

Turbine Modelling project

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The data

1) 4 Turbines:

R80711

R80721

R80736

R80790

2) Time series (approx 2013–2018)

3) Turbine and weather measures

Goal project

I made followed the Digital twins suggestion

- 1) Developed Machine Learning models
- 2) Compared their predictions with reality
- 3) Interpreted the output differences
- 4) Extra step:
How would this be interesting/engaging to Engie?

Methodology

- 1) Developed a Machine Learning pipeline
- 2) Developed 3 different approaches:
 - 1) Turbine Specific
 - 2) Turbine Leave-One-Out (LOO)
 - 3) Turbine Generalised
- 3) Using the Machine Learning pipeline, for each approach:
I modelled several regression problems
(different combinations of inputs and outputs)
- 4) Analysed and interpreted results

Turbine-specific/generalized/LOO approaches

Generalised (one model for all turbines):

- all turbines are configured similarly, so they all should work similarly
- when one turbine has divergent results, could it have a malfunction?

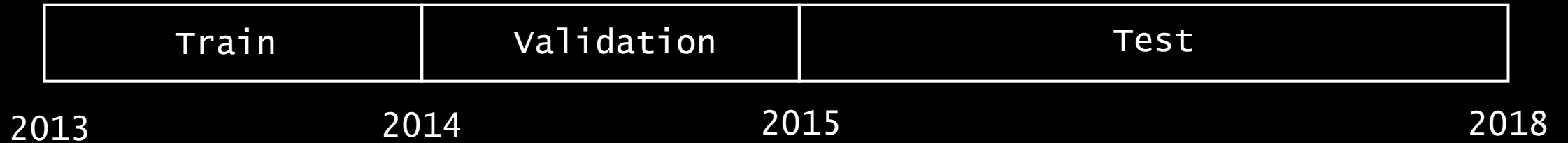
LOO (train with A,B,C and test with D, then rotate):

- same assumptions as LOO

Specific (one model for each turbine):

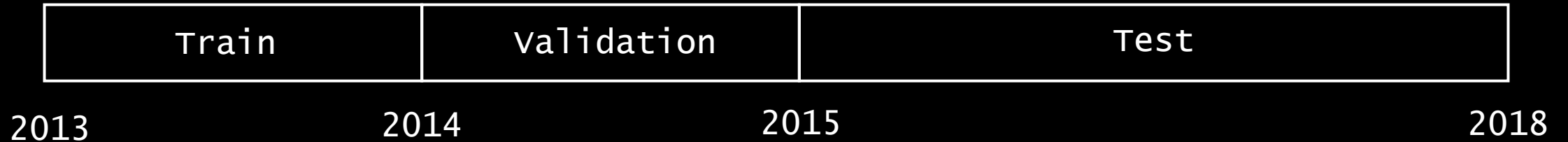
- each turbine has its setting, and should have its model.
- we can monitor, in a more detailed manner, the existence of performance changes

Machine Learning Pipeline



- Chronological data splitting to simulate real-life
- To account for time causality
- I assumed 1 year for training, 1 year for validation as routine visits to turbines may be from 6 months to 1 year

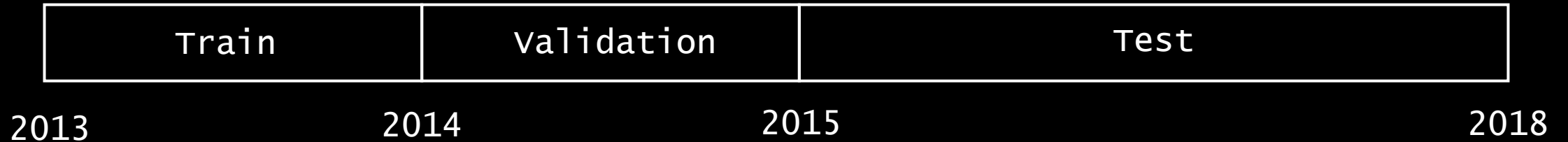
Machine Learning Pipeline



With training data:

- Verified redundancies (correlation coef.>0.95)
- Ordered features by relevance (correlation coef. with output)
- z-scored the features

Machine Learning Pipeline



With validation data:

- Eliminated training redundant features
- Ordered features by training relevance
- z-scored the features with training parameters
- Grid-search for choosing k features (possibility for other hyperparameters)

Grid-search pseudo-code:

```
model=decisionTreeRegressor()

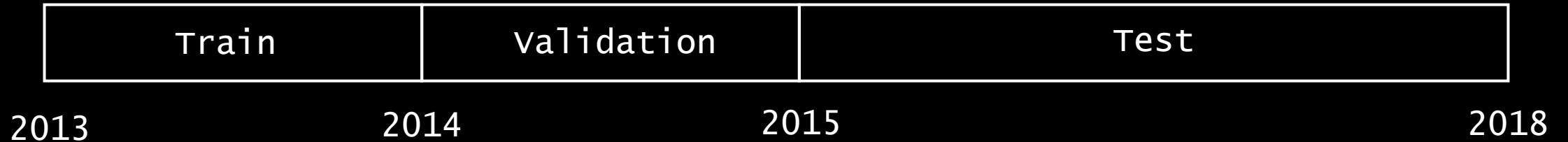
for i in range(0,k_features):
    model.fit(x_train(k_features(i)),y_train)
    y_pred=model.predict(x_validation)
    RMSE(i)=RMSE(y_validation,y_pred)

k_optimal=k_features(utils.choose_best_tradeoff_k(RMSE))
```

Final model:

```
model.fit(x_train(k_features(k_optimal(i))),y_train)
```


Machine Learning Pipeline



With testing data:

- Eliminated training redundant features
- Ordered features by training relevance
- z-score the features with training parameters
- Applied the final model
- Performance evaluation:
 - RMSE(normalized and non-normalized)
 - Normalize Mean Absolute Error (relative to its maximum value)
 - Mean error (and analyse it monthly or annually)

Modelled Regression Problems

Turbine power generation as a sequence of processes:

Wind \rightarrow Rotor Speed $\xrightarrow{\text{(Torque Converter)}}$ Torque \rightarrow Active Power
(Tip Speed Ratio)

Several regression outputs (Y):

- Tip Speed Ratio
- Rotor Speed
- Torque
- Torque Converter
- Active Power

For each regression output:

I tried different sets of features (X) concerning this chronology of processes

Modelled Regression Problems

Turbine power generation as a sequence of processes:

Wind $\xrightarrow{\text{(Tip Speed Ratio)}}$ Rotor Speed $\xrightarrow{\text{(Torque Converter)}}$ Torque \rightarrow Active Power

Example: For $Y=f(X)$ regression problem, for Active Power (Y)

- 1) $X = \text{weather measures, wind, Rotor Speed, Torque} \rightarrow Y = \text{Active Power}$
- 2) $X = \text{weather measures, wind, Rotor Speed} \rightarrow Y = \text{Active Power}$
- 3) $X = \text{weather measures, wind} \rightarrow Y = \text{Active Power}$

Modelled Regression Problems

Wind → Rotor Speed → Torque → Active Power

Generalised Turbine Models							
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00
R80711	all except P, Q, Rm	Ws, Rs	70,11	0,04	0,98	21,69	0,01
R80721	all except P, Q, Rm	Ws, Rs	44,23	0,02	0,99	0,30	0,00
R80736	all except P, Q, Rm	Ws, Rs	48,46	0,02	0,99	7,45	0,00
R80790	all except P, Q, Rm	Ws, Rs	61,99	0,03	0,98	15,11	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	97,16	0,05	0,96	35,65	0,02
R80721	all except P, Q, Rm, Rs,	Ws, Ba	67,61	0,03	0,97	0,30	0,00
R80736	all except P, Q, Rm, Rs,	Ws, Ba	72,80	0,04	0,97	5,40	0,00
R80790	all except P, Q, Rm, Rs,	Ws, Ba	88,98	0,04	0,96	17,35	0,01

Modelled Regression Problems

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB				
1																																
2		Generalised Turbine Models											LOO Turbine Models											Specific Turbine Models								
3																																
4	Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm				
5	R80711	all except P,Q	Rm	5.13	0.00	1.00	-0.06	0.00			R80711	all except P,Q	Rm	5.08	0.00	1.00	-0.20	0.00			R80711	all except P,Q	Rm	5.89	0.00	1.00	-0.24	0.00				
6	R80721	all except P,Q	Rm	4.86	0.00	1.00	0.01	0.00			R80721	all except P,Q	Rm	4.73	0.00	1.00	-0.07	0.00			R80721	all except P,Q	Rm	5.49	0.00	1.00	-0.25	0.00				
7	R80736	all except P,Q	Rm	3.39	0.00	1.00	-0.07	0.00			R80736	all except P,Q	Rm	3.45	0.00	1.00	-0.15	0.00			R80736	all except P,Q	Rm	4.11	0.00	1.00	0.23	0.00				
8	R80790	all except P,Q	Rm	3.52	0.00	1.00	-0.09	0.00			R80790	all except P,Q	Rm	4.33	0.00	1.00	0.42	0.00			R80790	all except P,Q	Rm	5.08	0.00	1.00	-1.25	0.00				
9																																
10	R80711	all except P,Q,Rm	Ws, Rs	70.11	0.04	0.98	21.69	0.01			R80711	all except P,Q,Rm	Rs, Ws	58.22	0.03	0.98	8.14	0.00			R80711	all except P,Q,Rm	Rs, Ws	63.62	0.03	0.98	17.20	0.01				
11	R80721	all except P,Q,Rm	Ws, Rs	44.23	0.02	0.99	0.30	0.00			R80721	all except P,Q,Rm	Rs, Ws	40.57	0.02	0.99	-0.27	0.00			R80721	all except P,Q,Rm	Rs, Ws	38.63	0.02	0.99	-5.54	0.00				
12	R80736	all except P,Q,Rm	Ws, Rs	48.46	0.02	0.99	7.45	0.00			R80736	all except P,Q,Rm	Rs, Ws	45.16	0.02	0.99	6.20	0.00			R80736	all except P,Q,Rm	Rs, Ws	45.12	0.02	0.99	1.86	0.00				
13	R80790	all except P,Q,Rm	Ws, Rs	61.99	0.03	0.98	15.11	0.01			R80790	all except P,Q,Rm	Rs, Ws	51.33	0.03	0.99	3.94	0.00			R80790	all except P,Q,Rm	Rs, Ws	69.26	0.03	0.98	22.79	0.01				
14																																
15	R80711	all except P,Q,Rm,Rs	Ws, Ba	86.96	0.04	0.97	17.99	0.01			R80711	all except P,Q,Rm,Rs,Ws,Ba		88.29	0.04	0.97	17.05	0.01			R80711	all except P,Q,Rm,Rs,Ws,Ba		88.31	0.04	0.97	26.48	0.01				
16	R80721	all except P,Q,Rm,Rs	Ws, Ba	59.10	0.03	0.98	-0.41	0.00			R80721	all except P,Q,Rm,Rs,Ws,Ba		58.92	0.03	0.98	-0.16	0.00			R80721	all except P,Q,Rm,Rs,Ws,Ba		62.11	0.03	0.98	-17.67	-0.01				
17	R80736	all except P,Q,Rm,Rs	Ws, Ba	68.18	0.03	0.98	4.88	0.00			R80736	all except P,Q,Rm,Rs,Ws,Ba		56.56	0.03	0.98	2.21	0.00			R80736	all except P,Q,Rm,Rs,Ws,Ba		60.01	0.03	0.98	10.27	0.01				
18	R80790	all except P,Q,Rm,Rs	Ws, Ba	17.19	0.01	0.97	17.19	0.01			R80790	all except P,Q,Rm,Rs,Ws,Ba		80.30	0.04	0.97	0.97	0.00			R80790	all except P,Q,Rm,Rs,Ws,Ba,Ws1	AAAAAA	0.06	0.93	31.52	0.02					
19																																
20																																
21																																
22	Torque Converter	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Torque Converter	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Torque Converter	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm				
23	R80711	all except P,Rm	Rs, Ws	4.28	0.04	0.98	1.43	0.01			R80711	all except P,Rm	Rs, Ws	3.4	0.03	0.99	0.99	0.01			R80711	all except P,Rm	Rs, Ws	3.88	0.03	0.98	1.03	0.01				
24	R80721	all except P,Rm	Rs, Ws	2.64	0.02	0.99	2.64	0.02			R80721	all except P,Rm	Rs, Ws	2.39	0.02	0.99	-0.02	0.00			R80721	all except P,Rm	Rs, Ws	2.35	0.02	0.99	-0.34	0.00				
25	R80736	all except P,Rm	Rs, Ws	2.88	0.02	0.99	2.88	0.02			R80736	all except P,Rm	Rs, Ws	2.7	0.02	0.99	0.39	0.00			R80736	all except P,Rm	Rs, Ws	2.74	0.02	0.99	0.06	0.00				
26	R80790	all except P,Rm	Rs, Ws	3.66	0.03	0.98	3.66	0.03			R80790	all except P,Rm	Rs, Ws	3.05	0.03	0.99	0.22	0.00			R80790	all except P,Rm	Rs, Ws	4.14	0.03	0.98	1.42	0.01				
27																																
28	R80711	all except P,Rm,Rs	Ws, Ba	5.93	0.05	0.95	1.84	0.02			R80711	all except P,Rm,Rs	Ws, Ba	5.42	0.05	0.96	1.1	0.01			R80711	all except P,Rm,Rs	Ws, Ba	5.37	0.04	0.96	1.66	0.01				
29	R80721	all except P,Rm,Rs	Ws, Ba	4.54	0.04	0.97	0.09	0.00			R80721	all except P,Rm,Rs	Ws, Ba	3.96	0.03	0.97	0.07	0.00			R80721	all except P,Rm,Rs	Ws, Ba	4.16	0.03	0.97	-1.11	-0.01				
30	R80736	all except P,Rm,Rs	Ws, Ba	4.83	0.04	0.97	0.19	0.00			R80736	all except P,Rm,Rs	Ws, Ba	4.88	0.04	0.97	1.13	0.01			R80736	all except P,Rm,Rs	Ws, Ba	4.1	0.03	0.98	0.72	0.01				
31	R80790	all except P,Rm,Rs	Ws, Ba	5.54	0.05	0.96	1.03	0.01			R80790	all except P,Rm,Rs	Ws, Ba	4.89	0.04	0.97	0.37	0.00			R80790	all except P,Rm,Rs	Ws, Ba	6.09	0.05	0.95	1.99	0.02				
32																																
33																																
34																																
35	Torque	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Torque	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Torque	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm				
36	R80711	all except P,Q,Rm	Rs, Ws	AAAAAA	0.03	0.98	81.96	0.01			R80711	all except P,Q,Rm	Rs, Ws	AAAAAA	0.04	0.98	110.68	0.01			R80711	all except P,Q,Rm	Rs, Ws	AAAAAA	0.03	0.98	89.34	0.01				
37	R80721	all except P,Q,Rm	Rs, Ws	AAAAAA	0.02	0.99	12.54	0.00			R80721	all except P,Q,Rm	Rs, Ws	AAAAAA	0.02	0.99	31.56	0.00			R80721	all except P,Q,Rm	Rs, Ws	AAAAAA	0.02	0.99	-11.33	0.00				
38	R80736	all except P,Q,Rm	Rs, Ws	AAAAAA	0.02	0.99	39.66	0.00			R80736	all except P,Q,Rm	Rs, Ws	AAAAAA	0.03	0.99	30.45	0.00			R80736	all except P,Q,Rm	Rs, Ws	AAAAAA	0.02	0.99	44.02	0.00				
39	R80790	all except P,Q,Rm	Rs, Ws	AAAAAA	0.03	0.98	94.40	0.01			R80790	all except P,Q,Rm	Rs, Ws	AAAAAA	0.03	0.99	35.74	0.00			R80790	all except P,Q,Rm	Rs, Ws	AAAAAA	0.04	0.98	118.06	0.01				
40																																
41	R80711	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.04	0.97	84.33	0.01			R80711	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.05	0.97	79.45	0.01			R80711	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.05	0.97	0.01	0.00				
42	R80721	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.03	0.98	17.73	0.00			R80721	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.03	0.98	20.42	0.00			R80721	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.03	0.98	-0.01	0.00				
43	R80736	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.04	0.98	18.78	0.00			R80736	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.03	0.98	6.42	0.00			R80736	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.03	0.98	57.14	0.01				
44	R80790	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.04	0.97	105.91	0.01			R80790	all except P,Q,Rm,Rs	Ws, Ba	AAAAAA	0.04	0.97	53.07	0.01			R80790	all except P,Q,Rm,Rs	Ba, Ws	AAAAAA	0.05	0.96	157.97	0.02				
45																																
46																																
47																																
48	Rotor speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Rotor speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Rotor speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm				
49	R80711	all except P,Q,Rm,Rs	Ba e Ws	0.61	0.04	0.99	0.13	0.01			R80711	all except P,Q,Rm,Rs	Ba e Ws	0.75	0.04	0.98	0.24	0.01			R80711	all except P,Q,Rm,Rs	Ba e Ws	0.63	0.04	0.99	0.12	0.01				
50	R80721	all except P,Q,Rm,Rs	Ba e Ws	0.47	0.03	0.99	0.01	0.00			R80721	all except P,Q,Rm,Rs	Ba e Ws	0.57	0.03	0.99	-0.07	0.00			R80721	all except P,Q,Rm,Rs	Ba e Ws	0.59	0.03	0.99	-0.05	0.00				
51	R80736	all except P,Q,Rm,Rs	Ba e Ws	0.51	0.03	0.99	0.01	0.00			R80736	all except P,Q,Rm,Rs	Ba e Ws	0.63	0.04	0.99	0.06	0.00			R80736	all except P,Q,Rm,Rs	Ba e Ws	0.51	0.03	0.99	-0.05	0.00				
52	R80790	all except P,Q,Rm,Rs	Ba e Ws	0.63	0.04	0.99	0.08	0.00			R80790	all except P,Q,Rm,Rs	Ba e Ws	0.62	0.04	0.99	0.06	0.00			R80790	all except P,Q,Rm,Rs	Ba e Ws	0.73	0.04	0.98	0.03	0.00				
53																																
54																																
55																																
56	Rate Tip Speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Rate Tip Speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm			Rate Tip Speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm				
57	R80711	all except P,Q,Rm,Rs	Ba, Ws	0.81	0.05	0.95	-0.05	0.00			R80711	all except P,Q,Rm,Rs	Ba, Ws	0.83	0.06	0.94	-0.04	0.00			R80711	all except P,Q,Rm,Rs	Ba, Ws	0.86	0.06	0.94	-0.06	0.00				
58	R80721	all except P,Q,Rm,Rs	Ba, Ws	0.75	0.05	0.96	-0.01	0.00			R80721	all except P,Q,Rm,Rs	Ba, Ws	0.79	0.05	0.96	0.00	0.00			R80721	all except P,Q,Rm,Rs	Ba, Ws	0.74	0.05	0.96	-0.05	0.00				
59	R80736	all except P,Q,Rm,Rs	Ba, Ws	0.76	0.05	0.96	-0.06	0.00			R80736	all except P,Q,Rm,Rs																				

Main findings

I was able to model almost all stages with good test results:

- all R^2 scores ≥ 0.90

- all $RMSE/\max(y) \leq 0.08$

With some exceptions, model results from Generalised, LOO, and Specific turbine approaches were not that different

Generalised and LOO models were good for a quick comparison

Specific models were good for providing more detail about each turbine

These turbines are working “well”, but there are small changes over time
(is it significant for the problem?)

Main findings

From Torque to Active Power, all turbines worked well
(Wind Speed → Rotor Speed → Torque).

Generalised Turbine Models							
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00

Main findings

From Torque to Active Power, all turbines worked well.
From Wind-speed to Active Power there are some difficulties.

From all the other processes, there are steps in which we have higher errors
(wind Speed → Rotor Speed → Torque).

Generalised Turbine Models							
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00
R80711	all except P, Q, Rm	Ws, Rs	70,11	0,04	0,98	21,69	0,01
R80721	all except P, Q, Rm	Ws, Rs	44,23	0,02	0,99	0,30	0,00
R80736	all except P, Q, Rm	Ws, Rs	48,46	0,02	0,99	7,45	0,00
R80790	all except P, Q, Rm	Ws, Rs	61,99	0,03	0,98	15,11	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	97,16	0,05	0,96	35,65	0,02
R80721	all except P, Q, Rm, Rs,	Ws, Ba	67,61	0,03	0,97	0,30	0,00
R80736	all except P, Q, Rm, Rs,	Ws, Ba	72,80	0,04	0,97	5,40	0,00
R80790	all except P, Q, Rm, Rs,	Ws, Ba	88,98	0,04	0,96	17,35	0,01

Main findings

In Generalised Models:

Turbines R80711 and R80790 clearly have a higher RMSE and absolute differences (except for modelling Torque->Active Power)

Generalised Turbine Models							
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00
R80711	all except P, Q, Rm	Ws, Rs	70,11	0,04	0,98	21,69	0,01
R80721	all except P, Q, Rm	Ws, Rs	44,23	0,02	0,99	0,30	0,00
R80736	all except P, Q, Rm	Ws, Rs	48,46	0,02	0,99	7,45	0,00
R80790	all except P, Q, Rm	Ws, Rs	61,99	0,03	0,98	15,11	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	97,16	0,05	0,96	35,65	0,02
R80721	all except P, Q, Rm, Rs,	Ws, Ba	67,61	0,03	0,97	0,30	0,00
R80736	all except P, Q, Rm, Rs,	Ws, Ba	72,80	0,04	0,97	5,40	0,00
R80790	all except P, Q, Rm, Rs,	Ws, Ba	88,98	0,04	0,96	17,35	0,01

Main findings

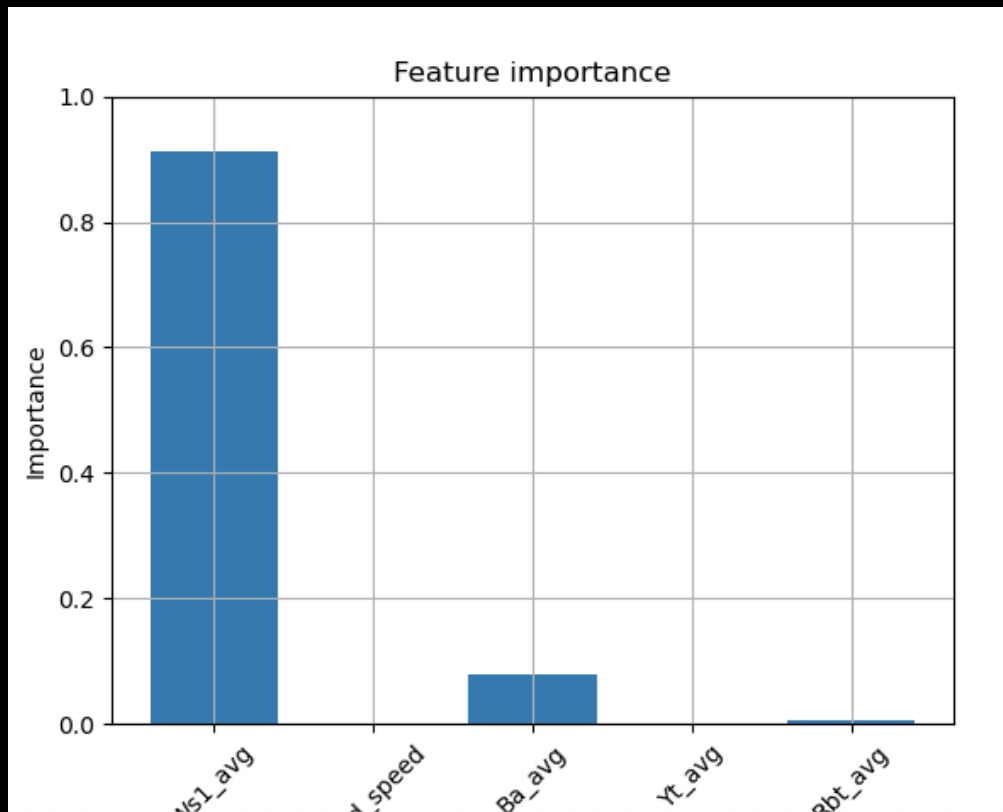
In specific Models, these changes may be highlighted

Turbines R80711 and R80790 clearly have a higher RMSE and absolute differences (except for modelling Torque->Active Power). Small changes over time?

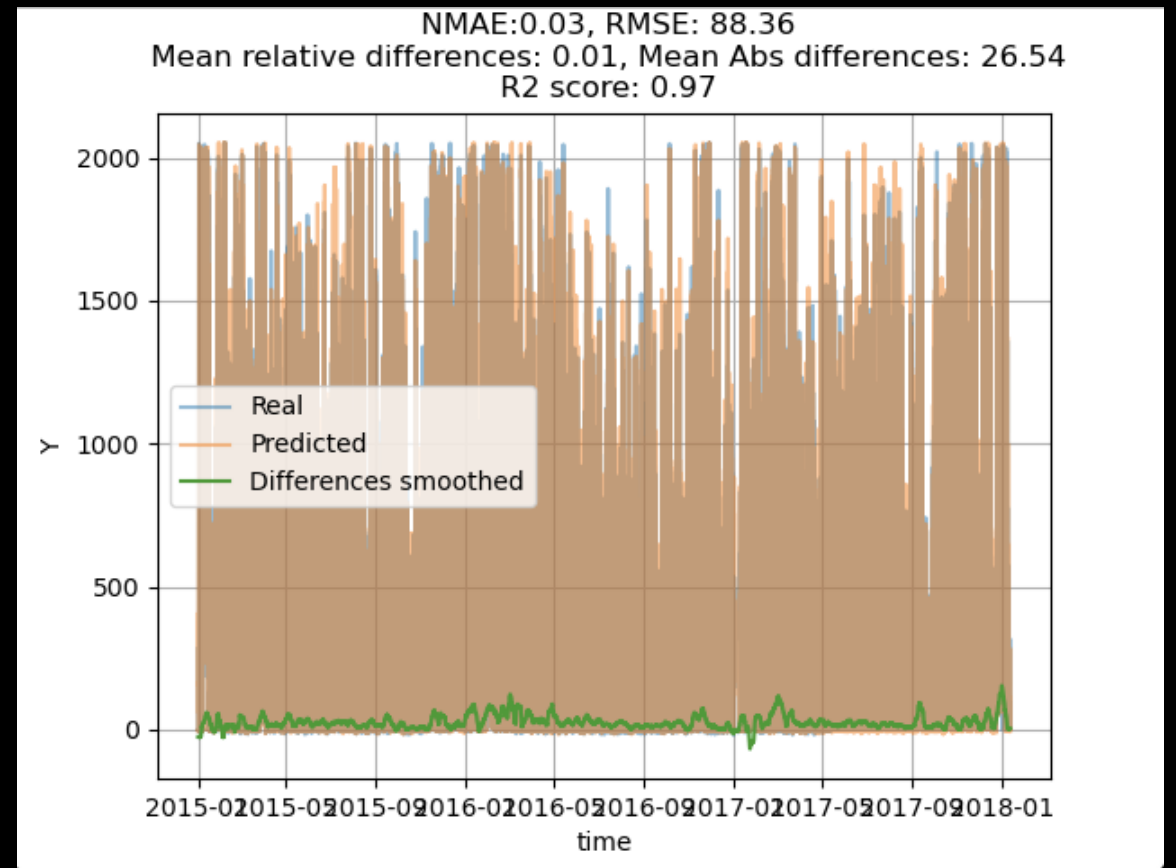
		Specific Turbine Models					
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,89	0,00	1,00	-0,24	0,00
R80721	all except P,Q	Rm	5,49	0,00	1,00	-0,25	0,00
R80736	all except P,Q	Rm	4,11	0,00	1,00	0,23	0,00
R80790	all except P,Q	Rm	5,08	0,00	1,00	-1,25	0,00
R80711	all except P, Q, Rm	Rs, Ws	63,62	0,03	0,98	17,20	0,01
R80721	all except P, Q, Rm	Rs, Ws	38,63	0,02	0,99	-5,54	0,00
R80736	all except P, Q, Rm	Rs, Ws	45,12	0,02	0,99	1,86	0,00
R80790	all except P, Q, Rm	Rs, Ws	69,26	0,03	0,98	22,79	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	88,31	0,04	0,97	26,48	0,01
R80721	all except P, Q, Rm, Rs,	Ws, Ba	62,11	0,03	0,98	-17,67	-0,01
R80736	all except P, Q, Rm, Rs,	Ws, Ba	60,01	0,03	0,98	10,27	0,01
R80790	all except P, Q, Rm, Rs,	Rbt, Ba, Ws1	119,96	0,06	0,93	31,52	0,02

Main findings

Specific Models, turbine R80711: modelling wind → Active Power

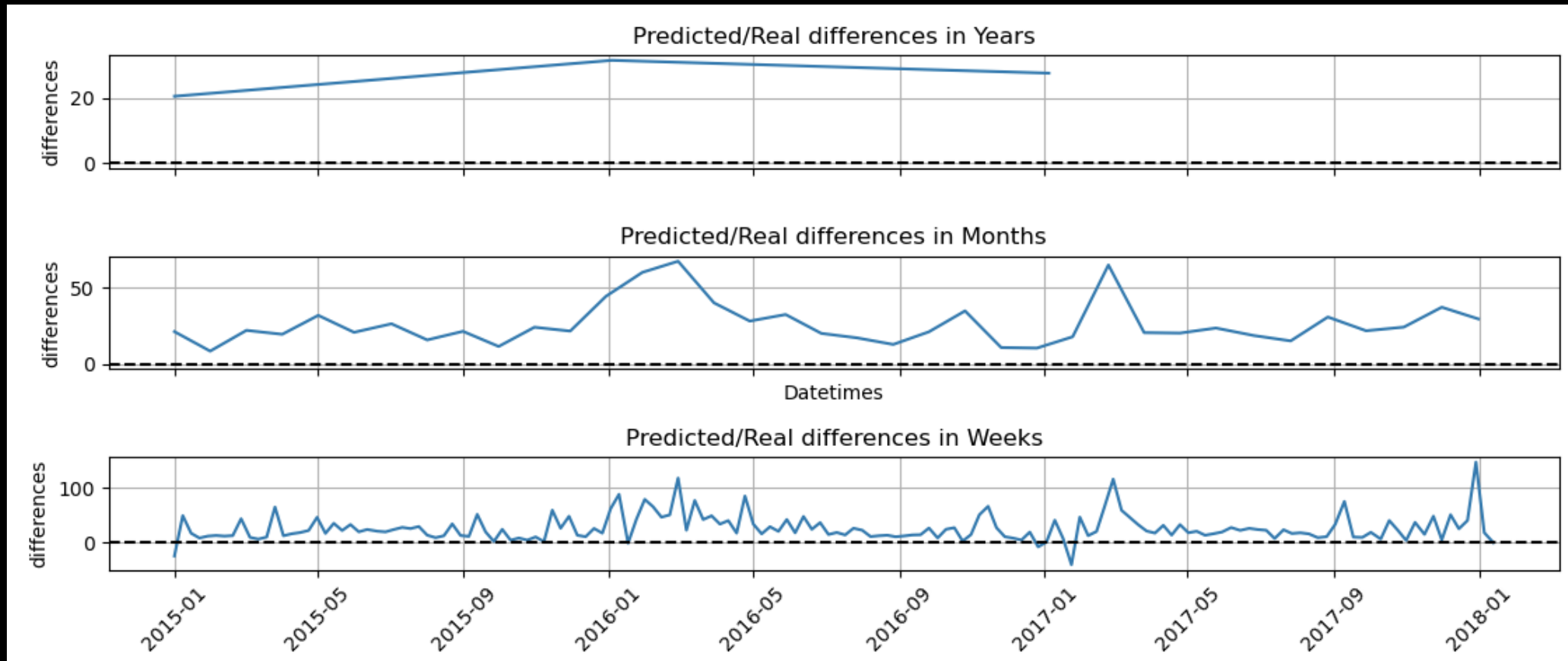


Important features: ws , Ba



Main findings

Specific Models, turbine R80711: modelling wind → Active Power



what would we say to Engie?

Besides showing these possible malfunctions, we can:

- 1) break down the process and model each step to verify turbine health
- 2) we can also model the expected active power (energy produced) based on different stages of the process

Break down the process and model every step

This ensures safety: we know what we are doing.

Generalised Turbine Model							
Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00
R80711	all except P, Q, Rm	Ws, Rs	70,11	0,04	0,98	21,69	0,01
R80721	all except P, Q, Rm	Ws, Rs	44,23	0,02	0,99	0,30	0,00
R80736	all except P, Q, Rm	Ws, Rs	48,46	0,02	0,99	7,45	0,00
R80790	all except P, Q, Rm	Ws, Rs	61,99	0,03	0,98	15,11	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	97,16	0,05	0,96	35,65	0,02
R80721	all except P, Q, Rm, Rs,	Ws, Ba	67,61	0,03	0,97	0,30	0,00
R80736	all except P, Q, Rm, Rs,	Ws, Ba	72,80	0,04	0,97	5,40	0,00
R80790	all except P, Q, Rm, Rs,	Ws, Ba	88,98	0,04	0,96	17,35	0,01
Torque Converter	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P, Rm	Rs, Ws	4,28	0,04	0,98	1,43	0,01
R80721	all except P, Rm	Rs, Ws	2,64	0,02	0,99	2,64	0,02
R80736	all except P, Rm	Rs, Ws	2,88	0,02	0,99	2,88	0,02
R80790	all except P, Rm	Rs, Ws	3,66	0,03	0,98	3,66	0,03
R80711	all except P, Rm, Rs	Ws, Ba	5,93	0,05	0,95	1,84	0,02
R80721	all except P, Rm, Rs	Ws, Ba	4,54	0,04	0,97	0,09	0,00
R80736	all except P, Rm, Rs	Ws, Ba	4,83	0,04	0,97	0,19	0,00
R80790	all except P, Rm, Rs	Ws, Ba	5,54	0,05	0,96	1,03	0,01

Torque	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q,Rm	Rs, Ws	330,11	0,03	0,98	81,96	0,01
R80721	all except P,Q,Rm	Rs, Ws	228,45	0,02	0,99	12,54	0,00
R80736	all except P,Q,Rm	Rs, Ws	245,36	0,02	0,99	39,66	0,00
R80790	all except P,Q,Rm	Rs, Ws	324,88	0,03	0,98	94,40	0,01
R80711	all except P,Q,Rm, Rs	Ws, Ba	448,01	0,04	0,97	84,33	0,01
R80721	all except P,Q,Rm, Rs	Ws, Ba	312,13	0,03	0,98	17,73	0,00
R80736	all except P,Q,Rm, Rs	Ws, Ba	357,21	0,04	0,98	18,78	0,00
R80790	all except P,Q,Rm, Rs	Ws, Ba	429,98	0,04	0,97	105,91	0,01
Rotor speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q,Rm,Rs	Ba e Ws	0,61	0,04	0,99	0,13	0,01
R80721	all except P,Q,Rm,Rs	Ba e Ws	0,47	0,03	0,99	0,01	0,00
R80736	all except P,Q,Rm,Rs	Ba e Ws	0,51	0,03	0,99	0,01	0,00
R80790	all except P,Q,Rm,Rs	Ba e Ws	0,63	0,04	0,99	0,08	0,00
Rate Tip Speed	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q,Rm, Rs	Ba, Ws	0,81	0,05	0,95	-0,05	0,00
R80721	all except P,Q,Rm, Rs	Ba, Ws	0,75	0,05	0,96	-0,01	0,00
R80736	all except P,Q,Rm, Rs	Ba, Ws	0,76	0,05	0,96	-0,06	0,00
R80790	all except P,Q,Rm, Rs	Ba, Ws	0,85	0,06	0,95	-0,14	-0,01

Predict the active power based on the different stages of the process

Active Power → Money (How much Money are you winning/losing?)

Active Power	Possible features	Selected features	RMSE	RMSE_norm	R2_score	Mean_diff	Mean_diff_norm
R80711	all except P,Q	Rm	5,13	0,00	1,00	-0,06	0,00
R80721	all except P,Q	Rm	4,86	0,00	1,00	0,01	0,00
R80736	all except P,Q	Rm	3,39	0,00	1,00	-0,07	0,00
R80790	all except P,Q	Rm	3,52	0,00	1,00	-0,09	0,00
R80711	all except P, Q, Rm	Ws, Rs	70,11	0,04	0,98	21,69	0,01
R80721	all except P, Q, Rm	Ws, Rs	44,23	0,02	0,99	0,30	0,00
R80736	all except P, Q, Rm	Ws, Rs	48,46	0,02	0,99	7,45	0,00
R80790	all except P, Q, Rm	Ws, Rs	61,99	0,03	0,98	15,11	0,01
R80711	all except P, Q, Rm, Rs,	Ws, Ba	97,16	0,05	0,96	35,65	0,02
R80721	all except P, Q, Rm, Rs,	Ws, Ba	67,61	0,03	0,97	0,30	0,00
R80736	all except P, Q, Rm, Rs,	Ws, Ba	72,80	0,04	0,97	5,40	0,00
R80790	all except P, Q, Rm, Rs,	Ws, Ba	88,98	0,04	0,96	17,35	0,01

what would we say to Engie?

We can:

3) Develop a general model to quickly and fairly compare all turbines (within the same turbine type)

4) Develop turbine-specific algorithms for detailed monitoring after some time of collecting data

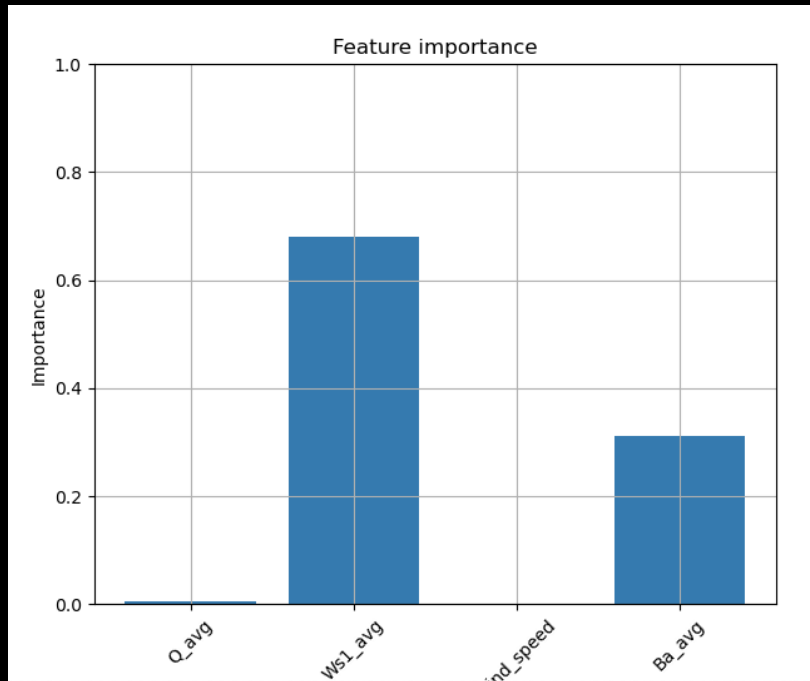
5) If Engies wishes to place a new similar turbine, we can start monitoring its performance and health since day 0 (check LOO results)

Are these models redundant?

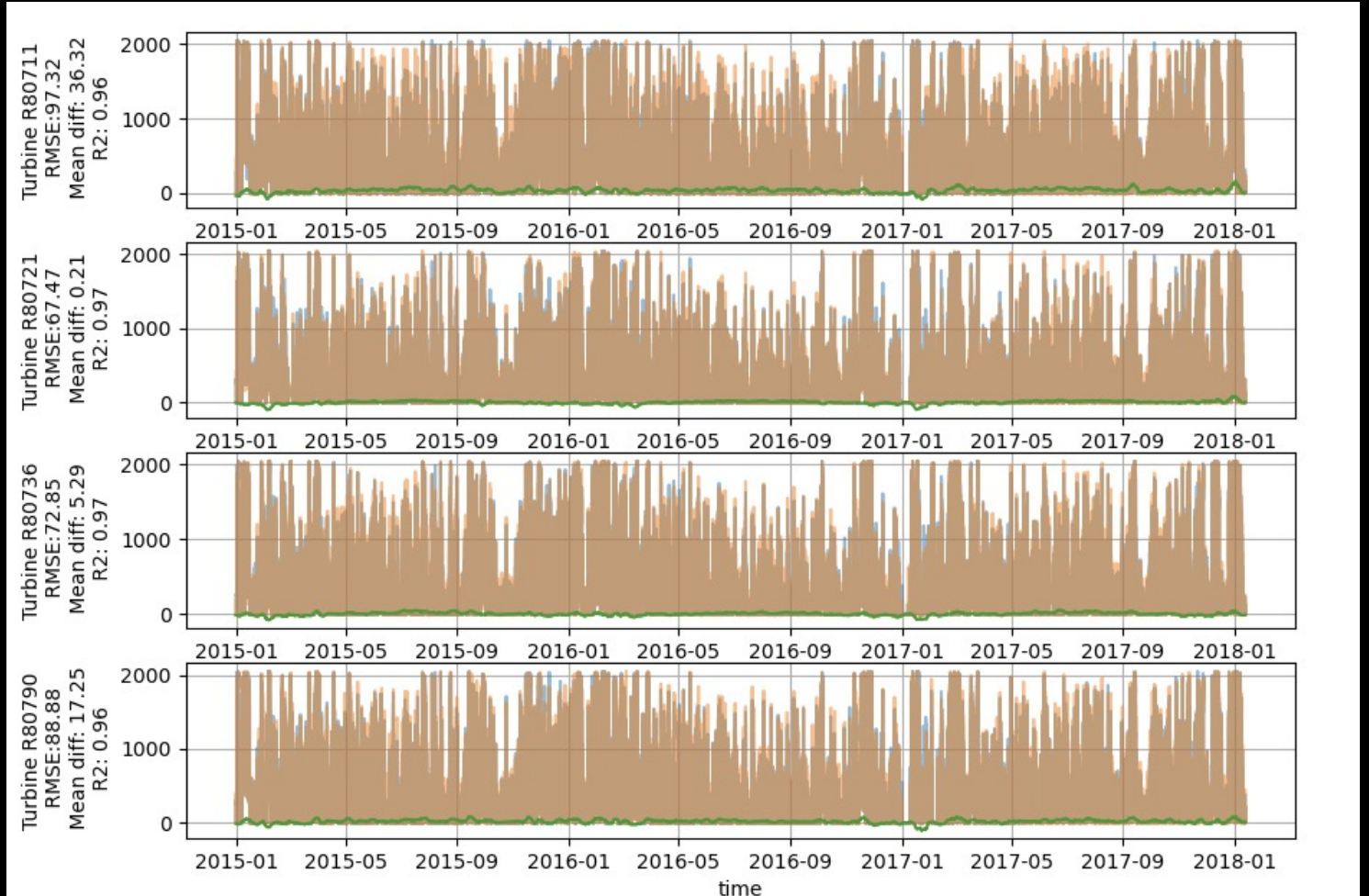
Yes, redundancy is safety

Modelling a general model to compare turbine performances

Modelling Y=Active Power



Features: Ws1_avg, Ba_avg

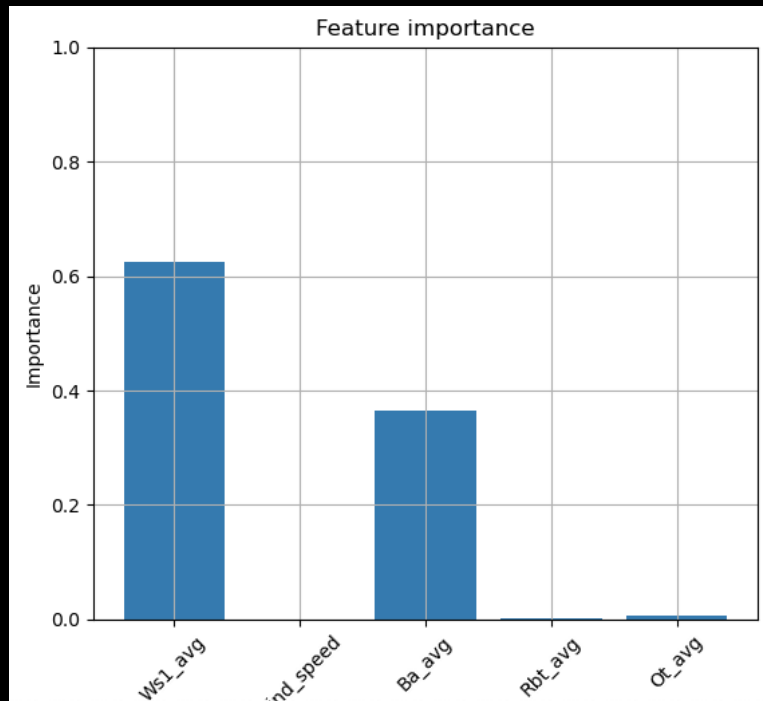


Start monitoring since day 1

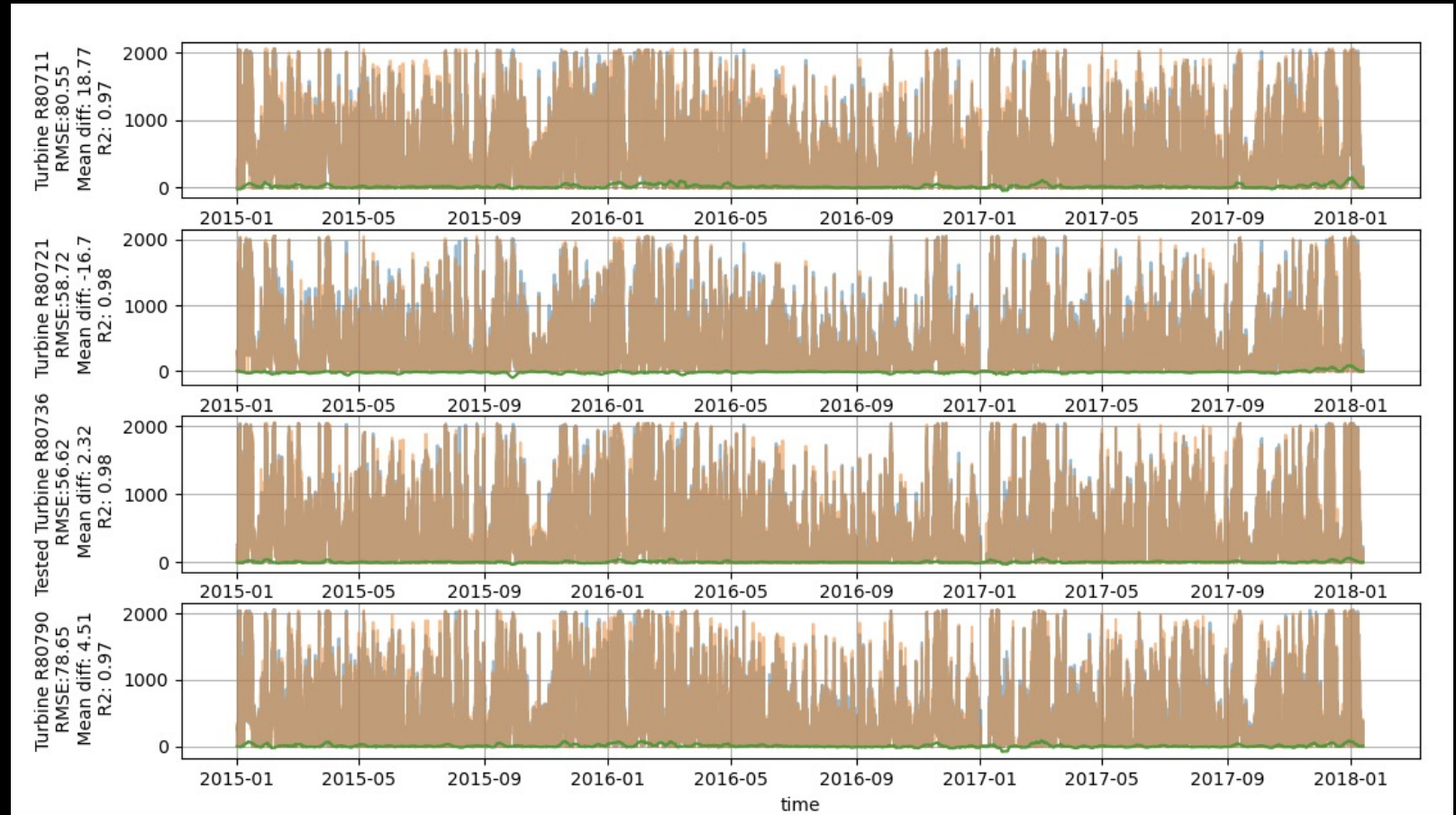
L00

Turbine R80736

Y=Active Power

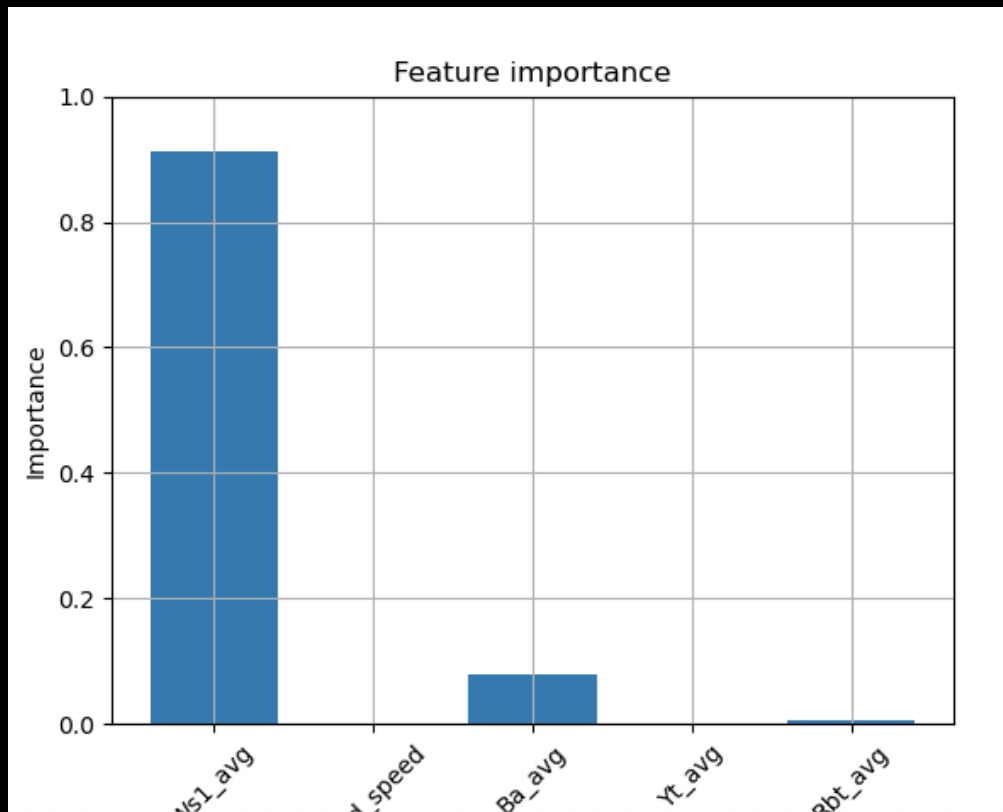


Features: ws1_avg, Ba_avg

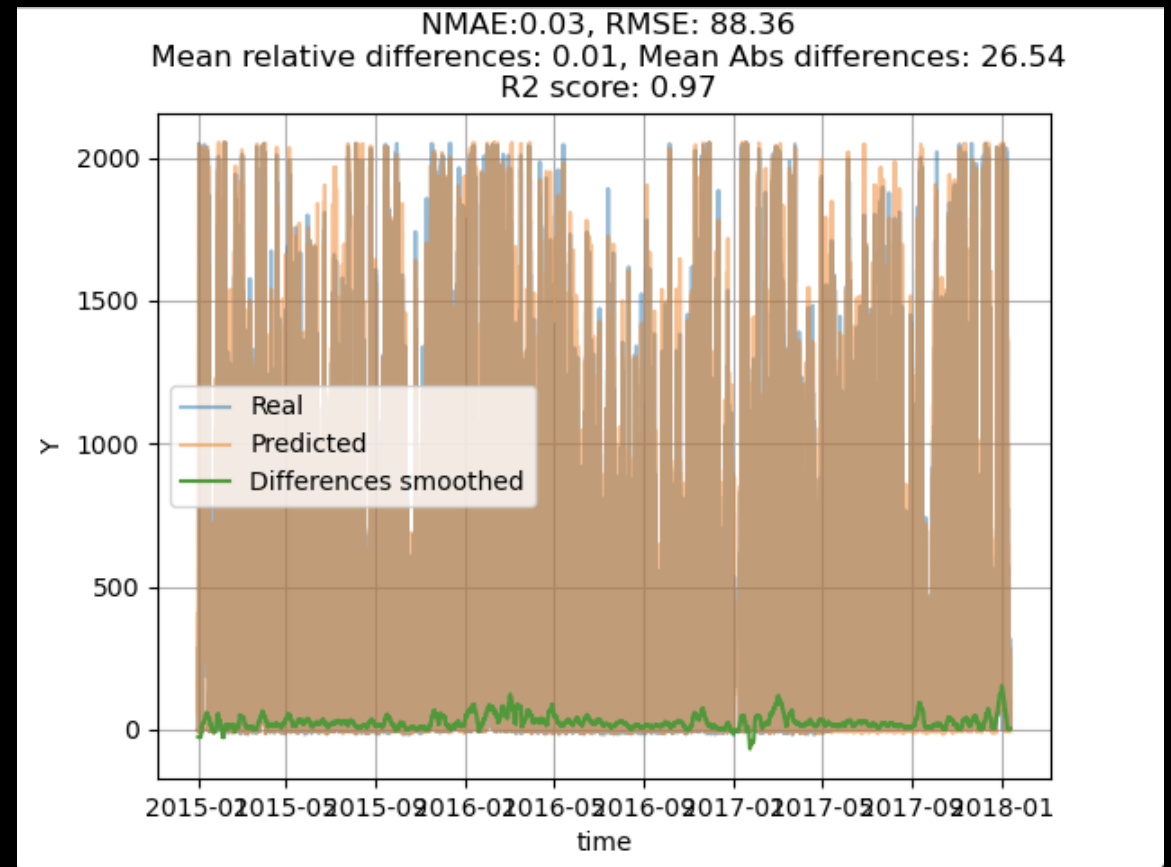


Modelling turbine-specific algorithms for great detail

Turbine R80711: modelling wind → Active Power

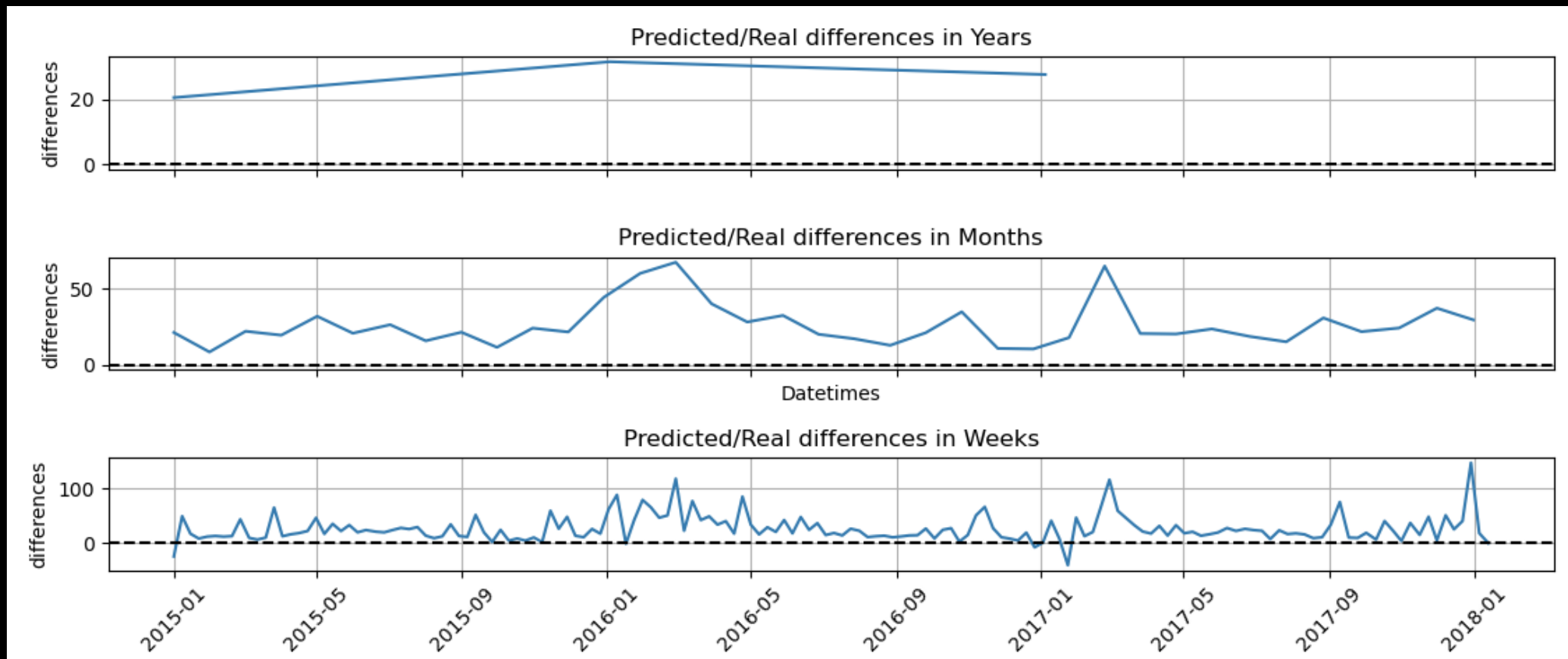


Important features: `ws`, `Ba`



Modelling turbine-specific algorithms for great detail

Turbine R80711: modelling wind → Active Power



Discussion

Error metric:

MAPE?

Discussing with experts if errors are significant or not

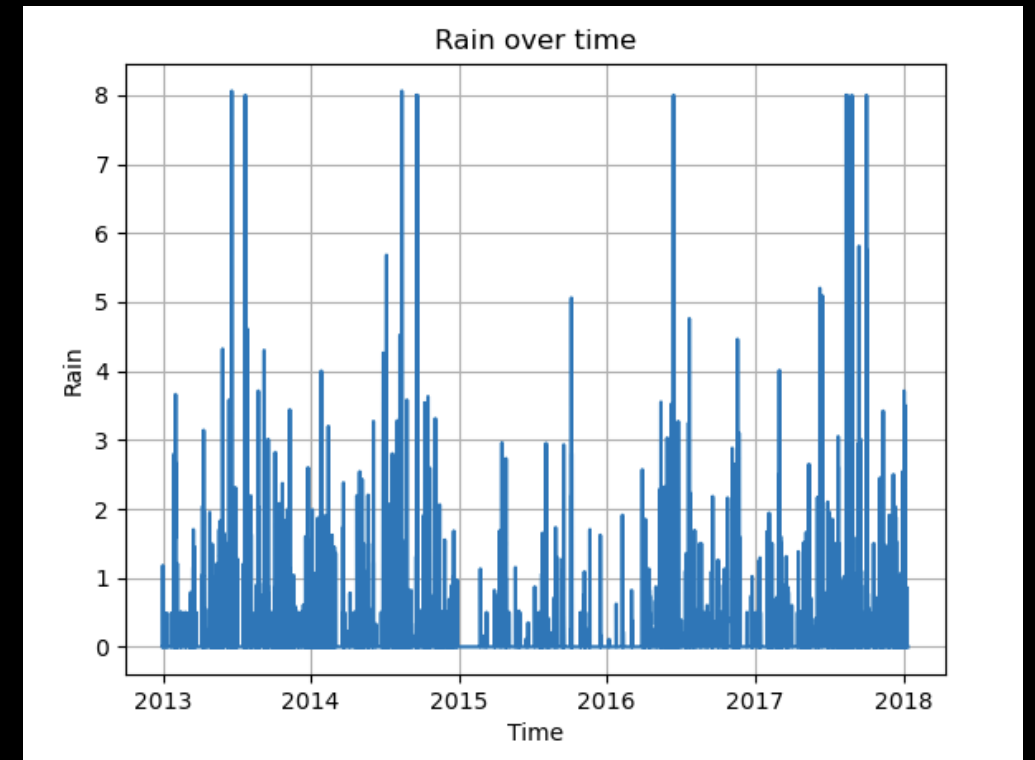
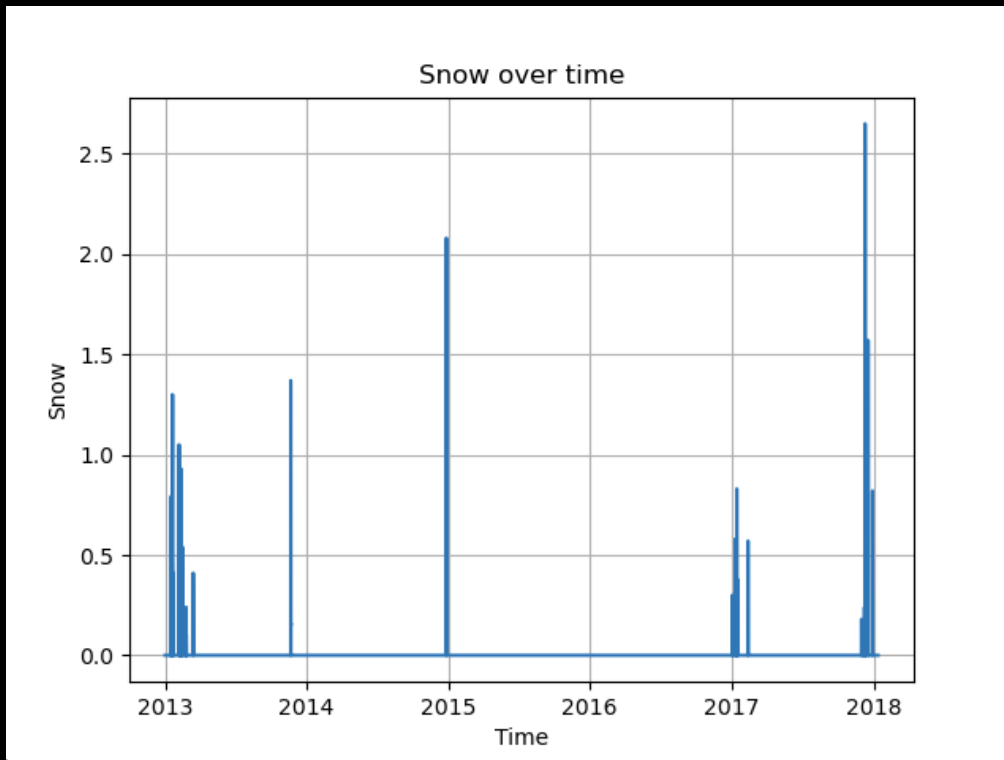
I was actually looking for something to go (really) wrong...

Study results correlations with the weather.

Try to explain with external factors the evolution of predicted/real differences due to rain/snow

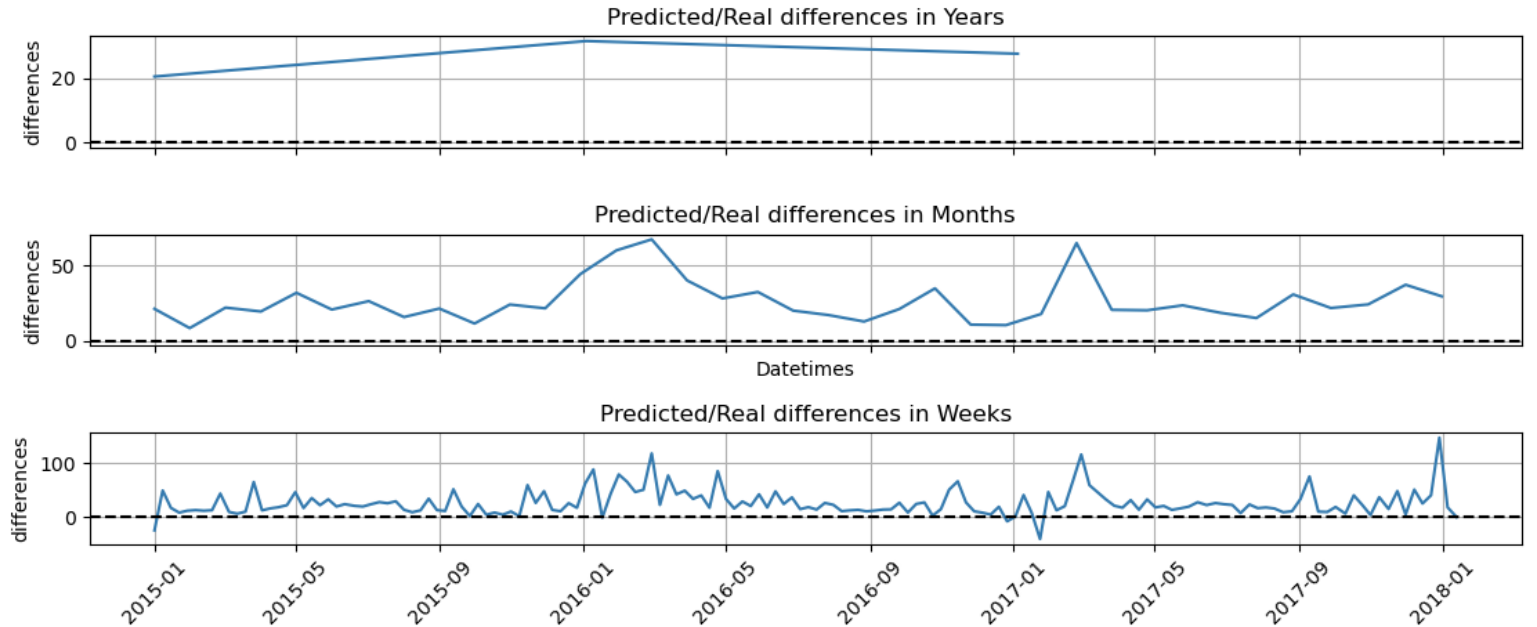
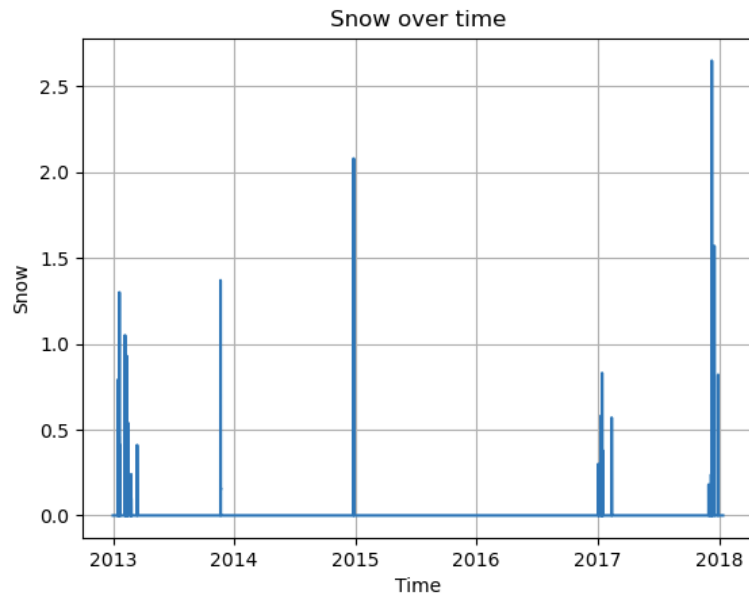
Discussion

Rain and Snow influence on the Turbines?
Missing correlation between these and $(y_{\text{predicted}} - y_{\text{true}})$



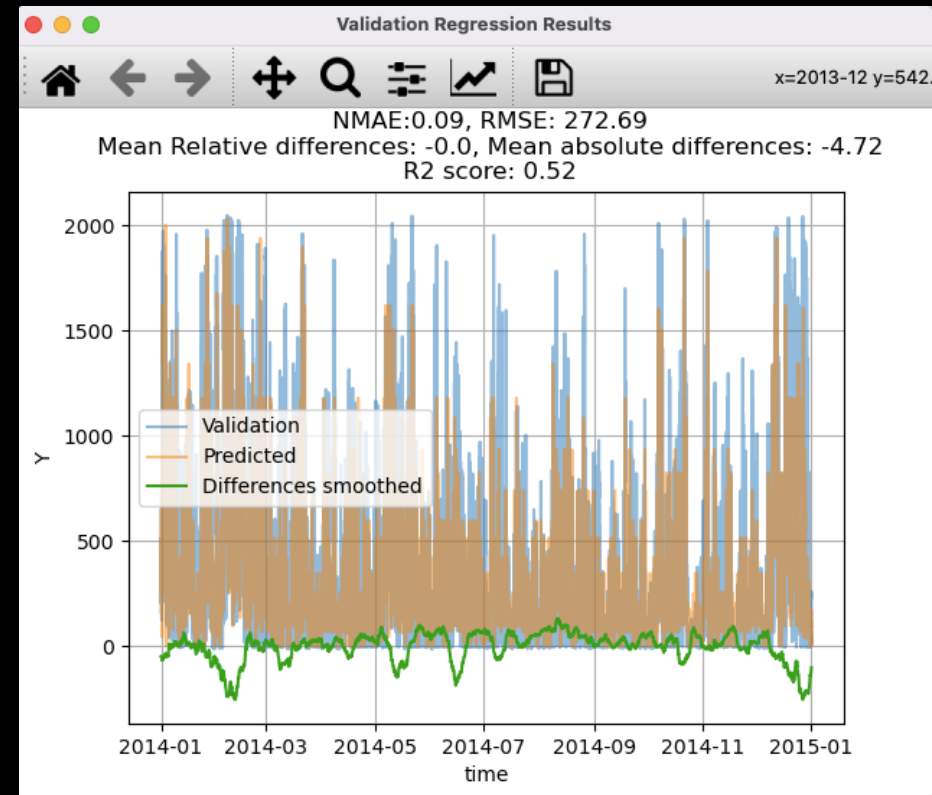
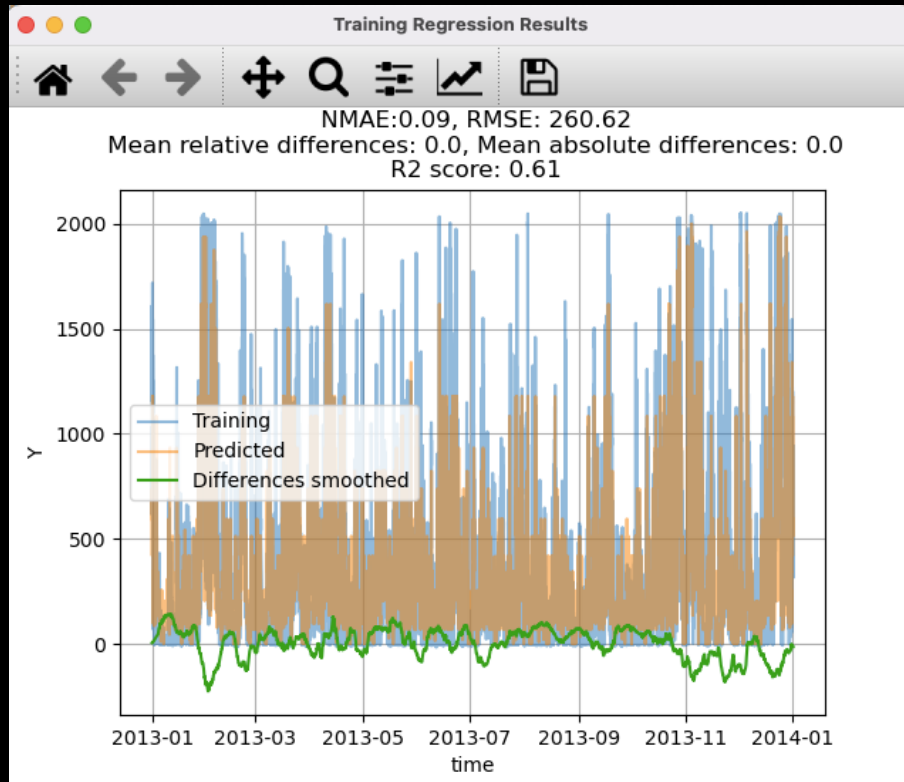
Discussion

Rain and Snow influence on the Turbines?
Missing correlation between these and $(y_{\text{predicted}} - y_{\text{true}})$



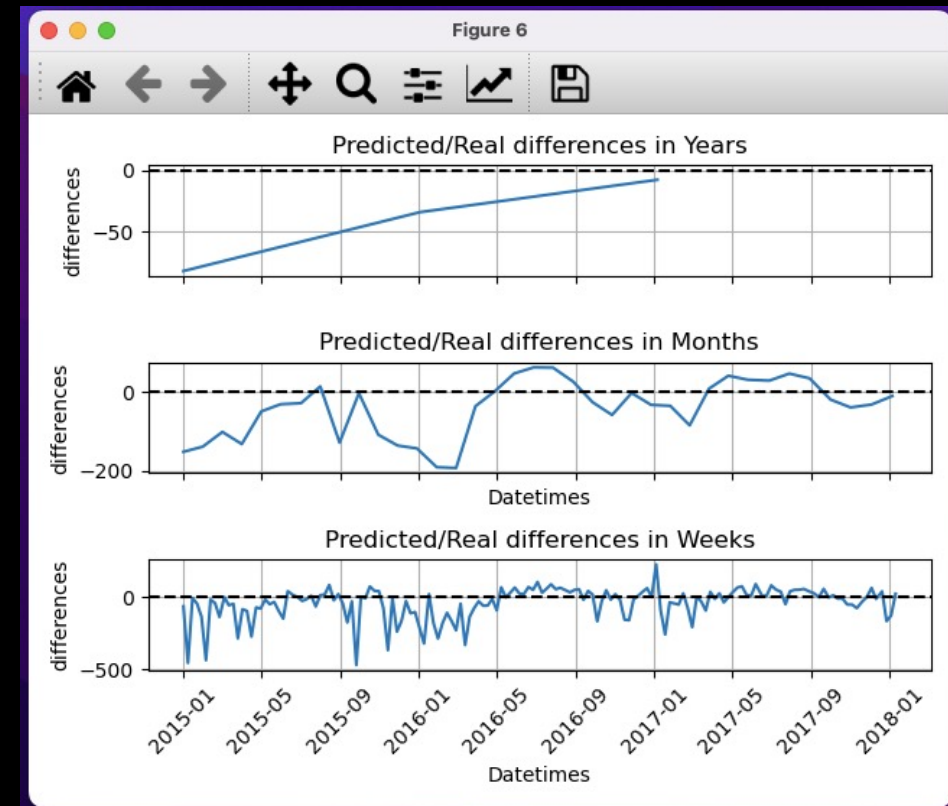
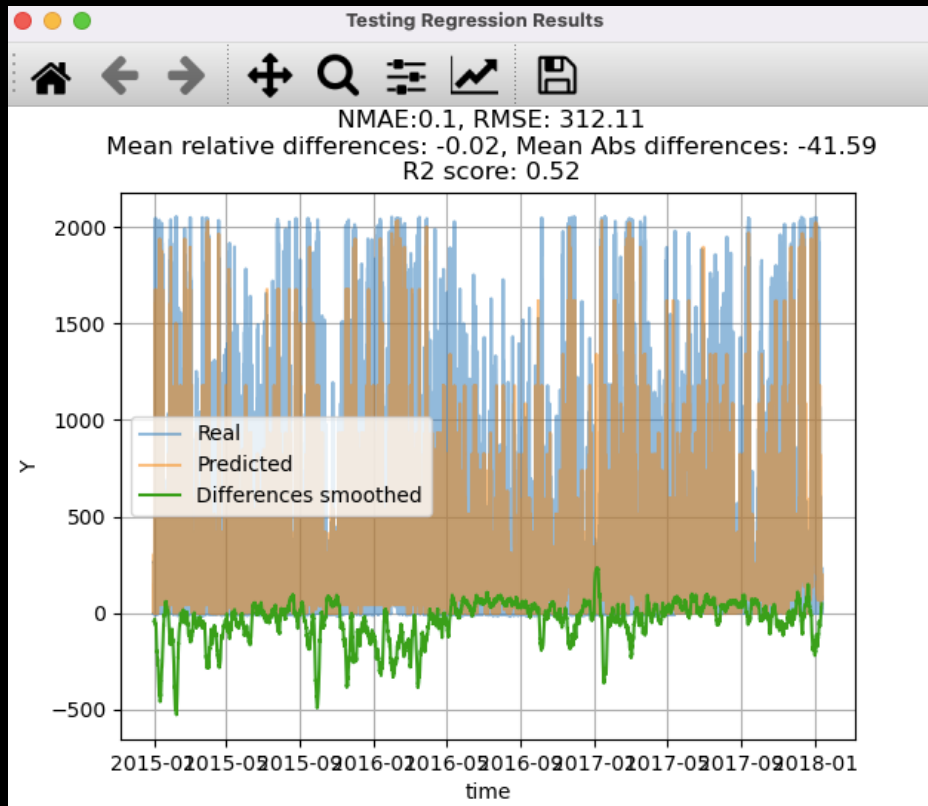
Discussion

Model Active Power - Turbine R80736 (the only with no pauses)
using weather only features



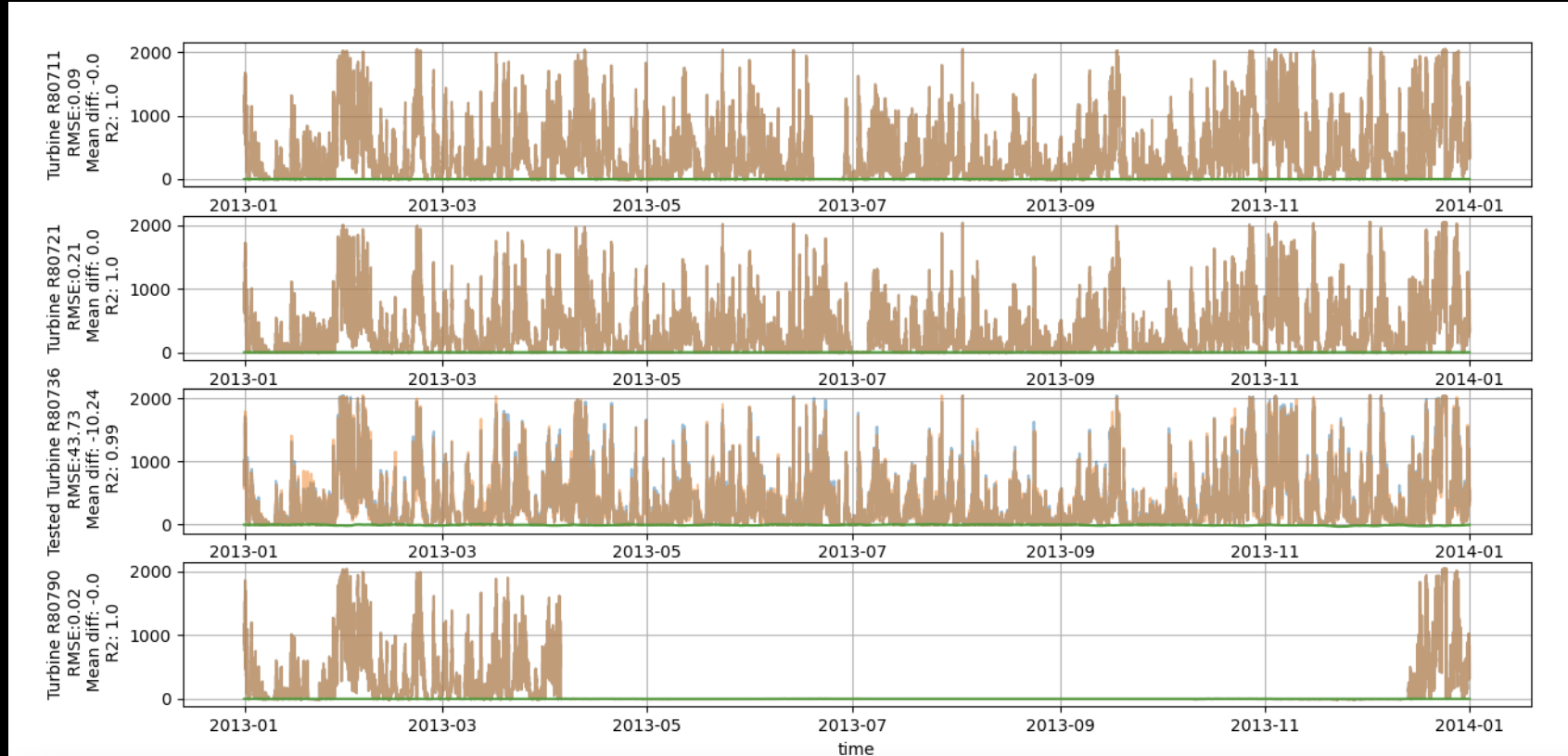
Discussion

Active Power - Turbine R80736
Using weather only features



Discussion

Partition data:
what happened in 2013 in some turbines?



Discussion

Most important features: W_s , B_a , R_s , R_m (not ordered)

I have some doubts about the relevance of some models:

- are these models excellent or the relation input/output is just too obvious?

- some features should have been eliminating for some regression problems
(not a big problem because they were not relevant to the model)

Reactive Power

My pipeline is computationally fast.

I like to do things that way: it allows me to make several tests and comparisons