Hochschule Flensburg
University of Applied Sciences

Wind Energy Technology Institute

Team 5: Power Prediction and Energy Arbitrage Modeling for Wind Farms Using ML

Market Integration and Commercial Optimization, WiSe 2025/26

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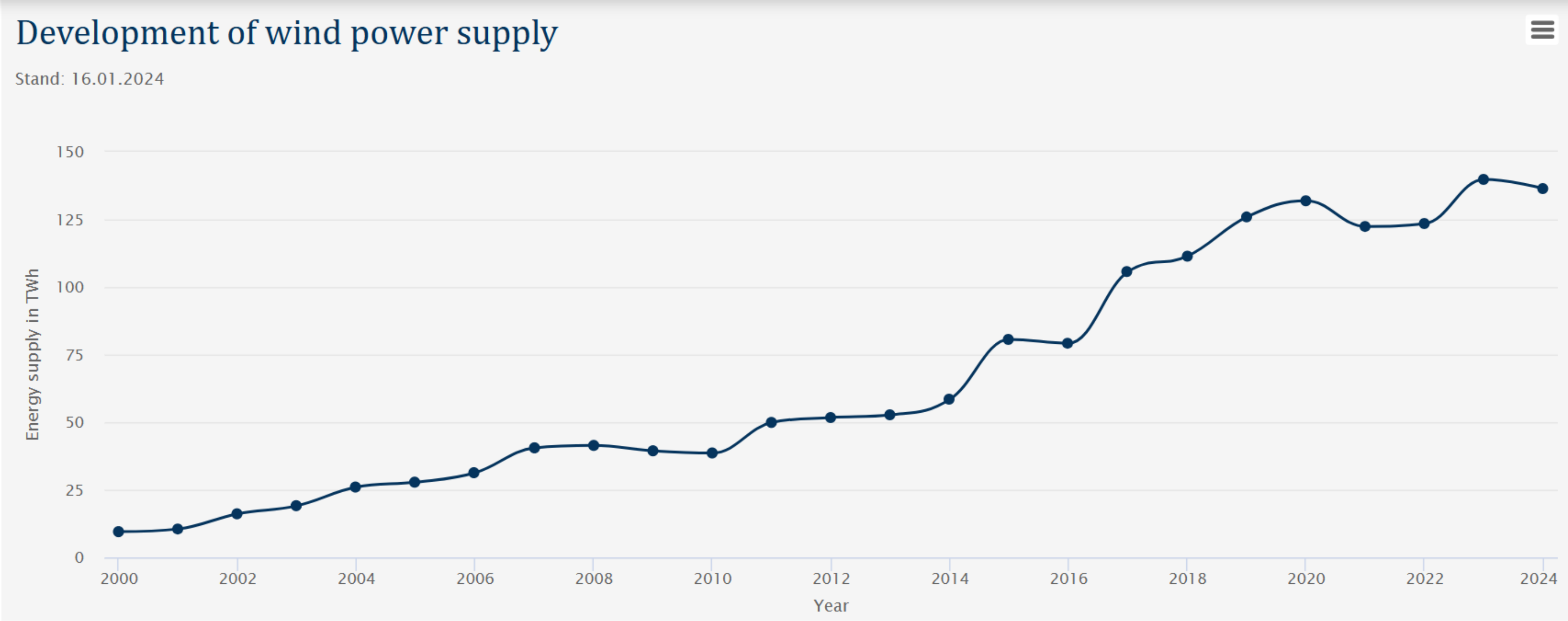
Date : 06.01.2026
Place: Flensburg

Overview

1. Introduction

- **Wind Energy:** One of the fastest-growing (Germany)
- Wind power (variable) → wind speeds (change)
- Electricity markets (fluctuate) → Wind production (high)

- Modern energy systems increasingly use **data** and **machine learning:**
  - improve forecasting
  - operational decisions



Reference: [Statistics Germany | BWE e.V.]

2. Problem Statements

- Wind power output changes every hour → difficult to predict
- Electricity prices fluctuate strongly → revenue is uncertain
- Selling at the wrong time reduces profit for wind-farm operators
- Hard to know when storing energy will be more profitable than selling
- A **data-driven ML model** is needed to support STORE vs SELL decisions

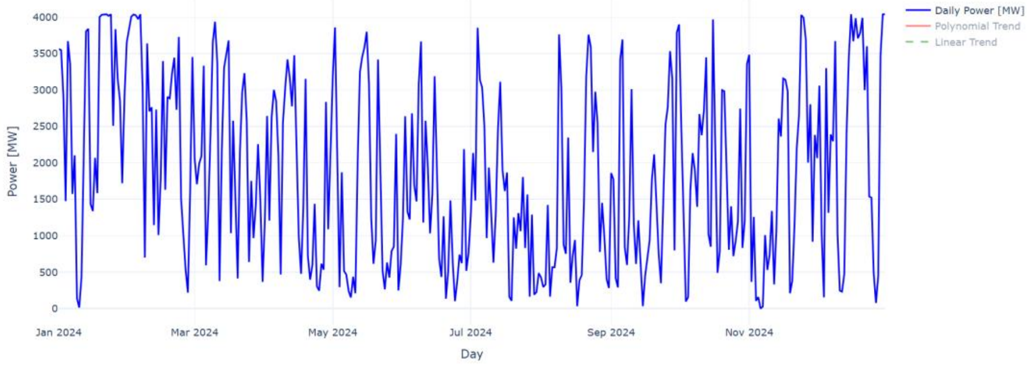


Fig 2.1: Day Vs Power generation (MW) (Own).

Research Question:

1. Can machine-learning models accurately predict wind-farm power output and identify the optimal hours to STORE or SELL energy?

2. If low-price energy is stored as hydrogen, can the hybrid system remain economically profitable without subsidies?

3. Data and Preprocessing

1. Wind Data (ERA5):

- Used ERA5 reanalysis dataset for wind components (**u100**, **v100**) **(3)**
- Calculated wind speed at **100m**
- Converted to a clean CSV file **(wind_speed.csv)**

2. Electricity Price Data:

- Imported **sport market prices** (EUR/MW) **(5)**
- Cleaned timestamps and extracted **hour** and **month**

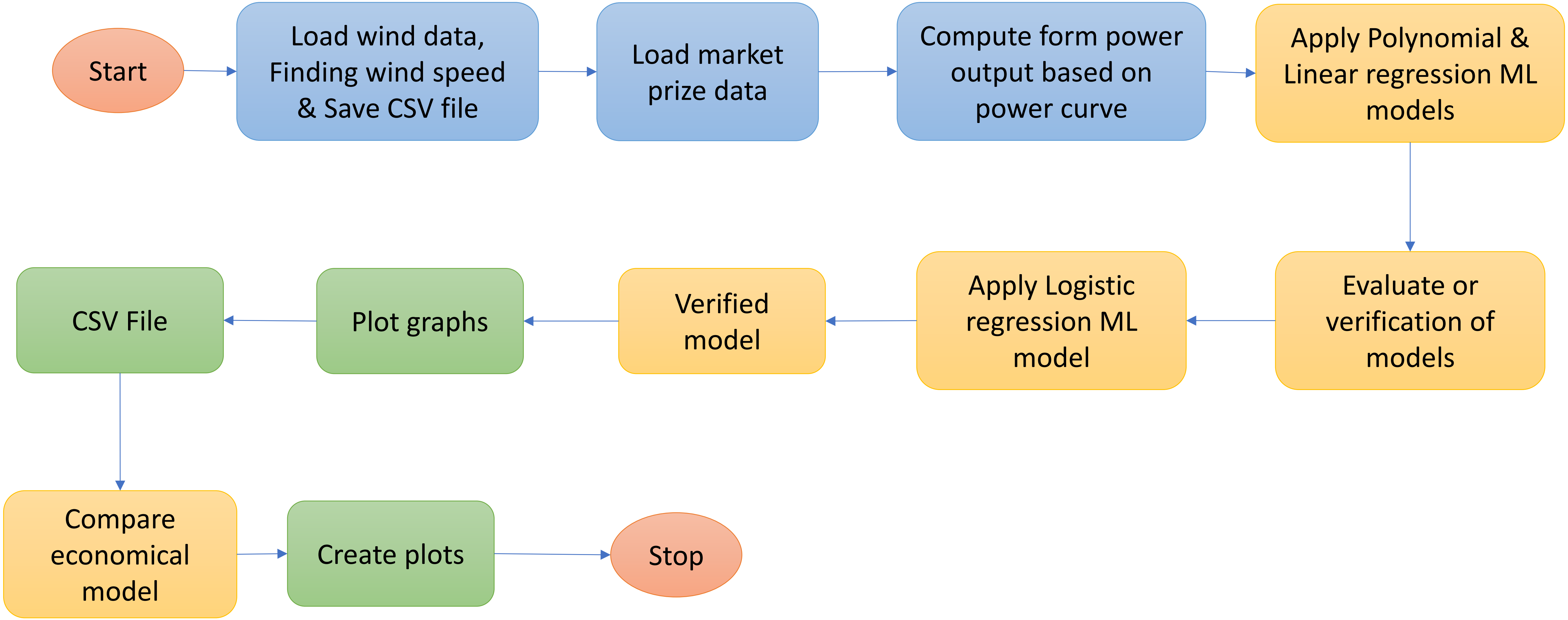
3. Power Curve Processing:

- Location: **Reusenkoog, Germany**
- Scaled for **51 turbines** (total farm capacity) **(1)**
- Used **Vestas V112-3.3 MW** turbine power curve **(2)**
- Converted wind speed → power output

4. Electricity Price Data:

- Model: 50 MW PEM System **(4)**
- Efficiency: 52.2 kWh /kg H2 Nominal
- Min Load: 10% (5MW)

4. Flowchart


Start
Load wind data, Finding wind speed & Save CSV file
Load market prize data
Compute form power output based on power curve
Apply Polynomial & Linear regression ML models
Evaluate or verification of models
Apply Logistic regression ML model
Verified model
Plot graphs
CSV File
Compare economical model
Create plots
Stop

5. Machine Learning Models

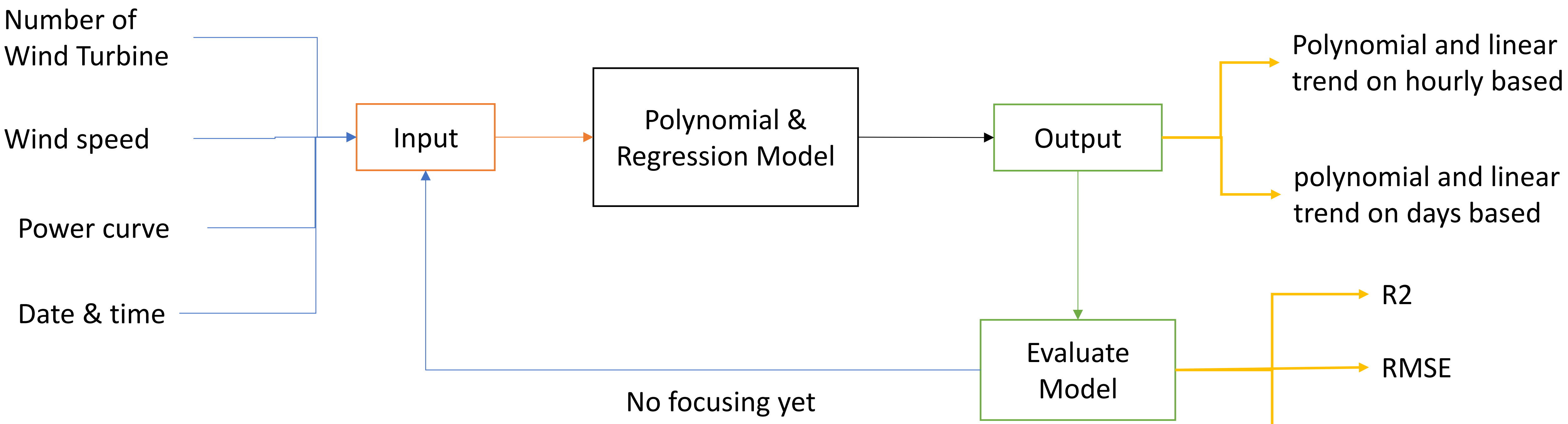
Why ML?

1. Fast growing and widely used field
2. ML helps automate STORE vs SELL decisions
3. Gives a more mathematical and accurate solution
4. Patterns are **non-linear** and difficult to capture manually
5. ML learns from historical data and improves decision accuracy

Reference: https://www.vecteezy.com/free-photos/machine-learning

5. Machine Learning Models

Block Diagram of Wind Farm Model:



5. Machine Learning Models

Decision Arbitrage Model:

Power (Model 1)

Price

Date & time

Seasonal Demand Index

Store if price < 25

Input

Logistic Regression Model

Output

No focusing yet

Season	Months	Factor
Winter	12, 1, 2	1.2
Spring	3, 4, 5	0.9
Summer	6, 7, 8	0.8
Autumn	9, 10, 11	1

Coefficient Interpretation

Decision Plot (SELL (0) or STORE (1))

Gives Hours and Days for store energy

Final CSV File

- Date
- Hour
- Power, price
- Store decision

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6. Hydrogen Storage Concept

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Set Economical and Technical Parameters:

- H_2 price = **4 (€/kg)**
- variable O&M = **20% (€/kg)**
- Electricity Required to produce 1 kg H_2= **52.2 (kWh/kg)**
- Maximum power capacity of the electrolyze = **50 (MW)**
- Min load fraction = **10%**

Compute Breakeven Electricity Prize:

$$P^{*}\left(\frac{€}{MWh}\right)=\frac{(H_2\text{ price }-\text{variable O\&M})*1000}{\text{Electricity Required to produce 1 kg }H_2}$$

For Each hour, decide and dispatch:

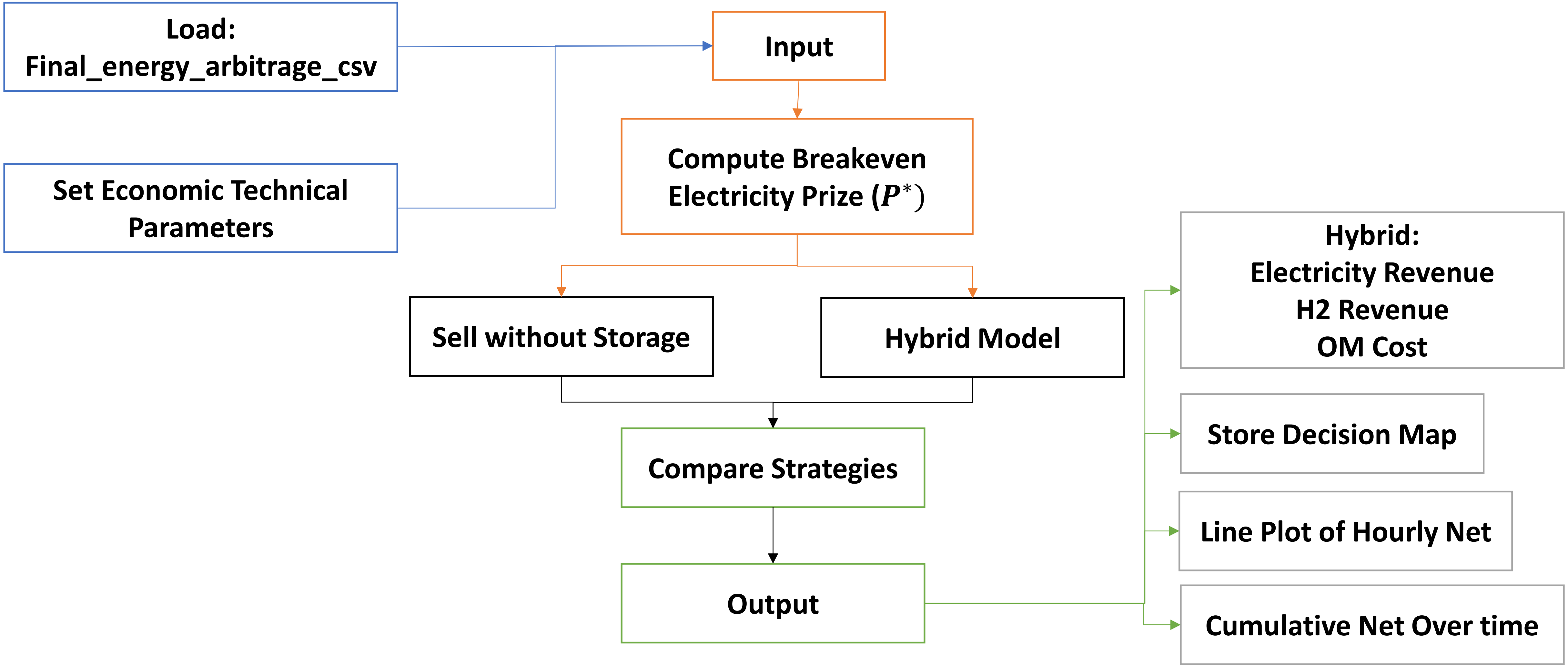
Store as H_2 :

Sell Electricity:

If store_decision = 1 and (optionally) price ≤ p*:

- Run electrolyzer at min(wind, 50 MW) if ≥ 5 MW; else off
- H_2 produced = (MW × 1000) / 52.2 kg/h
- Electricity sold = wind − electrolyzer_MW
- Hybrid net = elec revenue + H_2 revenue − var O&M

7. Economic Analysis Modelling



8. Results

Model 1: Polynomial and Regression Model

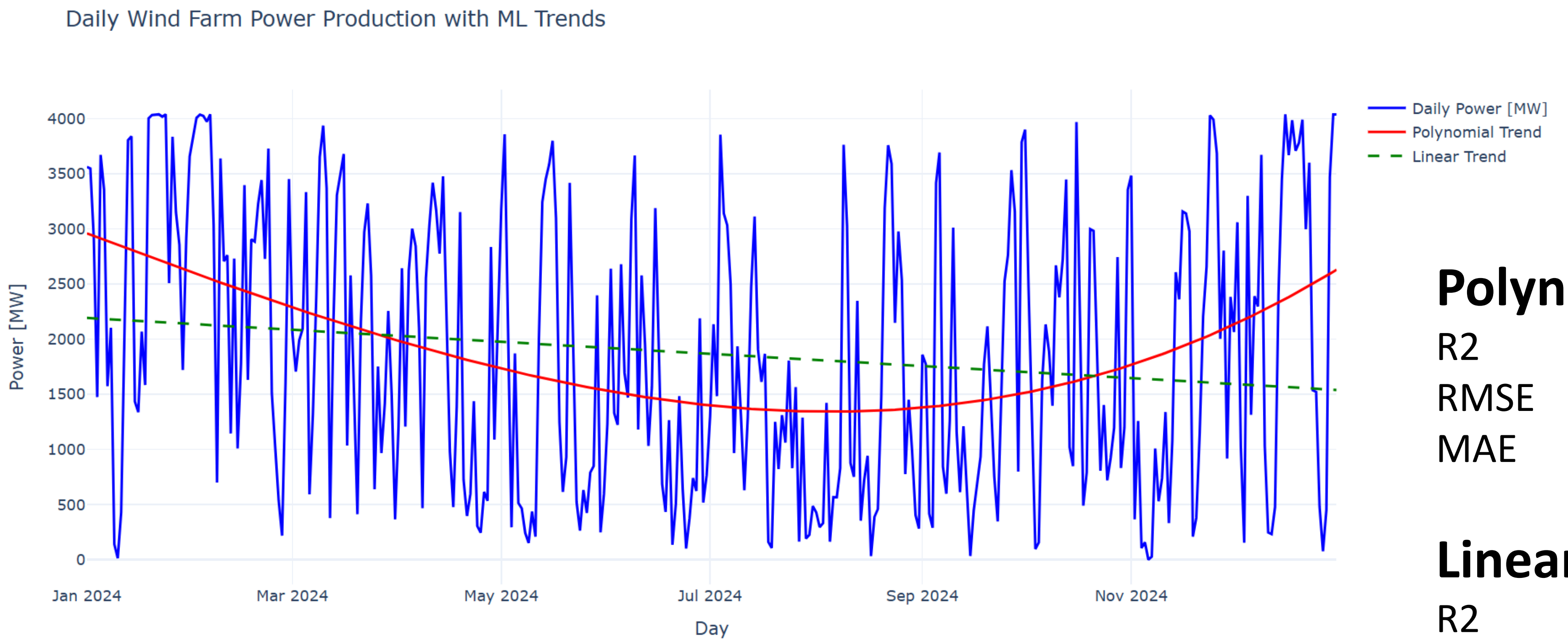


Fig 8.1: Day Vs Power

Microsoft Edge
HTML Document

Polynomial Regression Model:

R2 : 0.14
RMSE : 1155
MAE : 993

Linear Regression Model:

R2 : 0.02
RMSE : 1230
Mae : 1079

8. Results

Model 1: Polynomial and Regression Model

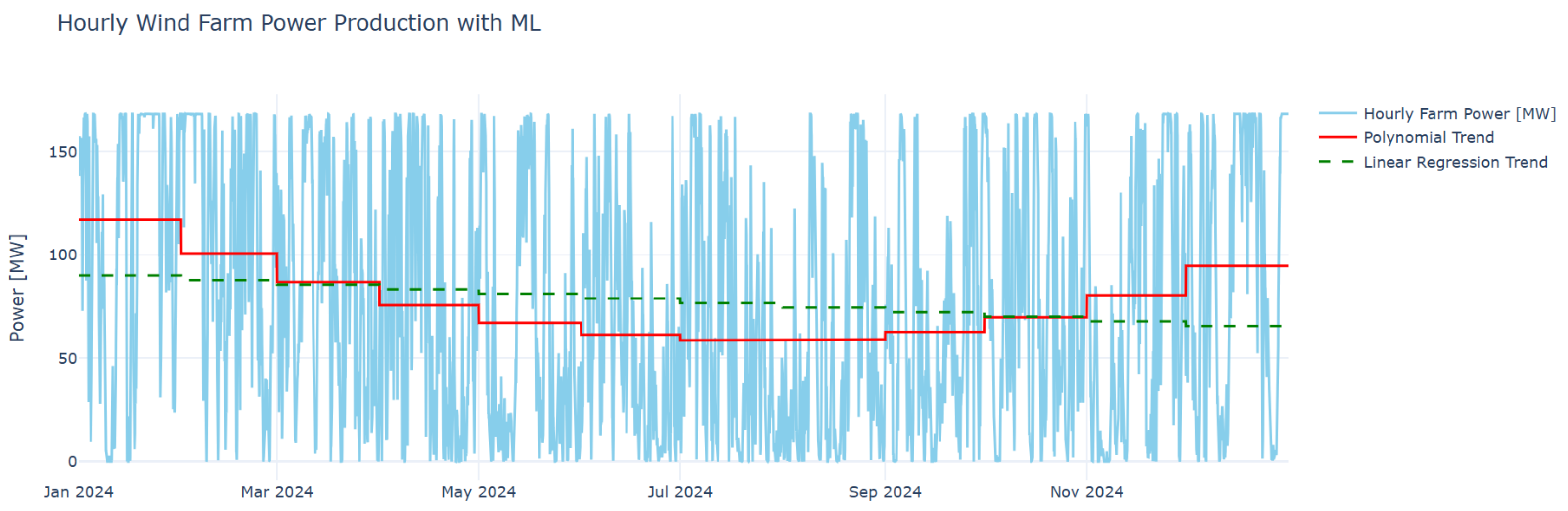


Fig 8.2: Hours Vs Power

Microsoft Edge HTML Document

Polynomial Regression Model:

R2 : 0.94
RMSE : 3347
MAE : 2723

Linear Regression Model:

R2 : 0.16
RMSE : 12308
Mae : 10524

8. Results

Model 2: Logistic Regression Model

Microsoft Edge HTML Document

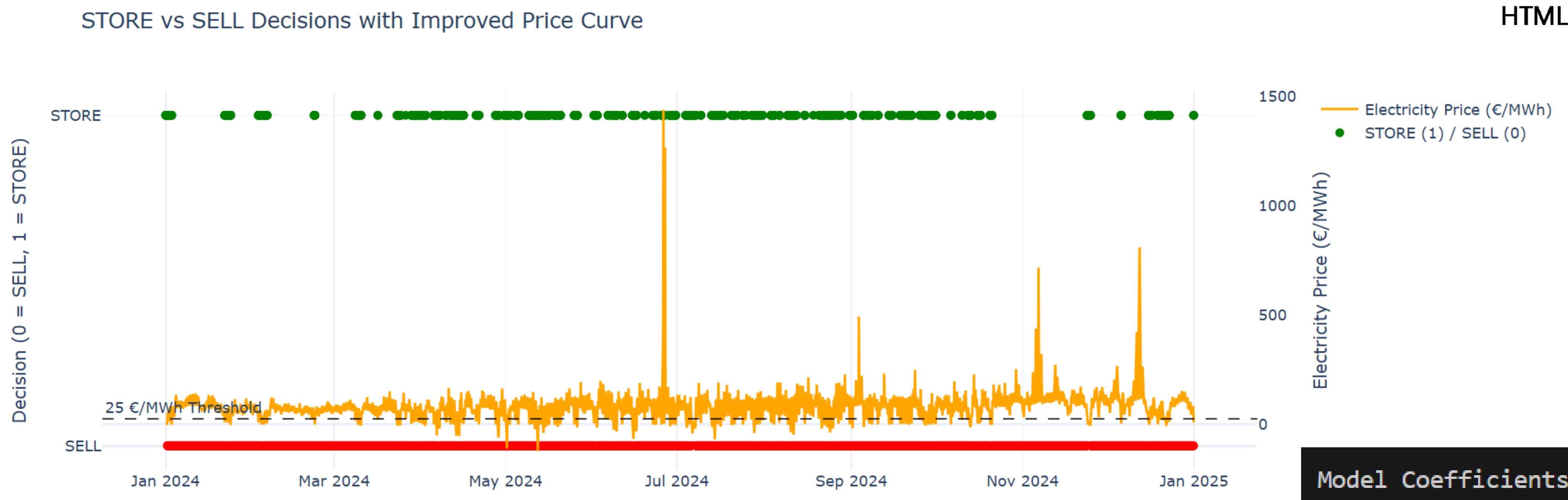


Fig 8.3: Hours Vs Store or Sell Vs Electricity Price

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Model Coefficients:

Power              : -0.01
Price              : -2.82
Seasonal Demand    : -0.09
```

8. Results

Model 3: Hydrogen Storage Concepts

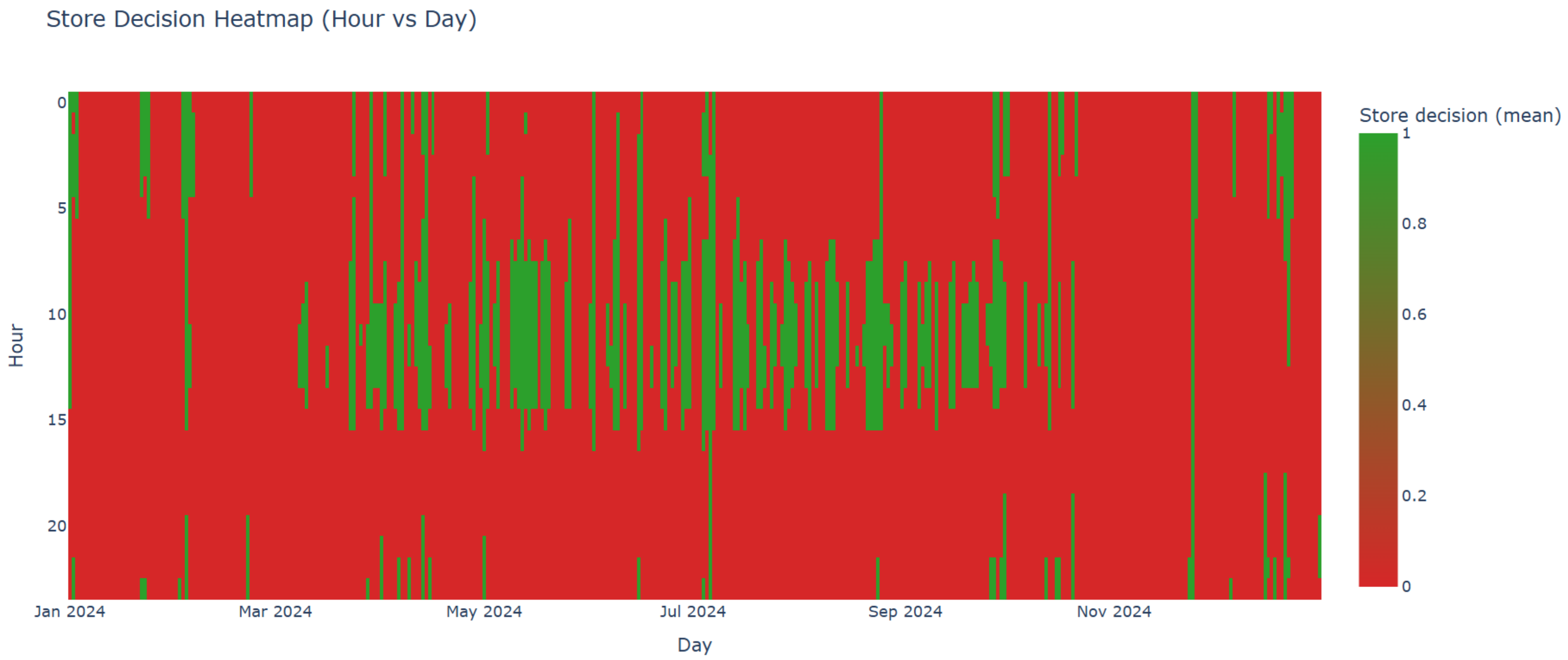

Fig 8.4: Store Decision Map

Microsoft Edge HTML Document

8. Results

Model 3: Hydrogen Storage Concepts

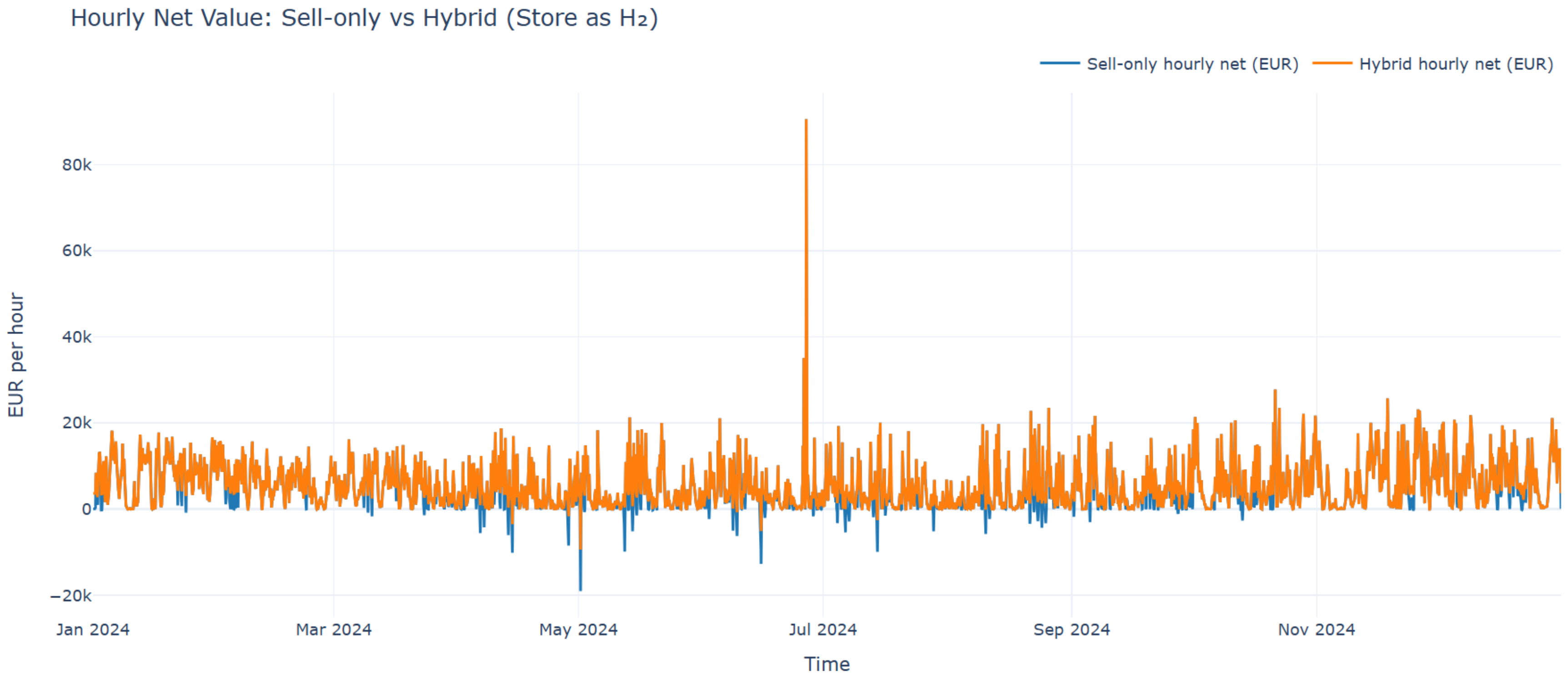

Fig 8.5: Hourly Net Value : Without Storage and With Storage

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Model 3: Hydrogen Storage Concepts

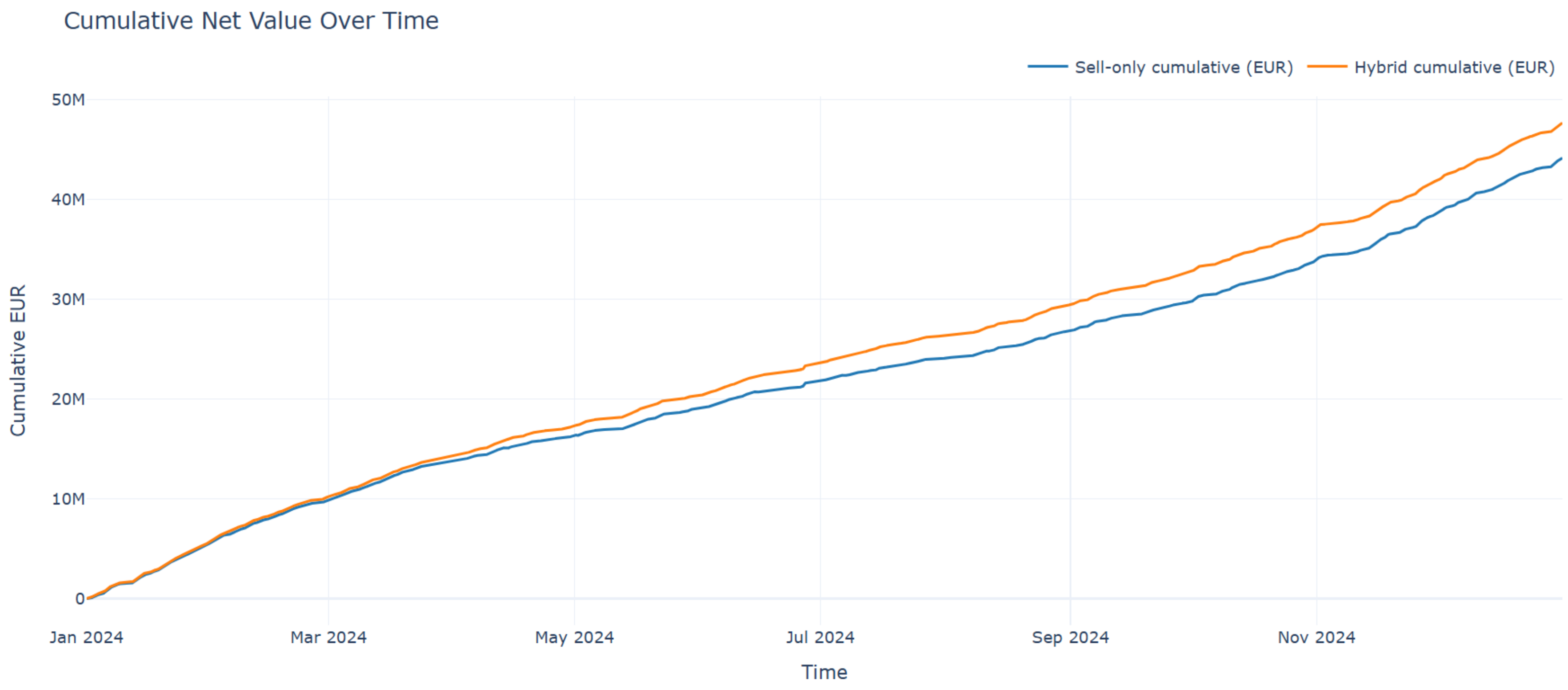

Fig 8.6: Cumulative Net Value Over Time

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9. Conclusion

- Improves predicting of wind power output
- Optimizing when to sell electricity or store as hydrogen

the current ML model is not fully accurate:

- It ignores some additional input variables
- Uses only one year of data (2024)

- Profitability depends on hydrogen price and system efficiency

10. Future Tasks

- Add more feature of wind (air density, wind direction, turbulence)
- Improve power curve for better outputs
- Try higher order polynomial regression
- Use some other ML models
- Improve data cleaning
- Possible to use more years of data
- Add more economic features (forecasted prices, market demand, so on)
- Optimize the decision threshold
- Use real seasonal power demands data

Reference: Wind Farm Layout Design at NAYXA || We´re Wind Energy Experts

References

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3. ECMWF. (2024). ERA5 Reanalysis Data. Copernicus Climate Change Service.
4. Siemens Energy. (2023). Silyzer 300 PEM Electrolyzer Datasheet.
5. Day-Ahead Auction prices (DE-LU Zone, 2024)