Timeseries-Based Approach for Volume Risk Assessment

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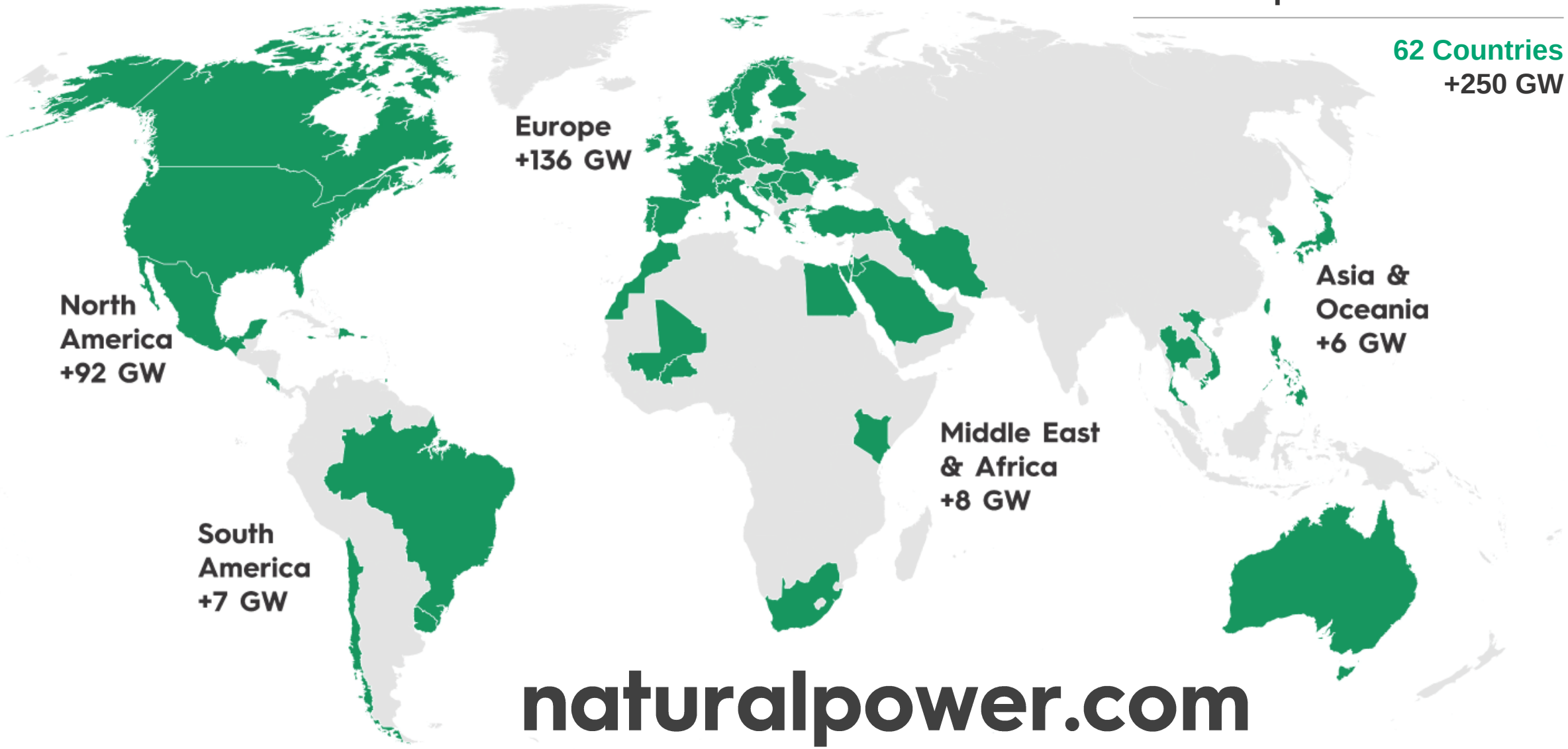
Global experience 1995-2020

62 Countries
+250 GW



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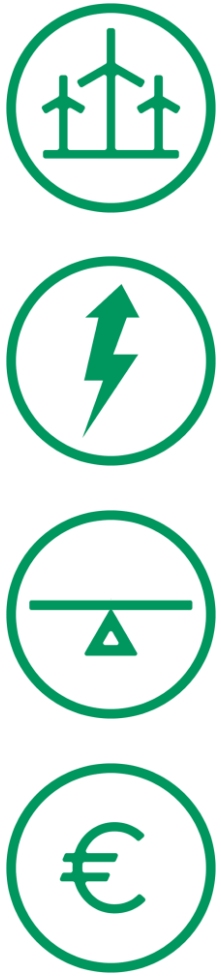
Power purchase agreements (PPA)

Mitigates the risk of selling all produced electricity based on the volatile market spot price

A threshold of guaranteed production volume (hedge) over a fixed time frame can be included in the contractual obligations



Shortfall risk

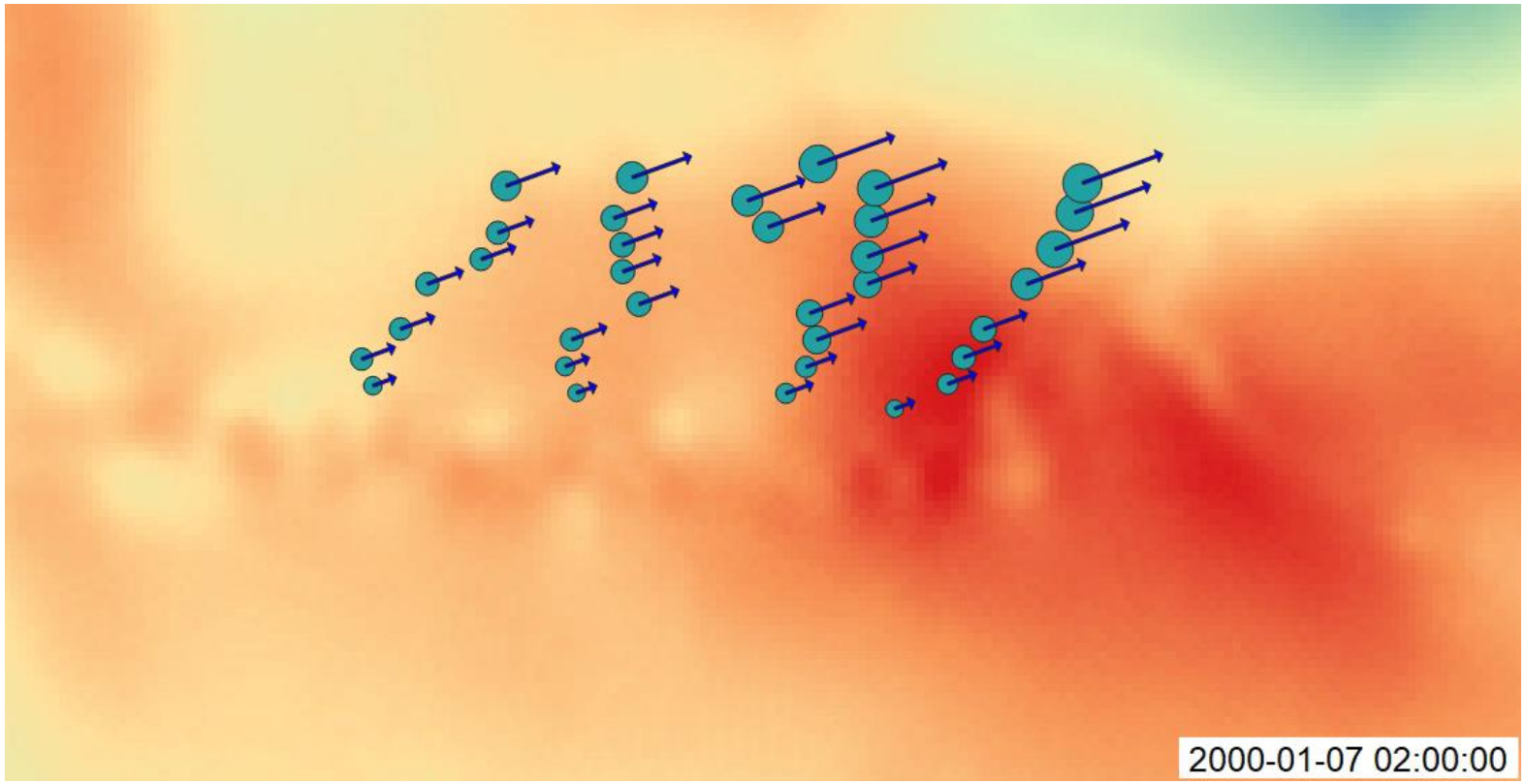
Variability in production contributes to uncertainty of meeting production targets

In some PPAs, production shortfall results in penalties

An accurate assessment of the probability and volume of production shortfall can inform a PPA negotiation resulting in reduced uncertainty and better terms

Model features

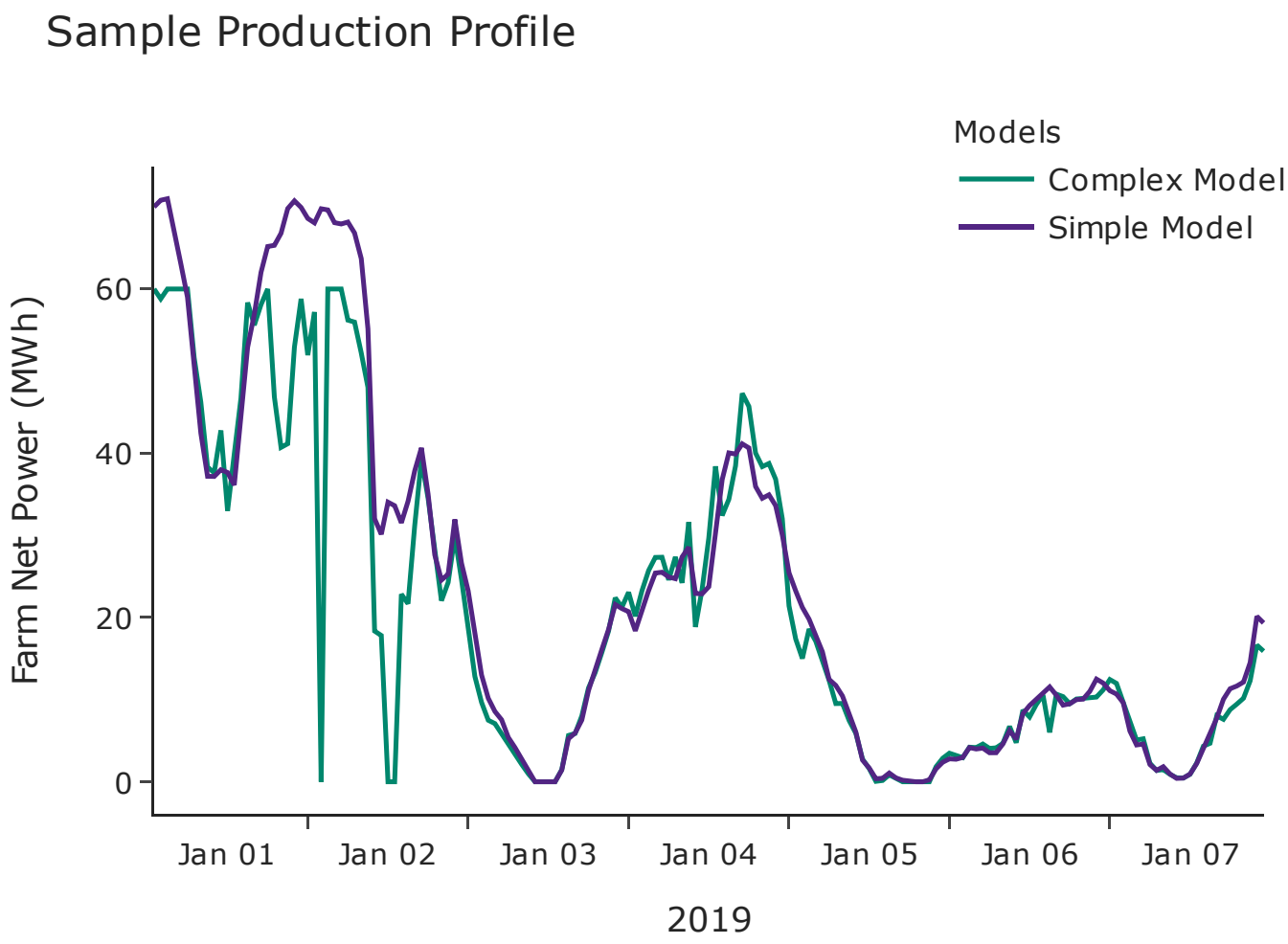
- Spatial modelling
- Wakes
- Curtailments
  - Bat/bird
  - Noise/shadow
  - WSM/icing
  - Grid
- Secondary loss interaction
  - Stochastic availability
  - Electrical
  - Dynamic icing
  - Operational modes



Benefits

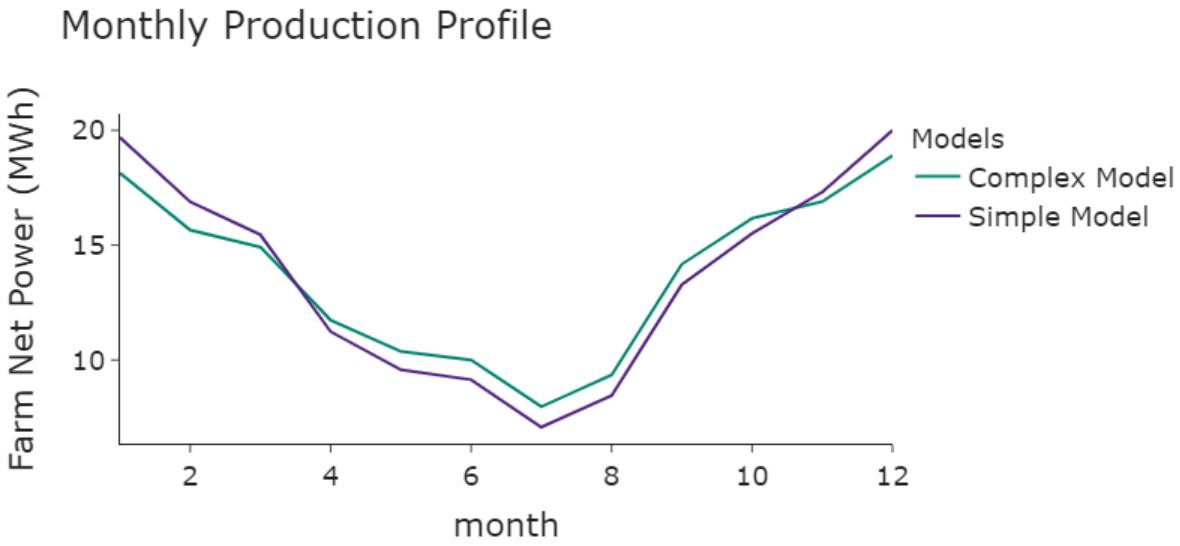
- Per-turbine pattern of production
- Enforcing export capacity limit
- Stochastic availability
- Dynamic icing performance degradation

Fluctuations in production are more representative of real wind farm operations



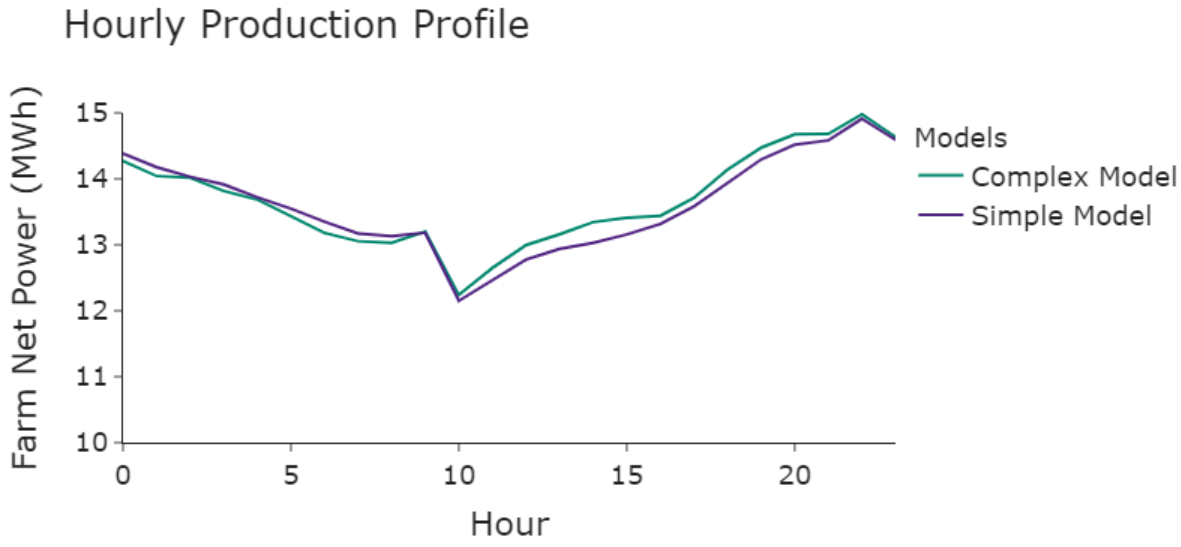
Seasonal profile

- Average annual production tuned to net yield from EYA
- Icing losses distributed in colder months



Diurnal profile

- Wake losses dependent on wind speed and direction
- Curtailment losses dynamically allocated
- Icing losses more frequent at night



Ice throw mitigation - turbine curtailment

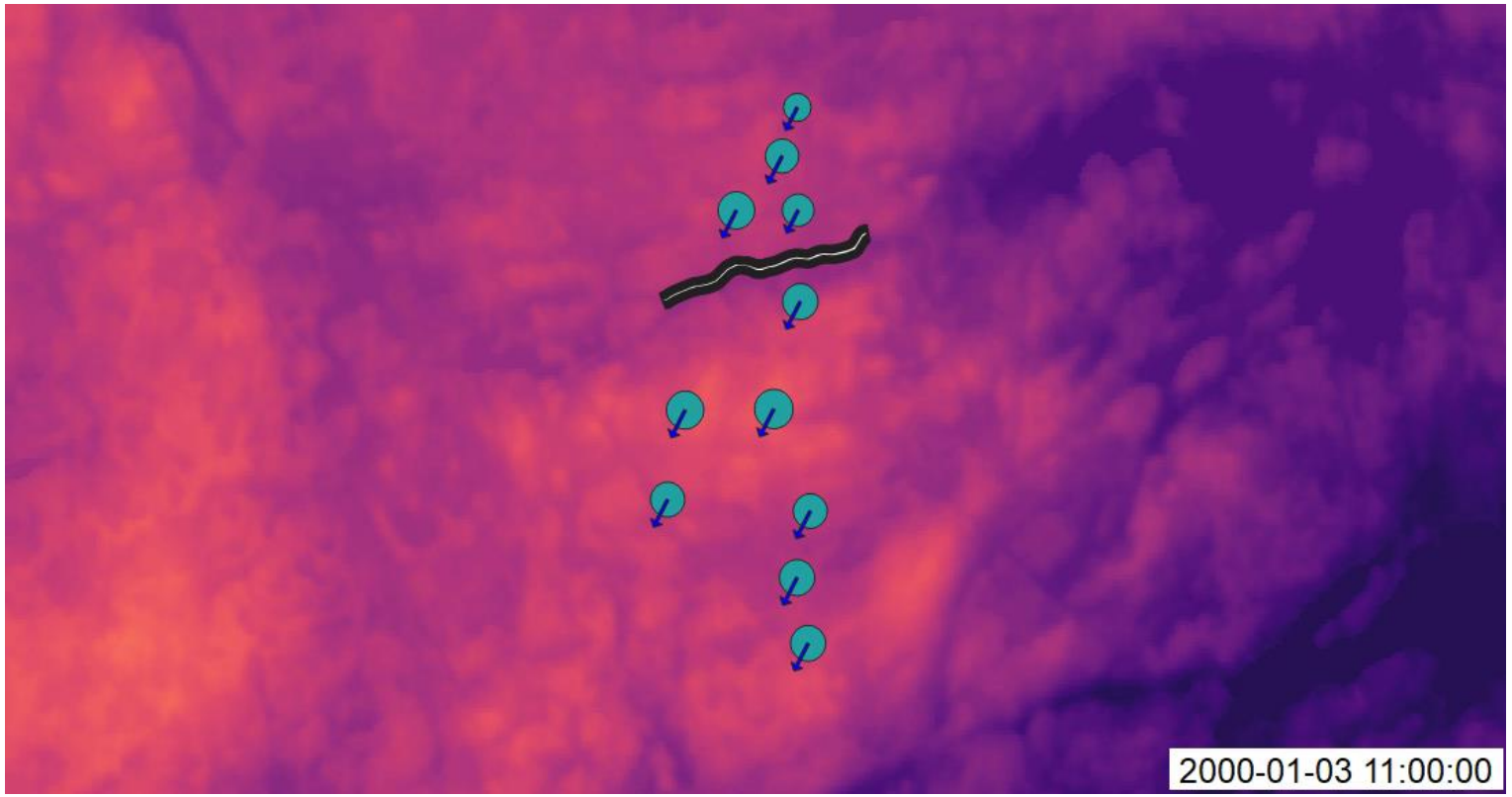
Model parameters

- Temperature changes from

  <0° C to >0° C

- Wind speed is greater than 7 m/s
- Selective turbine curtailment

Production loss ~ 0.09%

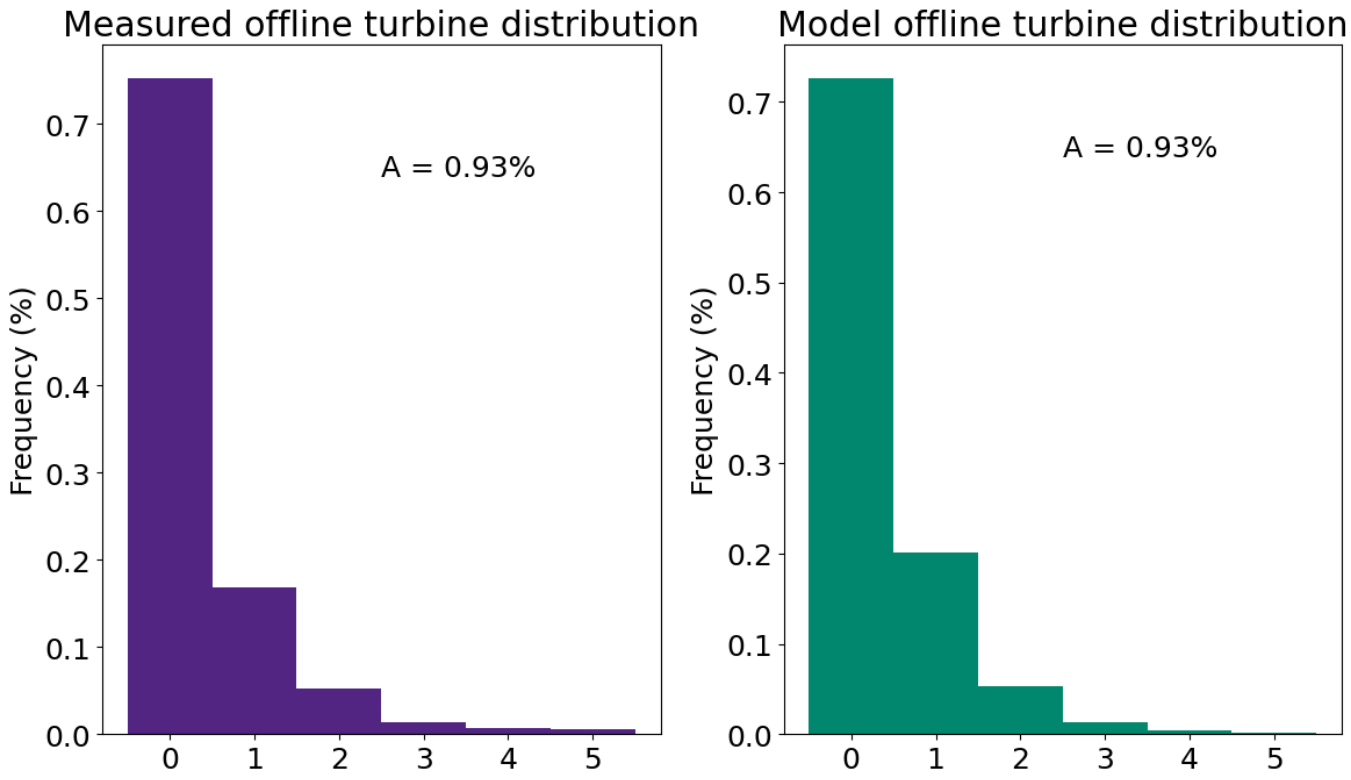


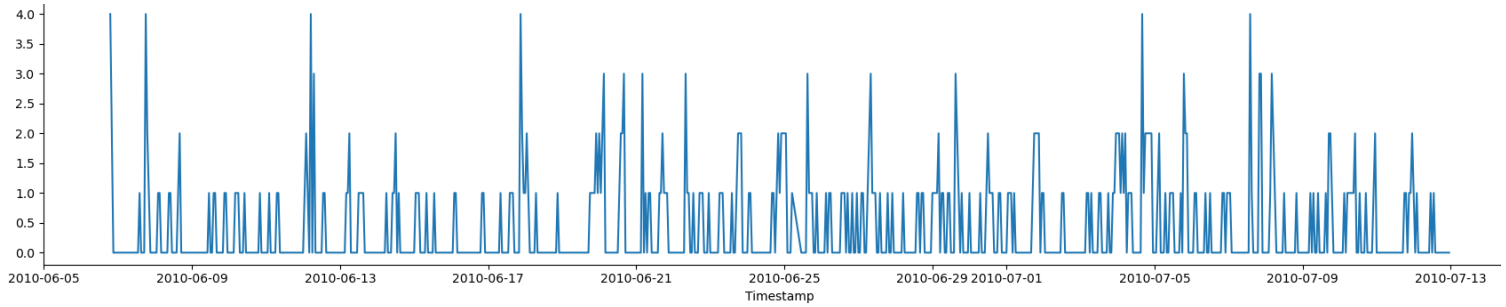
Stochastic availability - Markov chain modelling

Method

- Simulate distribution of offline turbines
- Markov chain estimation
- Generate a stochastic timeseries of number of offline turbines
- Introduce memory with constraints on which turbines switch on/off

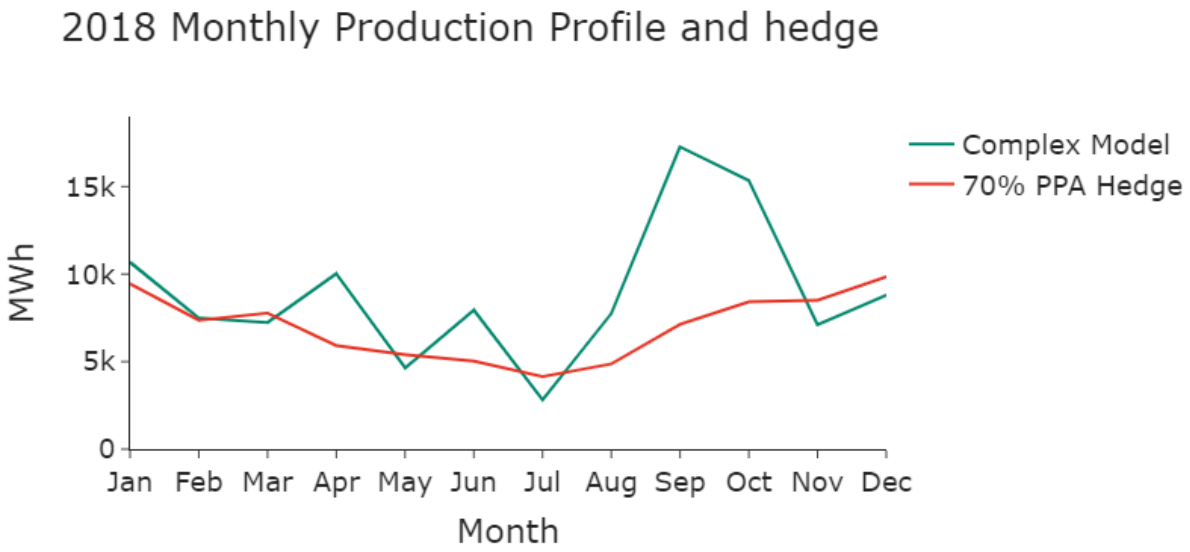
Improves realism of production variations on a timeseries basis

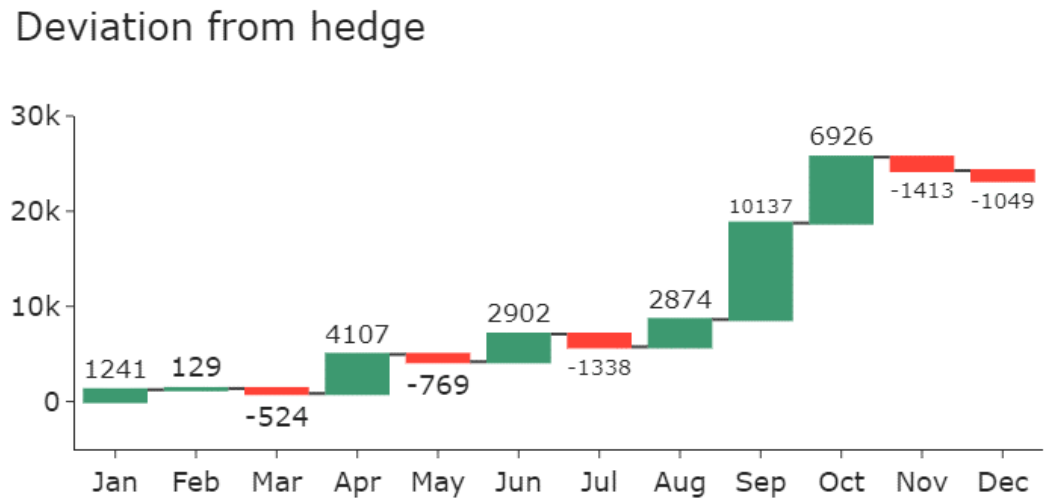




Monthly shortfall

- Hedges can be established on a per-month basis.
- Fine-graining results in larger fluctuations.
- Production shortfall needs to be compensated and can result in financial penalties.





Monthly shortfall frequency

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Shortfall
2000	20783	15848	13363	6149	7989	10384	4938	5352	7770	11135	9681	8405	-1407
2001	7132	12444	7696	8568	6985	6035	5350	8122	8067	13772	16530	10286	-2287
2002	15838	15645	15076	5970	7251	7661	4955	3185	6055	11854	7431	8475	-5157
2003	15797	4902	10507	12121	9937	7521	3373	7384	10647	8683	6887	17226	-4866
2004	8096	10015	10709	6454	8926	7347	5258	8091	12936	11424	12982	17312	-1307
2005	20056	11210	5844	8469	6762	5621	4489	6643	10628	8866	12482	13343	-1867
2006	11652	7047	6240	7122	6530	5385	4554	4235	9049	9096	15624	22424	-2447
2007	17752	8845	12715	10624	9888	6084	9575	9004	14216	8172	10430	13293	-242
2008	20400	16676	10574	5722	3520	8666	5989	8768	6663	18202	14246	8251	-4093
2009	13573	3539	8442	5499	8453	6132	8689	8737	14613	9573	13291	6617	-7449
2010	5997	6307	10099	7461	5460	4246	6580	6689	8894	11226	14311	8869	-6226
2011	13100	12138	16373	9392	11400	7606	5317	6004	13683	15007	11437	19473	0
2012	11935	11808	14232	8699	7832	7327	7460	5364	14264	10309	13496	10444	0
2013	9395	6529	8289	11724	9129	5598	5828	5145	5128	13521	14597	23481	-2878
2014	12807	11388	14719	7978	6401	5400	5233	6406	6391	14624	10004	14723	-744
2015	18094	13841	12678	10740	13040	9555	9811	7235	10046	8098	14771	21170	-315
2016	11659	9586	6264	7523	5997	4856	5905	10633	8133	14962	16078	19701	-1630
2017	12932	10054	14112	11457	5465	11611	5973	7096	7490	16536	12658	13348	0
2018	10621	7452	7200	9980	4631	7941	2811	7741	17272	15322	7101	8737	-5079
2019	11054	15893	15185	6932	8701	8976	6442	7243	11919	10001	8455	14781	-32
Probability of shortfall	20.0%	25.0%	25.0%	10.0%	10.0%	10.0%	10.0%	10.0%	20.0%	10.0%	20.0%	30.0%	**17.5%**

Quarterly shortfall aggregation

- Monthly fluctuations balance out
- Shortfall volume is reduced by an order of magnitude
- Shortfall frequency is significantly reduced

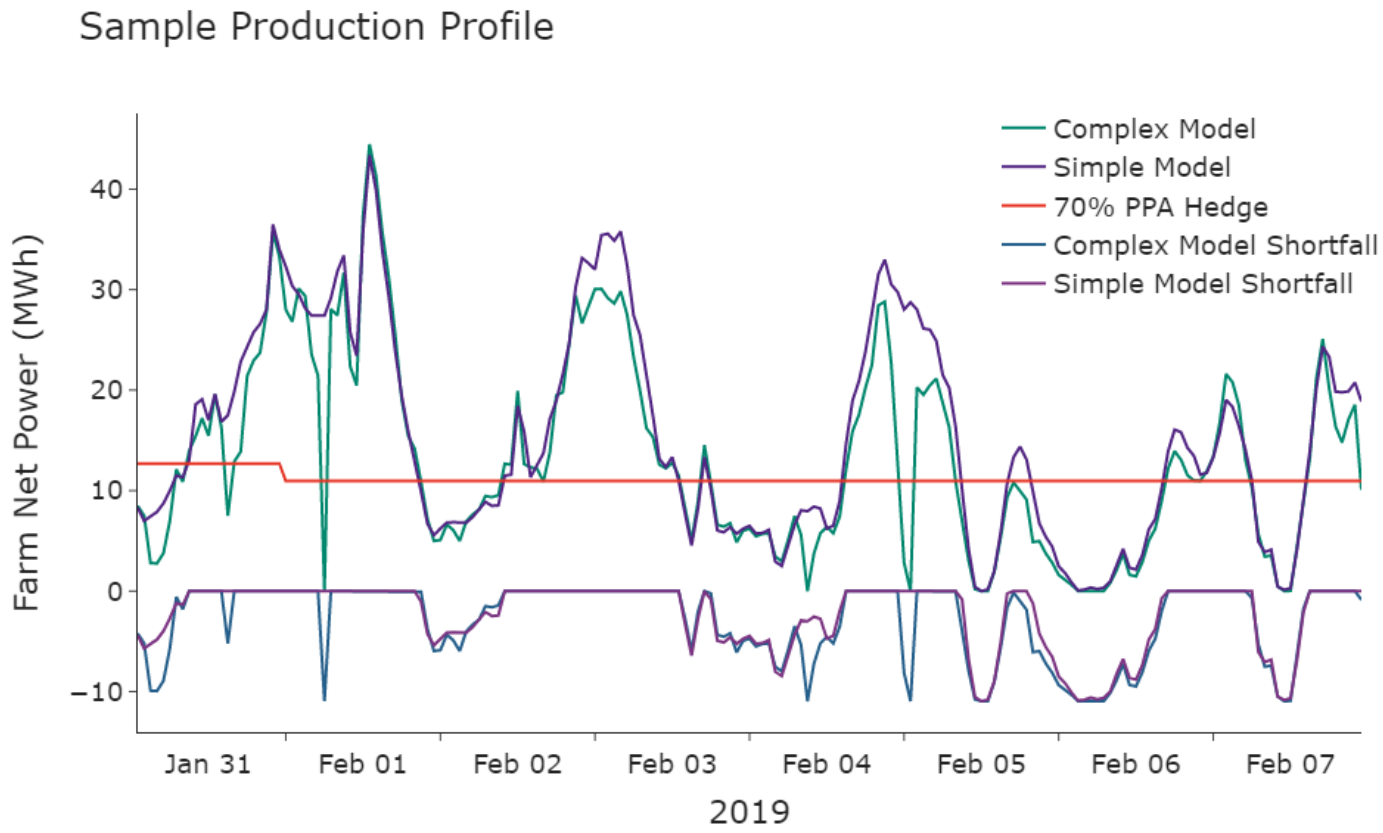
Aggregation	Shortfall frequency	Mean annual shortfall
Monthly	17.5%	-2401 MWh
Quarterly	3.8%	-132 MWh

Year	Q1	Q2	Q3	Q4	Annual shortfall
2000	49978	23935	18370	29357	0
2001	27023	21849	21507	40447	0
2002	46742	20802	13603	27873	-2548
2003	31642	29727	21453	32810	0
2004	28745	22638	26457	41458	0
2005	37323	20876	21739	34579	0
2006	24841	19259	17851	46541	0
2007	39770	26766	32071	32258	0
2008	47789	17885	21519	40543	0
2009	24847	20987	32004	29564	0
2010	22191	17076	22557	33653	0
2011	41893	28789	24492	46469	0
2012	37528	24113	26943	33561	0
2013	25254	26471	16058	50861	-93
2014	39629	19821	18006	38736	0
2015	45105	33452	26816	43846	0
2016	27890	18366	23552	50714	0
2017	38182	27962	20930	42736	0
2018	25478	22450	26959	31465	0
2019	42189	24644	25887	32596	0
Probability of shortfall	5.0%	0.0%	10.0%	0.0%	**3.8%**

Hourly shortfall

- Much greater frequency of shortfall ~50%
- Production in excess of the hedge also increases
- Complex model's additional variability results in a more conservative shortfall

Complex vs simple	
Difference in shortfall	-2.9%
% of Net P50	0.7%



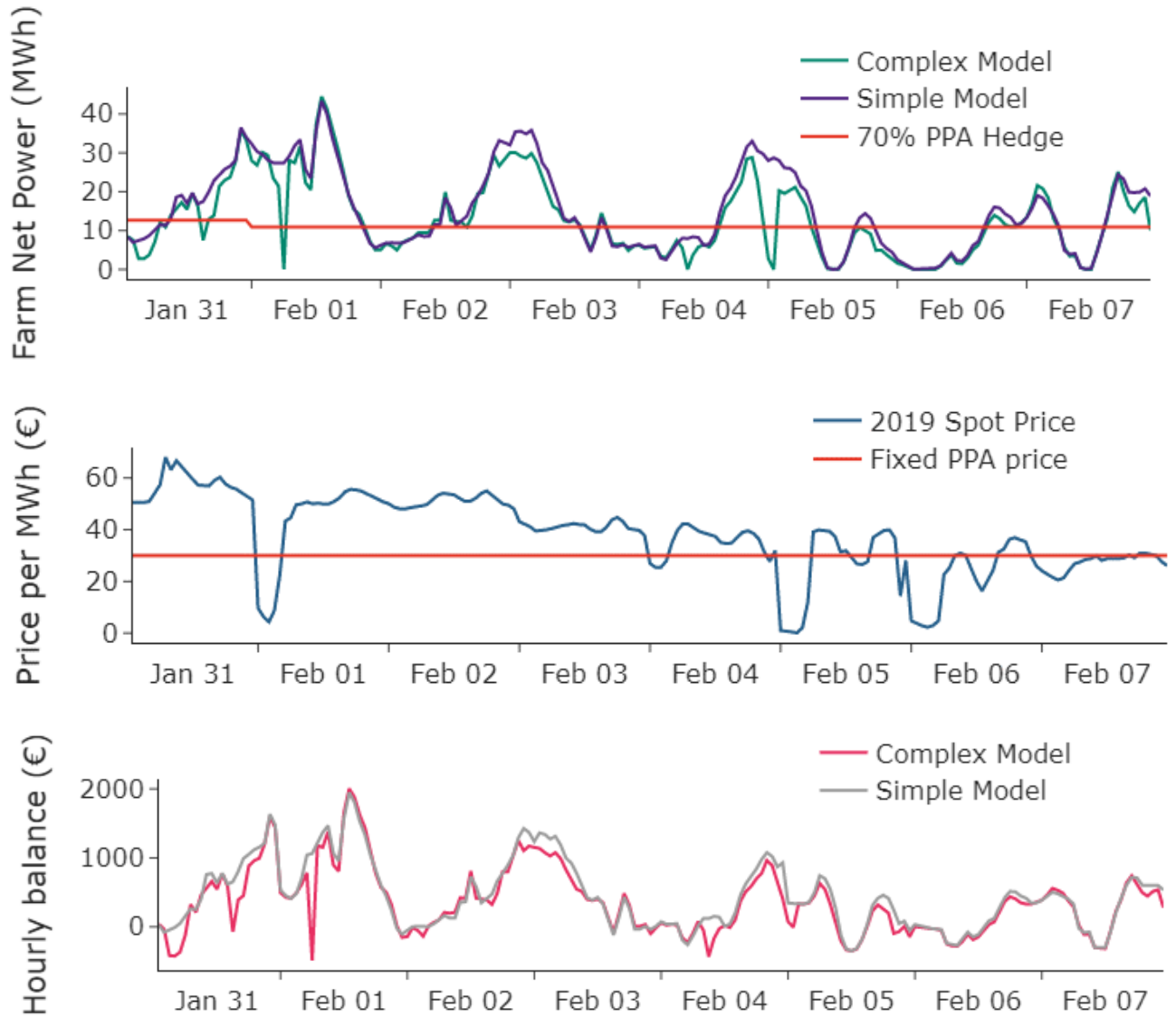
Financial modelling

- N = Wind Farm Net Power
- H = Hedge
- S = Spot Price
- P = PPA Fixed Price

Balance formula:

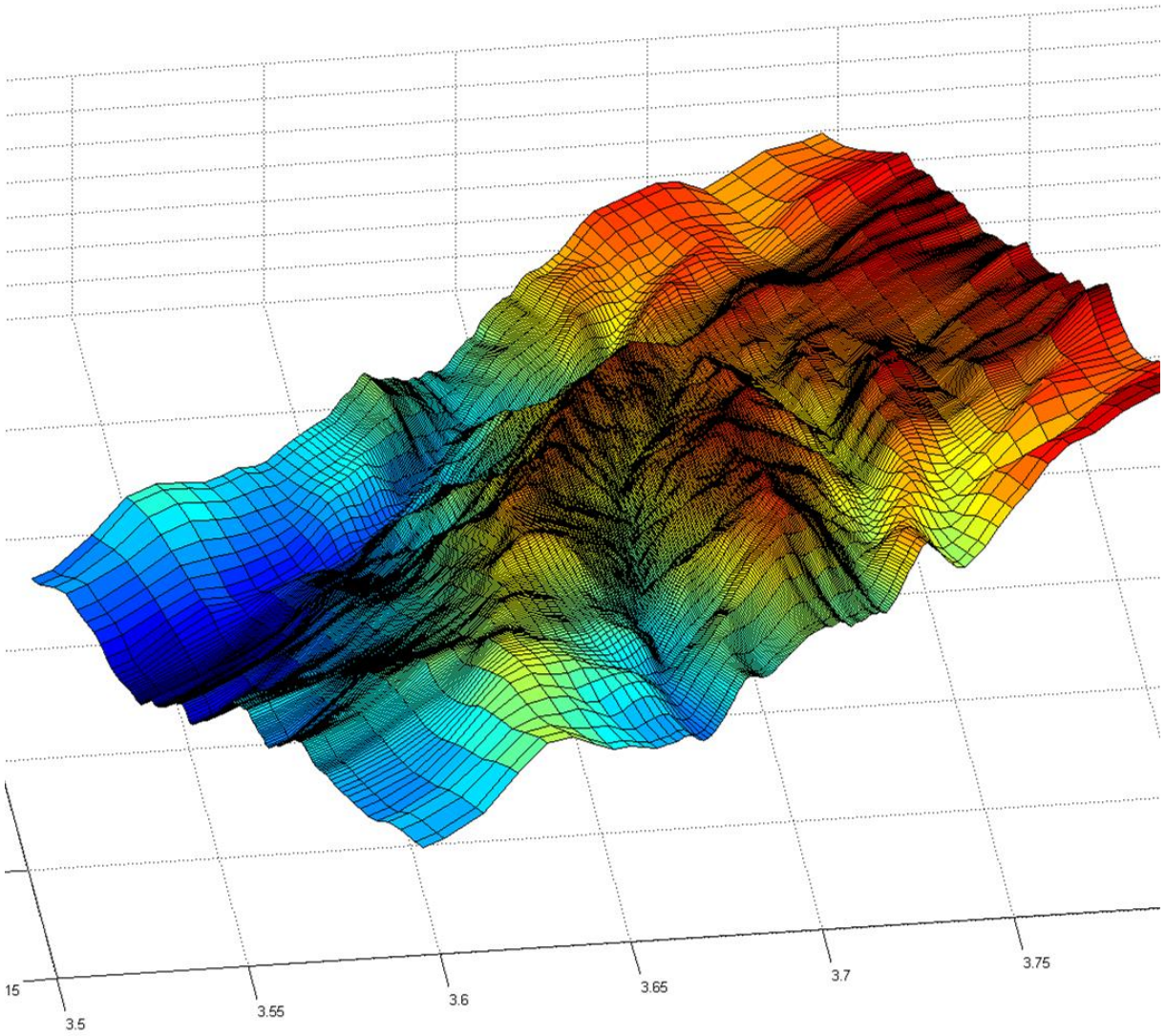
$$\begin{cases} HP + S(N-H) & \text{if } N > H \\ NP + S(N-H) & \text{if } N < H \end{cases}$$

Complex vs simple	
Cumulative balance	+2.4%



Future Steps

- Uncertainty estimation of stochastic losses
- Icing loss frequency distribution modelling – stochastic ice losses
- Validation study of benefits against operational sites in “GAP” analysis
- Streamline timeseries-based wake modelling
- Incorporate time-resolved VENTOS®/M CFD mesoscale-coupled spatial model



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