The Impact of Short-term Variability and Uncertainty on Long-term Power Planning Problems

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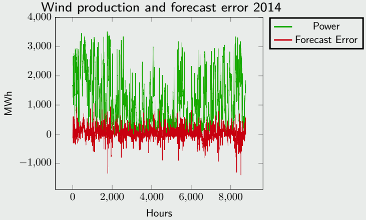
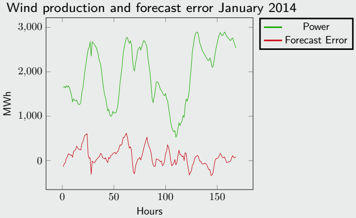
Introduction

Motivation

- More RES → more variability and uncertainty

Wind production in DK1



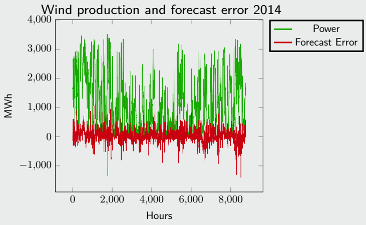


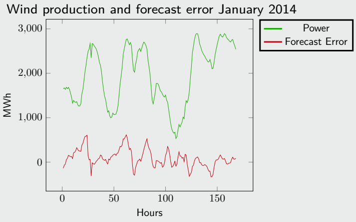
Introduction

Motivation

- More RES $\rightarrow$ more variability and uncertainty $\rightarrow$ dynamic and stochastic optimization $\rightarrow$ computational problems

Wind production in DK1





Introduction

Research questions

- Quantify the trade-off between including uncertainty and variability of renewable production in terms of performance and computational times.
- How to include short-term uncertainty and variations in the best way.

Short-term effects

Short-term effects

Two short-term effects that call for flexible generation:

- Inter-temporal variation.
- Uncertainty balancing.

They overlap but we try to analyse them separately - inter-temporal variations through ramping limits and uncertainty balancing market.

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Investment model

Static central planner investment model:

- Central planner minimizes investment and operating cost
- No existing generating capacity
- Minimum wind penetration constraint

For simplicity, disregard unit commitment decisions and network constraints.

Models

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Model overview (LP)

Min$_{\bar{p}_g, p_{gt}, \tilde{p}_{gts}}$	$\sum_g \left[C^I(\bar{p}_g) + \sum_t \left(C^{DA}(p_{gt}) + \sum_s \pi_s C^B(\tilde{p}_{gts}) \right) \right]$	Objective
s.t.	$p_{gt} \leq \bar{p}_g \quad \forall g$	
	$\sum_g p_{gt} = d_t$	Day-ahead
	$-r_g \leq p_{gt} - p_{g(t-1)} \leq r_g \quad \forall g$	
	$\sum_g \tilde{p}_{gts} = 0$	
	$0 \leq p_{gt} + \tilde{p}_{gts} \leq \bar{p}_g \quad \forall g$	Balancing
	$-r_g \leq p_{gt} + \tilde{p}_{gts} - p_{g(t-1)} - \tilde{p}_{g(t-1)s} \leq r_g \quad \forall g$	

Additional

- Load shedding (with cost)
- Wind curtailment (with cost)

Models

Approaches

	Daily approach With ramping	Hourly approach Without ramping
Conventional Deterministic	DC	HC
Stochastic With balancing market	DS	HS

Example

Illustrative Example

Illustrative example with a time horizon of 6 days

Example

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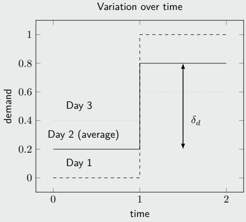
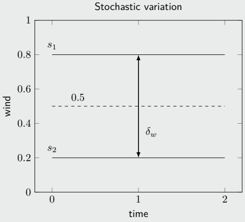
Illustrative example with a time horizon of 6 days

Demand and wind

Each day consists of two time periods.





Example

Units

In order to pinpoint the different effects, units are assumed very specialized (and unrealistic).
The considered units are: wind, inflex, flexDA, flexBal and flex.

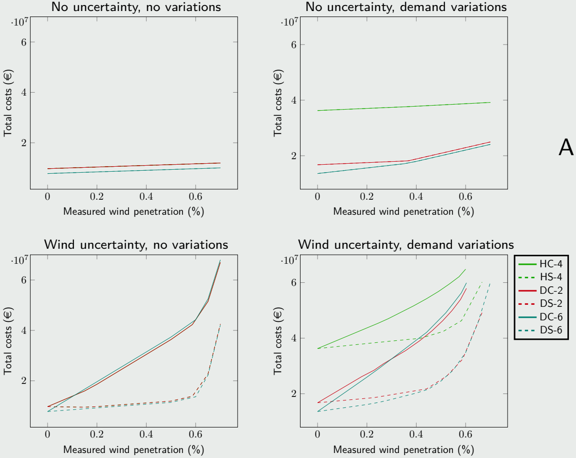
Evaluation

The investment decisions from each approach is fixed in the full (DS-6) model in order to evaluate the impact of investments in terms of total system costs.
For each approach, the procedure is:

1. Solve the problem.
2. Fix the investment decision in the full approach.
3. Solve the full approach for day-ahead and balancing production variables.

Example

Results



Analysis:

- Uncertainty and variations effects
- In this example, uncertainty is dominant.

Case Study

Data and approach

- Data from region DK1: Demand, Wind forecast and Wind production.
- Uncertainty in forecast error - modelled as an AR(2) process and scenarios sampled from this.
- Realistic investment data (annualized)
- Representative days/hours from clustering.
- Official 2020 target: 30% RES.
- No initial installed capacity.

DK1

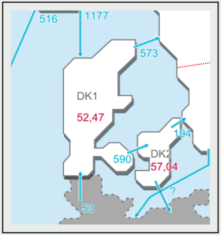


Figure: Source: nordpoolspot.com

Case Study

Units

g	wind	coal	gas	nuclear
c_g^I (T€/MW)	124	106	51	150
c_g (€/MWh)	0	31.4	63.1	15.4
c_g^+, c_g^- (€/MWh)	0	6.28	12.62	3.08
r_g^D, r_g^U (p.u.)	1	0.3	0.7	0.03

Table: Generation unit data for the case study. Sources: [1],[2],[3]

Balancing costs c_g^+, c_g^- are assumed as 20% of the linear production cost c_g.

Case Study

Full model results

Approach	wind	coal	gas	nuclear	Runtime (s)	TC	IC	OC	LSC
HC-8760	2631	243	897	1928	10	1,037	686	321	7
DC-365	2631	928	747	1426	164	995	676	308	4
HS-8760	2631	242	922	1954	2787	1,035	691	320	4
DS-365	2631	955	758	1420	10240	994	678	307	3

Table: Investment decisions and runtimes for the different approaches. Total costs (TC), investment costs (IC), operating costs (OC) and load shedding costs (LSC) all in M€

Analysis

- W/ ramping: nuclear is substituted by coal.
- W/ uncertainty: increase in coal and gas.
- Stochastic model increases runtime.

Case Study

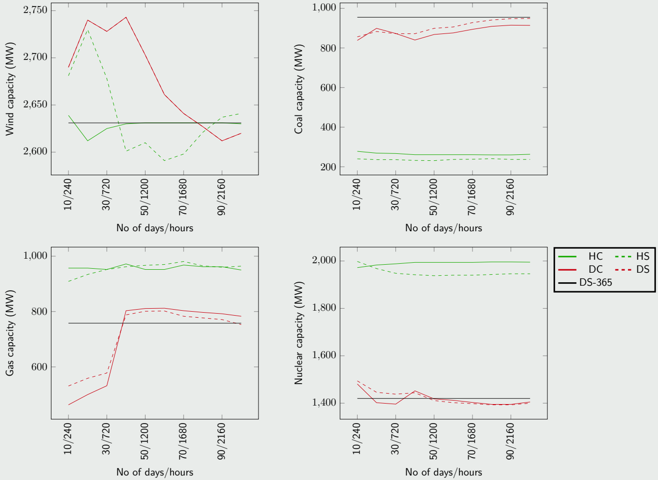
Varying no. of days/hours

Figure: Total costs difference in % between aggregated approaches and DS-365.

- Low impact from no. of hours.
- For more than 40 days, uncertainty is irrelevant.

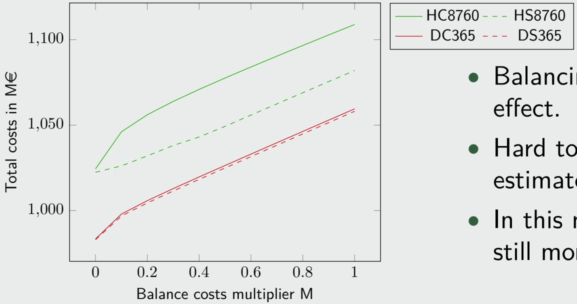
Case Study

Investment decisions



Sensitivity Analysis

Balancing costs reflects ramping $c_g^+ = M \frac{c_g}{r_g^u}$



- Balancing costs have an effect.
- Hard to get realistic estimate.
- In this model, ramping is still more important.

Conclusion

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- Including short-term uncertainty in generation expansion models yields a high computational burden but no significant better solution.
- Including inter-temporal constraints is crucial to capture flexibility needs.
- The coupling of flexibility in a realistic setup regarding short-term variability and uncertainty means including variability needs also serves the uncertainty needs.

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Further research

- Include network, unit commitment constraints, market power etc.
- Clustering days/hours more efficiently.

Thank you

Thank you for your attention.
Any questions?

References

Ea Energianalyse.
Elproduktionsomkostninger.
Energistyrelsen, 1(1):1–42, 2014.

Entsoe.
European Network of Transmission System Operators for Electricity, 2016.

Andreas Schröder, Friedrich Kunz, Jan Meiss, Roman Mendelevitch, and Christian von Hirschhausen.
Current and Prospective Costs of Electricity Generation until 2050 2013.
Deutsches Institut für Wirtschaftsforschung, 2013.

Appendix

Unit Data

g	wind	inflex	flexDA	flexBal	flex
c_g^I (€/MW)	10,000	10,000	10,000	10,000	10,000
c_g (€/MWh)	0	10	20	20	30
c_g^+, c_g^- (€/MWh)	0.001	500	500	0.001	0.001
r_g^D, r_g^U (p.u.)	1	0	1	0	1

Appendix

Evaluation steps

In order to evaluate the investment decisions resulting from the different approaches, the following procedure is incorporated:

1. Solve each of the approaches: DC-6, DS-6, DC-2, DS-2, HC-4, HS-4.
2. Fix the investment decision made by each approach and solve the generation expansion problem using the DS-6 approach (without minimum wind constraints).
3. Evaluate the investment decisions of each approach by simulating the real system operation that includes both time variability and short-term uncertainties.

Appendix

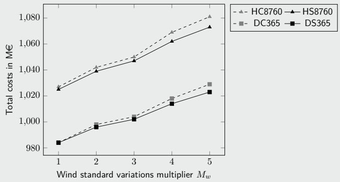
Approach	wind	coal	gas	nuclear	Runtime	Total Costs	Meas. Wind Pen.
DC-365	2631	928	747	1426	139	994.66	0.3
DS-365	2631	955	758	1420	10127	994.29	0.3
HC-240	2639	278	957	1972	0	1032.75	0.301
HC-480	2612	269	957	1983	0	1030.66	0.298
HC-720	2625	267	952	1988	0	1032.75	0.299
HC-960	2630	261	972	1994	0	1034.28	0.3
HC-1200	2631	261	952	1994	0	1034.39	0.3
HC-1440	2631	261	952	1994	0	1034.39	0.3
HC-1680	2631	261	968	1994	0	1034.33	0.3
HC-1920	2631	260	962	1996	1	1034.59	0.3
HC-2160	2631	260	962	1996	1	1034.54	0.3
HC-2400	2630	263	950	1995	1	1034.22	0.3
HS-240	2681	240	909	1998	3	1044.26	0.306
HS-480	2730	236	934	1968	8	1049.19	0.311
HS-720	2678	236	952	1948	18	1040.75	0.305
HS-960	2601	232	962	1942	30	1030.7	0.297
HS-1200	2610	231	967	1938	48	1031.68	0.298
HS-1440	2591	237	970	1940	78	1028.49	0.295
HS-1680	2598	238	981	1940	105	1029.1	0.296
HS-1920	2621	241	965	1943	128	1032.21	0.299
HS-2160	2637	237	960	1946	152	1035	0.301
HS-2400	2641	237	964	1946	202	1035.26	0.301
DC-10	2690	838	463	1481	0	1084.96	0.307
DC-20	2740	899	500	1402	1	1075.18	0.312
DC-30	2728	873	532	1396	1	1073.84	0.311
DC-40	2743	840	803	1452	2	1008.41	0.313
DC-50	2703	868	811	1418	3	1003.3	0.308
DC-60	2661	876	812	1412	3	998.45	0.303
DC-70	2641	894	803	1403	5	996.1	0.301
DC-80	2627	909	797	1395	6	994.44	0.3
DC-90	2612	915	792	1395	9	992.73	0.298
DC-100	2620	914	783	1405	11	993.52	0.299
DS-10	2690	856	531	1494	7	1035.71	0.307
DS-20	2740	883	559	1446	30	1037.74	0.312
DS-30	2728	872	578	1438	59	1036.29	0.311
DS-40	2743	872	788	1444	108	1007.83	0.313
DS-50	2703	899	801	1411	187	1002.76	0.308
DS-60	2661	906	802	1402	274	998.04	0.303
DS-70	2641	928	783	1398	337	995.73	0.301
DS-80	2627	941	777	1393	416	994.11	0.3
DS-90	2612	948	771	1393	719	992.42	0.298
DS-100	2620	949	753	1400	825	993.38	0.299

Table: Investment decisions and runtimes for the different approaches.

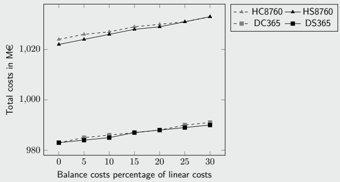
Appendix

Sensitivity Analysis

Increased wind uncertainty



Analysis on balancing costs



Sensitivity Analysis

- Stochastic approaches outperform the deterministic approaches as uncertainty increases.
- Daily approaches still outperform hourly approaches.
- No effect from balancing costs.

Appendix

Computer statistics

Model	AMD Opteron(tm) Processor 6380
CPU	2.5 GHz
No. of CPUs	64
Memory	250 GB
GAMS version	24.5.4
GAMS release	r54492 LEX-LEG x86 64bit/Linux