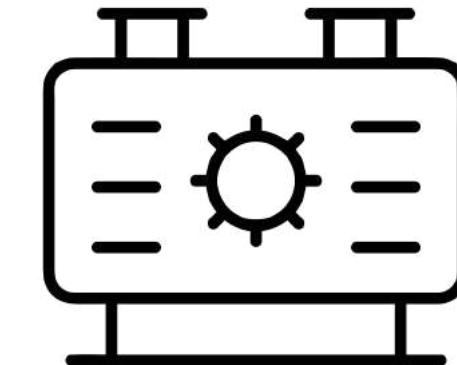
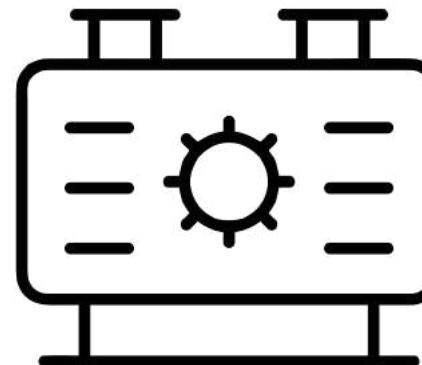
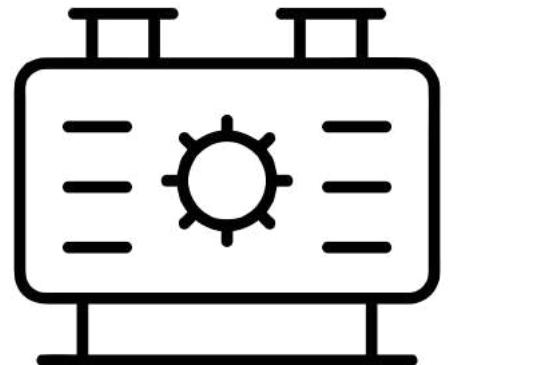
Supply



Demand

**Task:** Schedule generation so it follows demand

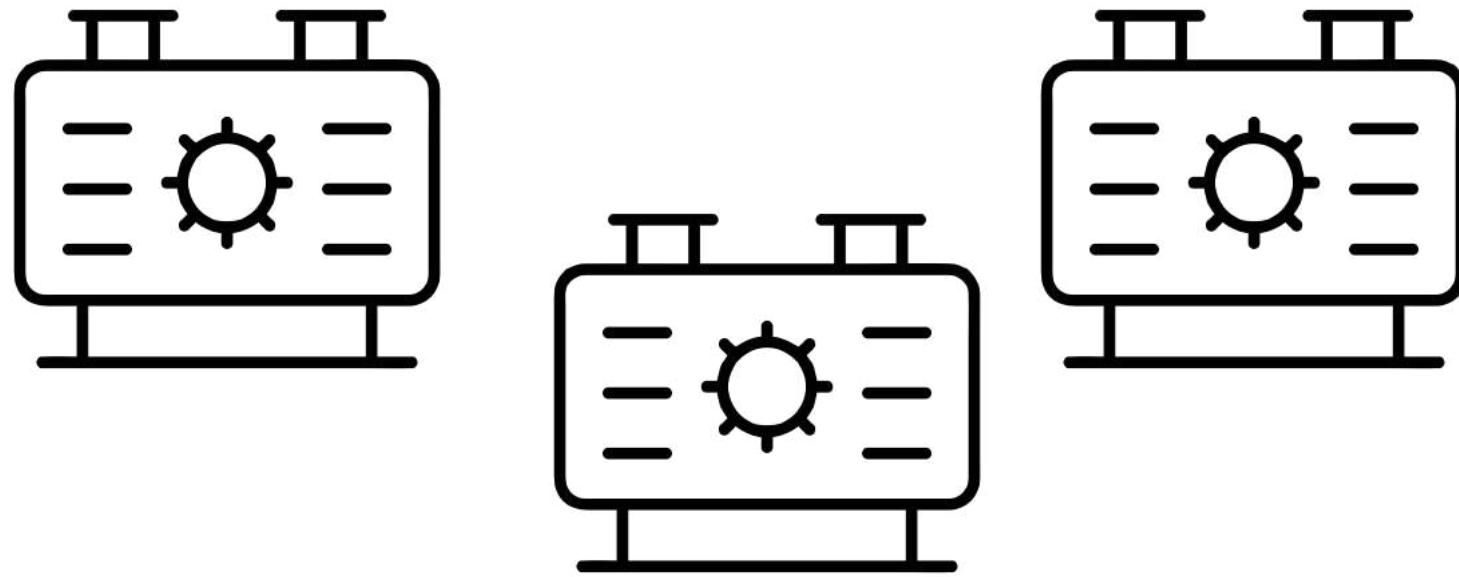
# Optimizing dispatchable generation



**Spinning Reserve**

- Generators running at ~50%
- Allows generators to easily match demand despite changes in supply
- Generators are not as fuel efficient at half capacity
- High cost and high carbon emissions

# Optimizing dispatchable generation



- Generators running **close to 100%**
- Generators are most fuel efficient
- Low cost and low carbon emission
- High risk if there are changes in supply.

## Optimizing Capacity

# Perceiver IO

Published as a conference paper at ICLR 2022

## PERCEIVER IO: A GENERAL ARCHITECTURE FOR STRUCTURED INPUTS & OUTPUTS

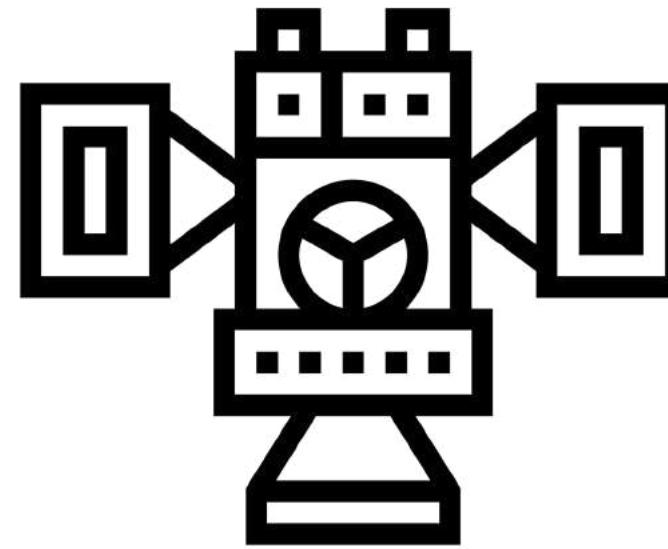
**Andrew Jaegle, Sebastian Borgeaud, Jean-Baptiste Alayrac, Carl Doersch, Catalin Ionescu,**

**David Ding, Skanda Koppula, Daniel Zoran, Andrew Brock, Evan Shelhamer, Olivier Hénaff,**

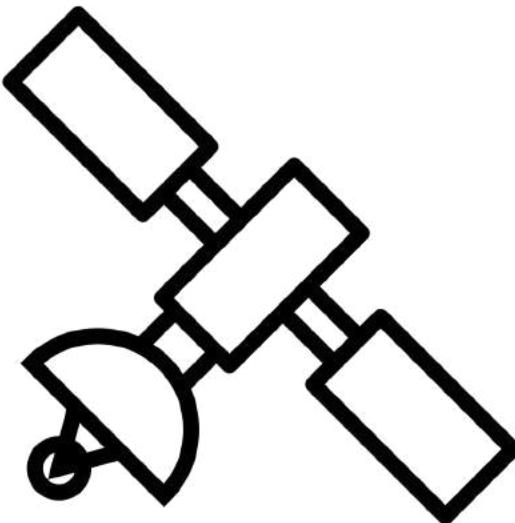
**Matthew M. Botvinick, Andrew Zisserman, Oriol Vinyals, João Carreira**

DeepMind

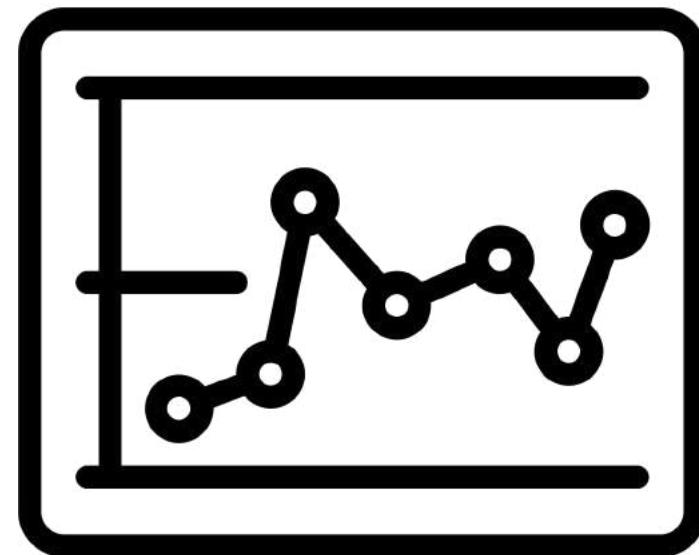
# Solar power forecasting



**Weather Stations**

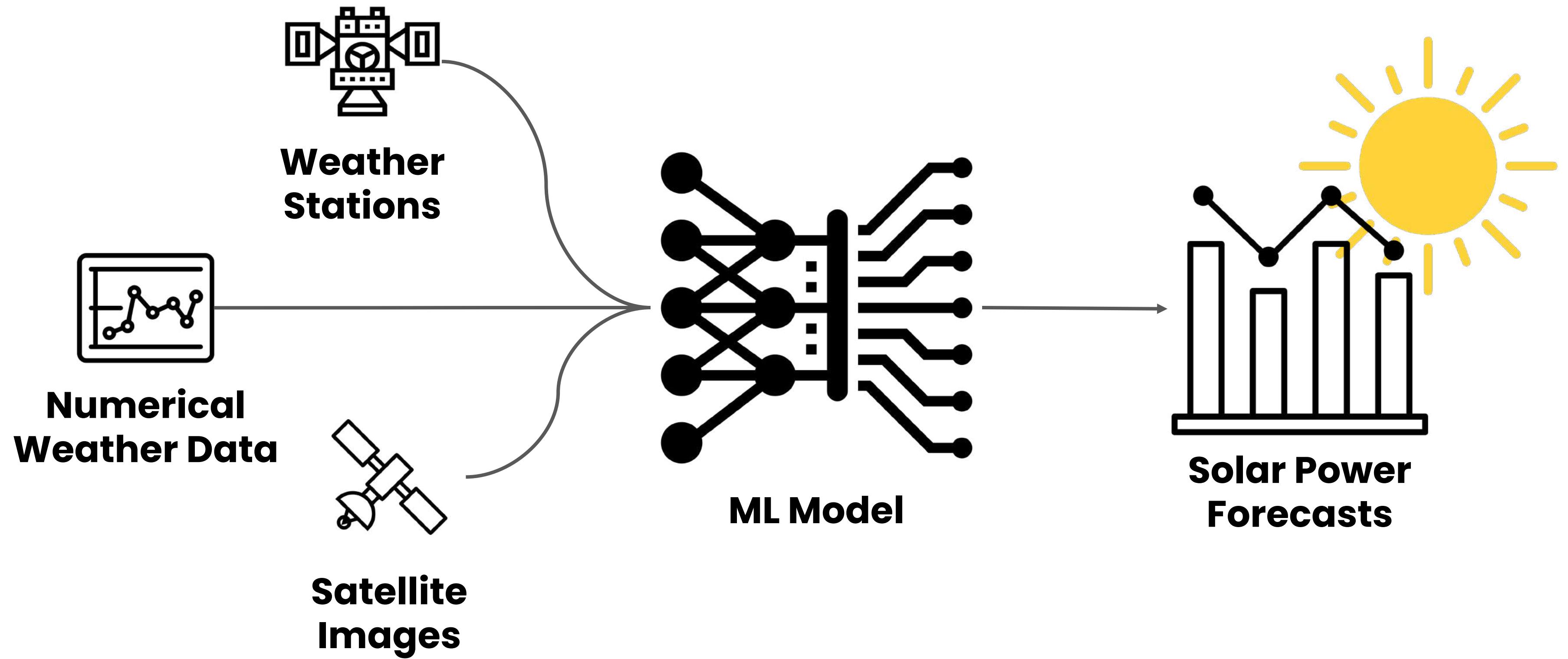


**Satellite Images**



**Numerical  
Weather Data**

# Solar power forecasting





Search or jump to...

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# Open Climate Fix

Using open science to mitigate climate change

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London

<http://openclimatefix.org>

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README.md

Open Climate Fix (OCF) is a non-profit product lab, totally focused on reducing greenhouse gas emissions as rapidly as possible. Every part of the organisation is designed to maximise climate impact, such as our open and collaborative approach, our rapid prototyping, and our attention on finding scalable & practical solutions.

## How to get involved?

At OCF we are passionate that all the knowledge we produce remains open, to break down intellectual property barriers and subsequently reduce the "time to impact". We therefore encourage external users to use our base code.

There are a number of ways for you to get involved:

- Submit pull requests. Right now we are laser-focused on [our solar electricity forecasting project](#):
  - List of "good first issues": GitHub "issues" which describe changes we'd like to make to the code
  - OCF's coding style
  - The main tools we use include: PyTorch, PyTorch Lighting, xarray, pandas, pvlib
- Sign up to [our newsletter](#) and follow us on [Twitter](#) and [LinkedIn](#) to learn the latest about our work
- Spread the word with your networks
- Use our code(!) by following the guidelines below.



What if you use our code?

## People



## Sponsors



## Top languages

Python Jupyter Notebook  
JavaScript TypeScript HTML

## Most used topics

nowcasting pytorch deep-learning  
python machine-learning

[Report abuse](#)

# AI and Climate Change

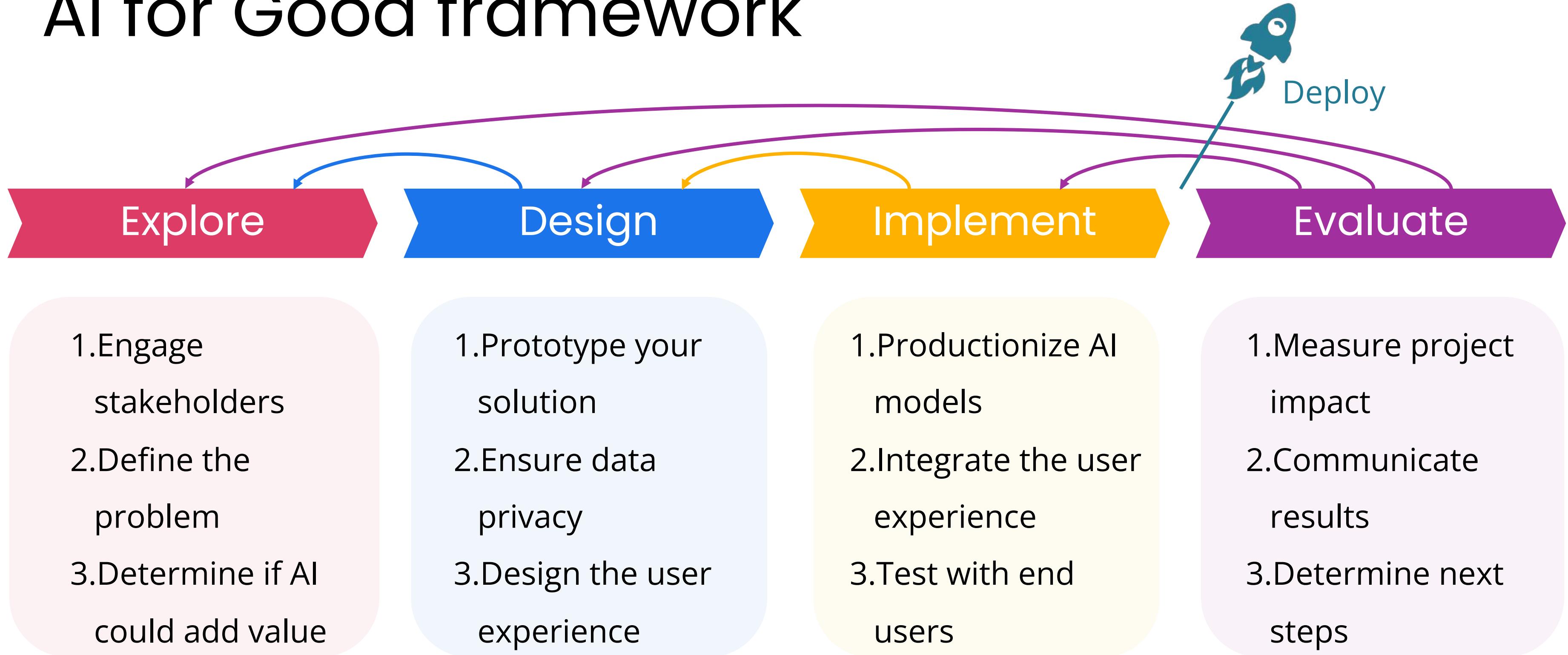
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**AI for Good  
Framework**

# AI for Good framework



# AI and Climate Change

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DeepLearning.AI

**Wind Power -  
Explore Phase**

# Wind power forecasting

Wind power provides around **10%** of total electricity in the U.S.\*

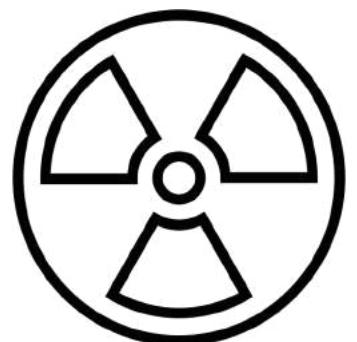
**Reliable forecasts** of wind power make it a more viable replacement for fossil fuels



\*U.S. Energy Information Administration. EIA. eia.gov

# Electrical grid

**Non-renewable**

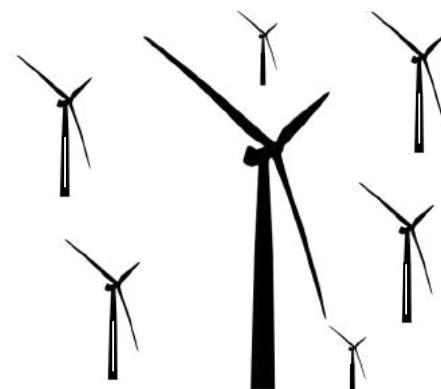


Nuclear

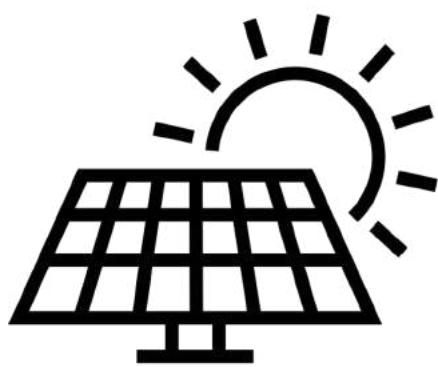


Fossil fuels

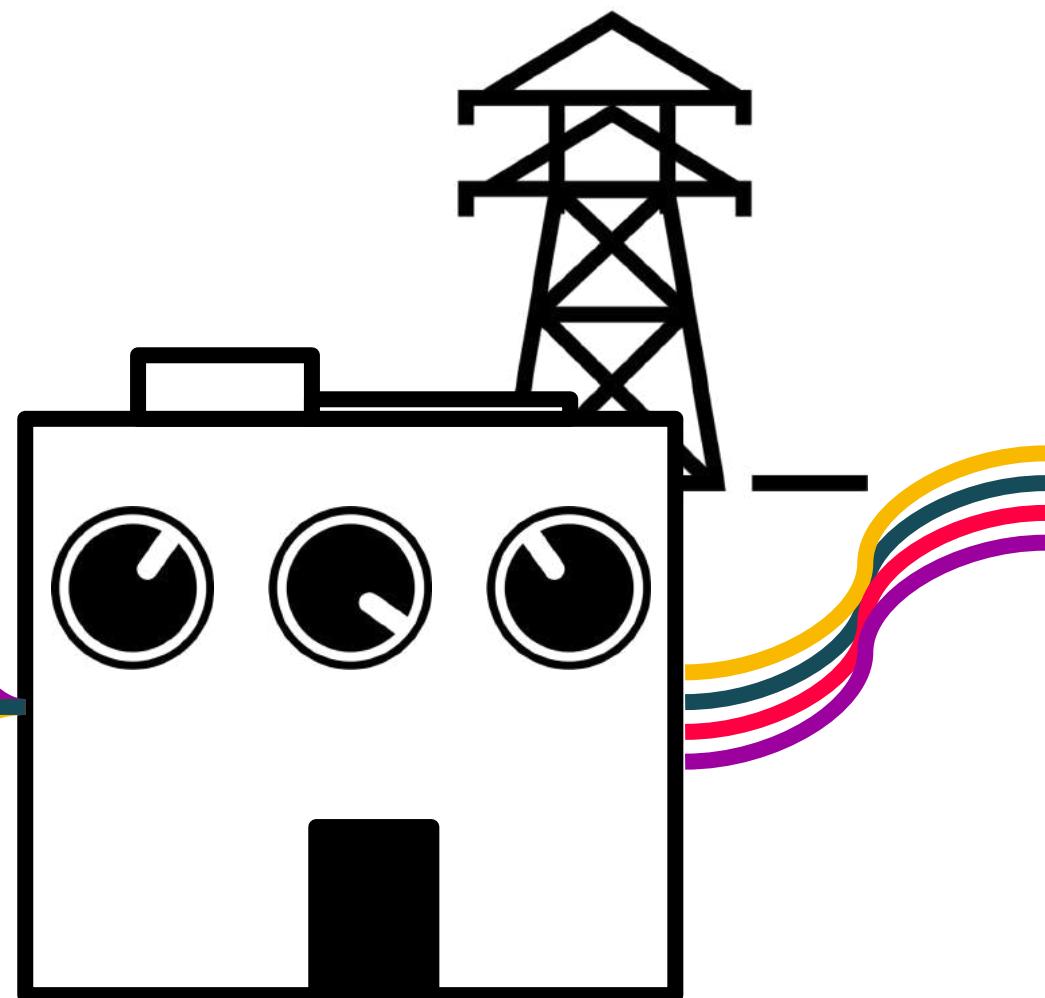
**Renewable**



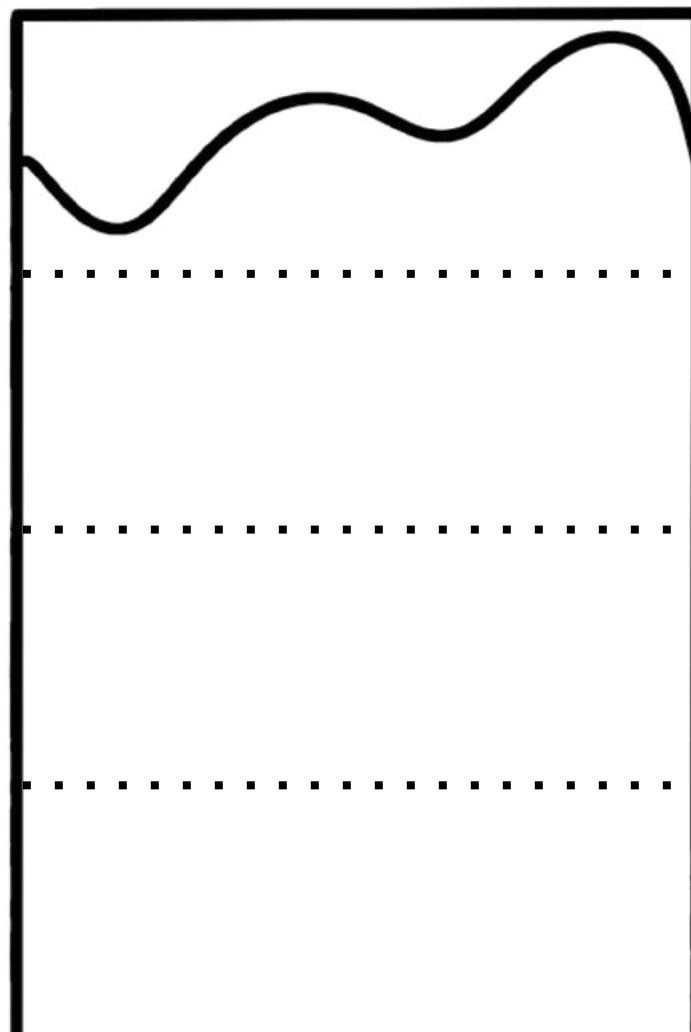
Wind



Solar



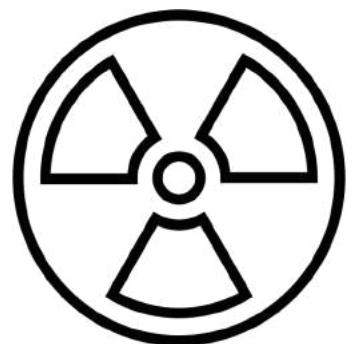
Power consumption



Time of day

# Electrical grid

**Non-renewable**

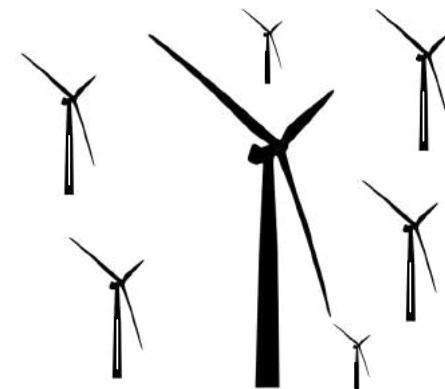


Nuclear

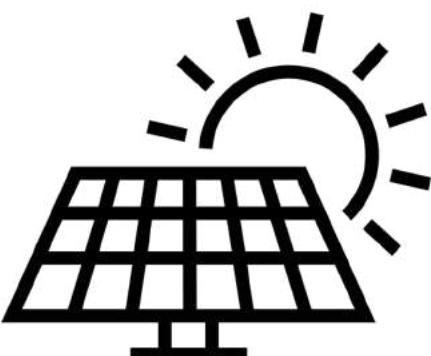


Fossil fuels

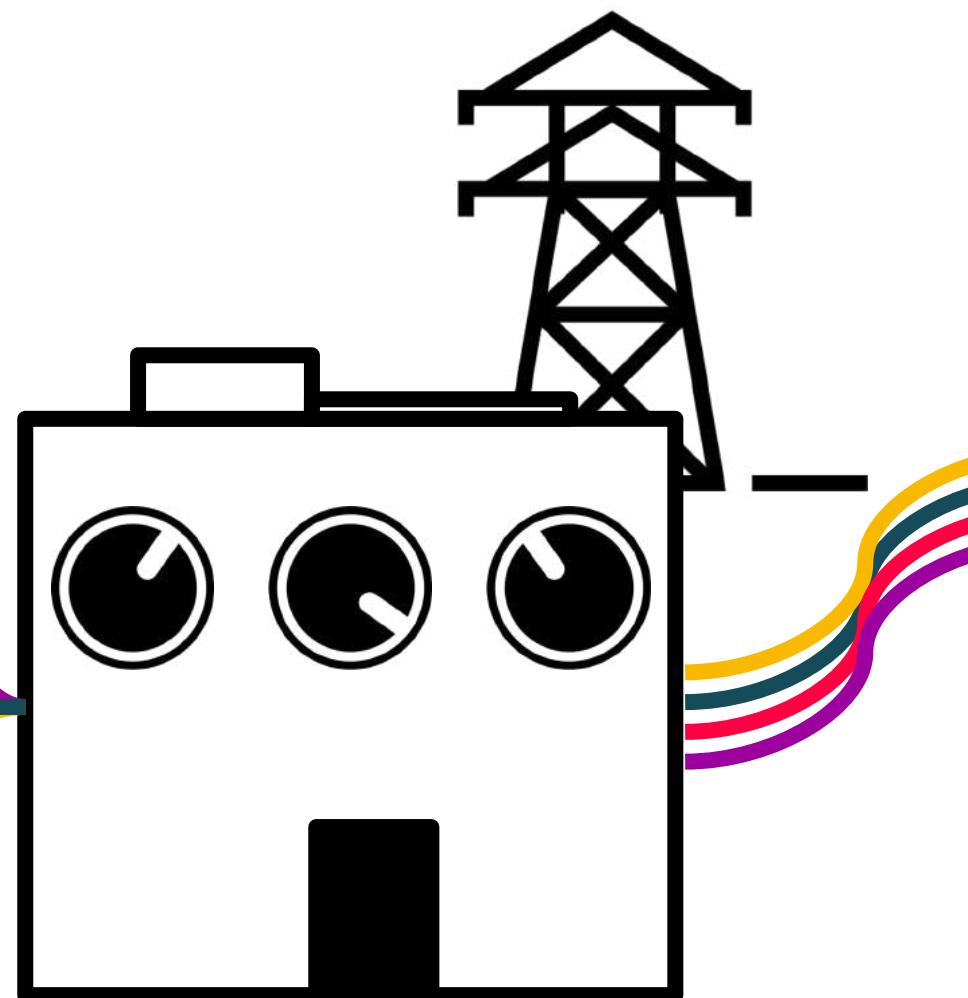
**Renewable**



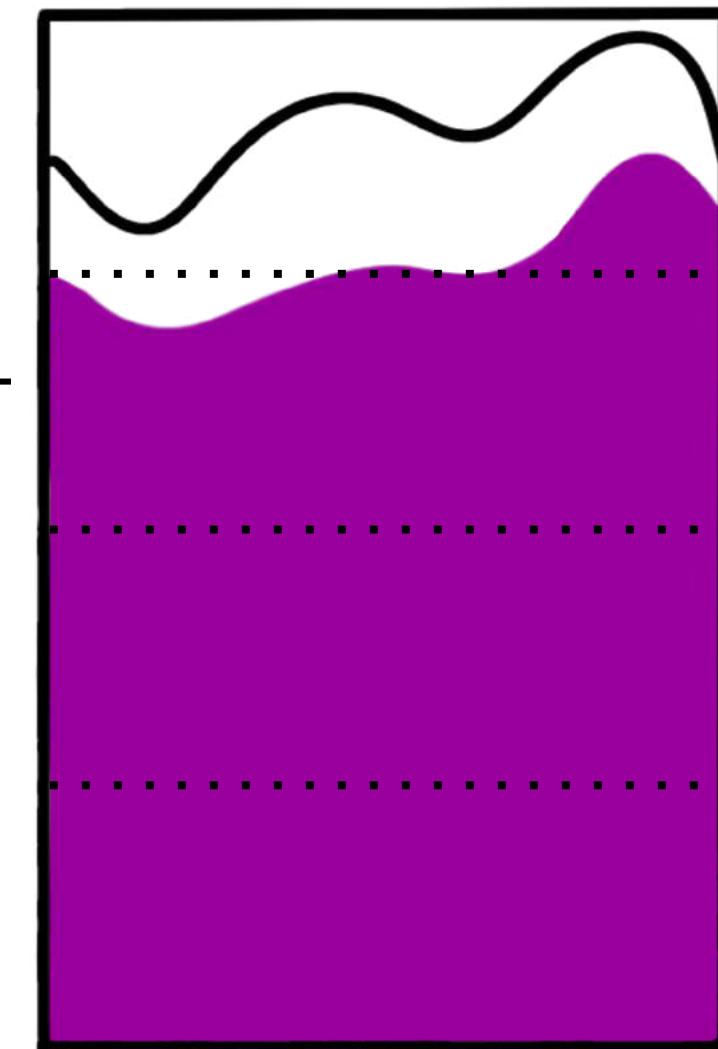
Wind



Solar



Power consumption

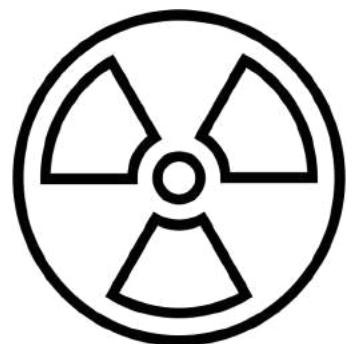


Fossil  
fuels

Time of day

# Electrical grid

**Non-renewable**

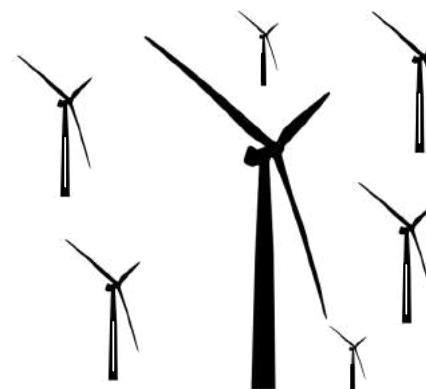


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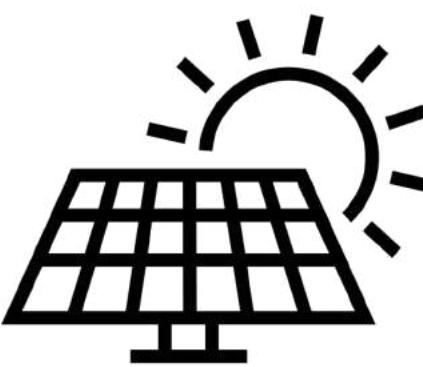


Fossil fuels

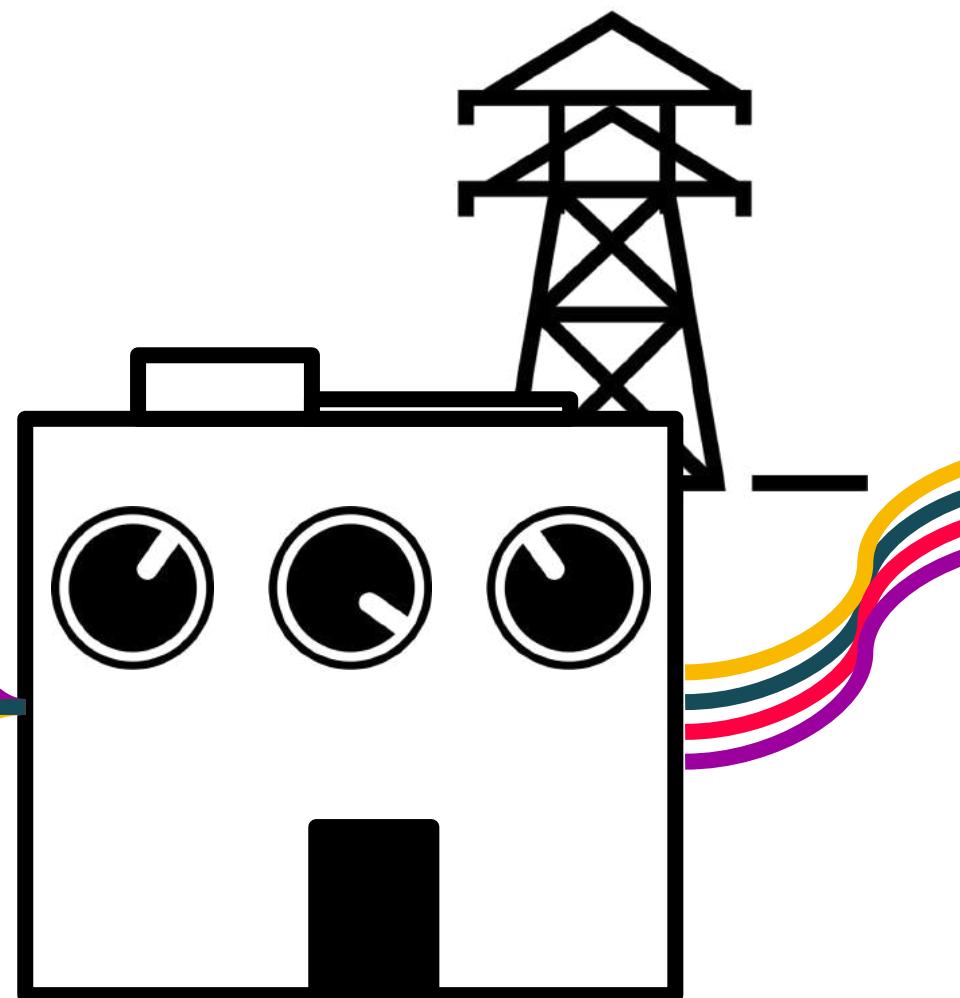
**Renewable**



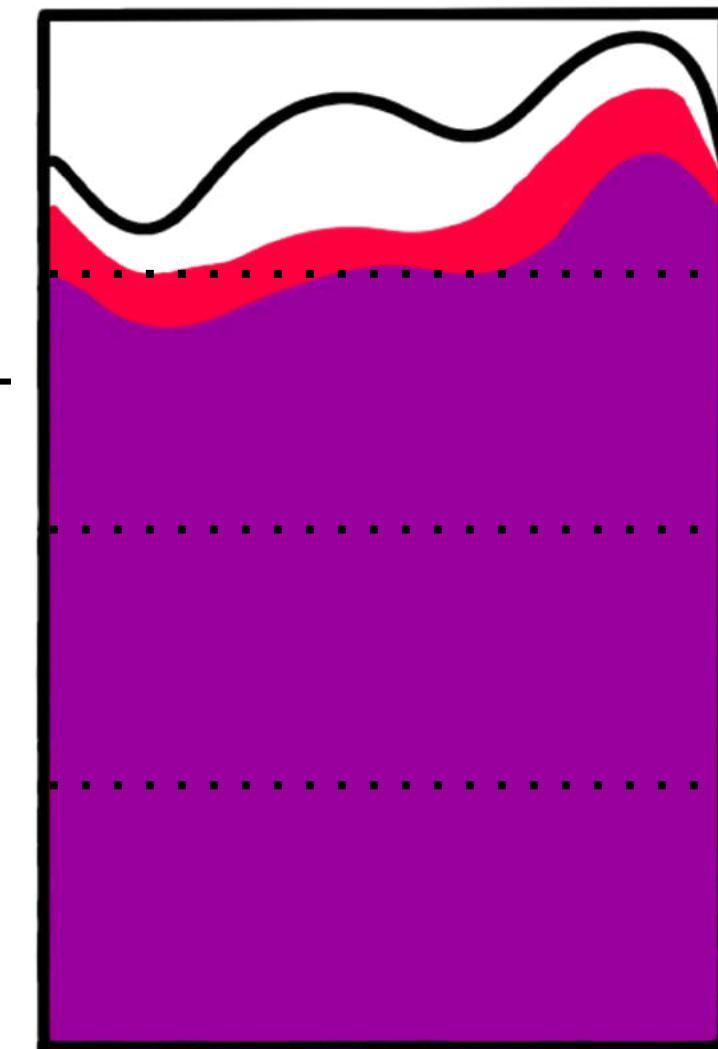
Wind



Solar



Power consumption



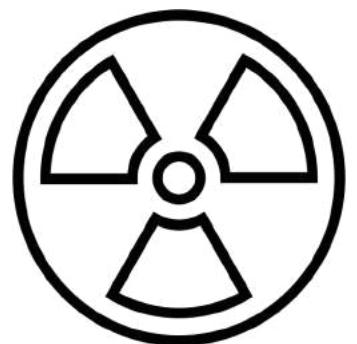
Time of day

Nuclear

Fossil  
fuels

# Electrical grid

**Non-renewable**

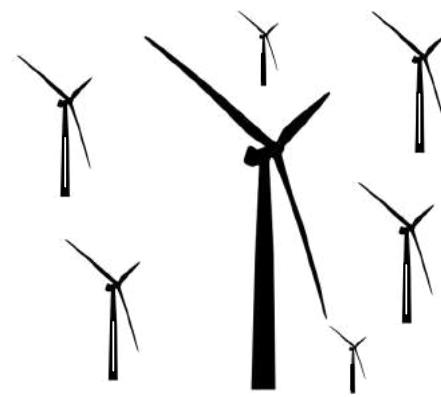


Nuclear

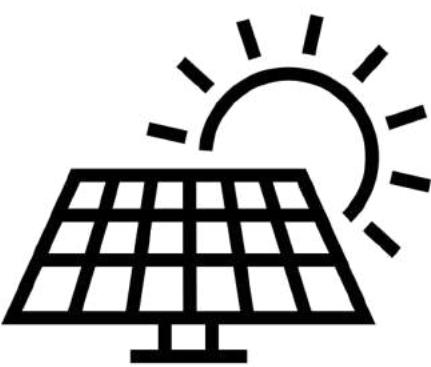


Fossil fuels

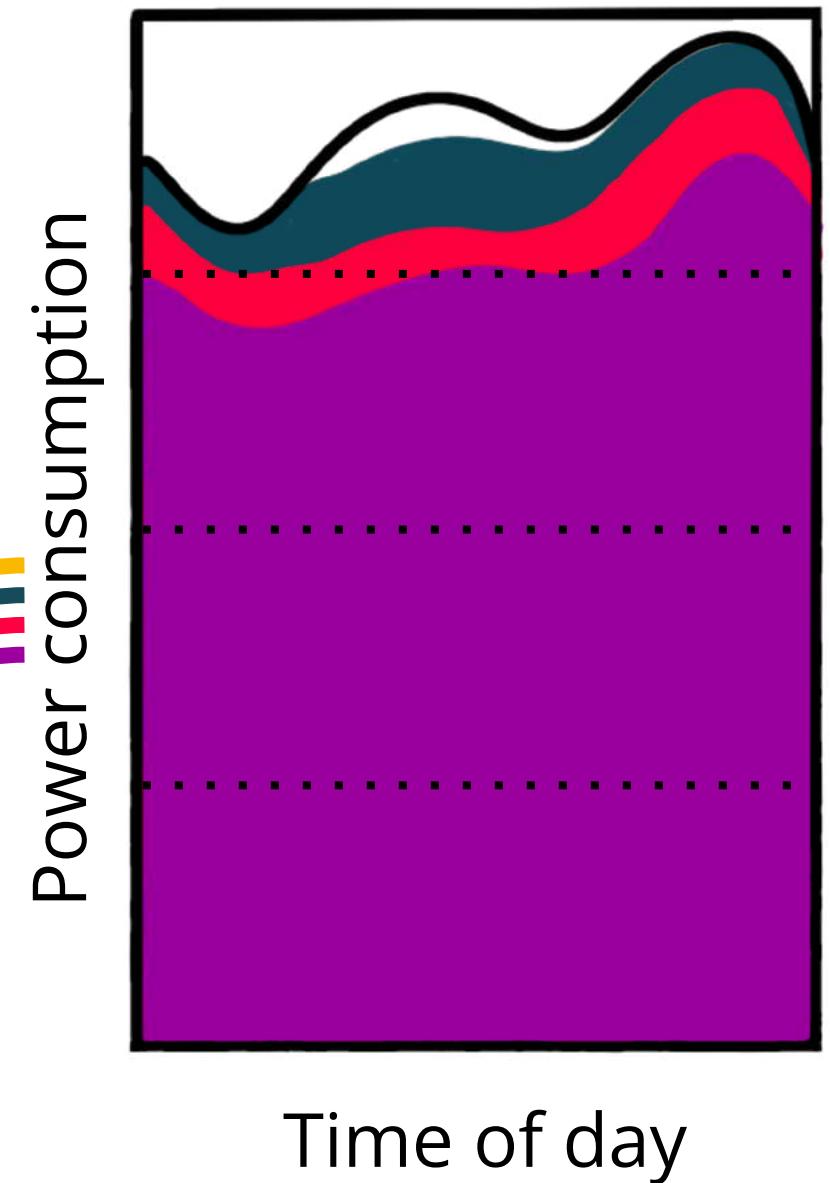
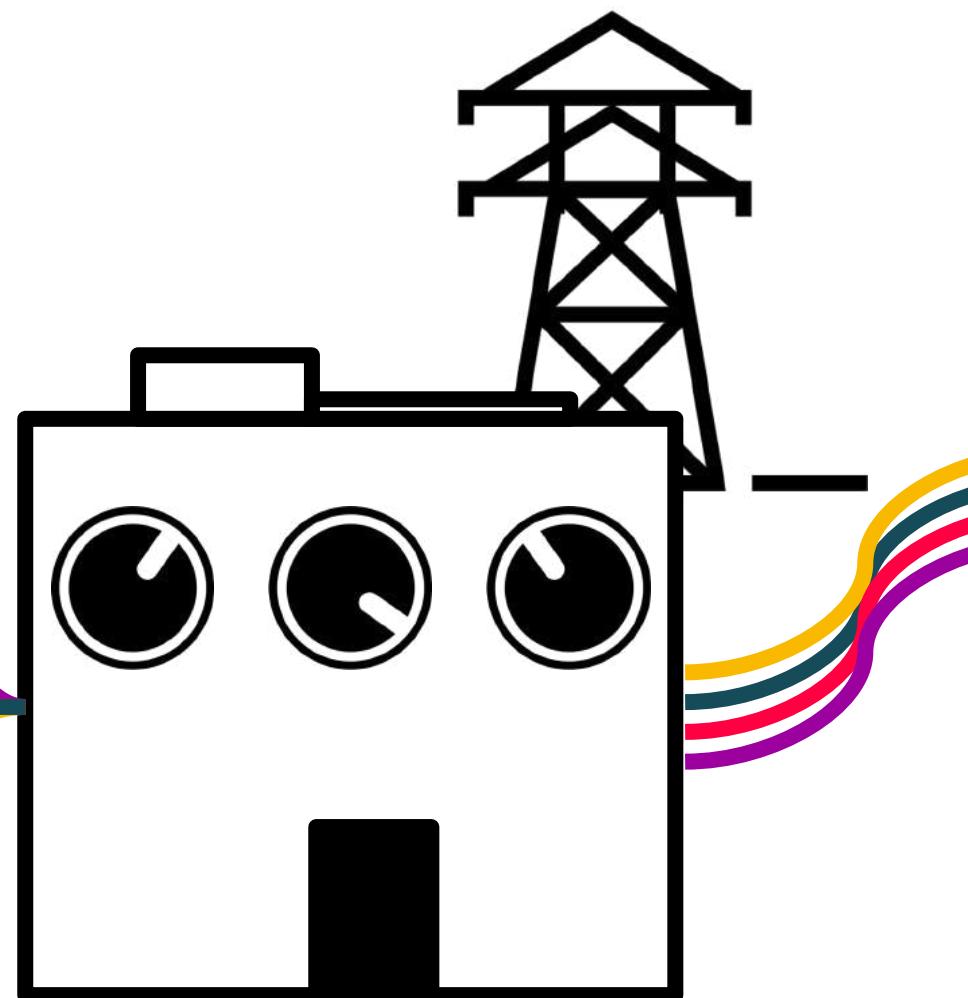
**Renewable**



Wind



Solar



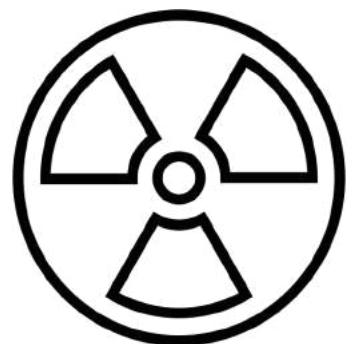
Wind  
Nuclear

Fossil  
fuels

Time of day

# Electrical grid

**Non-renewable**

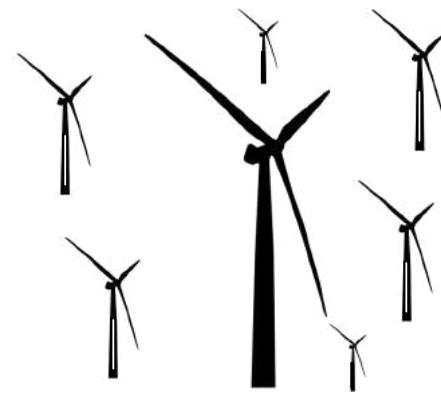


Nuclear

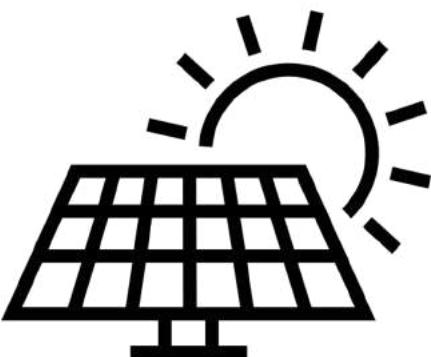


Fossil fuels

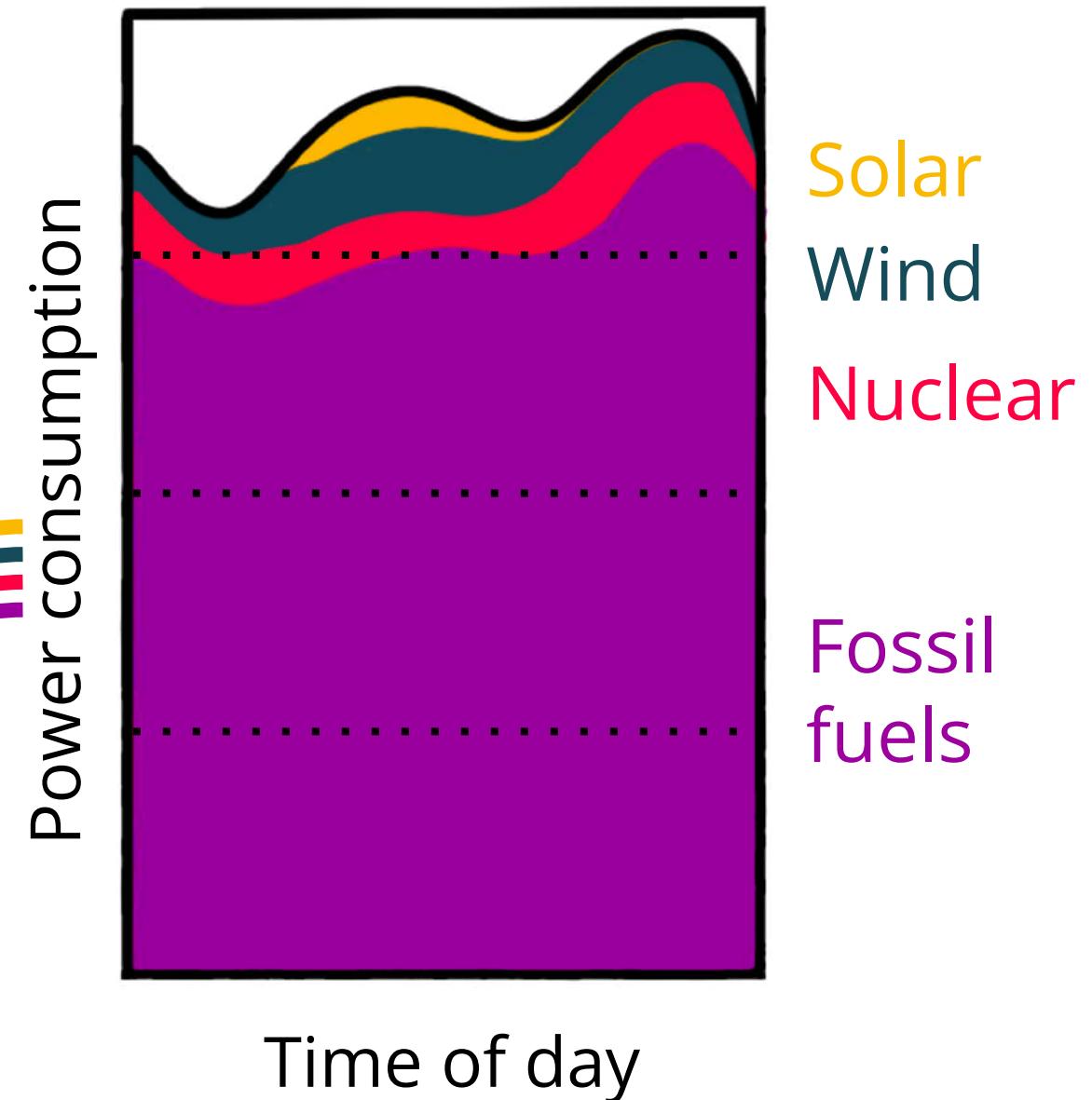
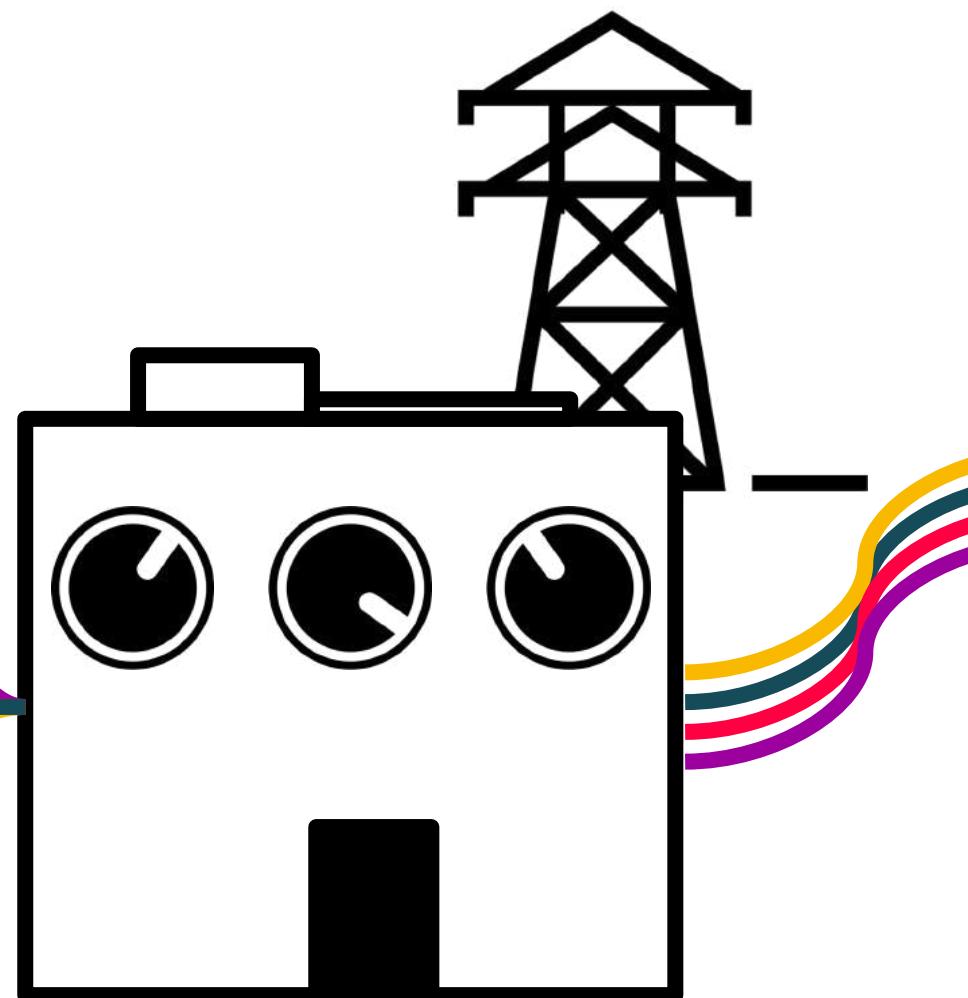
**Renewable**



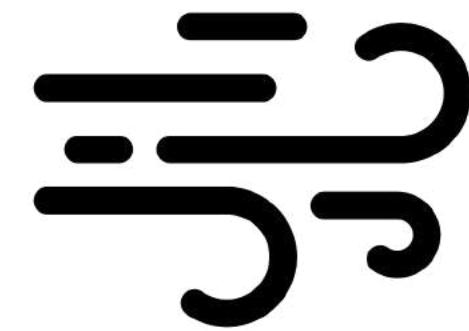
Wind



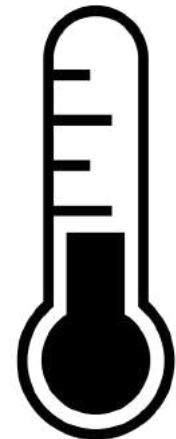
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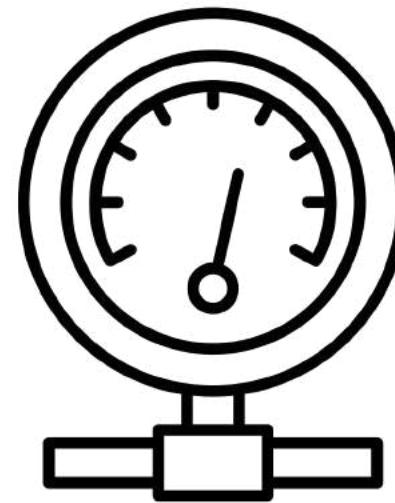
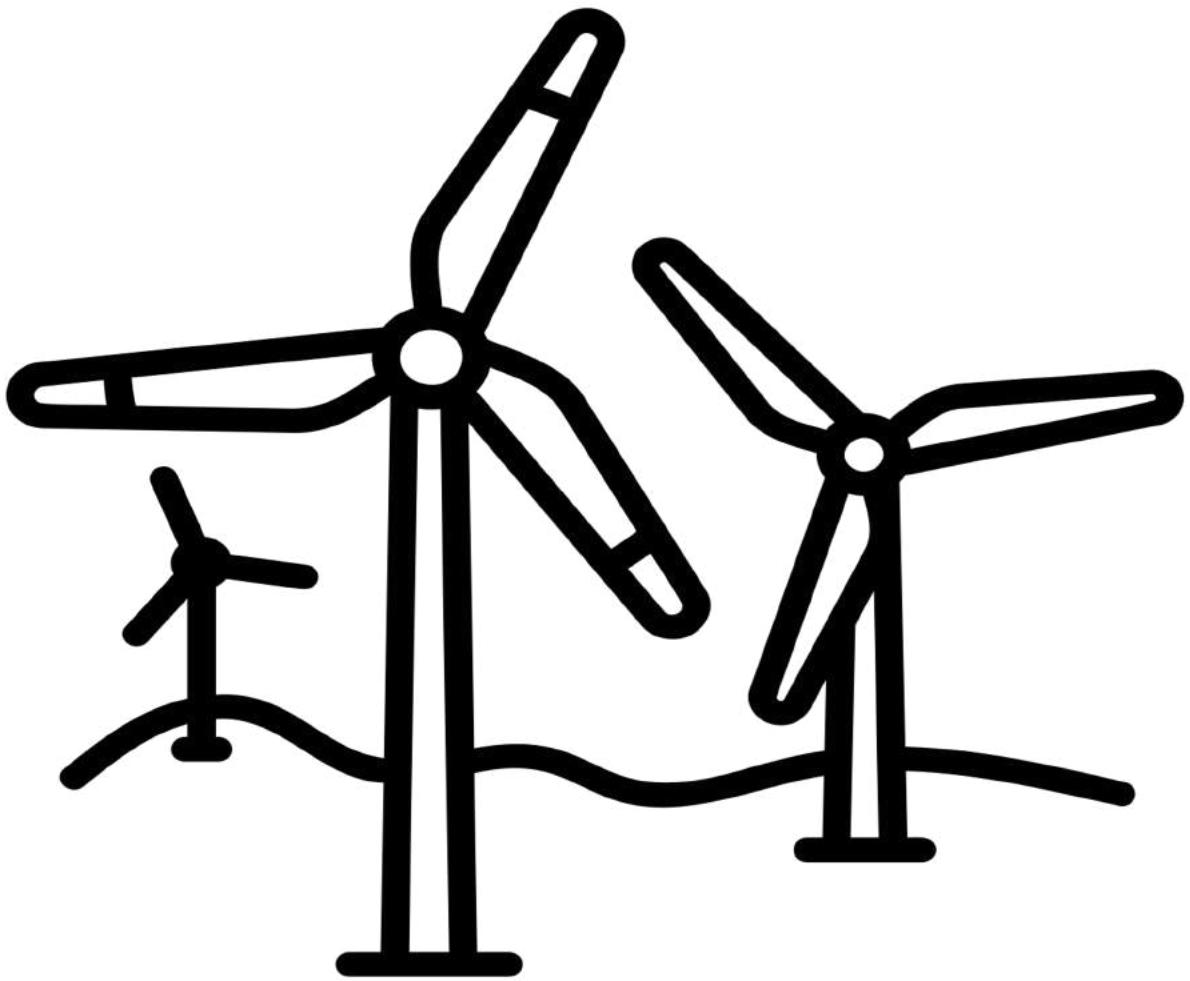
# Factors contributing to wind power



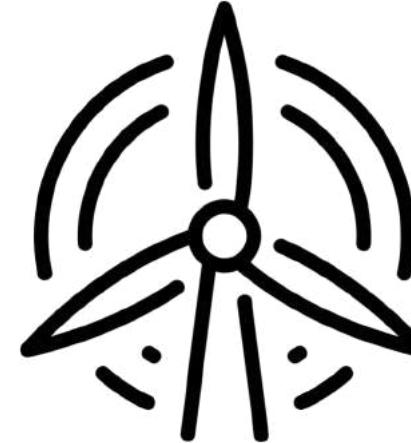
Wind



Temperature

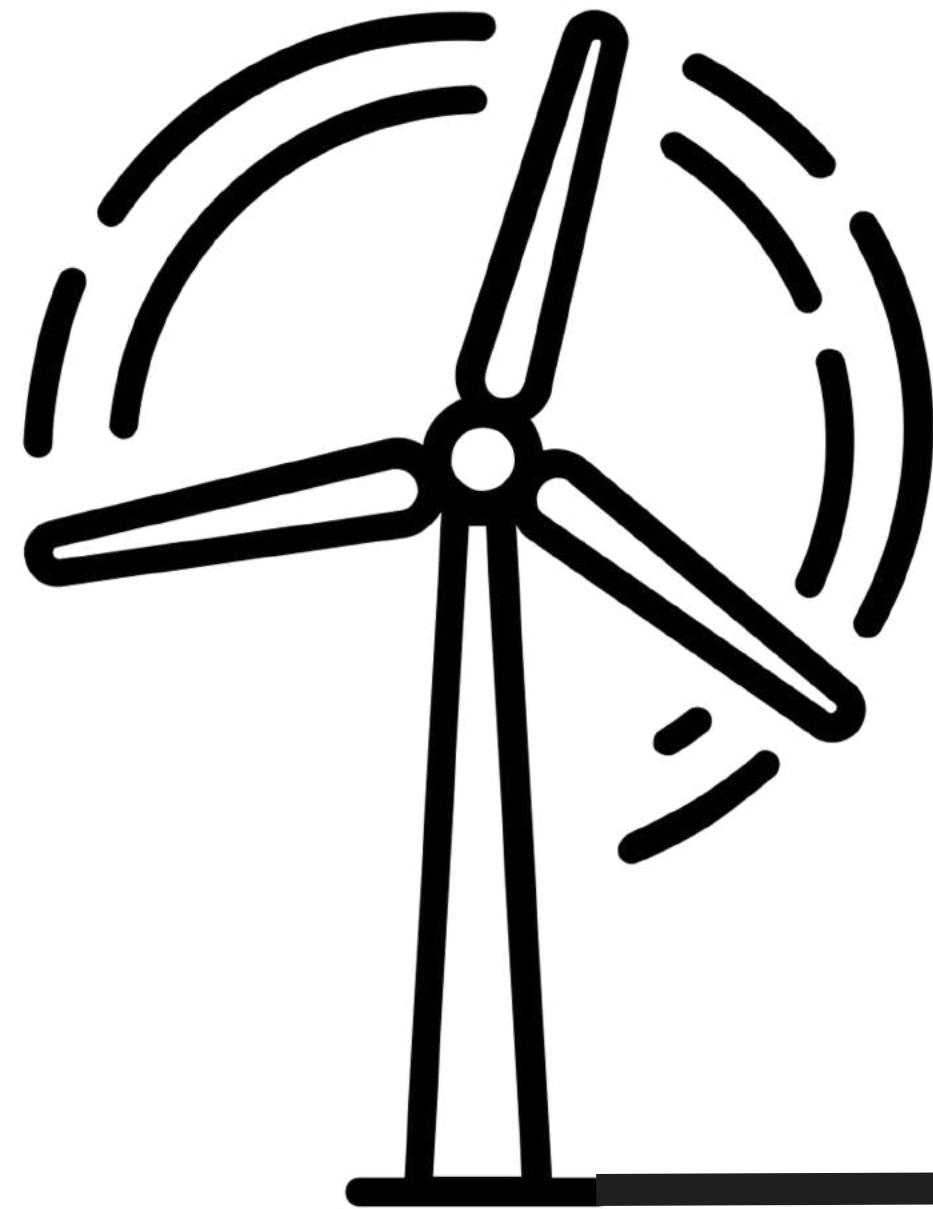


Pressure

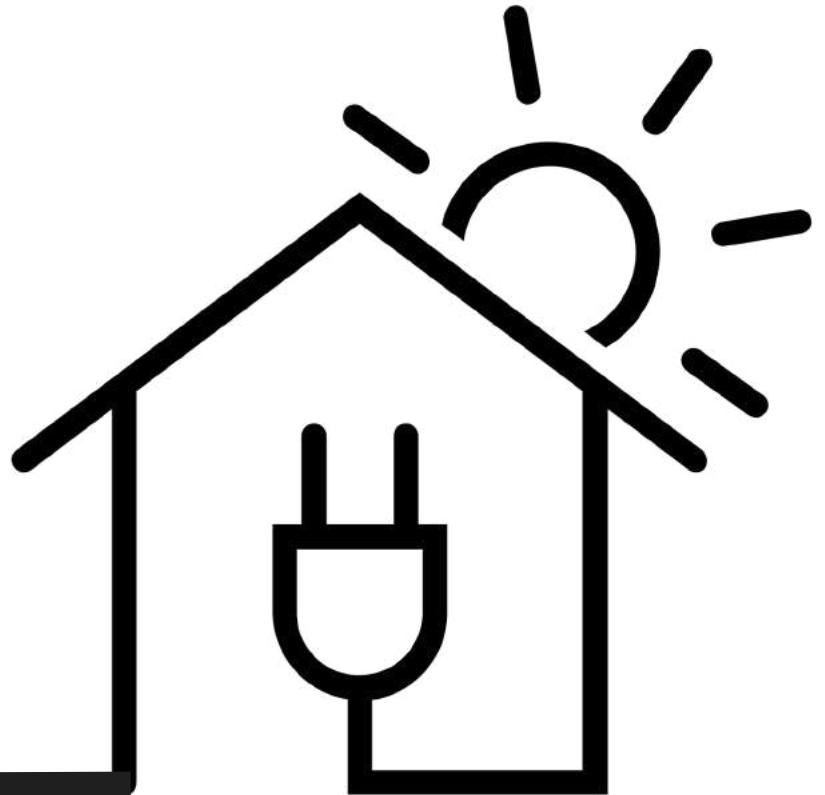


Turbine  
Configuration

# Wind power reliability



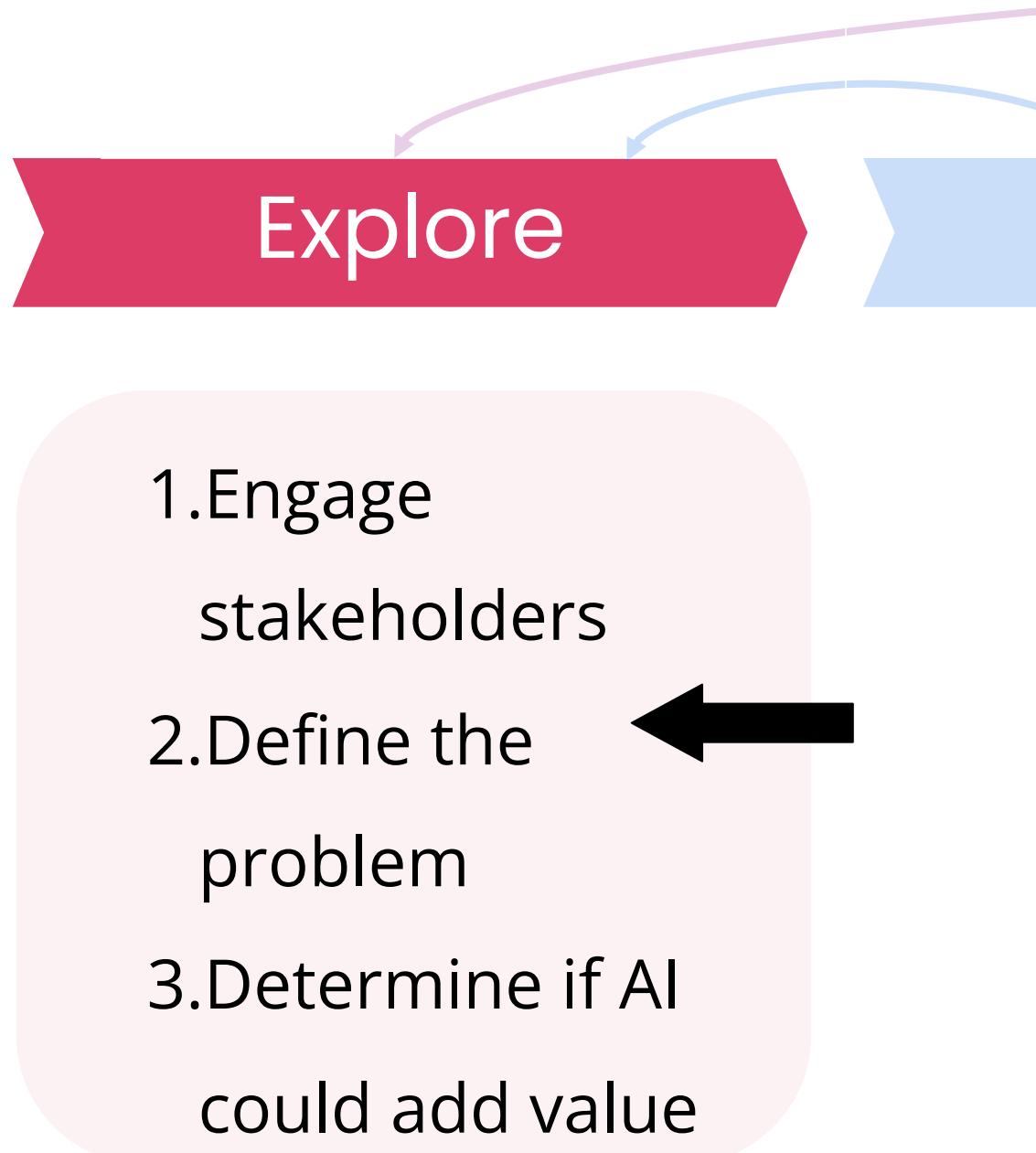
Wind power output  
forecast ~24 hours in  
advance



# Explore phase



# AI for Good framework



## A good problem statement should:

1. Be clear, concise, and specific.
2. Define the problem you are hoping to address
3. Identify key stakeholders.
4. Not mention the specific technology you aim to deploy
5. Give an idea of what success looks like.

# AI for Good framework



1.Engage  
stakeholders

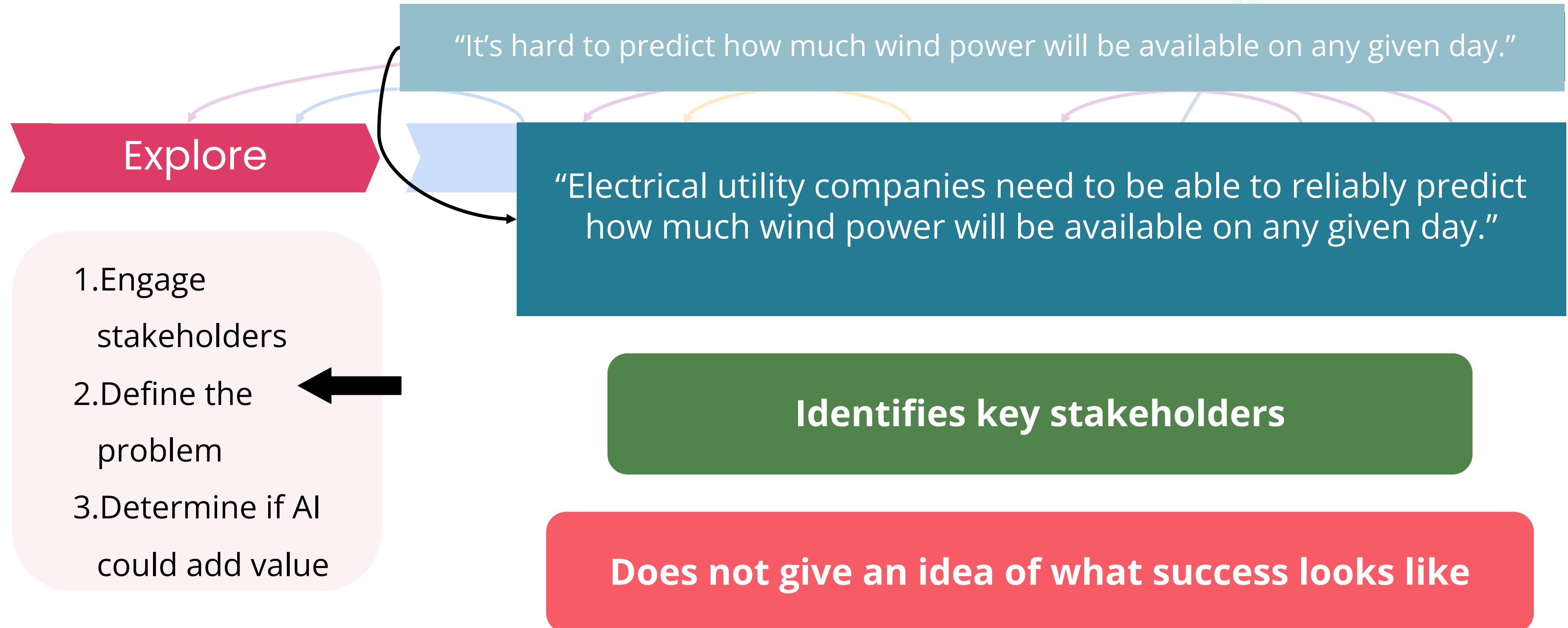
2.Define the  
problem

3.Determine if AI  
could add value

**Does not identify key stakeholders**



# AI for Good framework



# AI for Good framework



## Explore

1. Engage stakeholders
2. Define the problem
3. Determine if AI could add value

"It's hard to predict how much wind power will be available on any given day."

"Electrical utility companies need to be able to reliably predict how much wind power will be available on any given day."

"Electrical utility companies **need reliable predictions of wind power output** at least 24 hours in advance in order to better plan the requirements for other power input sources into the electrical grid."

# AI for Good framework



## Explore

1. Engage stakeholders

2. Define the problem

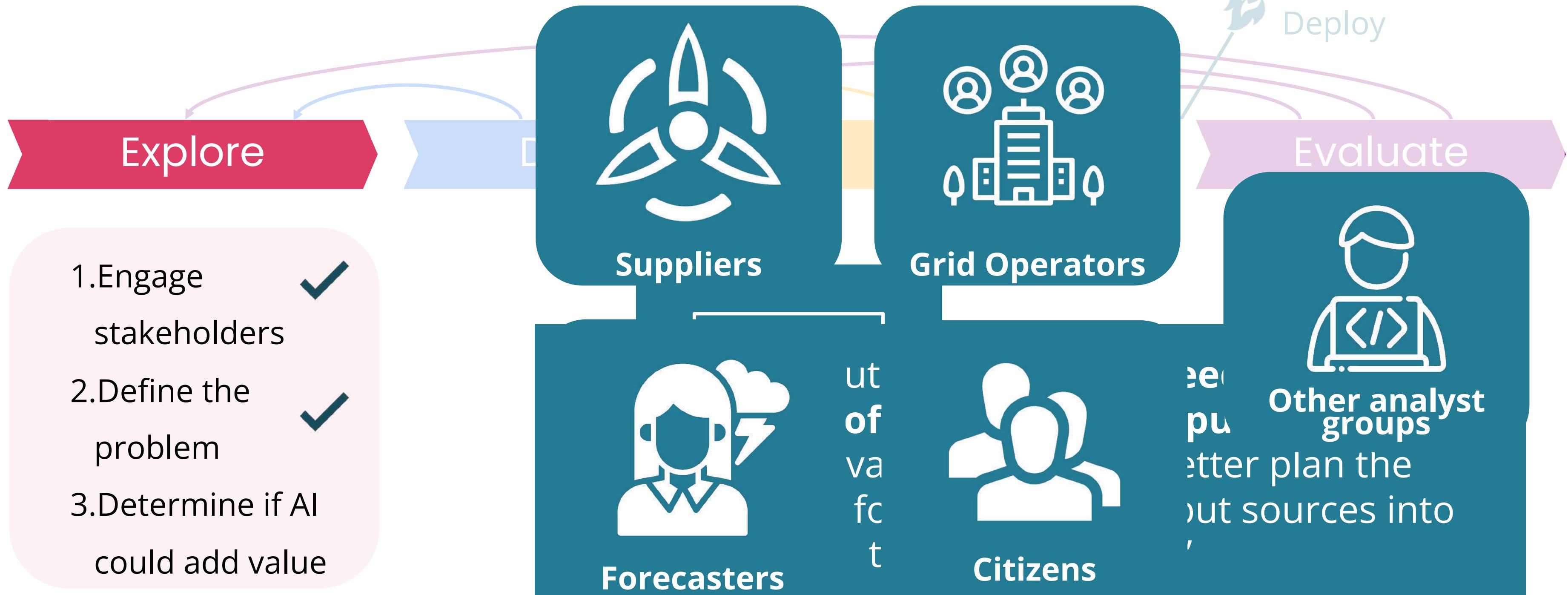
3. Determine if AI could add value

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“Electrical utility companies **need reliable predictions of wind power output** at least 24 hours in advance in order to better plan the requirements for other power input sources into the electrical grid.”

# AI for Good framework



# AI and Climate Change

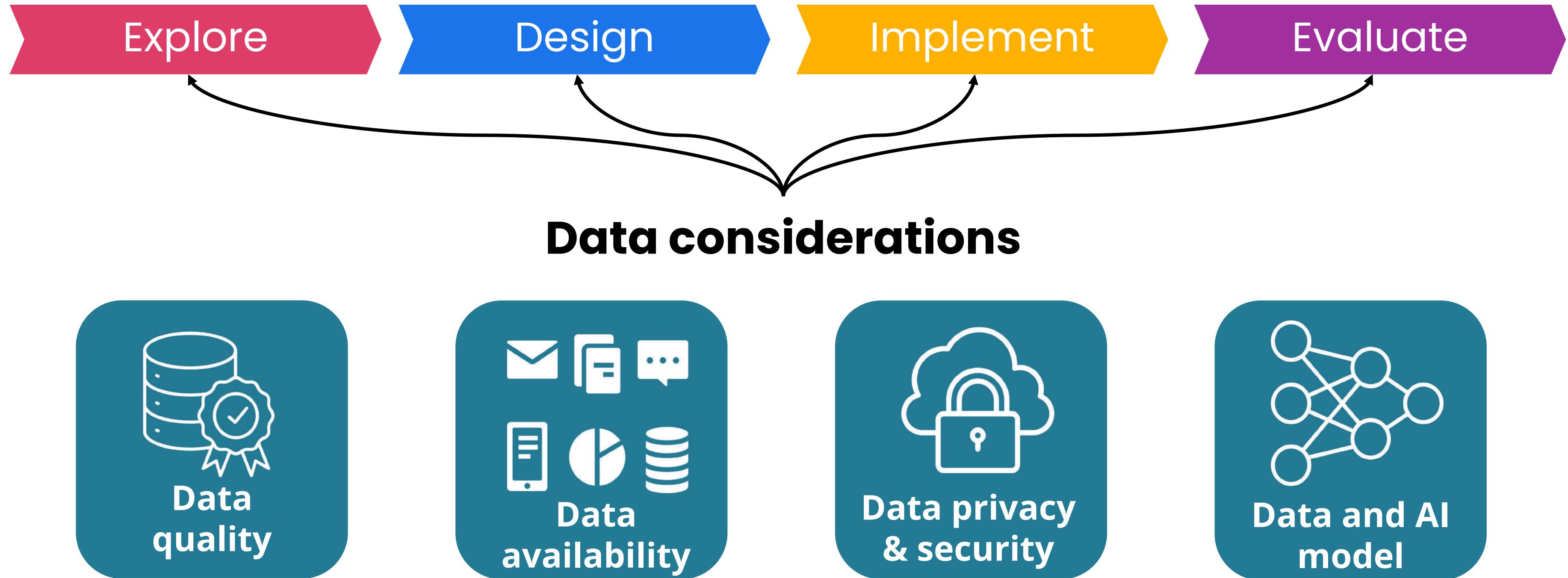
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**Wind Power**  
**Explore the Data**

# AI for Good framework



# **Potential wind speed datasets**

**may include:**

- Historical wind speed data
- Actual/Live wind speed data
- Meteorological (Weather) Data
- Turbine control system sensor measurements
- Active power production

## **Competition datasets includes:**

- Historical wind speed data
- Actual/Live wind speed data
- Meteorological (Weather) Data
- Turbine control system sensor measurements
- Active power production

# AI and Climate Change

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**Wind Power**  
**Visualize the Data**

# AI and Climate Change

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**Project Spotlight: Climate  
Modeling and Prediction -  
Lester Mackey**



# Judah Cohen

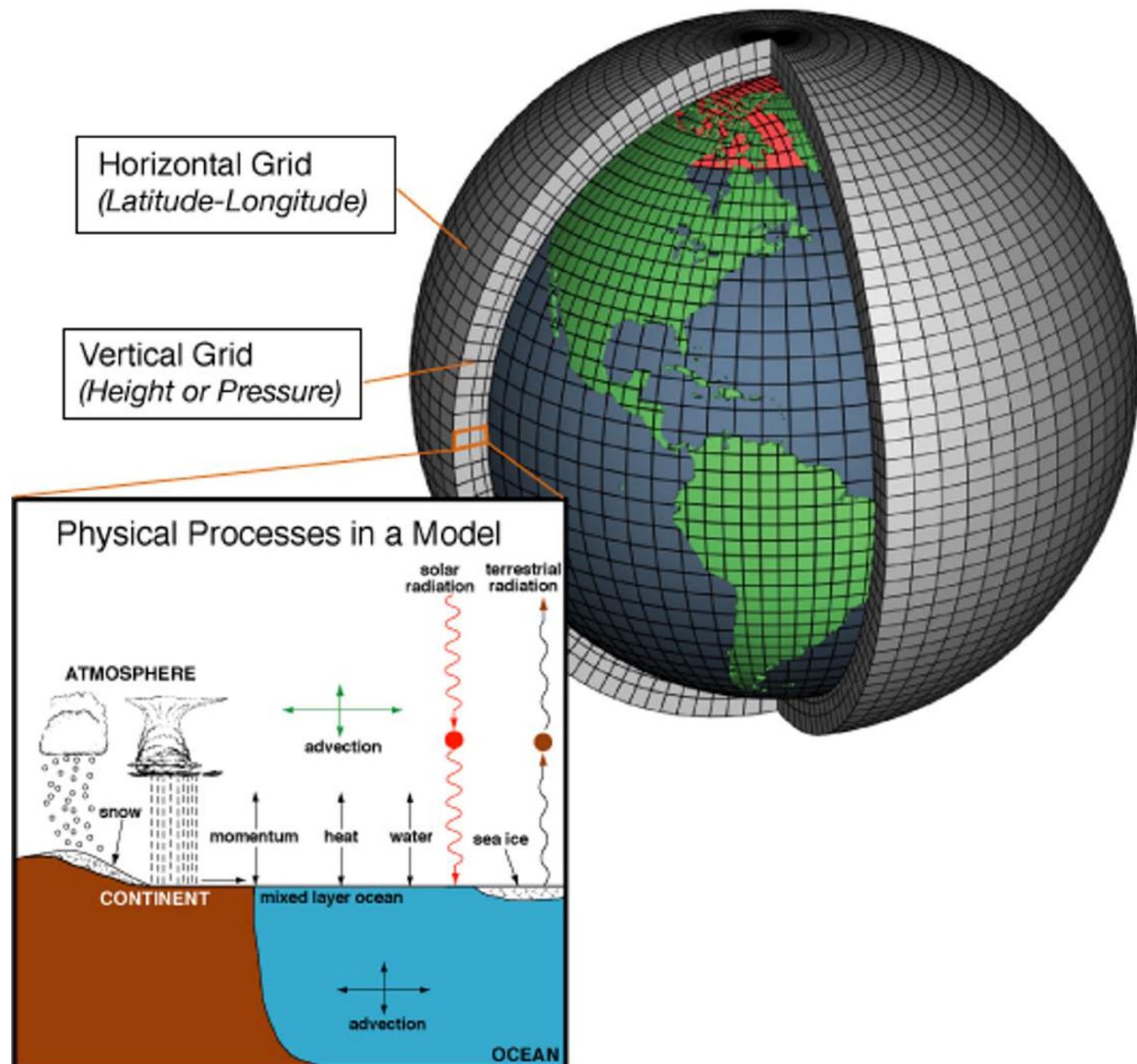
- Climatologist
- Director of seasonal forecasting at Atmospheric and Environmental Research



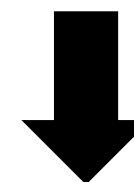
## Concerns:

- Community not making the best use of historical data in weather / climate forecasting

# Dynamic models



- Estimate current weather conditions
- Simulate future weather / climate
- Accuracy limited by **chaotic** nature



Ensembling

Debiasing

"The First Climate Model - A Model Based on Ocean and Atmosphere Interactions." NOAA



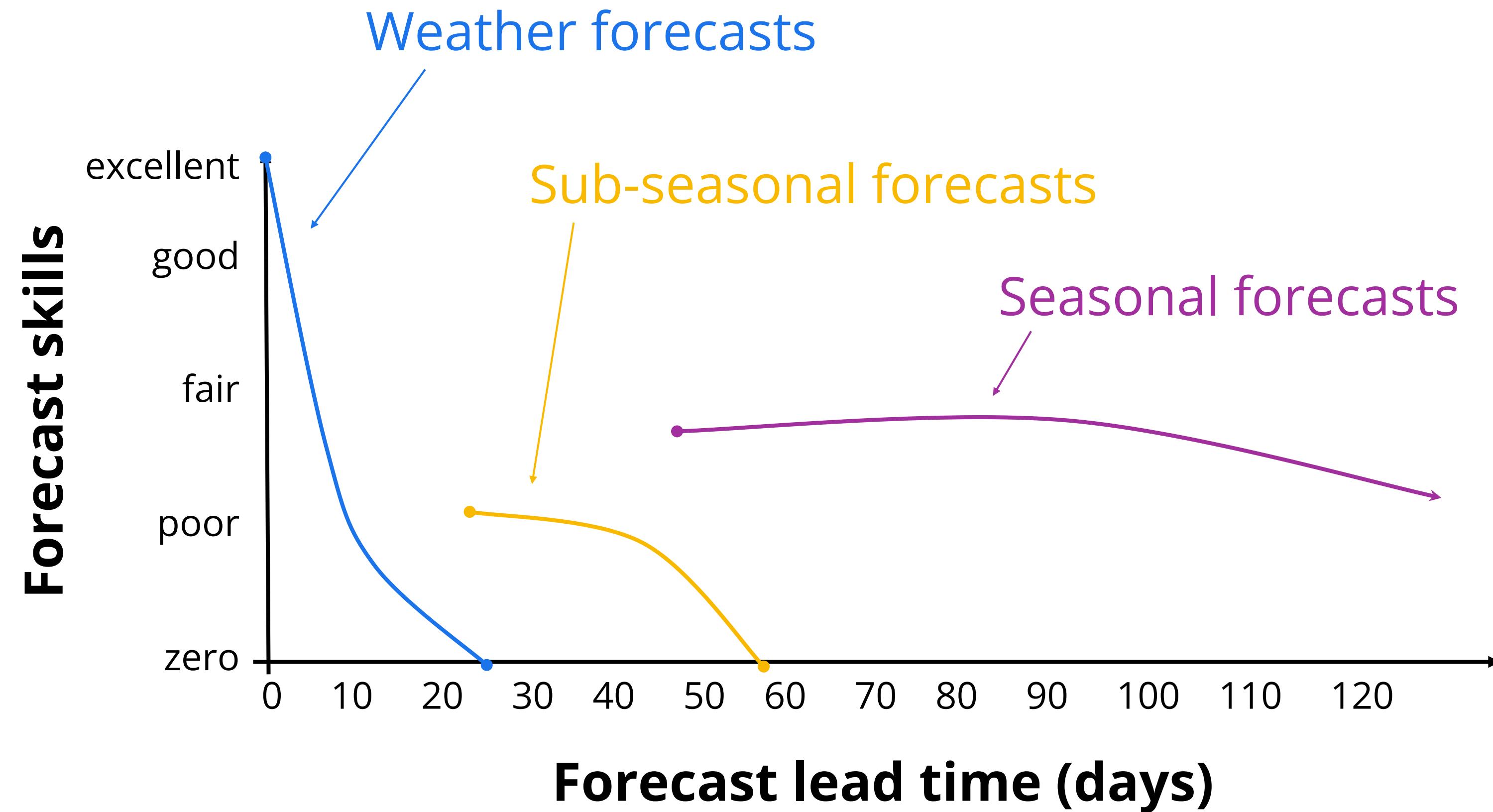
## Concerns:

- Community not making the best use of historical data in weather / climate forecasting



## Concerns:

- Community not making the best use of historical data in weather / climate forecasting
- Subseasonal forecasts are especially poor



Adapted from "Q&A: Subseasonal Prediction Project." International Research Institute for Climate and Society: IRI

# U.S. Bureau of Reclamation



- Manages water in 17 western states
- During the past eight years, every state in the Western United States has **experienced drought**

**WATER PRIZE COMPETITION CENTER**

**\$800,000 in prize \$\$\$!**

**March 2, 2016 Forecast (in)** .01 .10 .25 .50 1 2 3 4 5 7.5 10 15

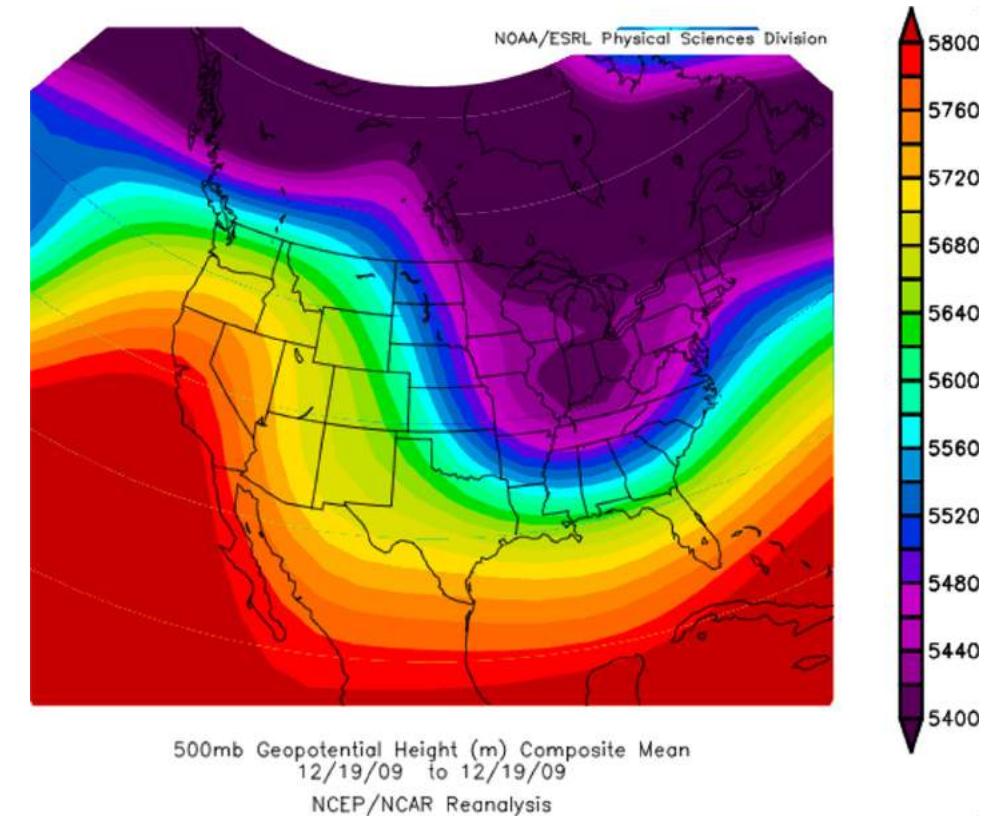
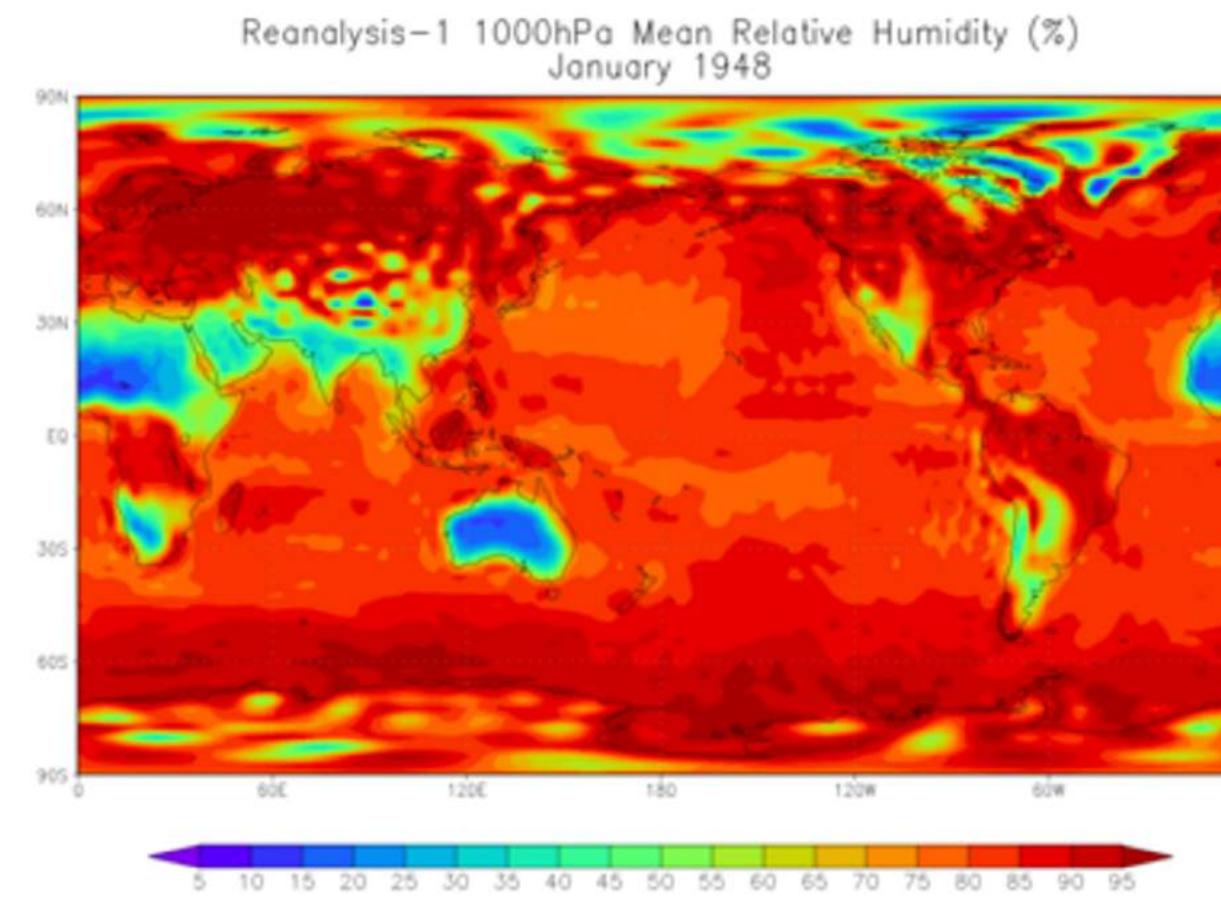
**Saddle up for the Sub-Seasonal Climate Forecast Rodeo!**

[usbr.gov/research/challenges](http://usbr.gov/research/challenges)

Competition Sponsor: **RECLAMATION**  
Managing Water in the West

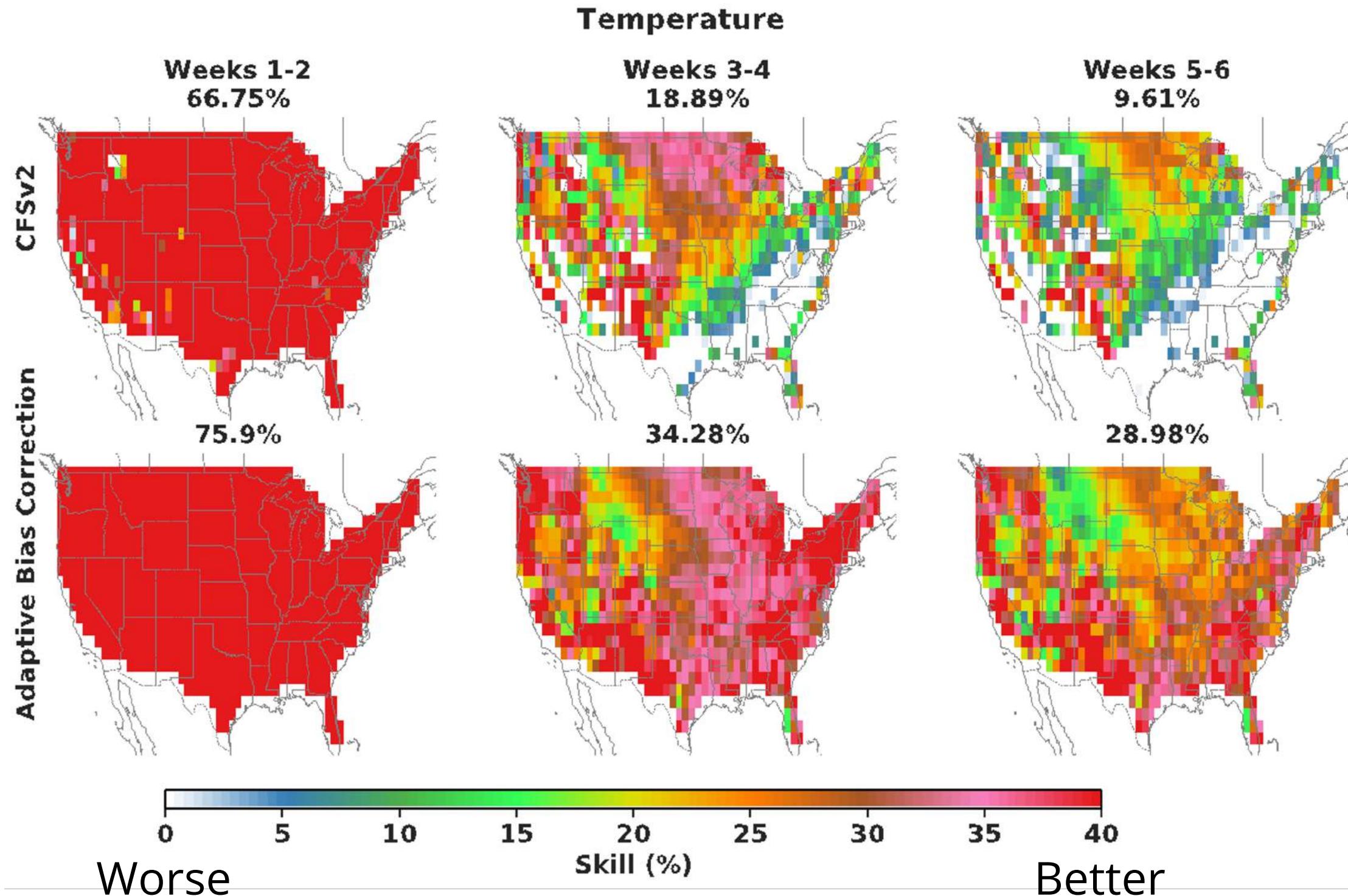
Competition Partners: **NOAA**, **US Army Corps of Engineers**, **USGS** science for a changing world

# SubseasonalClimateUSA Dataset



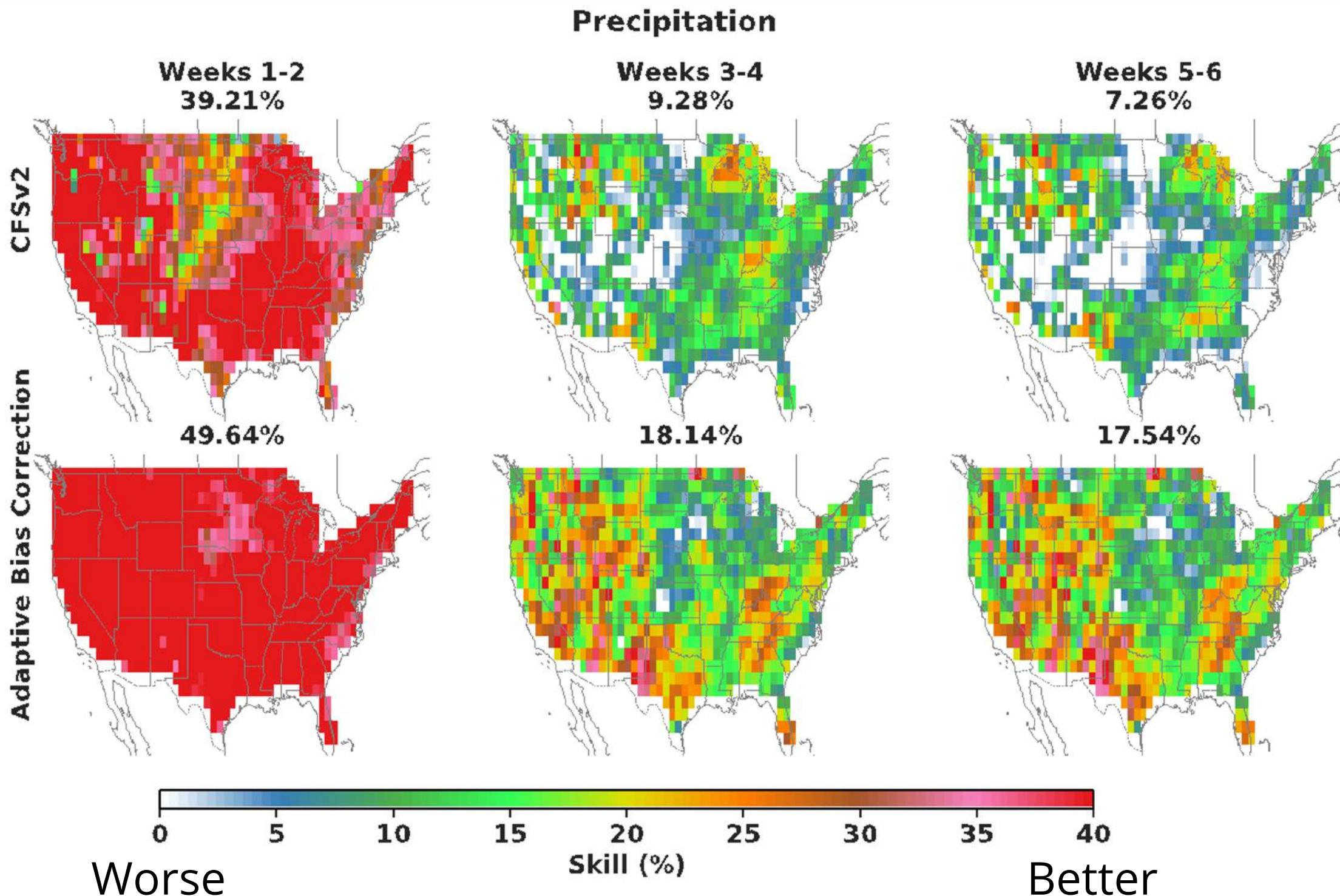
Updated daily + accessed via **subseasonal\_data** Python package

# Hybrid Learning + Physics Approach



- Doubles / triples the forecasting skill
- Outperforms SOTA ML / DL methods

# Hybrid Learning + Physics Approach



- Doubles / triples the forecasting skill
- Outperforms SOTA ML / DL methods

# AI and Climate Change

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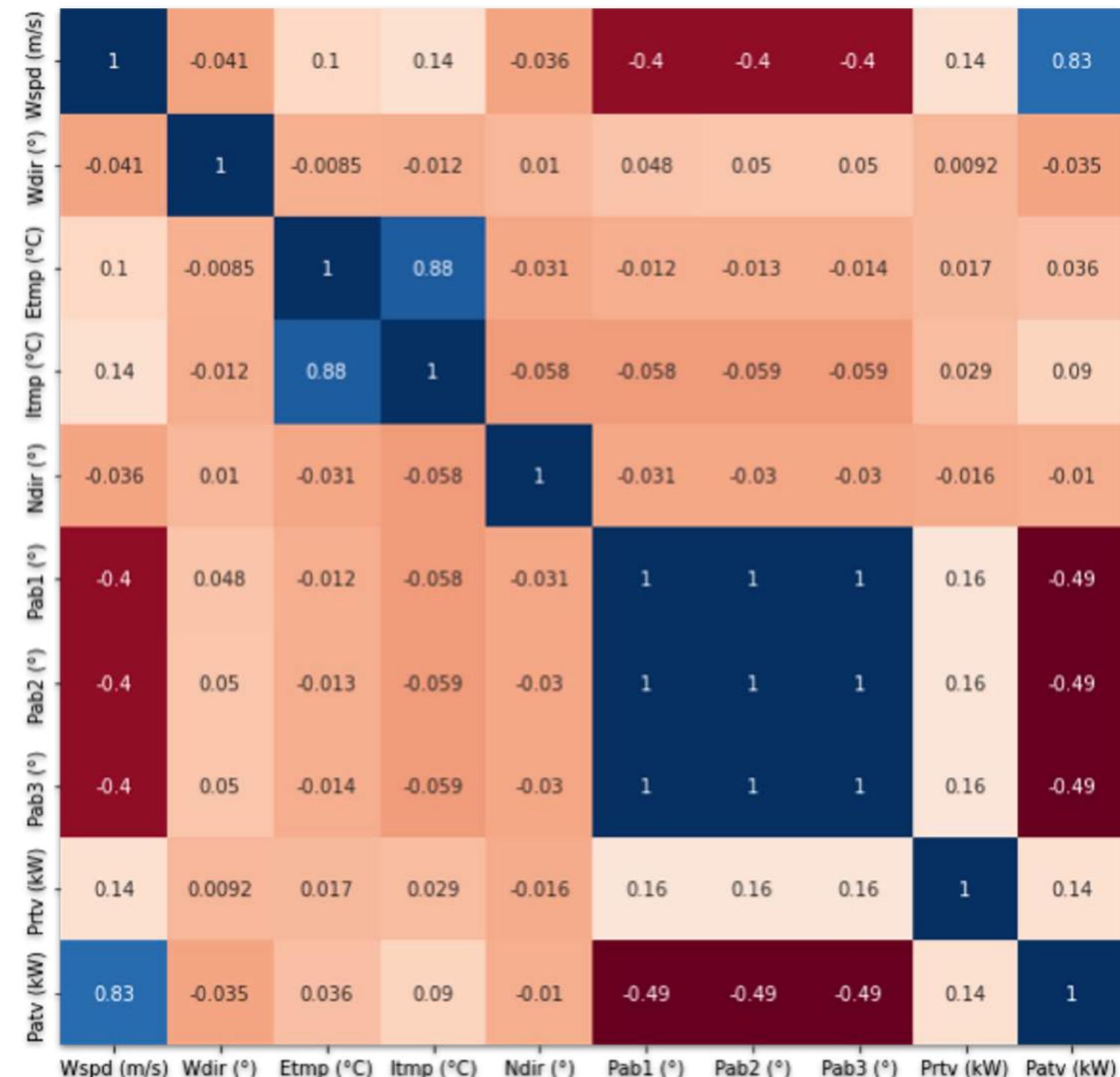


DeepLearning.AI

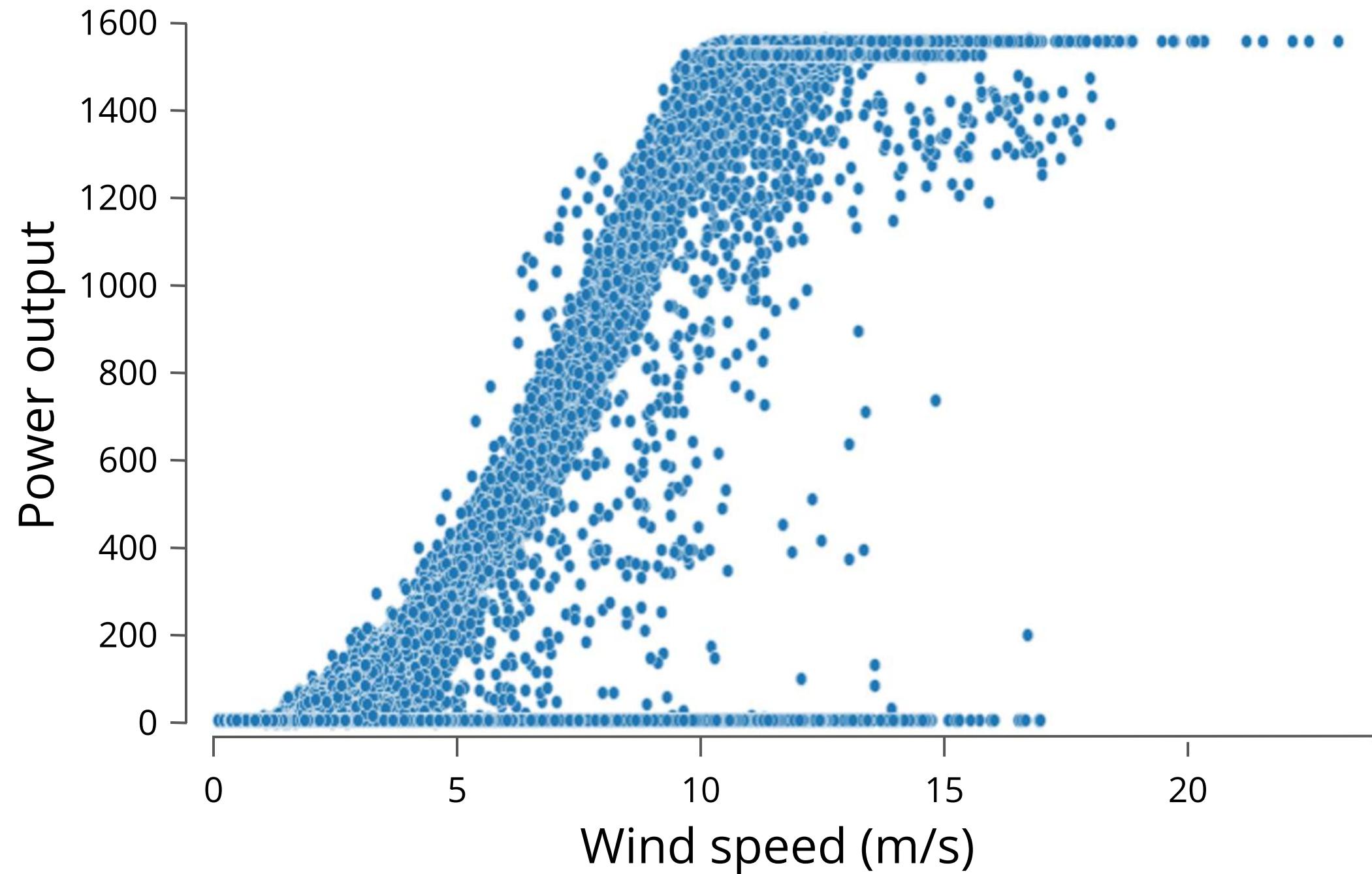
**wind Power**  
**Explore Phase Checkpoint**

# Explore phase

Correlation matrix of features



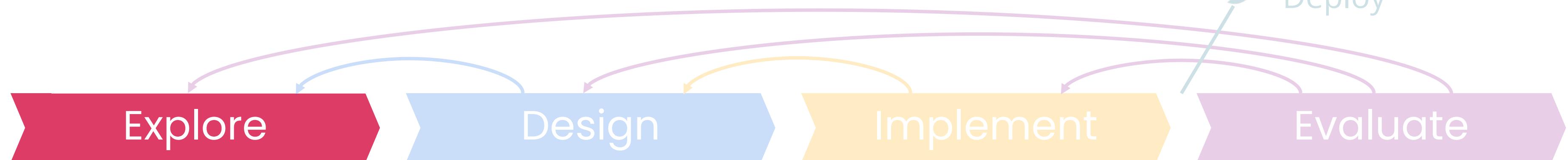
Scatterplot of Wspd versus Patv



# Explore phase



# Explore: Does AI add value?

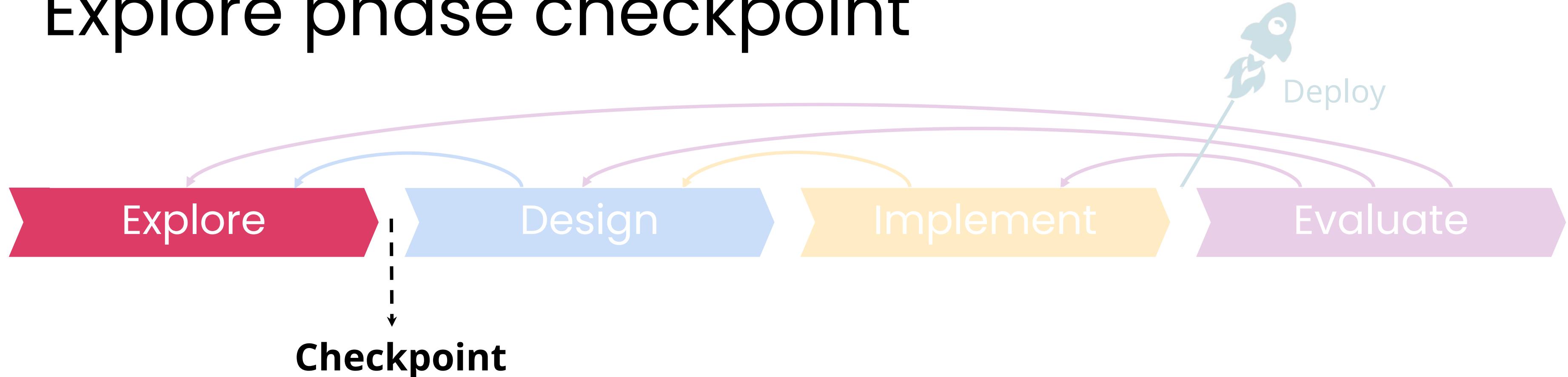


1. Engage stakeholders ✓
2. Define the problem ✓
3. Determine if AI could add value ✓

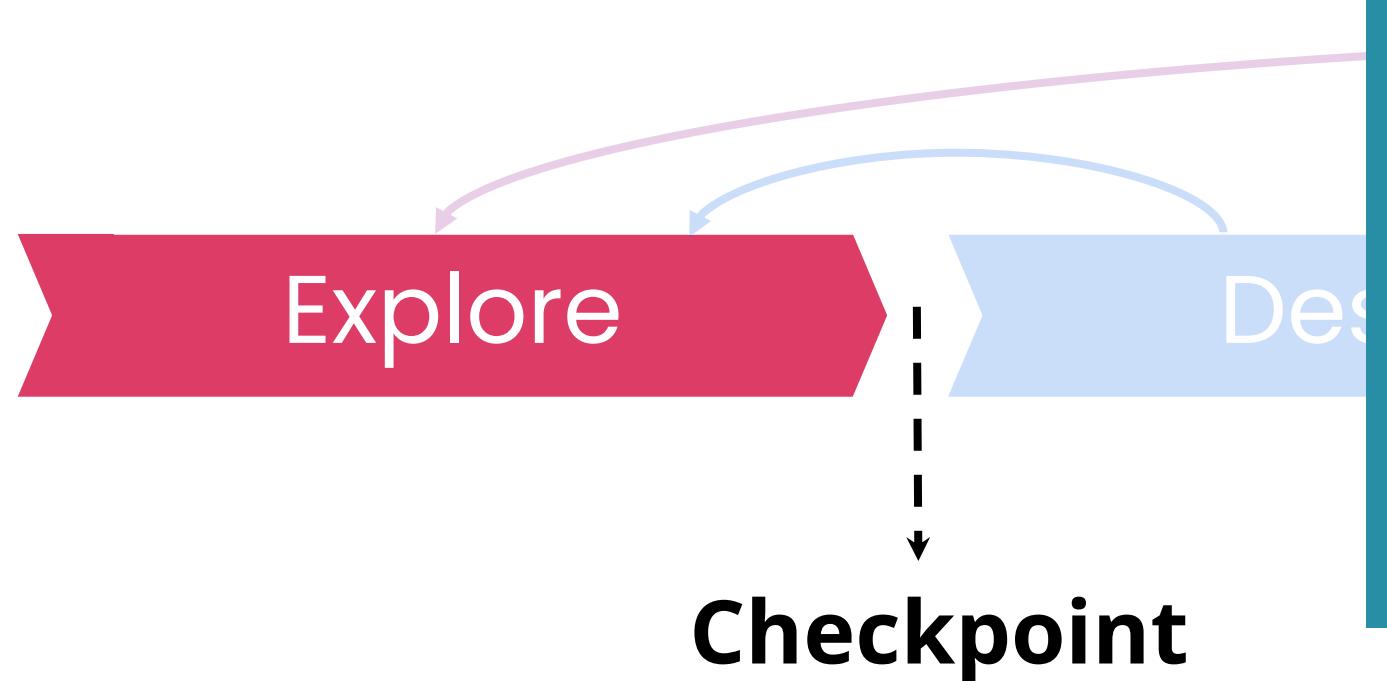
## Do no harm

**Everyone** impacted by a project is improved or unchanged.

# Explore phase checkpoint



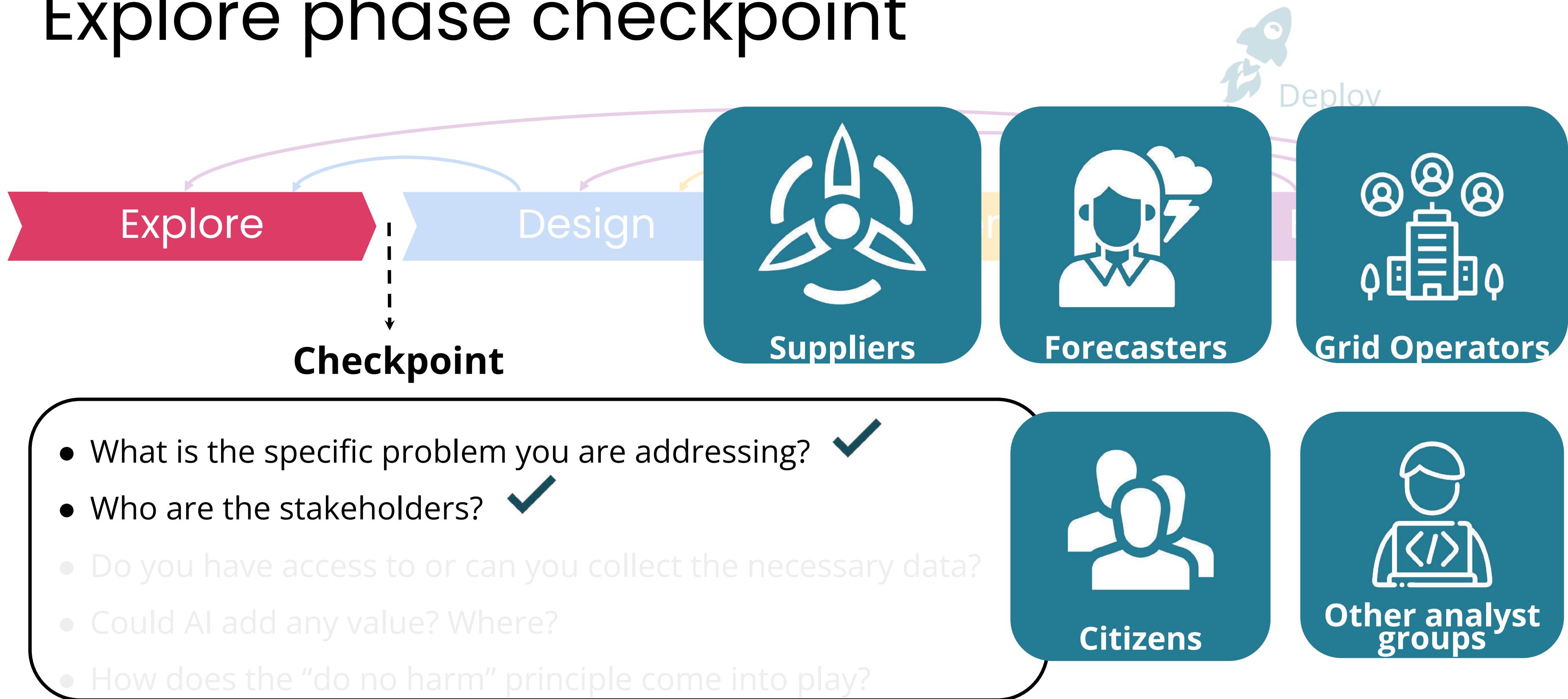
# Explore phase checkpoint



"Electrical utility companies **need reliable predictions of wind power output** at least 24 hours in advance in order to better plan the requirements for other power input sources into the electrical grid."

- What is the specific problem you are addressing? ✓
- Who are the stakeholders?
- Do you have access to or can you collect the necessary data?
- Could AI add any value? Where?
- How does the “do no harm” principle come into play?

# Explore phase checkpoint



# Explore phase checkpoint



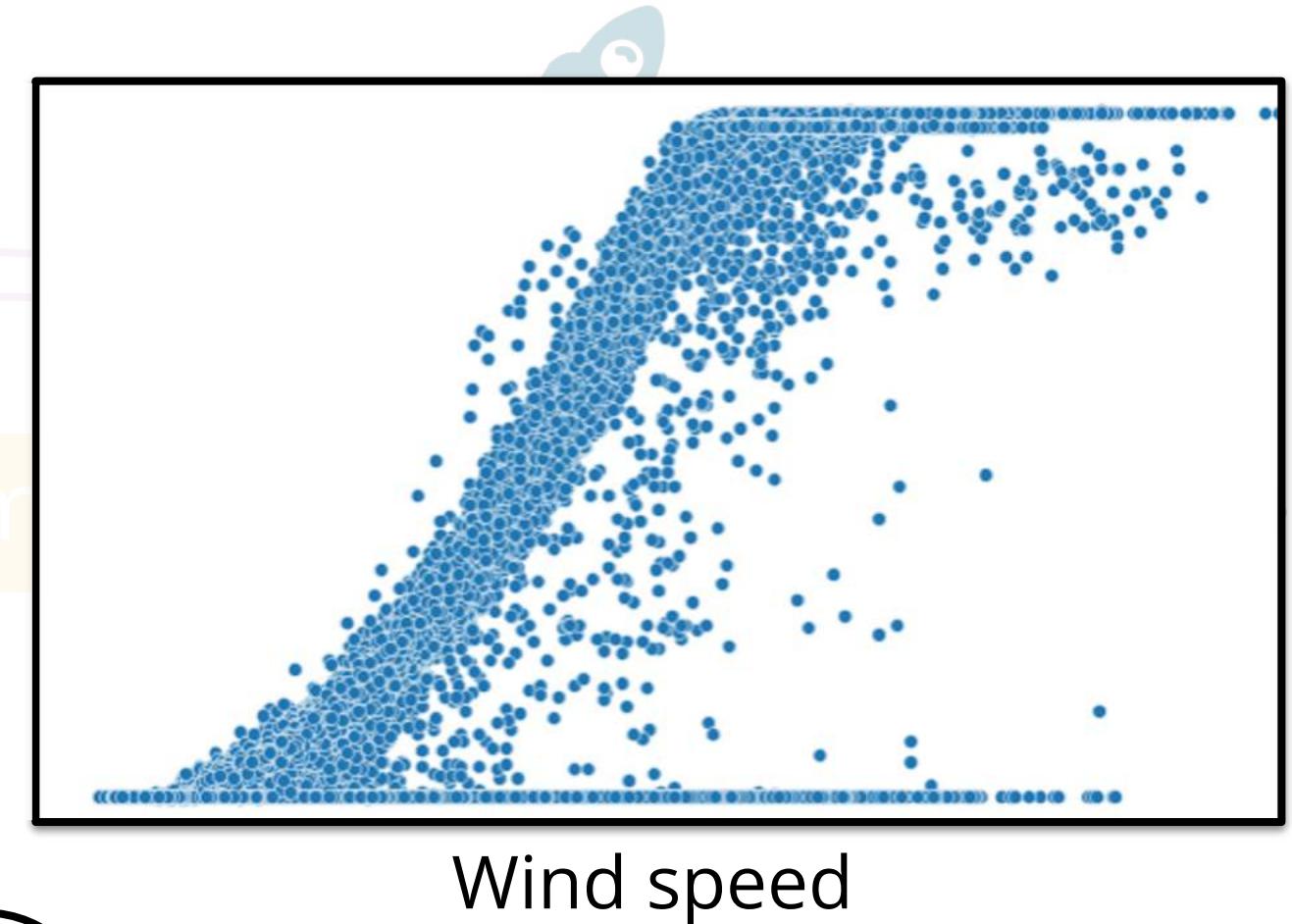
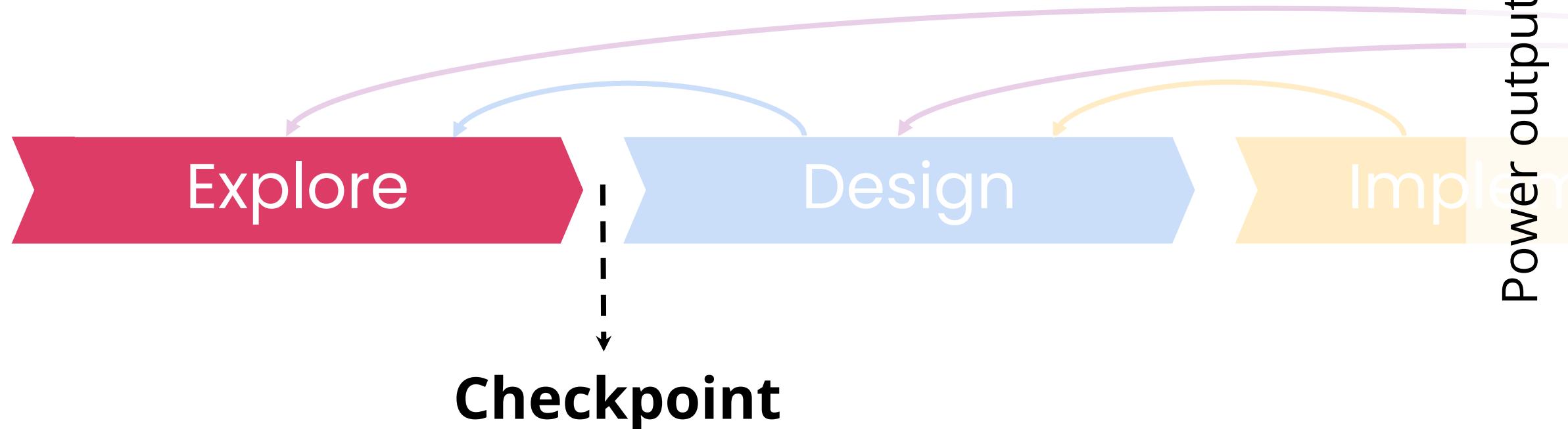
Explore

Checkpoint

Datetime	TurbID	Wspd (m/s)	Wdir (°)	Etmp (°C)	Itmp (°C)	Ndir (°)	Pab1 (°)	Pab2 (°)	Pab3 (°)	Prtv (kW)	Patv (kW)
2020-05-01 00:10:00	1	6.17	-3.99	30.73	41.80	25.92	1.0	1.0	1.0	-0.25	494.66
2020-05-01 00:20:00	1	6.27	-2.18	30.60	41.63	20.91	1.0	1.0	1.0	-0.24	509.76
2020-05-01 00:30:00	1	6.42	-0.73	30.52	41.52	20.91	1.0	1.0	1.0	-0.26	542.53

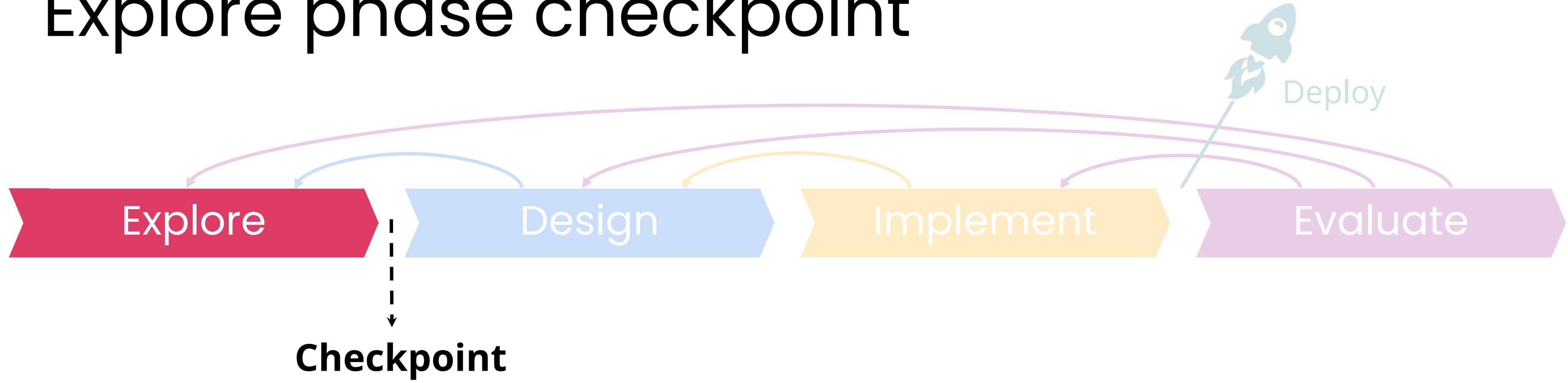
- What is the specific problem you are addressing? ✓
- Who are the stakeholders? ✓
- Do you have access to or can you collect the necessary data? ✓
- Could AI add any value? Where?
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# Explore phase checkpoint



- What is the specific problem you are addressing? ✓
- Who are the stakeholders? ✓
- Do you have access to or can you collect the necessary data? ✓
- Could AI add any value? Where? ✓
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# Explore phase checkpoint



- What is the specific problem you are addressing? ✓
- Who are the stakeholders? ✓
- Do you have access to or can you collect the necessary data? ✓
- Could AI add any value? Where? ✓
- How does the “do no harm” principle come into play? ✓

# W2 Lesson 2

# Wind Power Forecasting:

# Design and Implement

# AI and Climate Change

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DeepLearning.AI

**Wind Power**  
**Establish a**  
**Baseline Model**

## Reasons for establishing a simple baseline



**Save time and money**

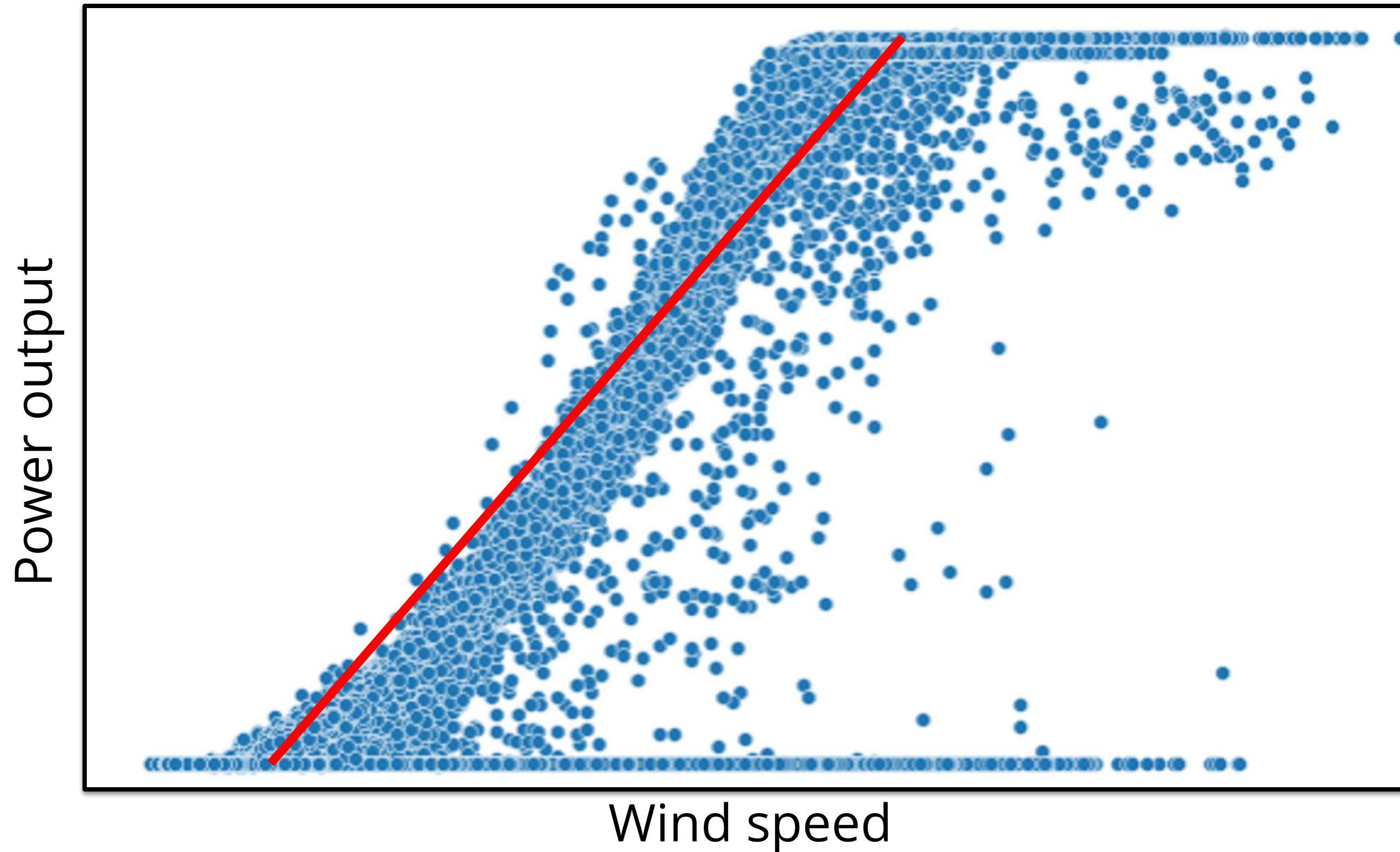


**Model results are more  
understandable and  
interpretable**



**Establish a baseline  
performance for comparison  
with complex models**

# Wind power forecasting - Explore

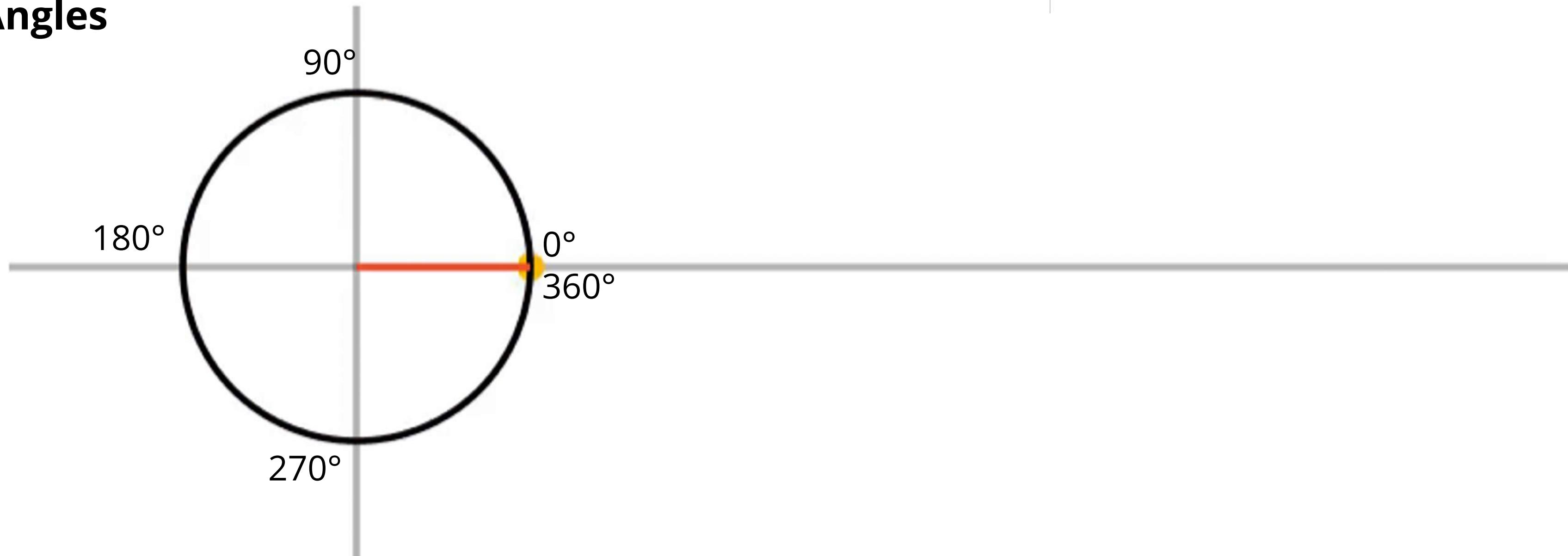


# Sine and cosine representation

**Sin = +0.000**

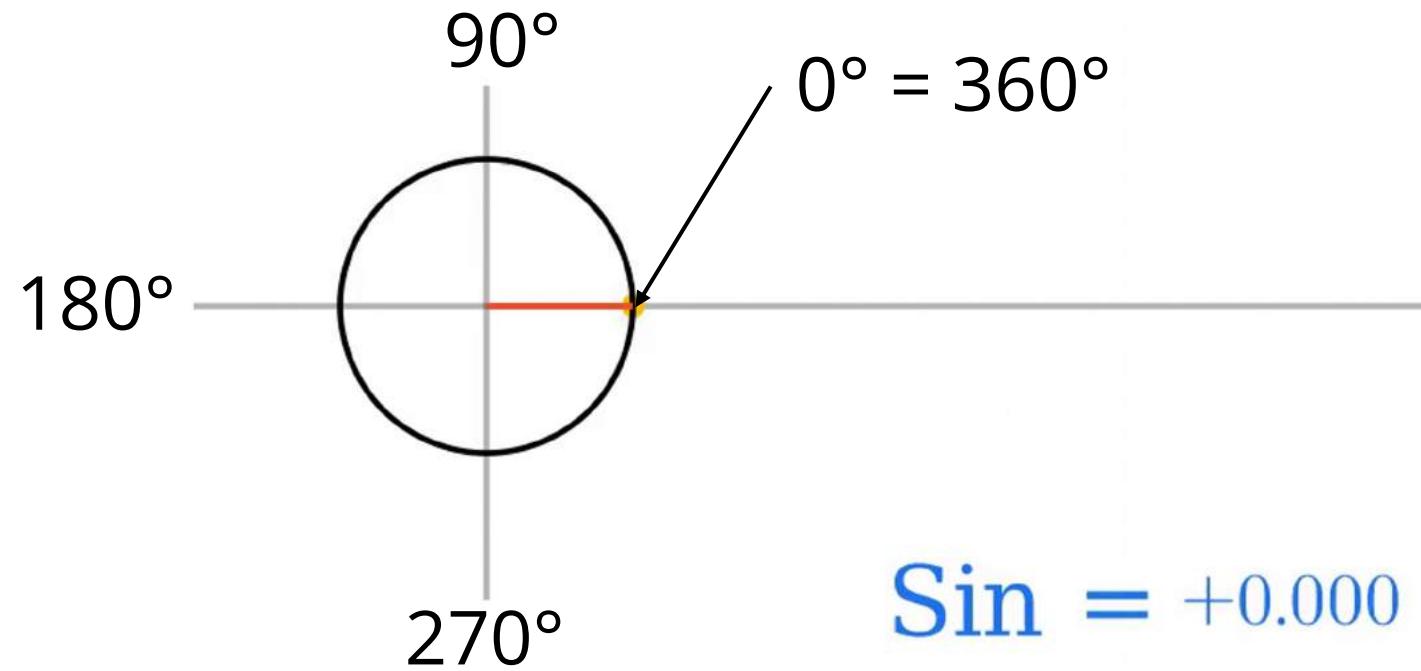
**Cos = +1.000**

**Angles**

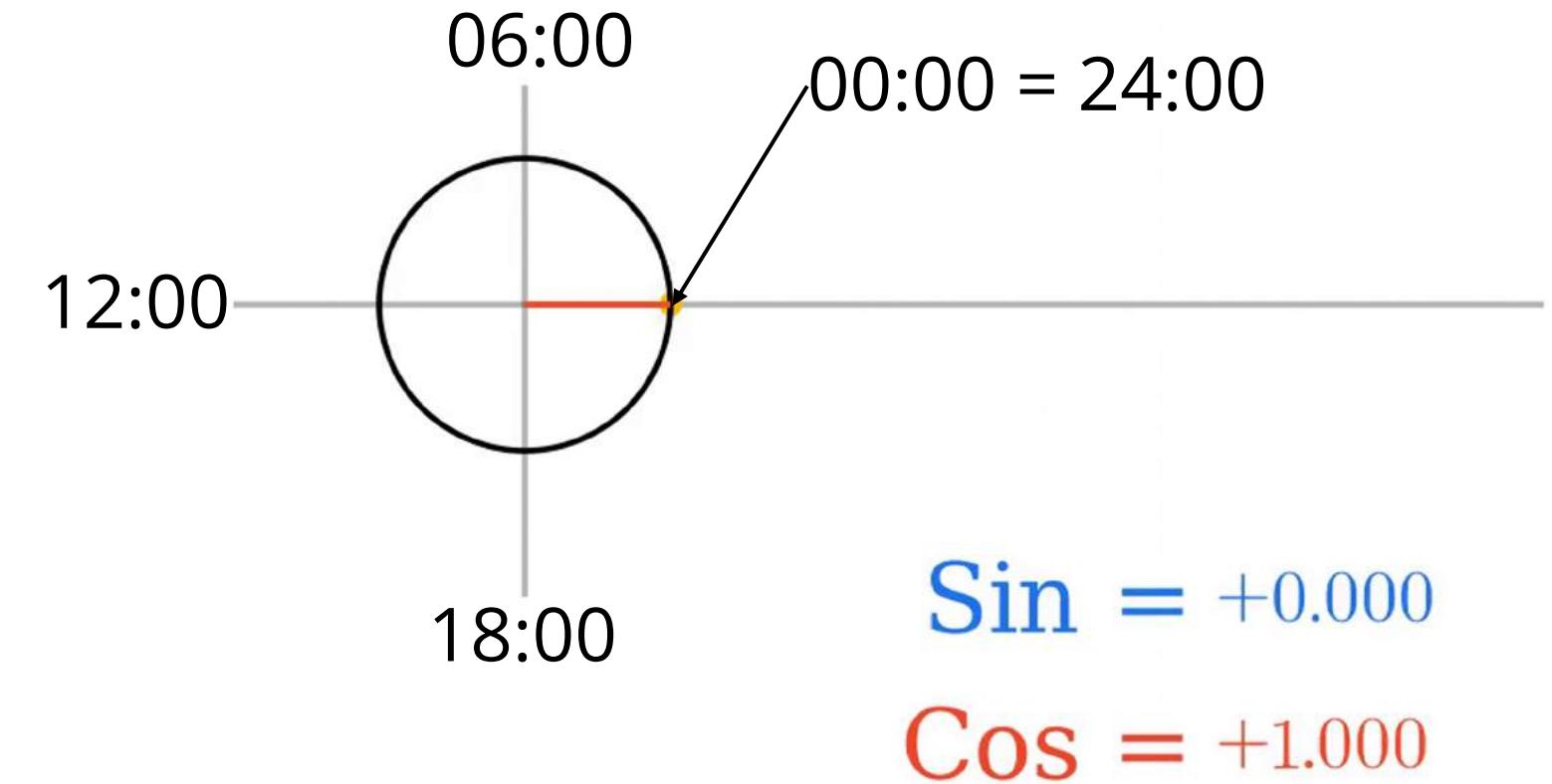


# Sine and cosine representation of:

**Angles**



**Hours of day**



# AI and Climate Change

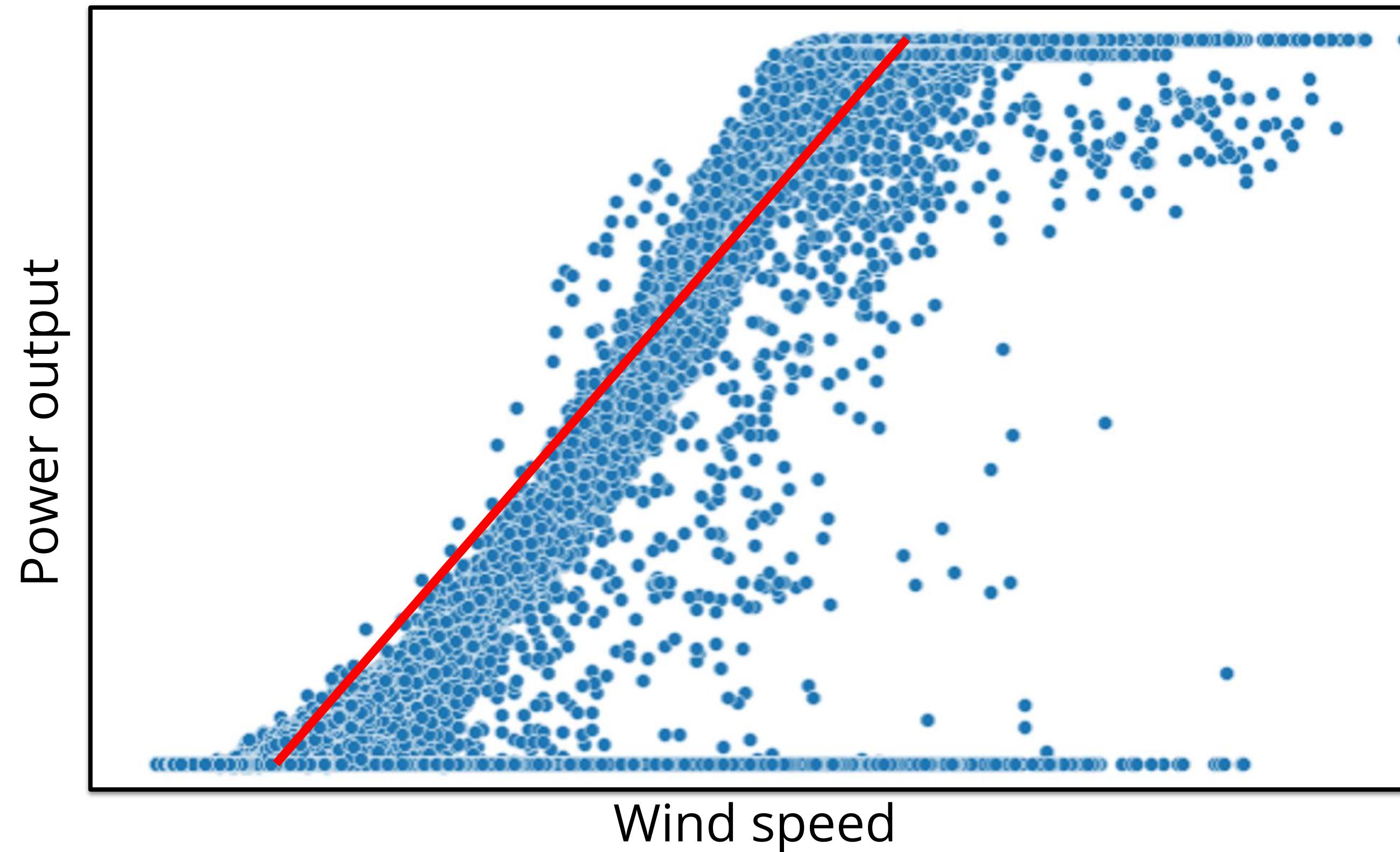
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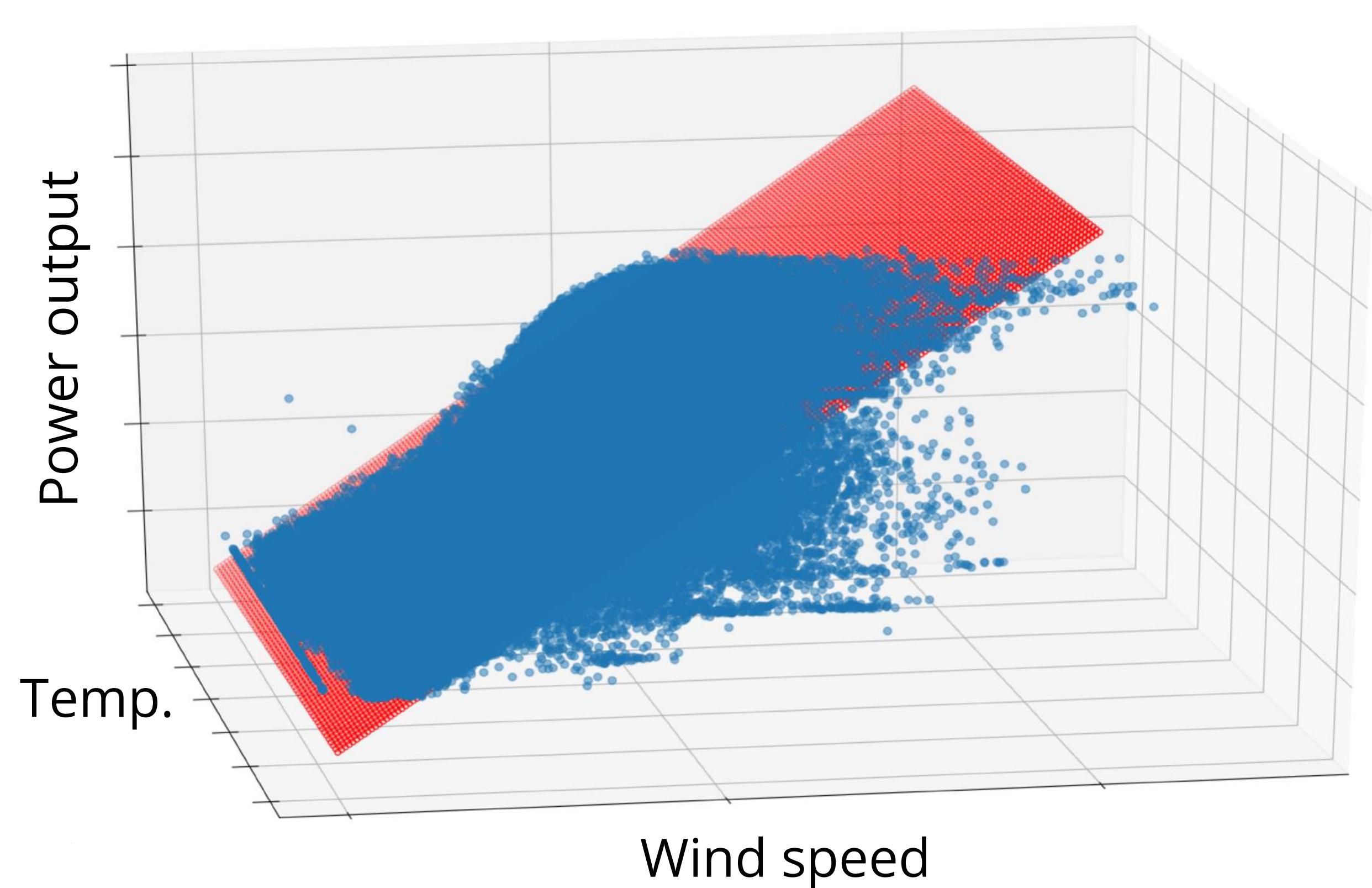
DeepLearning.AI

**Wind Power  
Improve the  
Baseline Model**

# Linear model 2D visualization



# Linear model 3D visualization



# AI and Climate Change

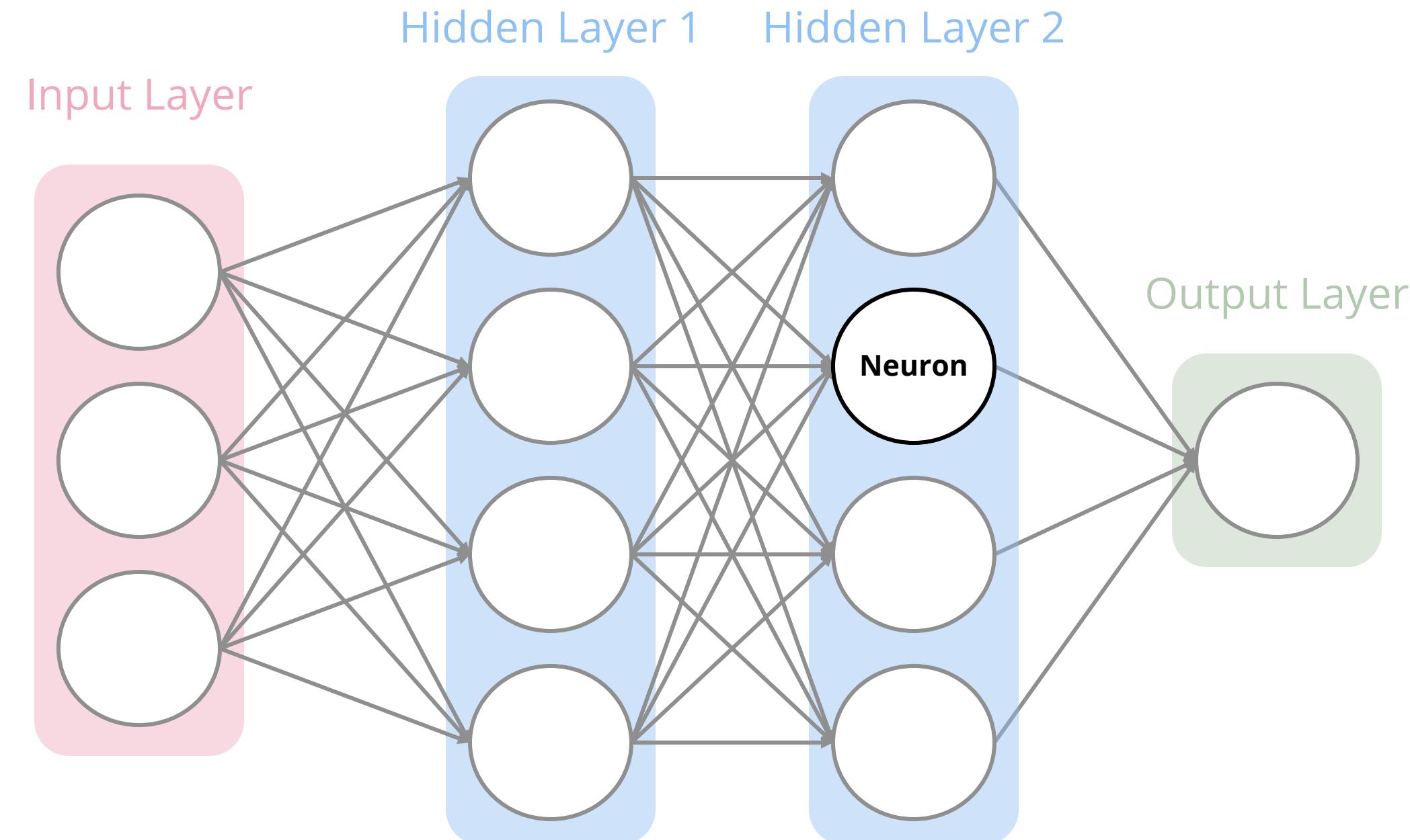
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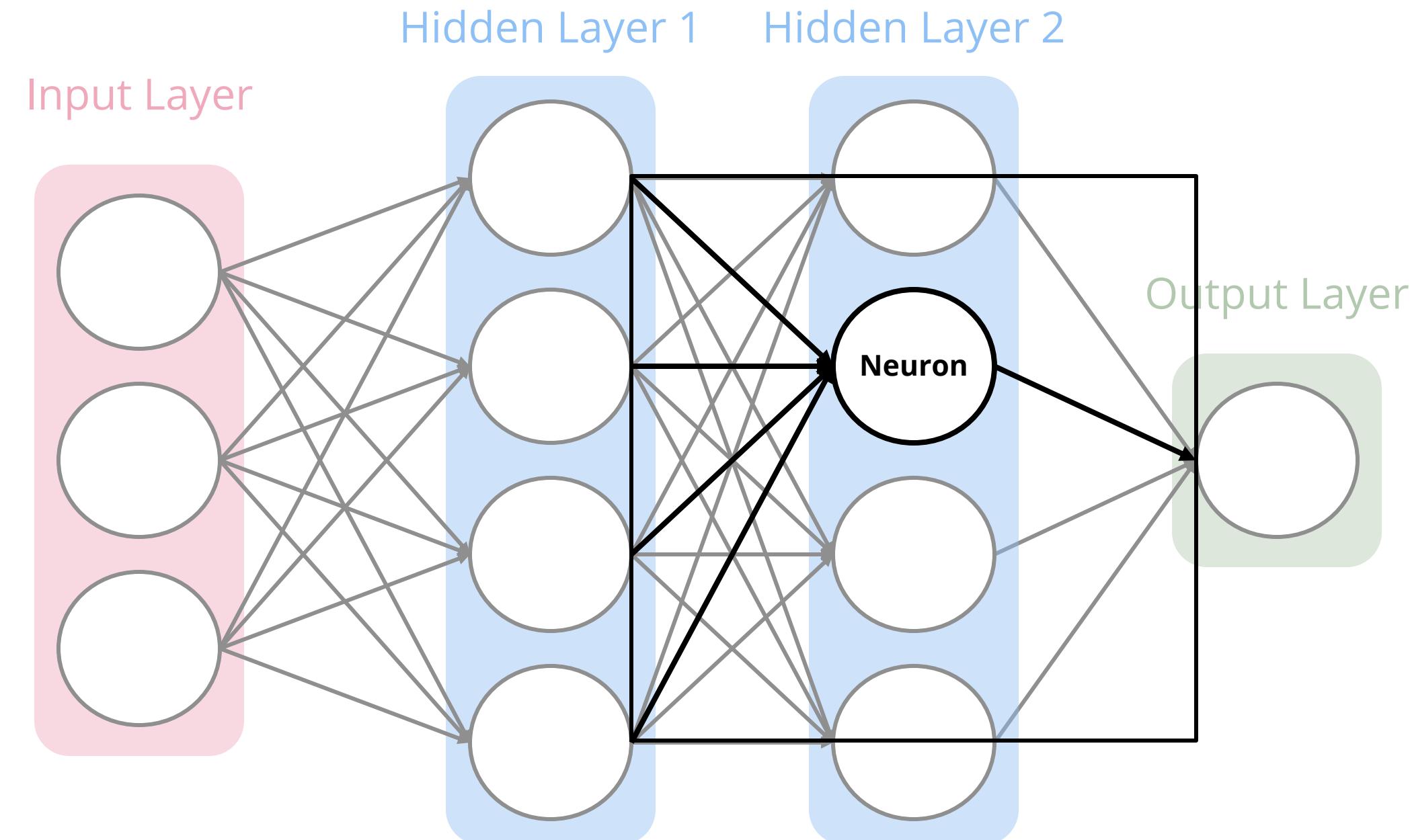
DeepLearning.AI

**Wind Power**  
**Train a Neural**  
**Network Model**

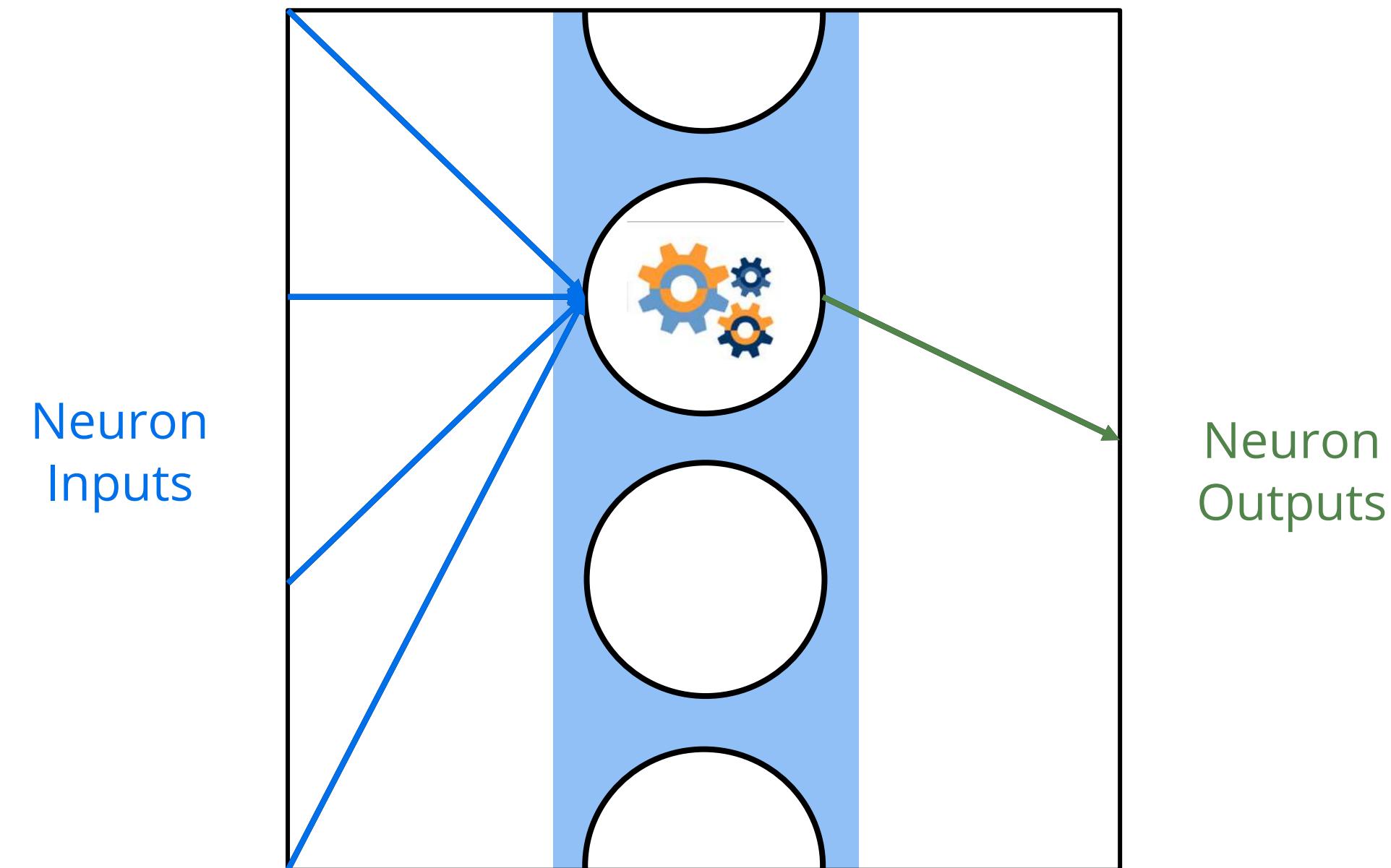
# Neural Networks



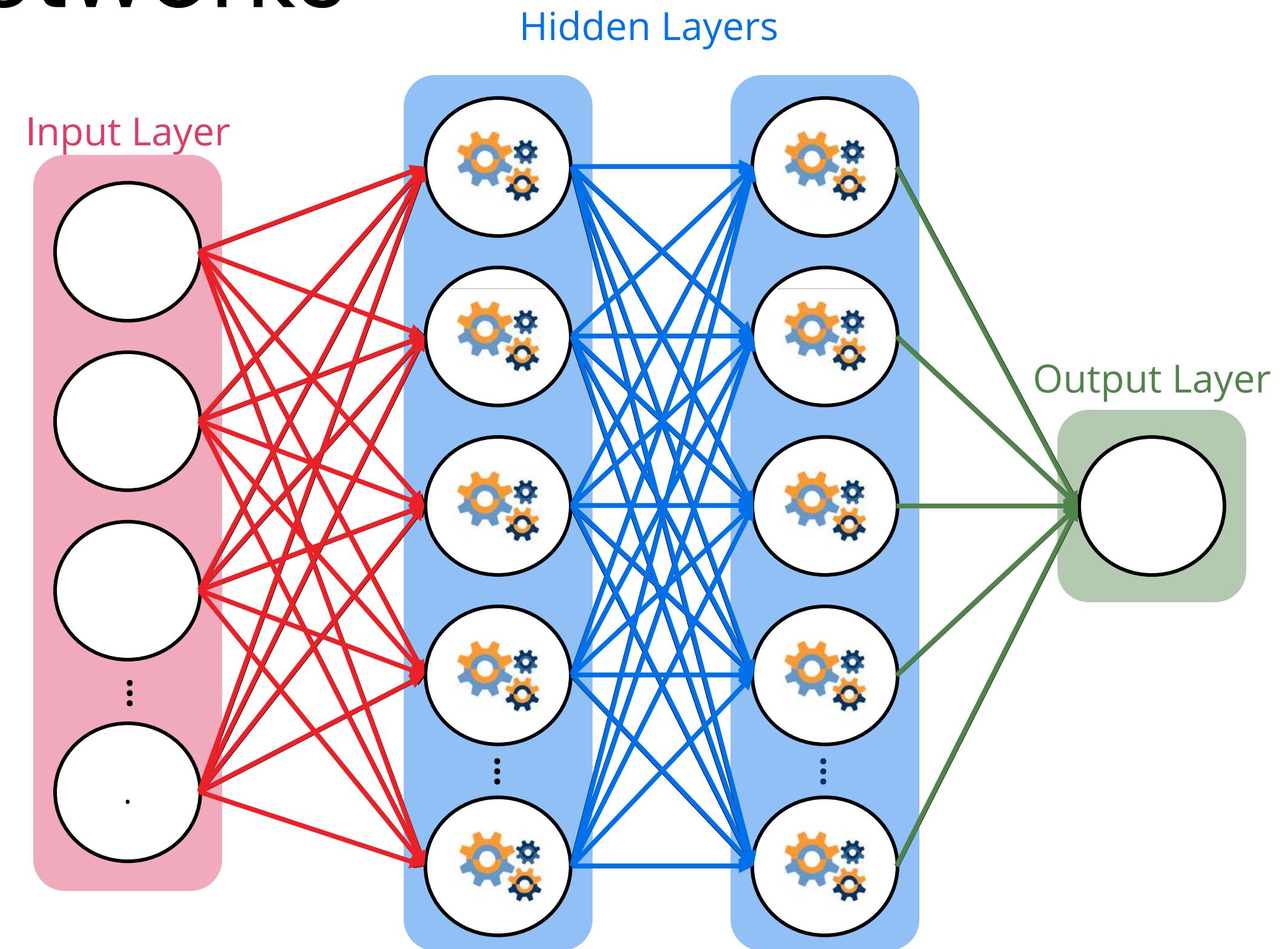
# Neural Networks



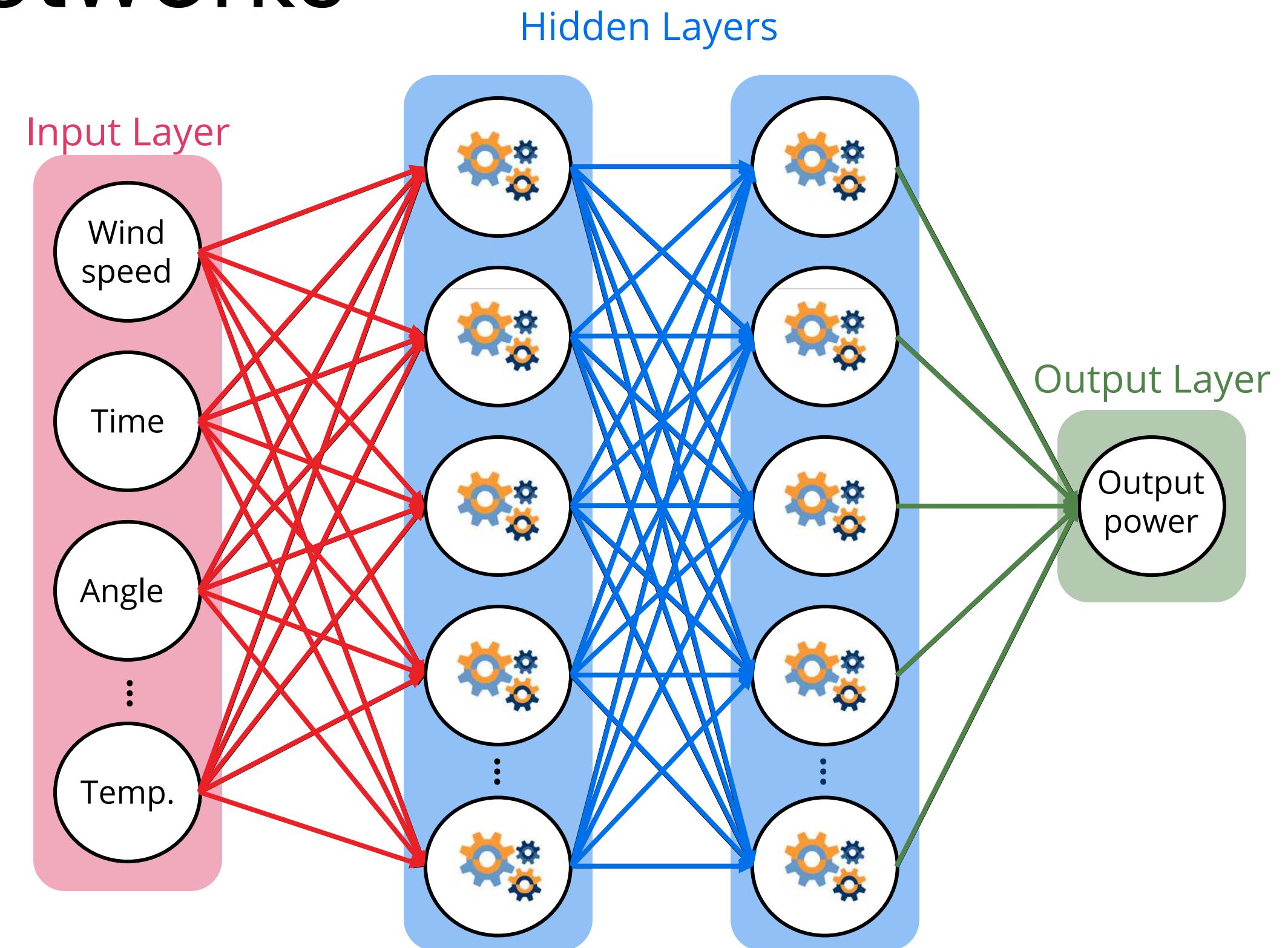
# Neural Networks



# Neural Networks



# Neural Networks



# AI and Climate Change

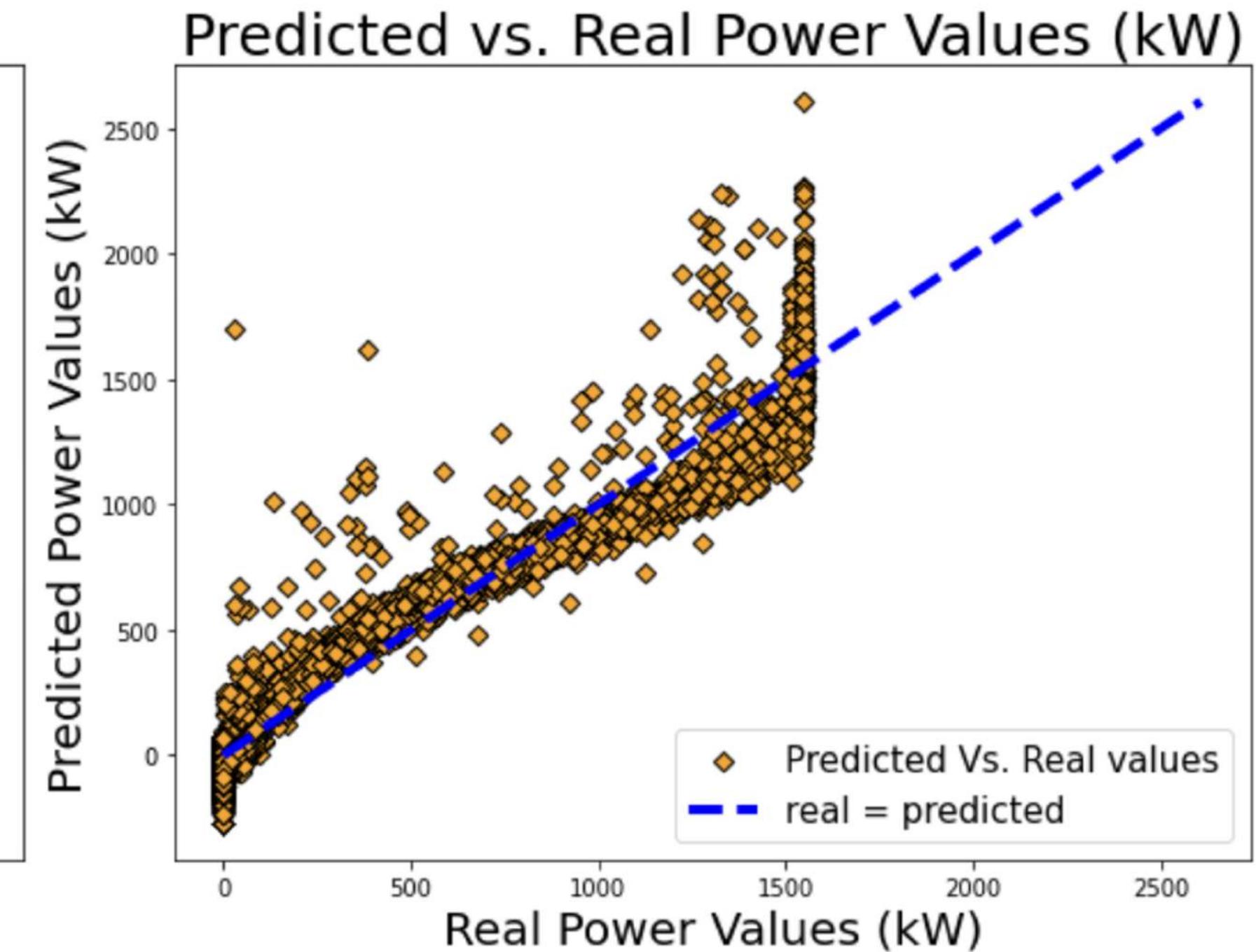
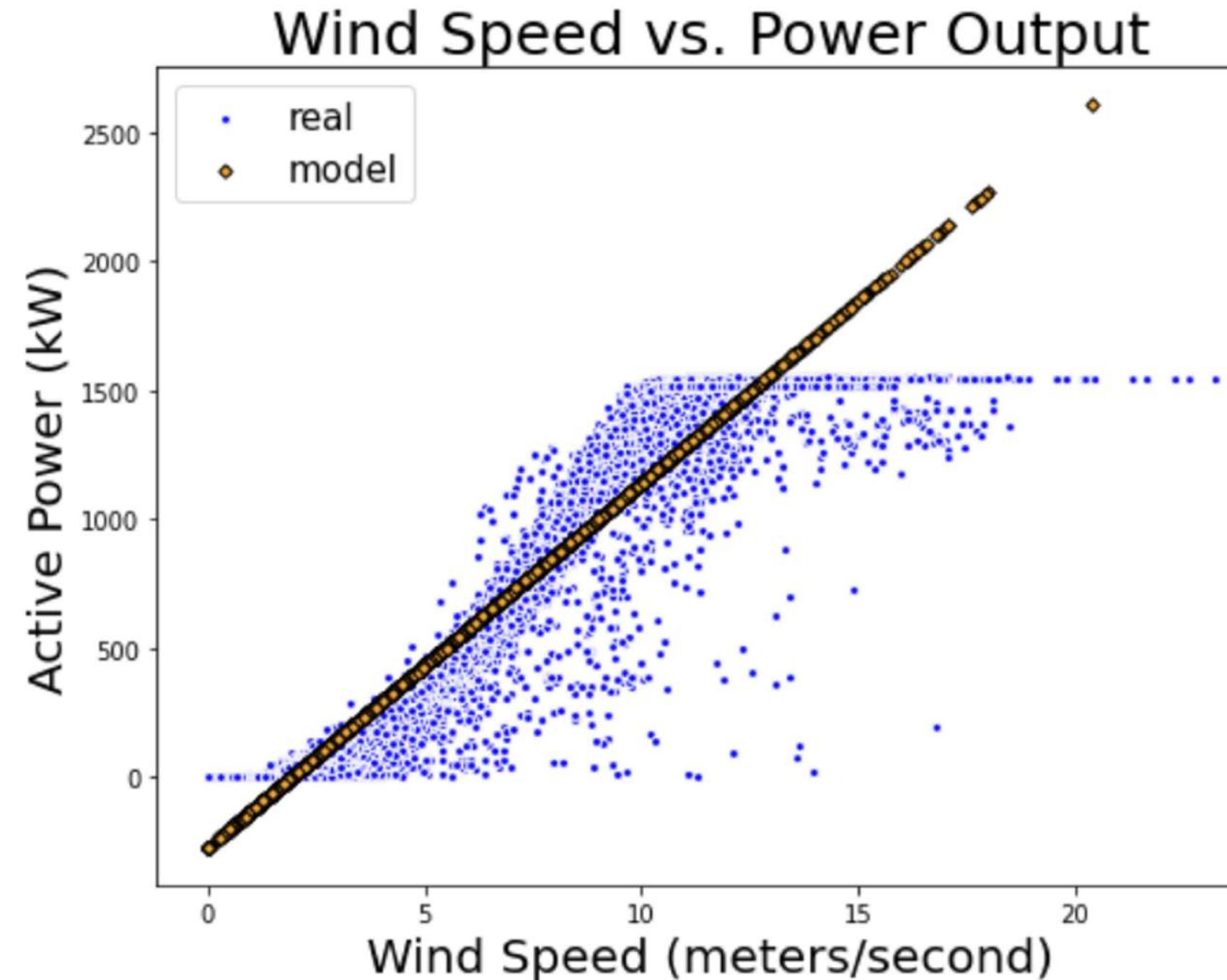
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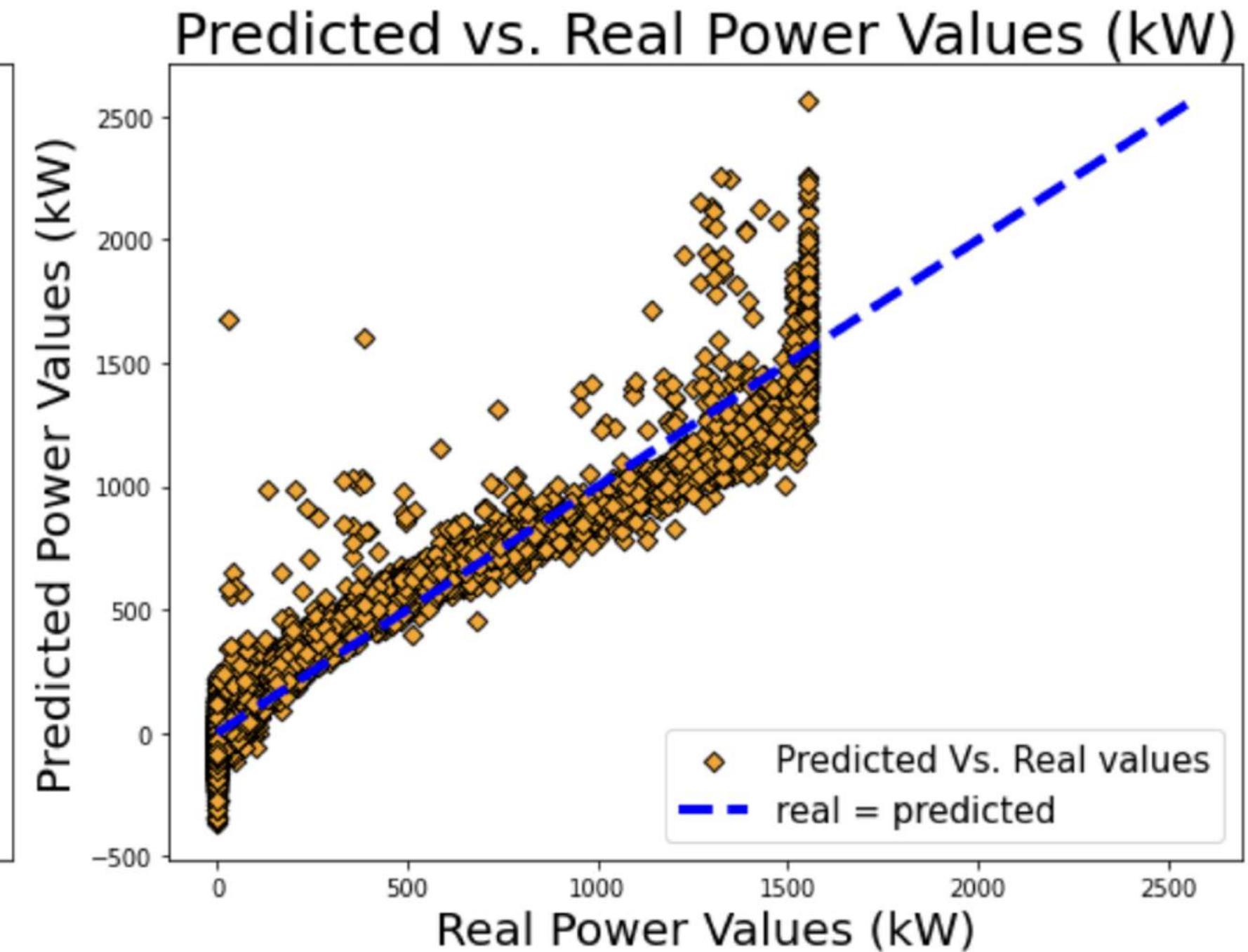
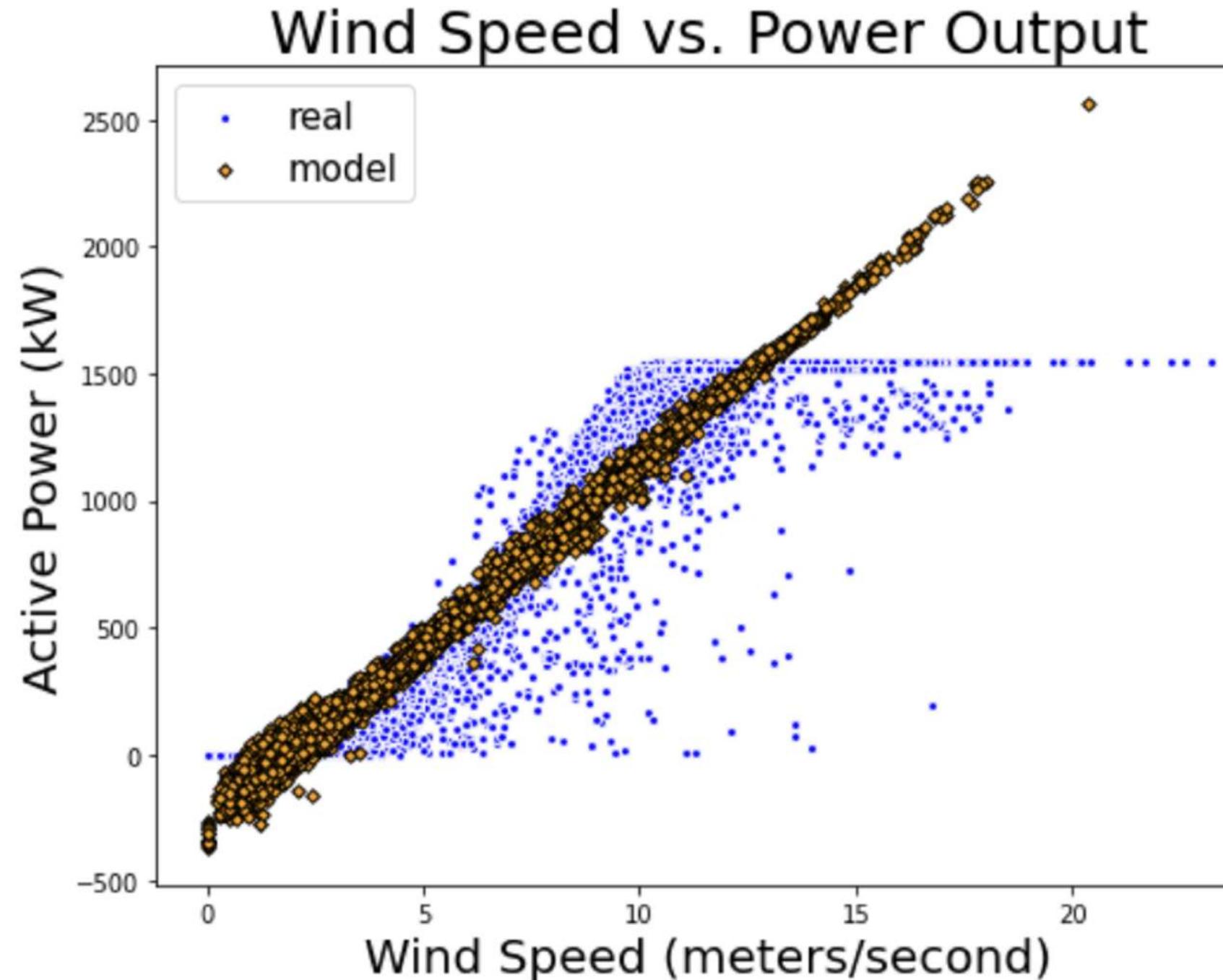
DeepLearning.AI

**What is a  
Sequence Model?**

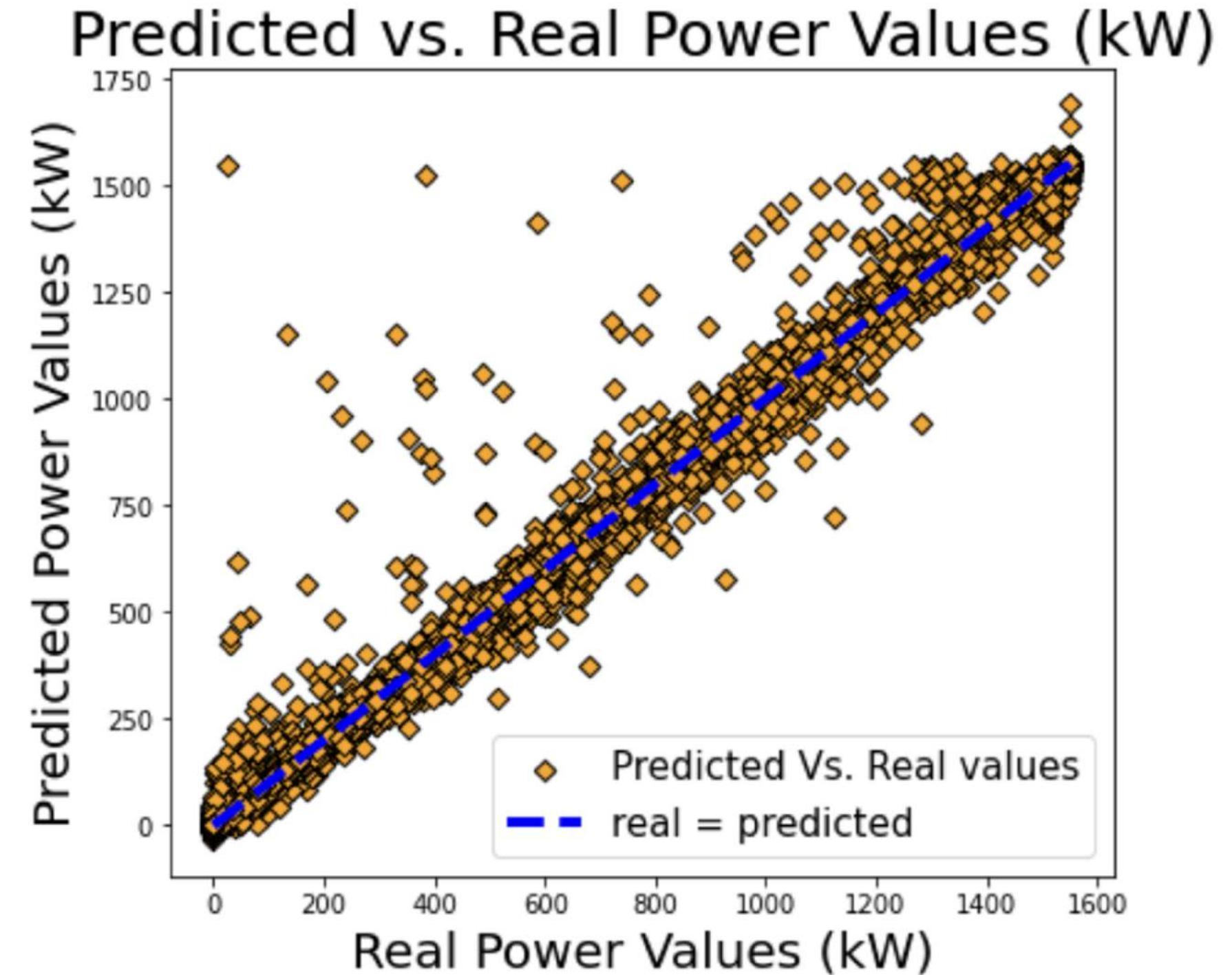
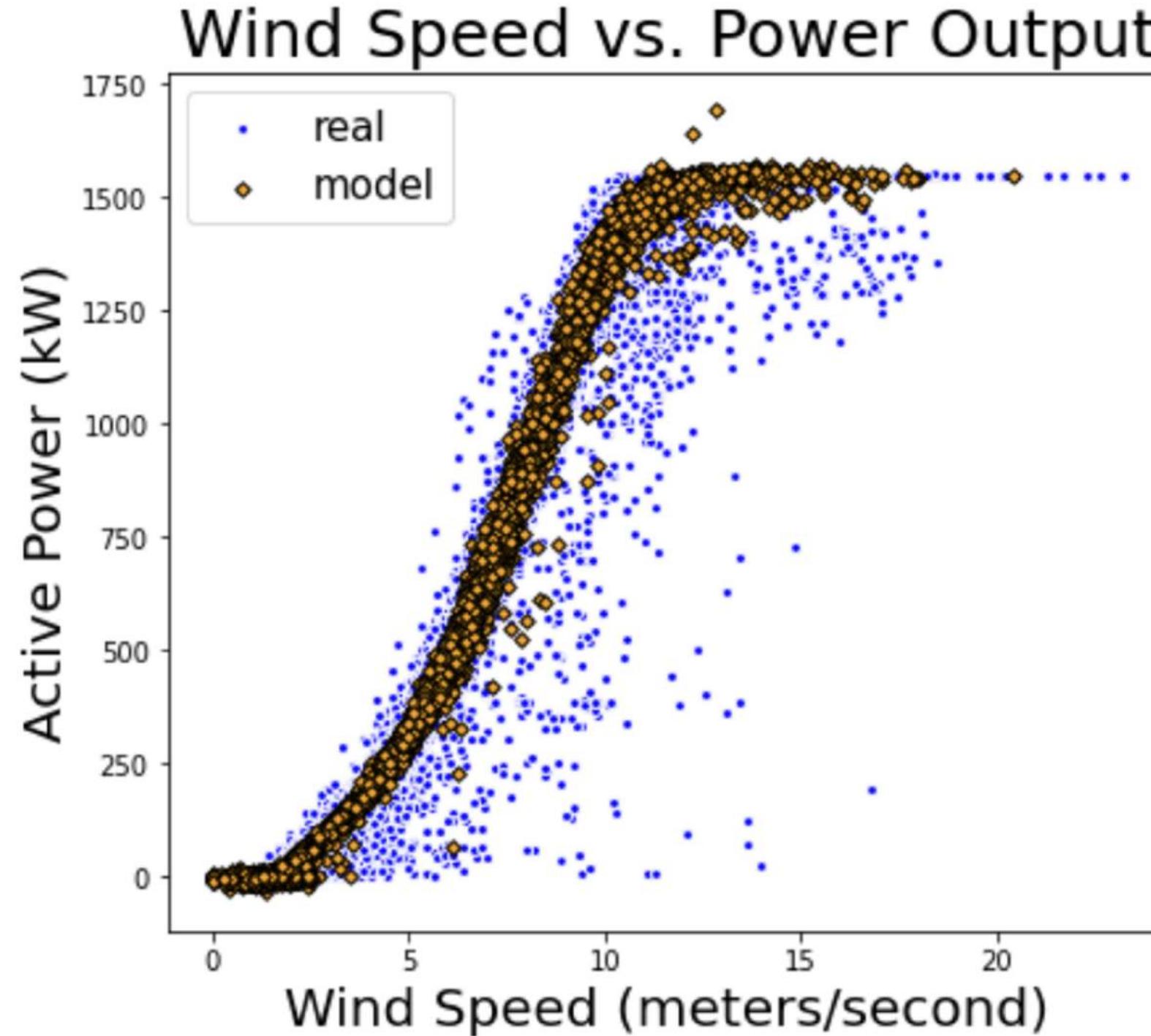
# Wind power forecasting - Linear regression



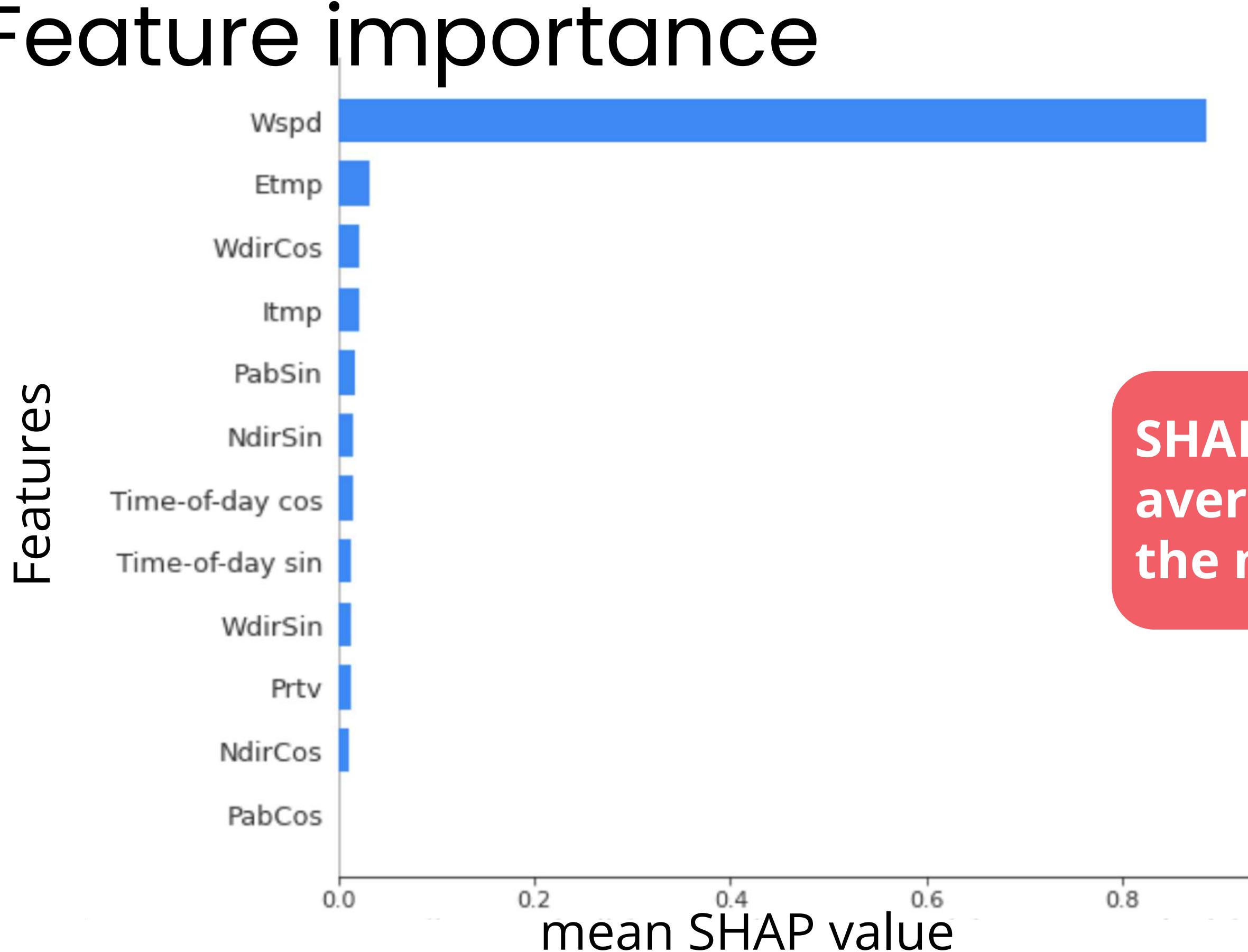
# Wind power forecasting - Linear regression



# Wind power forecasting - Neural network



# Feature importance



**SHAP value displays the average value of impact on the model output**

 Text

 Images

 Documents

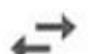
 Websites

Detect language

Spanish

English

French



English

Maltese

Estonian



## Translation

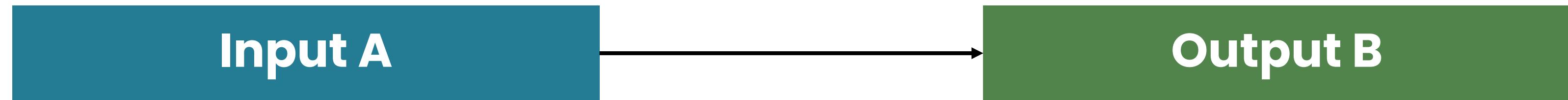


0 / 5,000



*Send feedback*

# Sequence-to-sequence models



**Text in Spanish**

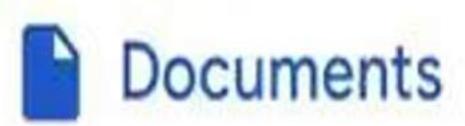
**¿Qué tan fuerte  
soplará el viento  
mañana?**

**Text in English**

**How strong will the  
wind blow  
tomorrow?**

 Text

 Images

 Documents

 Websites

Detect language

Spanish

English

French



English

Swahili

Korean



Translation



0 / 5,000



*Send feedback*

**Artificial  
Intelligence**

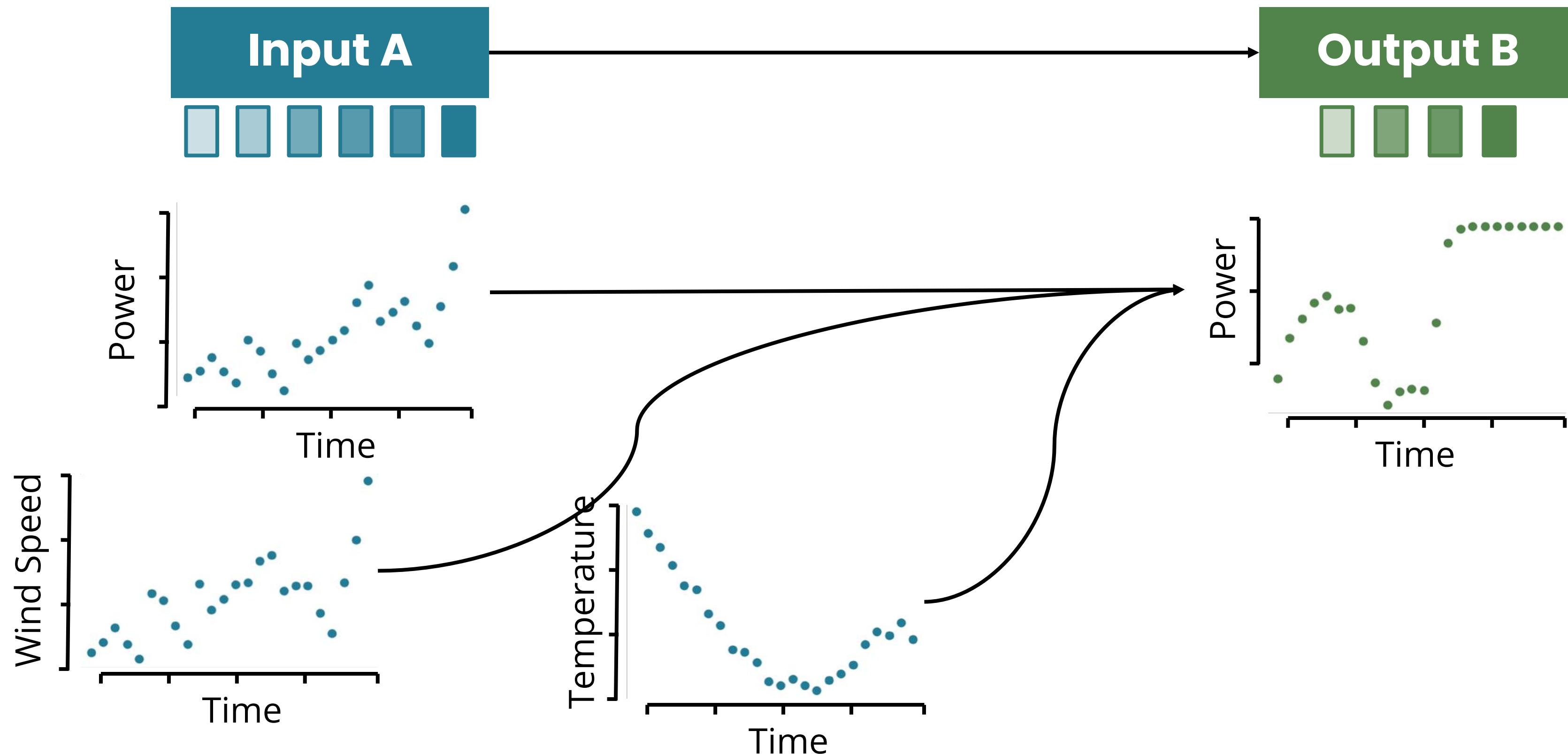
**Machine  
Learning**

**Supervised Learning:**

**A** —————→ **B**

**Sequence-to-sequence**

# Supervised learning: Sequence models



# AI and Climate Change

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DeepLearning.AI

**Wind Power  
Establish  
Baseline Forecasts**

# AI and Climate Change

---



DeepLearning.AI

**Wind Power**  
**Improve Performance with**  
**Sequence Models**

# AI and Climate Change

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DeepLearning.AI

**Wind Power  
Include Wind  
Speed Forecasts**

# AI and Climate Change

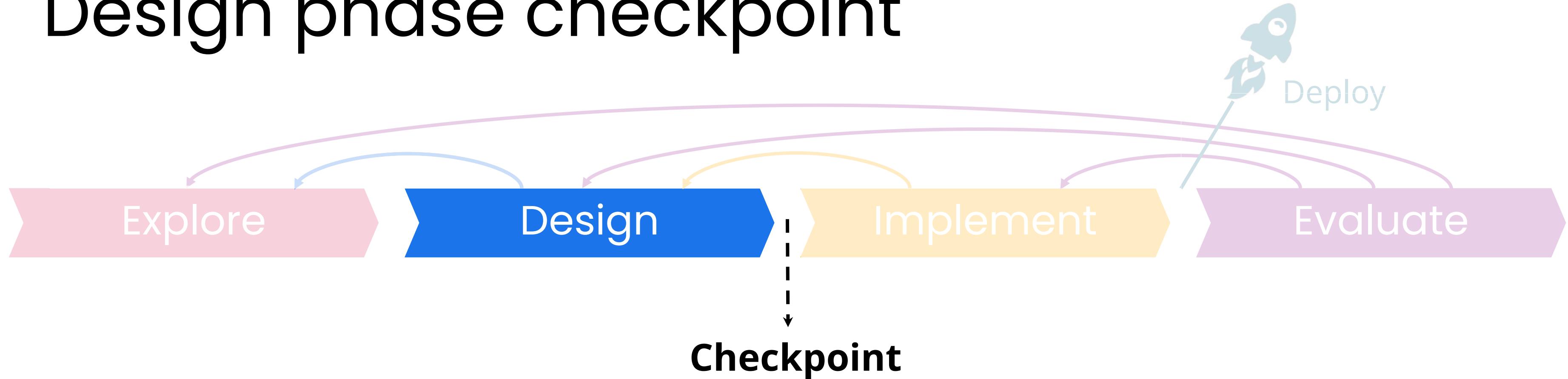
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DeepLearning.AI

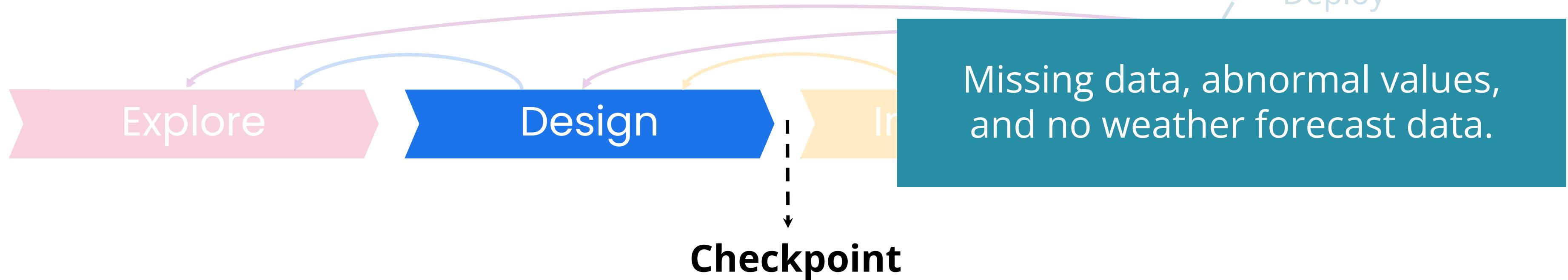
**Wind Power  
Design Phase Checkpoint**

# Design phase checkpoint



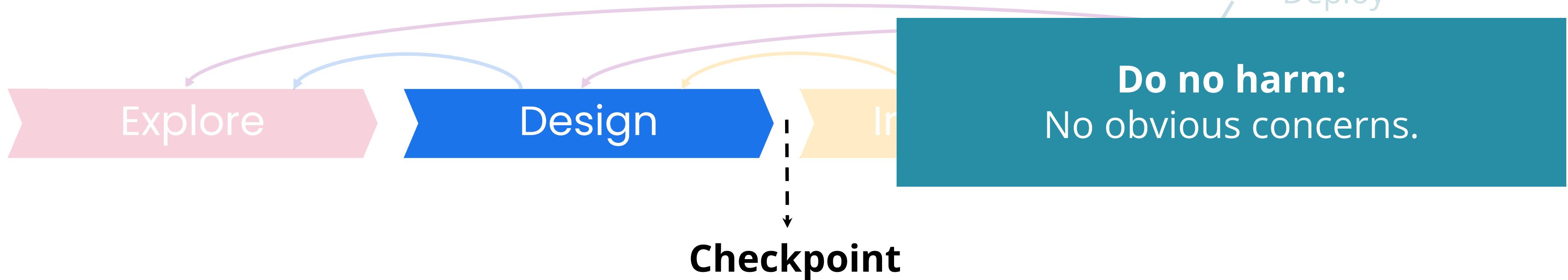
- How will you address issues with imbalances, biases, privacy, or other concerns with your data?
- What kind of model will you implement, and how will you measure its performance?
- How will your design address the problem you set out to work on?
- How will the end user interact with your system?

# Design phase checkpoint



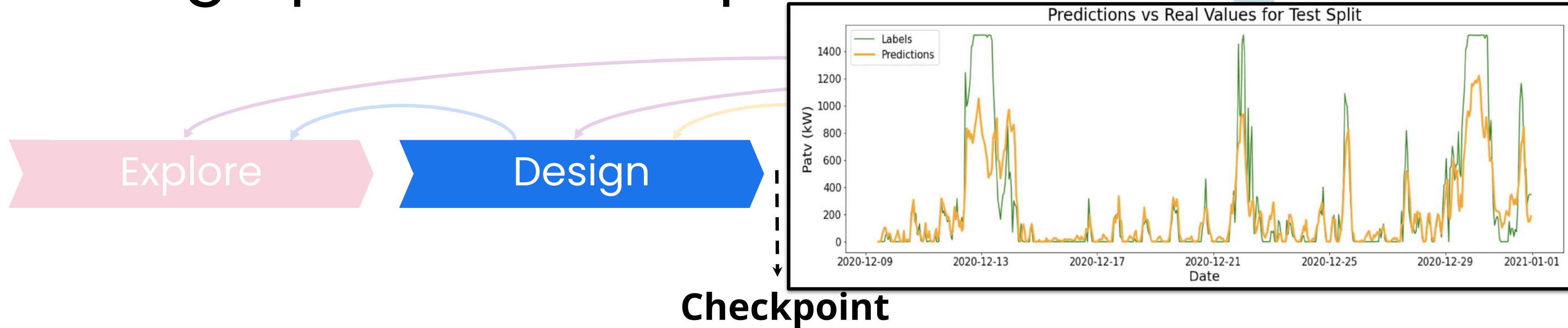
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# Design phase checkpoint



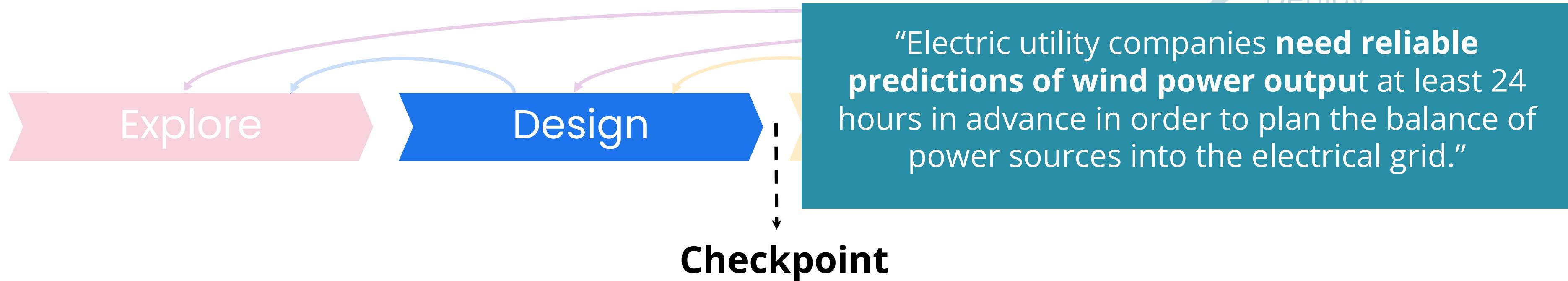
- How will you address issues with imbalances, biases, privacy, or other concerns with your data? ✓
- What kind of model will you implement, and how will you measure its performance?
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# Design phase checkpoint



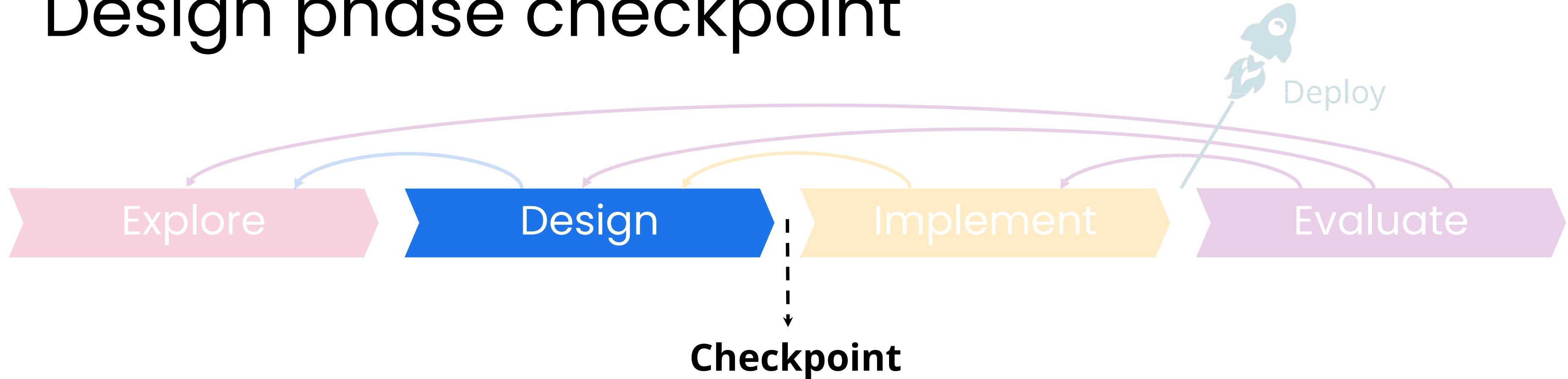
- How will you address issues with imbalances, biases, privacy, or other concerns with your data? ✓
- What kind of model will you implement, and how will you measure its performance? ✓
- How will your design address the problem you set out to work on?
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# Design phase checkpoint



- How will you address issues with imbalances, biases, privacy, or other concerns with your data? ✓
- What kind of model will you implement, and how will you measure its performance? ✓
- How will your design address the problem you set out to work on? ✓
- How will the end user interact with your system?

# Design phase checkpoint



- How will you address issues with imbalances, biases, privacy, or other concerns with your data? ✓
- What kind of model will you implement, and how will you measure its performance? ✓
- How will your design address the problem you set out to work on? ✓
- How will the end user interact with your system? ✓

# AI and Climate Change

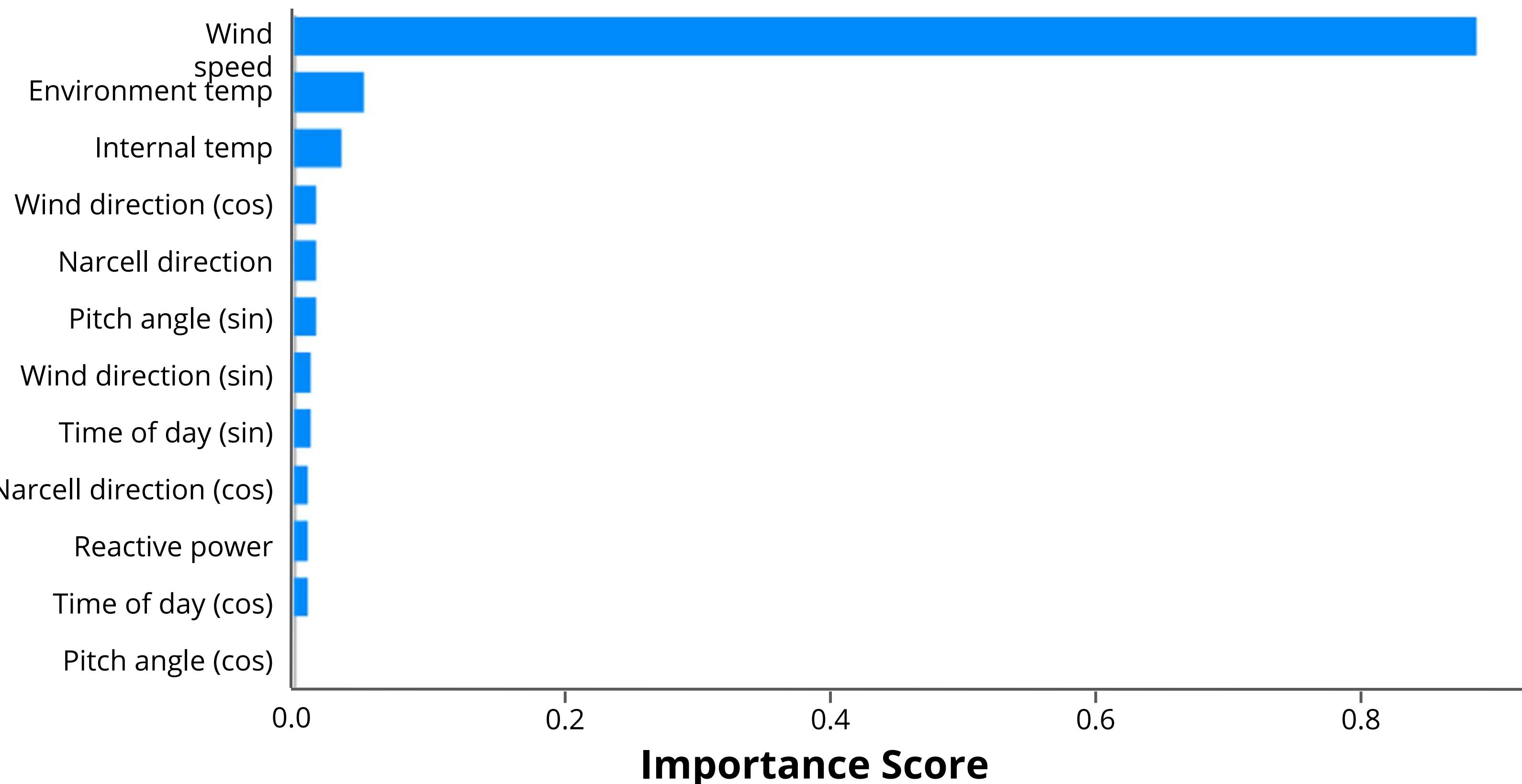
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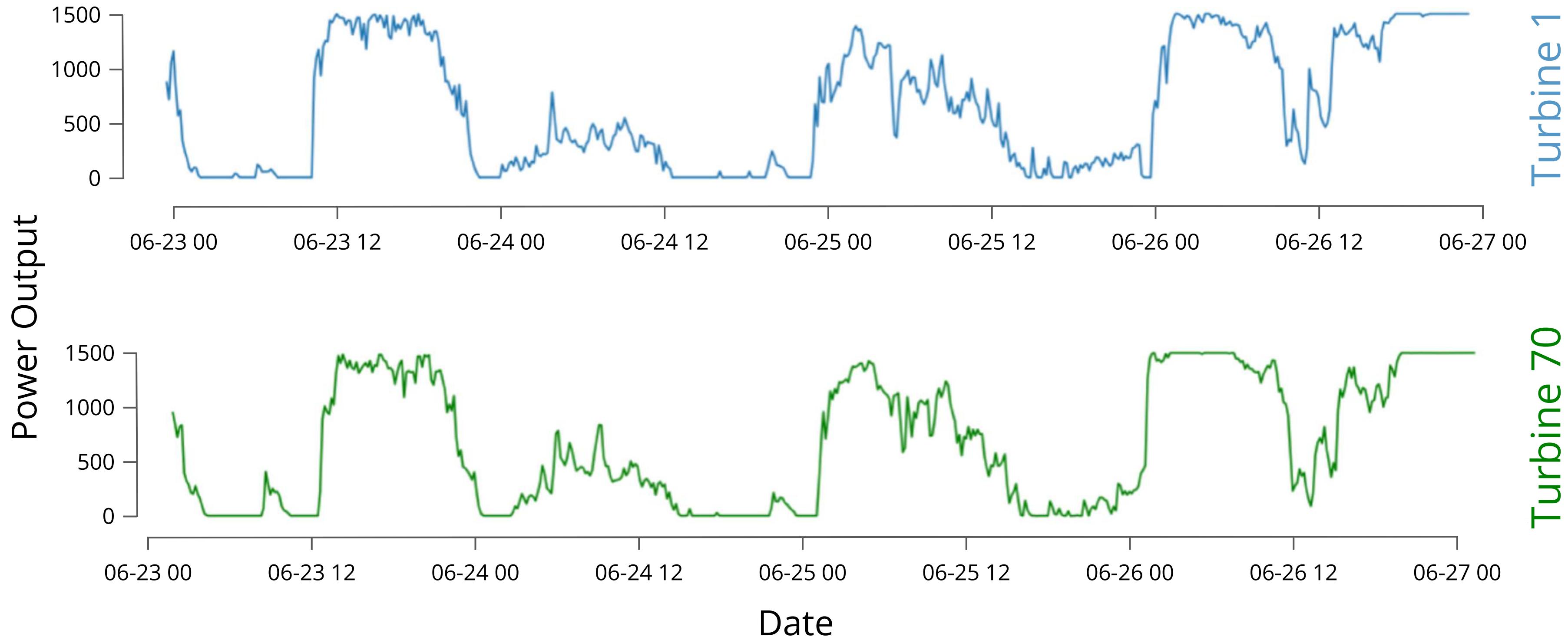
DeepLearning.AI

**Wind Power  
Project Wrap Up**

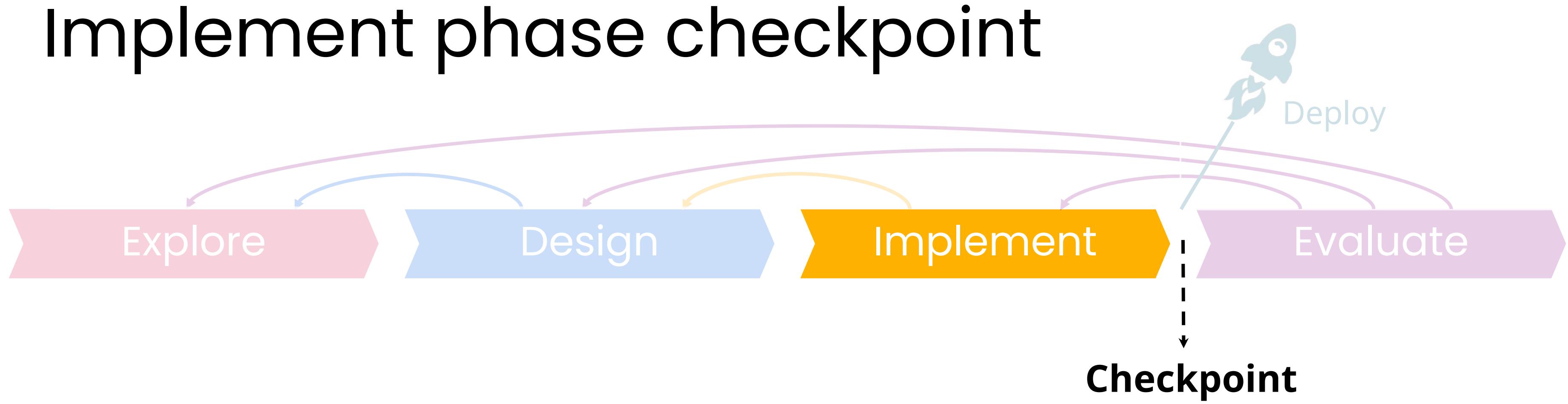
# Wind power forecasting - Feature importance



# Power output for two turbines



# Implement phase checkpoint



- Is your model performance acceptable?
- Are end users able to successfully use your system?

# AI and Climate Change

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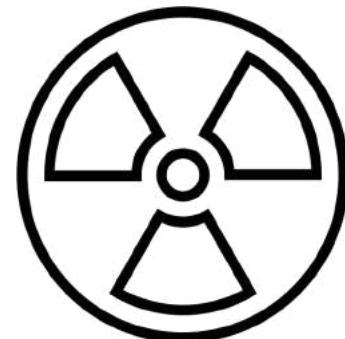


DeepLearning.AI

**Week 2  
Summary**

# Problem definition

## Non-renewable



Nuclear

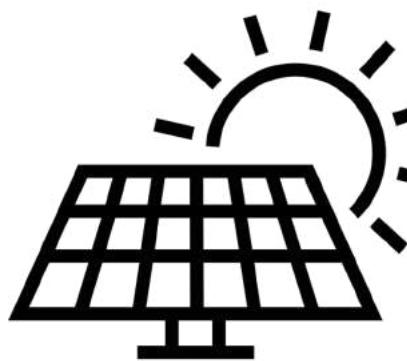


Fossil fuels

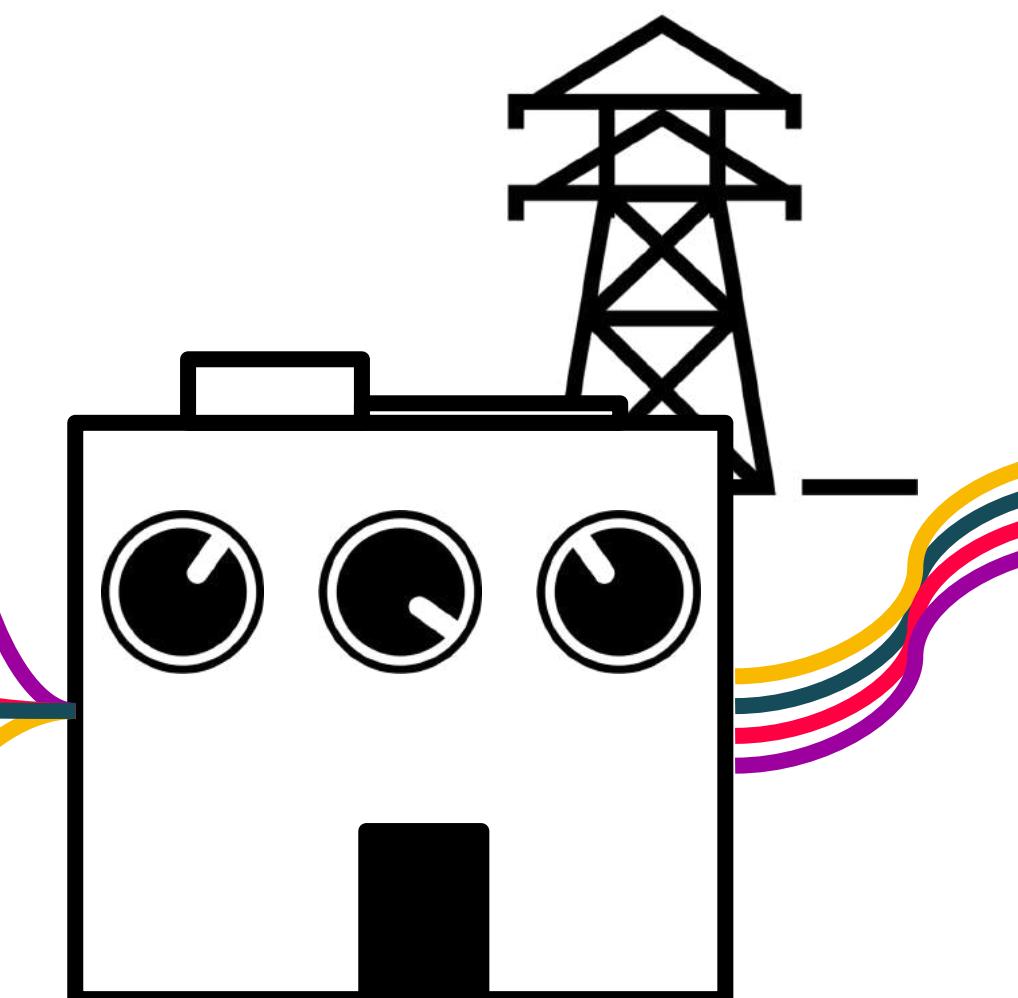
## Renewable



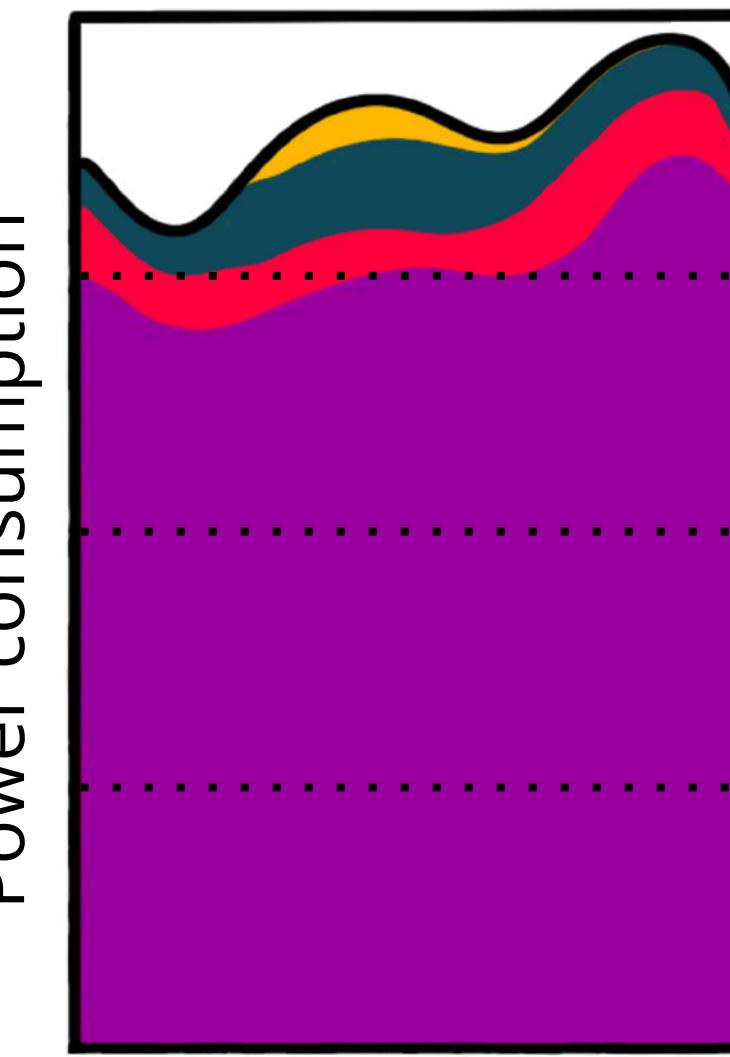
Wind



Solar



"Electrical utility companies need reliable predictions of wind power output at least 24 hours in advance in order to better plan the requirements for other power input sources into the electrical grid."



Solar

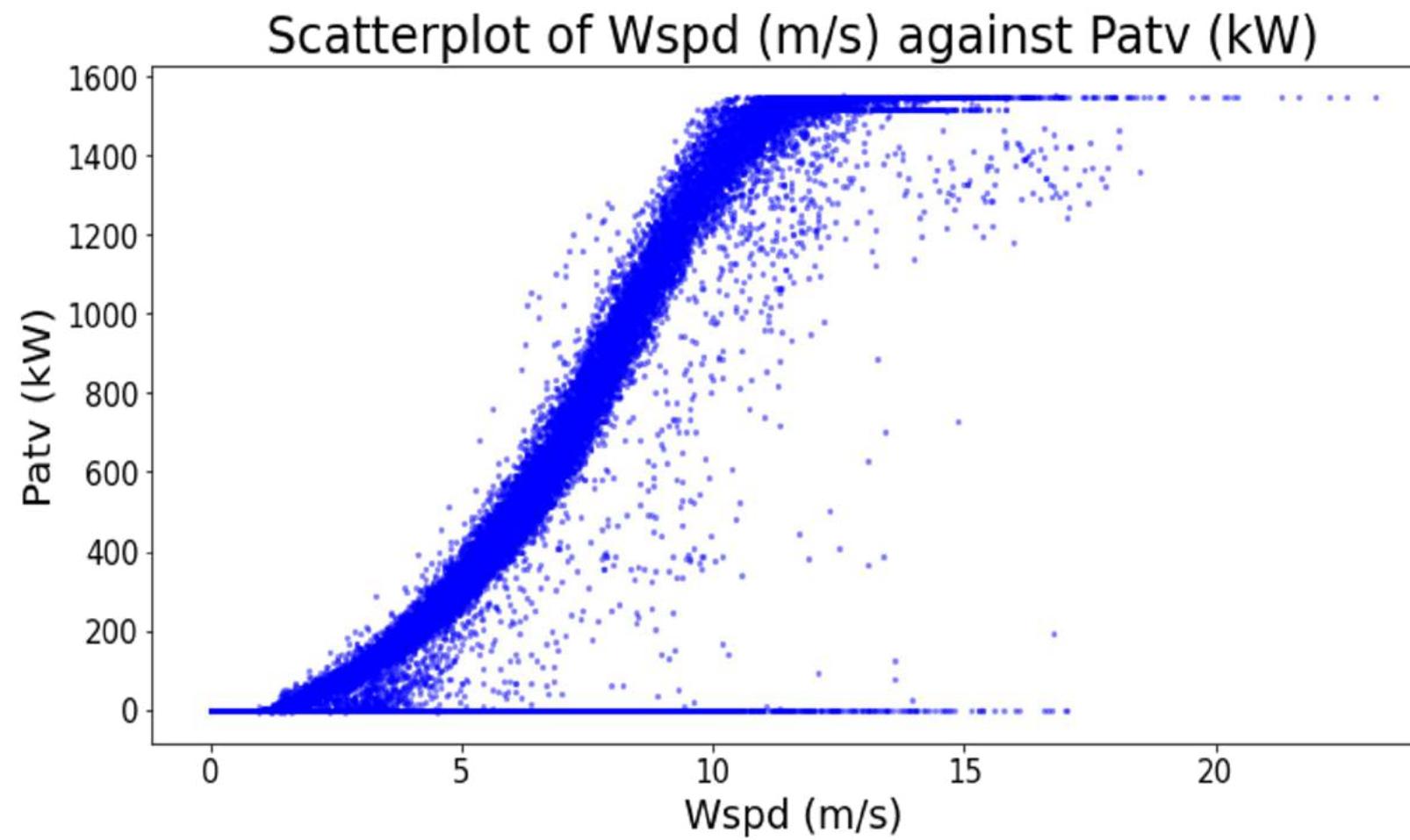
Wind

Nuclear

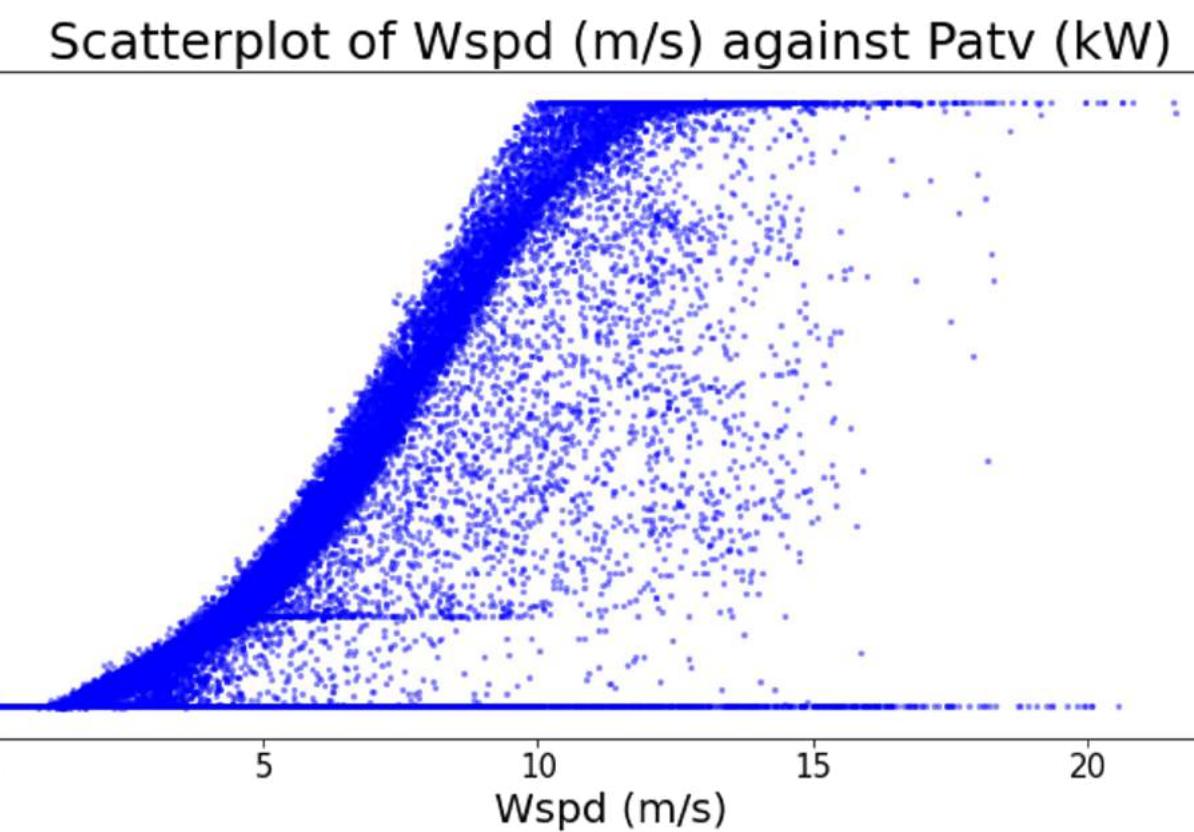
Fossil  
fuels

# Data exploration

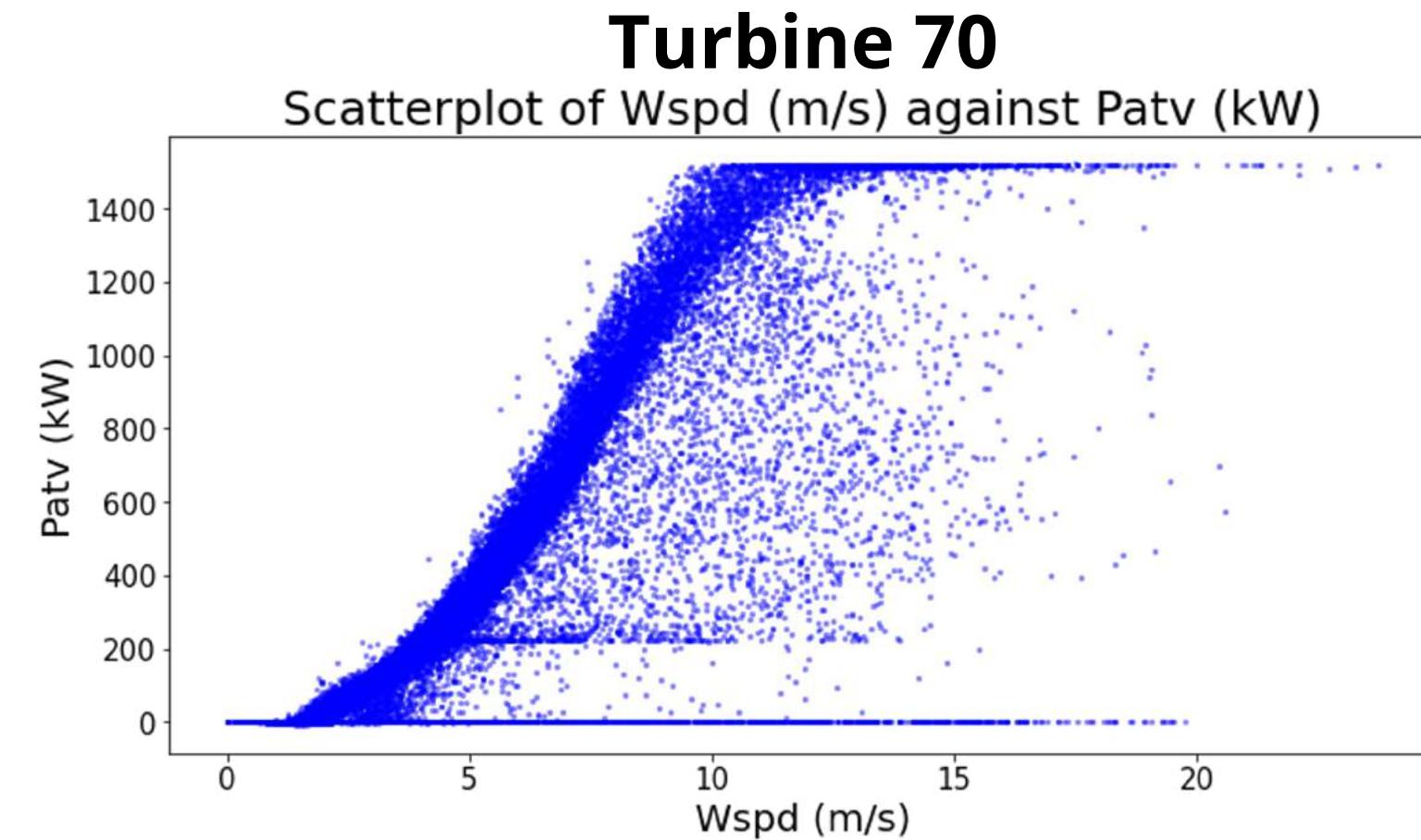
**Turbine 1**



**Turbine 10**



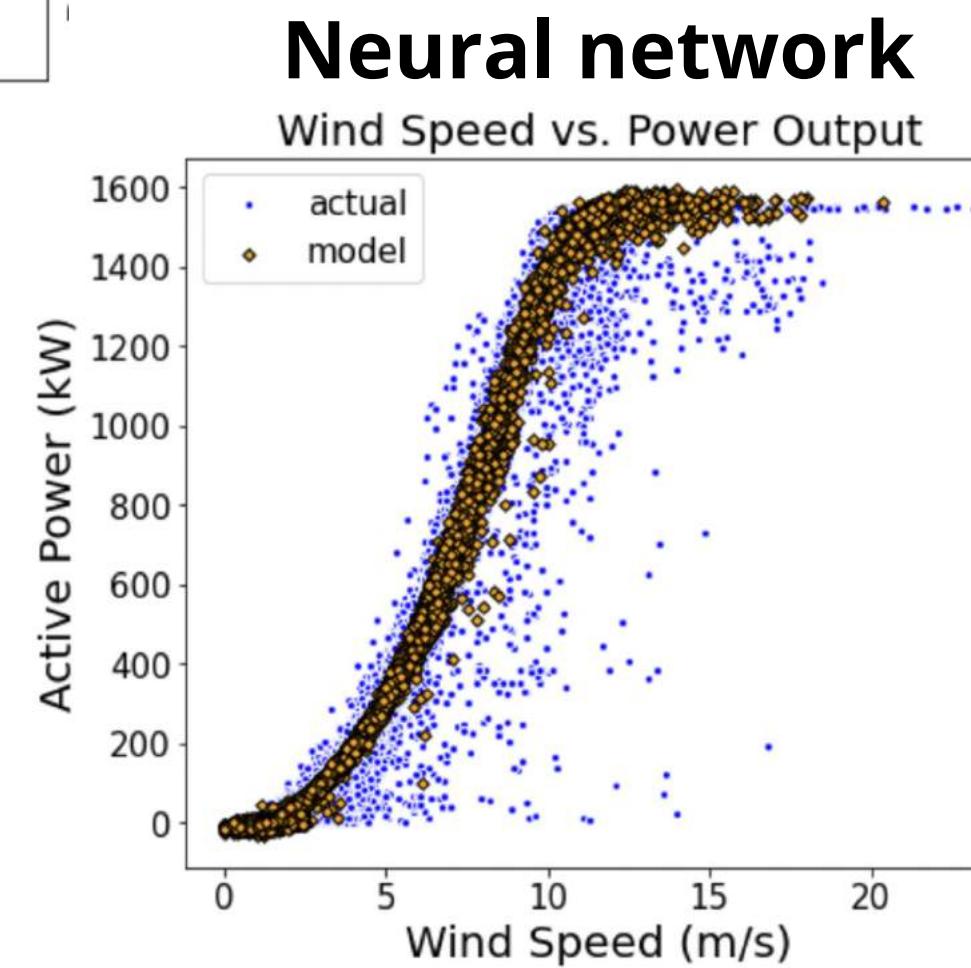
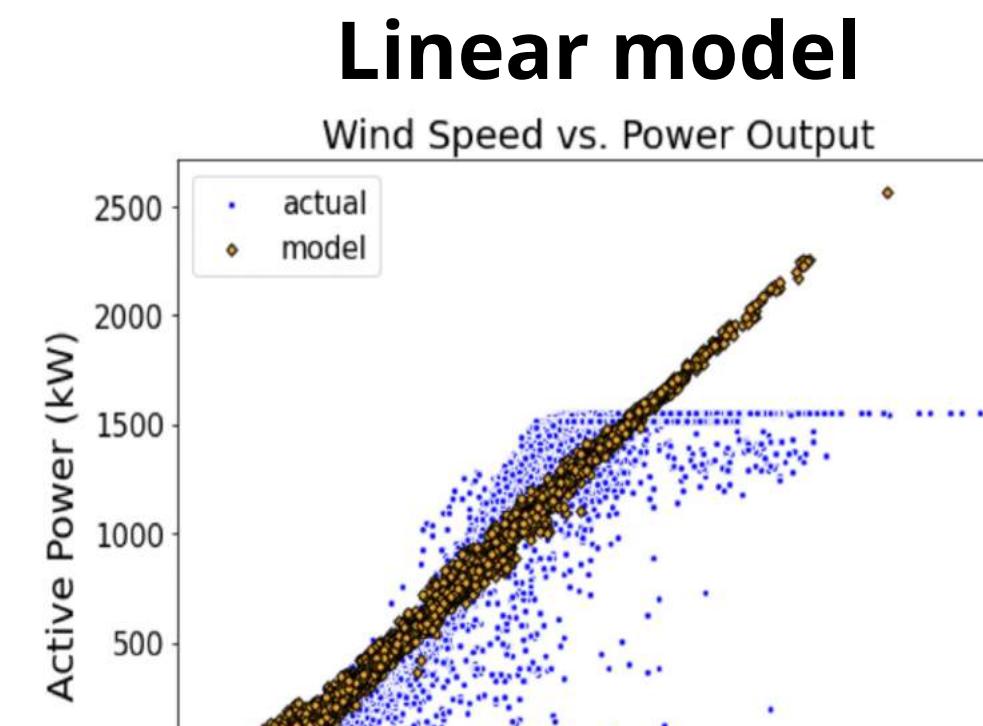
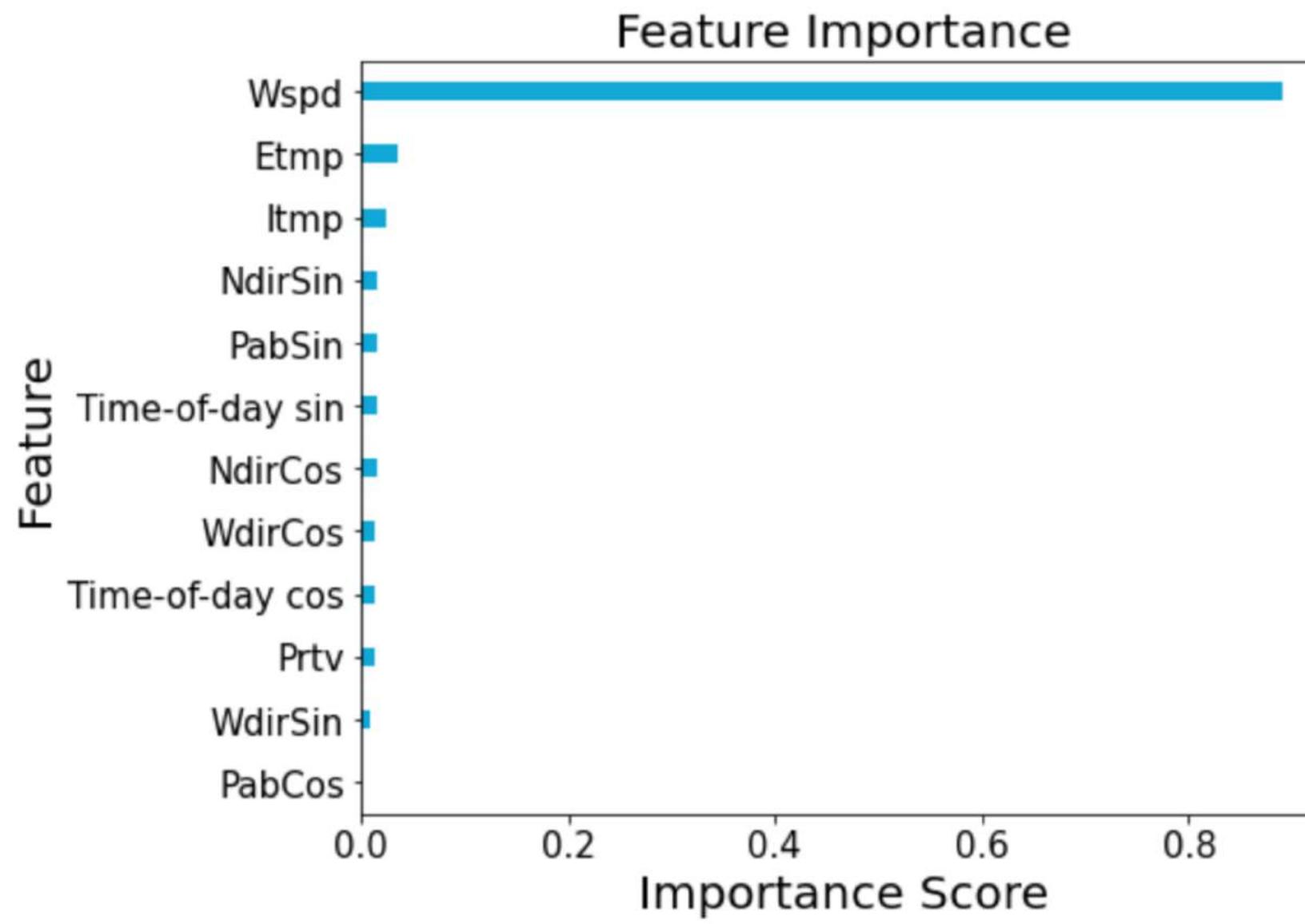
**Turbine 70**



# Data exploration



# Design phase



# Design phase

