Statistical Analysis of Offshore Wind and other VRE Generation to Estimate the Variability in Future Residual Load

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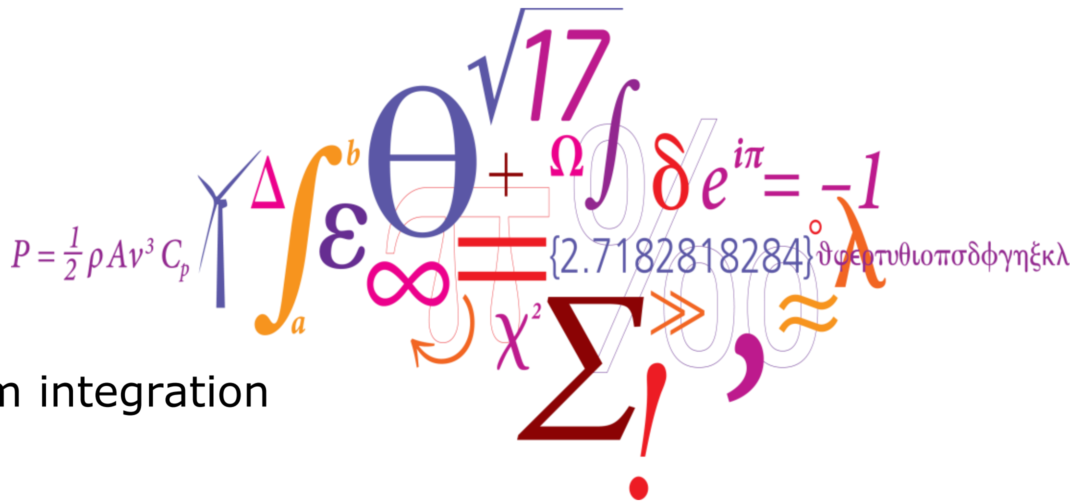


Outline of the presentation

1. The analyzed base scenarios
2. The time series data used
3. Correlations between load and VRE generation
4. A modified 2050 scenario
5. Resulting residual loads in the scenarios
6. Discussion and future work
7. Conclusions

The analyzed base scenarios

- The base scenarios
  - Around 36 GW of VRE generation in 2030 for the analysed countries
  - Around 60 GW in 2050
  - From Nordic Energy Technology Perspectives (NETP) 2016
  - http://www.nordicenergy.org/project/nordic-energy-technology-perspectives/
- These are the base scenarios used in the Flex4RES project
  - http://www.nordicenergy.org/flagship/flex4res/
  - The authors would like to acknowledge support from the Flex4RES project and the NSON-DK (ForskEL) project

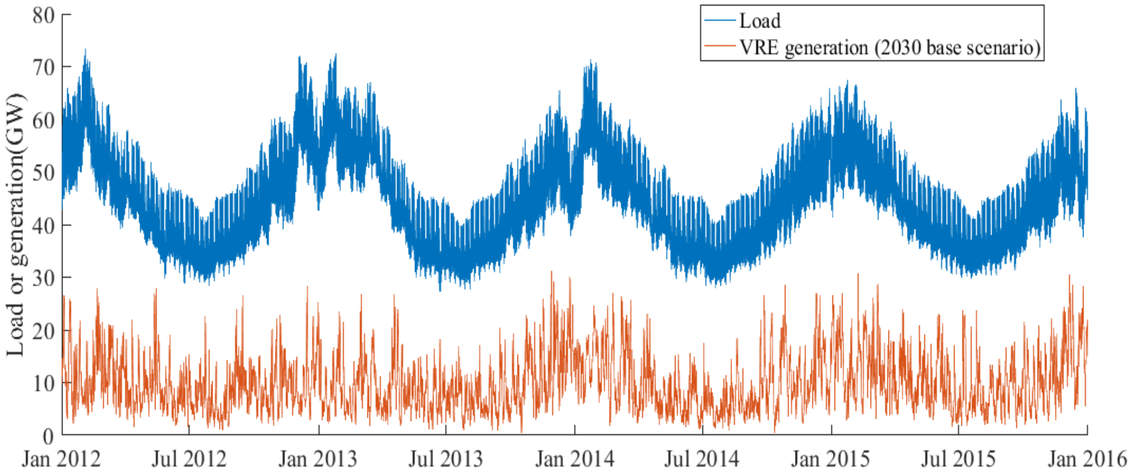
The analysed countries with regions marked. © EuroGeographics for the administrative boundaries (regions are combined of the EU NUTS classification).

Simulated VRE generation

- The VRE generation time series are simulated using the CorRES tool developed at DTU Wind Energy
  - Based on meteorological data obtained from the mesoscale Weather Research and Forecasting (WRF) model
  - Reanalysis of past weather
- Mesoscale models tend to underestimate short-term variability in wind speeds, especially for offshore wind
  - To reach more realistic simulations, stochastic fluctuations are added on top of the mesoscale wind speed data
- VRE installation locations
  - When available, existing locations were used
  - For offshore, also planned locations were used
  - For solar PV, installations were assumed to be scattered through the analysed regions

Historical load time series

- Four years of hourly historical load data (2012 to 2015) for the analysed countries were acquired from Nord Pool
  - https://www.nordpoolgroup.com/historical-market-data/
- A few clearly incorrect data points were fixed by using the data from the previous day of the same type (e.g., working day) from the same hour of the day



Time series of aggregate load and VRE generation with the 2030 base scenario installations for the four analysed years.

Correlations in load time series

- Correlations are generally very high
- Countries further away (e.g., DK and FI) have lower correlations
- SD of the aggregate load is 9.01 GW
  - If all load time series would be fully correlated, the SD of the aggregate would be 9.41 GW
  - There is thus only about 4 % reduction in RSD due to loads not being fully correlated

Correlations between the load time series

	DK	EE	FI	LT	LV	NO	SE
DK		0.90	0.76	0.92	0.87	0.73	0.83
EE	0.90		0.90	0.87	0.85	0.87	0.93
FI	0.76	0.90		0.70	0.71	0.93	0.95
LT	0.92	0.87	0.70		0.89	0.62	0.74
LV	0.87	0.85	0.71	0.89		0.65	0.73
NO	0.73	0.87	0.93	0.62	0.65		0.96
SE	0.83	0.93	0.95	0.74	0.73	0.96	

	DK	EE	FI	LT	LV	NO	SE	Aggregate
Mean (GW)	3.82	0.91	9.42	1.13	0.80	14.6	15.6	46.3
SD (GW)	0.80	0.20	1.52	0.23	0.17	3.12	3.36	9.01
RSD	0.21	0.22	0.16	0.21	0.21	0.21	0.21	0.19

Relative standard deviation (RSD) is standard deviation (SD) divided by mean

Correlations in load time series ramp rates

- Ramp rates are analysed as first differences of hourly data
  - $\mathrm{diff}(y_t) = y_t - y_{t\text{-}1}$
- Correlations are generally very high
- SD of the aggregate load 1st difference is 1.59 GW/h
  - If all load time series would be fully correlated, the SD of the aggregate 1st difference would be 1.72 GW/h
  - There is thus about 8 % reduction in ramp rate SD due to loads not being fully correlated

Correlations between the load time series 1st differences

	DK	EE	FI	LT	LV	NO	SE
DK		0.80	0.66	0.79	0.71	0.86	0.90
EE	0.80		0.79	0.94	0.86	0.80	0.86
FI	0.66	0.79		0.78	0.70	0.65	0.71
LT	0.79	0.94	0.78		0.86	0.76	0.84
LV	0.71	0.86	0.70	0.86		0.70	0.76
NO	0.86	0.80	0.65	0.76	0.70		0.91
SE	0.90	0.86	0.71	0.84	0.76	0.91	

	DK	EE	FI	LT	LV	NO	SE	Aggregate
SD (GW/h)	0.24	0.05	0.27	0.07	0.05	0.45	0.60	1.59

Behavior of different VRE generation types

- SDs are on average higher in offshore than onshore wind generation
- However, the higher mean generation causes the RSD to be on average 8 % lower in offshore than in onshore wind generation
- Hourly ramp rate SDs are much higher in offshore than in onshore generation
- Solar PV has higher RSD than either of the wind generation types

	Offshore wind	Onshore wind	Solar PV
Mean	0.36	0.27	0.10
SD	0.30	0.25	0.17
RSD	0.85	0.92	1.59
1st difference SD	0.09	0.04	0.05

Correlations between VRE generation sources and aggregate load (1/2)

		Load	Offshore wind								Onshore wind																Solar PV															
		Aggregate	DKe	DKw	EE	FI	LT	LV	NO	SE	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
Load	Aggregate		0.10	0.15	0.08	0.09	0.08	0.07	0.24	0.13	0.15	0.16	0.11	0.11	0.13	0.10	0.11	0.24	0.37	0.29	0.24	0.21	0.16	0.14	0.14	0.11	-0.05	-0.06	-0.10	-0.21	-0.17	-0.10	-0.08	-0.10	-0.18	-0.09	-0.07	-0.07	-0.17	-0.14	-0.09	-0.07
Offshore wind	DKe	0.10		0.73	0.15	0.11	0.34	0.30	0.09	0.35	0.82	0.72	0.17	0.07	0.11	0.34	0.30	0.09	0.15	0.26	0.41	0.23	0.05	0.13	0.41	0.72	-0.11	-0.11	-0.10	-0.09	-0.10	-0.08	-0.09	-0.09	-0.08	-0.10	-0.10	-0.10	-0.10	-0.10	-0.11	-0.12
	DKw	0.15	0.73		0.21	0.18	0.34	0.33	0.18	0.43	0.76	0.84	0.23	0.11	0.18	0.32	0.32	0.18	0.24	0.42	0.58	0.38	0.06	0.21	0.53	0.74	-0.14	-0.15	-0.14	-0.13	-0.13	-0.11	-0.13	-0.15	-0.14	-0.16	-0.19	-0.18	-0.15	-0.16	-0.16	-0.15
	EE	0.08	0.15	0.21		0.42	0.53	0.64	0.18	0.46	0.21	0.22	0.82	0.23	0.50	0.52	0.73	0.26	0.18	0.33	0.11	0.15	0.21	0.41	0.55	0.29	-0.15	-0.15	-0.18	-0.19	-0.20	-0.17	-0.17	-0.19	-0.18	-0.14	-0.13	-0.15	-0.17	-0.17	-0.16	-0.16
	FI	0.09	0.11	0.18	0.42		0.26	0.35	0.33	0.50	0.14	0.17	0.50	0.79	0.85	0.21	0.33	0.38	0.37	0.37	0.07	0.23	0.58	0.61	0.42	0.18	-0.10	-0.10	-0.11	-0.16	-0.14	-0.10	-0.10	-0.14	-0.16	-0.11	-0.10	-0.12	-0.16	-0.13	-0.11	-0.10
	LT	0.08	0.34	0.34	0.53	0.26		0.80	0.12	0.41	0.38	0.33	0.52	0.16	0.28	0.86	0.81	0.18	0.16	0.28	0.17	0.15	0.13	0.25	0.51	0.47	-0.17	-0.16	-0.19	-0.17	-0.18	-0.17	-0.19	-0.19	-0.17	-0.16	-0.16	-0.18	-0.18	-0.18	-0.18	-0.18
	LV	0.07	0.30	0.33	0.64	0.35	0.80		0.17	0.44	0.36	0.33	0.63	0.19	0.36	0.74	0.87	0.22	0.16	0.31	0.15	0.17	0.13	0.29	0.56	0.43	-0.08	-0.08	-0.12	-0.10	-0.11	-0.07	-0.10	-0.11	-0.10	-0.08	-0.09	-0.11	-0.11	-0.11	-0.11	-0.10
	NO	0.24	0.09	0.18	0.18	0.33	0.12	0.17		0.22	0.12	0.18	0.20	0.28	0.30	0.09	0.16	0.75	0.59	0.58	0.19	0.57	0.26	0.34	0.29	0.13	-0.11	-0.11	-0.12	-0.16	-0.14	-0.11	-0.11	-0.18	-0.19	-0.14	-0.15	-0.18	-0.18	-0.17	-0.13	-0.12
	SE	0.13	0.35	0.43	0.46	0.50	0.41	0.44	0.22		0.45	0.43	0.46	0.33	0.51	0.37	0.47	0.32	0.29	0.45	0.20	0.24	0.31	0.63	0.73	0.52	-0.12	-0.12	-0.15	-0.16	-0.17	-0.14	-0.14	-0.15	-0.14	-0.14	-0.12	-0.14	-0.15	-0.16	-0.15	-0.14
Onshore wind	DKe	0.15	0.82	0.76	0.21	0.14	0.38	0.36	0.12	0.45		0.87	0.23	0.10	0.16	0.41	0.38	0.13	0.17	0.34	0.48	0.30	0.06	0.19	0.54	0.84	-0.09	-0.10	-0.09	-0.11	-0.11	-0.10	-0.08	-0.09	-0.08	-0.09	-0.08	-0.08	-0.09	-0.10	-0.10	-0.10
	DKw	0.16	0.72	0.84	0.22	0.17	0.33	0.33	0.18	0.43	0.87		0.24	0.11	0.18	0.35	0.35	0.18	0.22	0.43	0.64	0.44	0.07	0.22	0.56	0.76	-0.09	-0.10	-0.09	-0.11	-0.11	-0.09	-0.09	-0.11	-0.08	-0.11	-0.10	-0.10	-0.10	-0.11	-0.11	-0.09
	EE	0.11	0.17	0.23	0.82	0.50	0.52	0.63	0.20	0.46	0.23	0.24		0.30	0.61	0.51	0.71	0.28	0.19	0.33	0.11	0.17	0.25	0.42	0.52	0.28	-0.13	-0.13	-0.17	-0.18	-0.19	-0.14	-0.15	-0.17	-0.17	-0.13	-0.11	-0.15	-0.16	-0.16	-0.15	-0.14
	FIn	0.11	0.07	0.11	0.23	0.79	0.16	0.19	0.28	0.33	0.10	0.11	0.30		0.75	0.13	0.19	0.31	0.39	0.28	0.06	0.19	0.71	0.49	0.25	0.12	-0.11	-0.11	-0.11	-0.16	-0.14	-0.11	-0.10	-0.13	-0.17	-0.11	-0.10	-0.11	-0.16	-0.13	-0.12	-0.11
	FIs	0.13	0.11	0.18	0.50	0.85	0.28	0.36	0.30	0.51	0.16	0.18	0.61	0.75		0.25	0.39	0.37	0.37	0.36	0.08	0.21	0.60	0.65	0.45	0.20	-0.09	-0.09	-0.10	-0.16	-0.15	-0.10	-0.09	-0.13	-0.15	-0.09	-0.08	-0.10	-0.14	-0.12	-0.10	-0.09
	LT	0.10	0.34	0.32	0.52	0.21	0.86	0.74	0.09	0.37	0.41	0.35	0.51	0.13	0.25		0.85	0.17	0.15	0.28	0.20	0.14	0.11	0.24	0.49	0.49	-0.15	-0.15	-0.19	-0.18	-0.19	-0.18	-0.18	-0.18	-0.16	-0.14	-0.13	-0.16	-0.17	-0.17	-0.16	-0.16
	LV	0.11	0.30	0.32	0.73	0.33	0.81	0.87	0.16	0.47	0.38	0.35	0.71	0.19	0.39	0.85		0.24	0.17	0.34	0.18	0.18	0.15	0.33	0.62	0.47	-0.11	-0.11	-0.14	-0.15	-0.16	-0.13	-0.13	-0.15	-0.13	-0.10	-0.09	-0.12	-0.13	-0.13	-0.12	-0.12
	NMI	0.24	0.09	0.18	0.26	0.38	0.18	0.22	0.75	0.32	0.13	0.18	0.28	0.31	0.37	0.17	0.24		0.59	0.68	0.13	0.39	0.31	0.50	0.39	0.17	-0.12	-0.12	-0.14	-0.19	-0.16	-0.13	-0.13	-0.21	-0.22	-0.14	-0.13	-0.17	-0.19	-0.18	-0.14	-0.12
	NNO	0.37	0.15	0.24	0.18	0.37	0.16	0.16	0.59	0.29	0.17	0.22	0.19	0.39	0.37	0.15	0.17	0.59		0.50	0.26	0.42	0.41	0.41	0.31	0.21	-0.19	-0.19	-0.19	-0.23	-0.21	-0.18	-0.19	-0.23	-0.29	-0.22	-0.22	-0.23	-0.27	-0.25	-0.22	-0.20
	NOS	0.29	0.26	0.42	0.33	0.37	0.28	0.31	0.58	0.45	0.34	0.43	0.33	0.28	0.36	0.28	0.34	0.68	0.50		0.38	0.58	0.28	0.53	0.59	0.38	-0.14	-0.15	-0.17	-0.22	-0.20	-0.16	-0.16	-0.25	-0.22	-0.19	-0.19	-0.23	-0.22	-0.21	-0.17	-0.15
	NSY	0.24	0.41	0.58	0.11	0.07	0.17	0.15	0.19	0.20	0.48	0.64	0.11	0.06	0.08	0.20	0.18	0.13	0.26	0.38		0.59	0.02	0.08	0.33	0.46	-0.09	-0.11	-0.09	-0.11	-0.10	-0.09	-0.08	-0.10	-0.10	-0.13	-0.14	-0.12	-0.11	-0.11	-0.11	-0.10
	NVE	0.21	0.23	0.38	0.15	0.23	0.15	0.17	0.57	0.24	0.30	0.44	0.17	0.19	0.21	0.14	0.18	0.39	0.42	0.58	0.59		0.13	0.23	0.34	0.27	-0.11	-0.12	-0.11	-0.16	-0.14	-0.11	-0.11	-0.16	-0.15	-0.16	-0.16	-0.17	-0.16	-0.15	-0.14	-0.11
	SE1	0.16	0.05	0.06	0.21	0.58	0.13	0.13	0.26	0.31	0.06	0.07	0.25	0.71	0.60	0.11	0.15	0.31	0.41	0.28	0.02	0.13		0.63	0.20	0.07	-0.14	-0.14	-0.14	-0.19	-0.16	-0.14	-0.14	-0.17	-0.22	-0.14	-0.13	-0.14	-0.19	-0.16	-0.14	-0.14
	SE2	0.14	0.13	0.21	0.41	0.61	0.25	0.29	0.34	0.63	0.19	0.22	0.42	0.49	0.65	0.24	0.33	0.50	0.41	0.53	0.08	0.23	0.63		0.53	0.23	-0.11	-0.12	-0.14	-0.18	-0.17	-0.14	-0.13	-0.19	-0.20	-0.13	-0.11	-0.14	-0.17	-0.16	-0.13	-0.12
	SE3	0.14	0.41	0.53	0.55	0.42	0.51	0.56	0.29	0.73	0.54	0.56	0.52	0.25	0.45	0.49	0.62	0.39	0.31	0.59	0.33	0.34	0.20	0.53		0.69	-0.14	-0.14	-0.15	-0.18	-0.18	-0.15	-0.14	-0.18	-0.16	-0.16	-0.14	-0.17	-0.17	-0.18	-0.17	-0.15
	SE4	0.11	0.72	0.74	0.29	0.18	0.47	0.43	0.13	0.52	0.84	0.76	0.28	0.12	0.20	0.49	0.47	0.17	0.21	0.38	0.46	0.27	0.07	0.23	0.69		-0.12	-0.13	-0.11	-0.13	-0.13	-0.11	-0.10	-0.13	-0.10	-0.12	-0.11	-0.12	-0.12	-0.12	-0.13	-0.13
Solar PV	DKe	-0.05	-0.11	-0.14	-0.15	-0.10	-0.17	-0.08	-0.11	-0.12	-0.09	-0.09	-0.13	-0.11	-0.09	-0.15	-0.11	-0.12	-0.19	-0.14	-0.09	-0.11	-0.14	-0.11	-0.14	-0.12		0.97	0.91	0.85	0.86	0.88	0.92	0.88	0.87	0.91	0.87	0.87	0.88	0.91	0.94	0.97
	DKw	-0.06	-0.11	-0.15	-0.15	-0.10	-0.16	-0.08	-0.11	-0.12	-0.10	-0.10	-0.13	-0.11	-0.09	-0.15	-0.11	-0.12	-0.19	-0.15	-0.11	-0.12	-0.14	-0.12	-0.14	-0.13	0.97		0.90	0.85	0.85	0.87	0.91	0.88	0.87	0.92	0.89	0.88	0.88	0.91	0.94	0.95
	EE	-0.10	-0.10	-0.14	-0.18	-0.11	-0.19	-0.12	-0.12	-0.15	-0.09	-0.09	-0.17	-0.11	-0.10	-0.19	-0.14	-0.14	-0.19	-0.17	-0.09	-0.11	-0.14	-0.14	-0.15	-0.11	0.91	0.90		0.88	0.91	0.91	0.98	0.90	0.90	0.88	0.84	0.86	0.90	0.92	0.92	0.91
	FIn	-0.21	-0.09	-0.13	-0.19	-0.16	-0.17	-0.10	-0.16	-0.16	-0.11	-0.11	-0.18	-0.16	-0.16	-0.18	-0.15	-0.19	-0.23	-0.22	-0.11	-0.16	-0.19	-0.18	-0.18	-0.13	0.85	0.85	0.88		0.96	0.90	0.87	0.88	0.91	0.84	0.73	0.76	0.92	0.90	0.87	0.85
	FIs	-0.17	-0.10	-0.13	-0.20	-0.14	-0.18	-0.11	-0.14	-0.17	-0.11	-0.11	-0.19	-0.14	-0.15	-0.19	-0.16	-0.16	-0.21	-0.20	-0.10	-0.14	-0.16	-0.17	-0.18	-0.13	0.86	0.85	0.91	0.96		0.92	0.89	0.87	0.87	0.85	0.73	0.75	0.88	0.90	0.89	0.86
	LT	-0.10	-0.08	-0.11	-0.17	-0.10	-0.17	-0.07	-0.11	-0.14	-0.10	-0.09	-0.14	-0.11	-0.10	-0.18	-0.13	-0.13	-0.18	-0.16	-0.09	-0.11	-0.14	-0.14	-0.15	-0.11	0.88	0.87	0.91	0.90	0.92		0.94	0.87	0.86	0.86	0.74	0.76	0.86	0.88	0.89	0.88
	LV	-0.08	-0.09	-0.13	-0.17	-0.10	-0.19	-0.10	-0.11	-0.14	-0.08	-0.09	-0.15	-0.10	-0.09	-0.18	-0.13	-0.13	-0.19	-0.16	-0.08	-0.11	-0.14	-0.13	-0.14	-0.10	0.92	0.91	0.98	0.87	0.89	0.94		0.90	0.90	0.89	0.84	0.86	0.90	0.92	0.93	0.92
	NMI	-0.10	-0.09	-0.15	-0.19	-0.14	-0.19	-0.11	-0.18	-0.15	-0.09	-0.11	-0.17	-0.13	-0.13	-0.18	-0.15	-0.21	-0.23	-0.25	-0.10	-0.16	-0.17	-0.19	-0.18	-0.13	0.88	0.88	0.90	0.88	0.87	0.87	0.90		0.91	0.91	0.83	0.89	0.91	0.94	0.91	0.88
	NNO	-0.18	-0.08	-0.14	-0.18	-0.16	-0.17	-0.10	-0.19	-0.14	-0.08	-0.08	-0.17	-0.17	-0.15	-0.16	-0.13	-0.22	-0.29	-0.22	-0.10	-0.15	-0.22	-0.20	-0.16	-0.10	0.87	0.87	0.90	0.91	0.87	0.86	0.90	0.91		0.86	0.82	0.85	0.95	0.92	0.89	0.87
	NOS	-0.09	-0.10	-0.16	-0.14	-0.11	-0.16	-0.08	-0.14	-0.14	-0.09	-0.11	-0.13	-0.11	-0.09	-0.14	-0.10	-0.14	-0.22	-0.19	-0.13	-0.16	-0.14	-0.13	-0.16	-0.12	0.91	0.92	0.88	0.84	0.85	0.86	0.89	0.91	0.86		0.90	0.91	0.88	0.93	0.96	0.92
	NSY	-0.07	-0.10	-0.19	-0.13	-0.10	-0.16	-0.09	-0.15	-0.12	-0.08	-0.10	-0.11	-0.10	-0.08	-0.13	-0.09	-0.13	-0.22	-0.19	-0.14	-0.16	-0.13	-0.11	-0.14	-0.11	0.87	0.89	0.84	0.73	0.73	0.74	0.84	0.83	0.82	0.90		0.95	0.84	0.86	0.88	0.87
	NVE	-0.07	-0.10	-0.18	-0.15	-0.12	-0.18	-0.11	-0.18	-0.14	-0.08	-0.10	-0.15	-0.11	-0.10	-0.16	-0.12	-0.17	-0.23	-0.23	-0.12	-0.17	-0.14	-0.14	-0.17	-0.12	0.87	0.88	0.86	0.76	0.75	0.76	0.86	0.89	0.85	0.91	0.95		0.86	0.88	0.89	0.87
	SE1	-0.17	-0.10	-0.15	-0.17	-0.16	-0.18	-0.11	-0.18	-0.15	-0.09	-0.10	-0.16	-0.16	-0.14	-0.17	-0.13	-0.19	-0.27	-0.22	-0.11	-0.16	-0.19	-0.17	-0.17	-0.12	0.88	0.88	0.90	0.92	0.88	0.86	0.90	0.91	0.95	0.88	0.84	0.86		0.95	0.91	0.89
	SE2	-0.14	-0.10	-0.16	-0.17	-0.13	-0.18	-0.11	-0.17	-0.16	-0.10	-0.11	-0.16	-0.13	-0.12	-0.17	-0.13	-0.18	-0.25	-0.21	-0.11	-0.15	-0.16	-0.16	-0.18	-0.12	0.91	0.91	0.92	0.90	0.90	0.88	0.92	0.94	0.92	0.93	0.86	0.88	0.95		0.95	0.91
	SE3	-0.09	-0.11	-0.16	-0.16	-0.11	-0.18	-0.11	-0.13	-0.15	-0.10	-0.11	-0.15	-0.12	-0.10	-0.16	-0.12	-0.14	-0.22	-0.17	-0.11	-0.14	-0.14	-0.13	-0.17	-0.13	0.94	0.94	0.92	0.87	0.89	0.89	0.93	0.91	0.89	0.96	0.88	0.89	0.91	0.95		0.96
	SE4	-0.07	-0.12	-0.15	-0.16	-0.10	-0.18	-0.10	-0.12	-0.14	-0.10	-0.09	-0.14	-0.11	-0.09	-0.16	-0.12	-0.12	-0.20	-0.15	-0.10	-0.11	-0.14	-0.12	-0.15	-0.13	0.97	0.95	0.91	0.85	0.86	0.88	0.92	0.88	0.87	0.92	0.87	0.87	0.89	0.91	0.96	

The colouring is based on how beneficial the correlations are for achieving a lower residual load variance

Correlations between VRE generation sources and aggregate load (2/2)

- Both wind generation types are positively correlated with load
- As expected, solar PV is negatively correlated with load
- Solar generation is negatively correlated with wind generation
  - Can reduce residual load variability
  - $\mathrm{Var}(y_t + x_t) = \sigma_x^2 + \sigma_y^2 + 2\sigma_x\sigma_y\rho_{x,y}$

	Aggregate load	Offshore wind	Onshore wind	Solar PV
Aggregate load		0.12	0.17	-0.11
Offshore wind	0.12		0.36	-0.14
Onshore wind	0.17	0.36		-0.14
Solar PV	-0.11	-0.14	-0.14	

Correlations between VRE generation and aggregate load 1st differences (1/2)

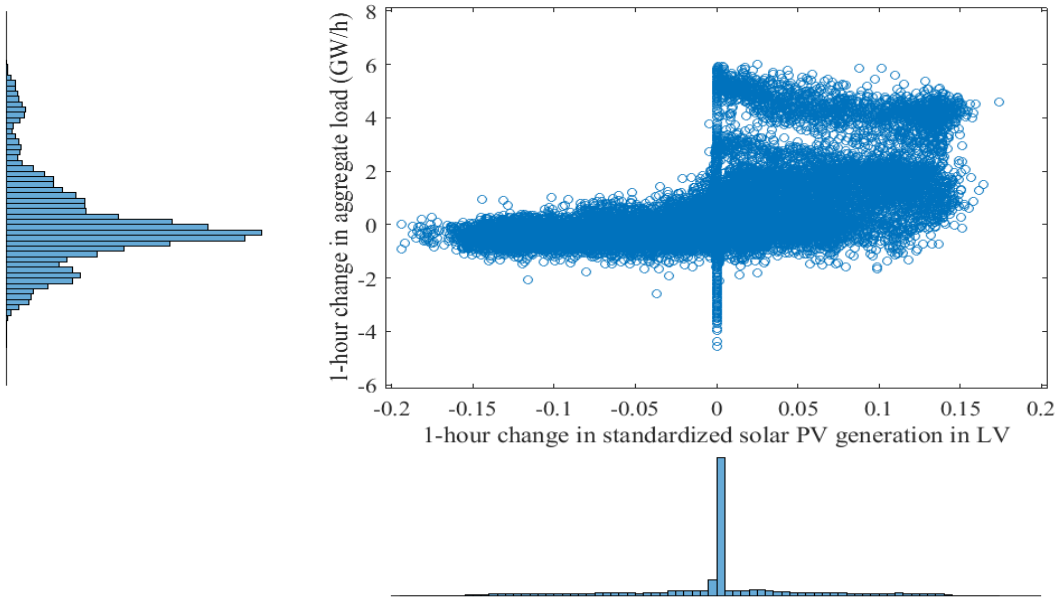
		Load	Offshore wind								Onshore wind																Solar PV															
		Aggregate	DKe	DKw	EE	FI	LT	LV	NO	SE	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
Load	Aggregate		-0.02	0.05	-0.07	0.03	-0.03	-0.04	0.01	-0.01	0.03	0.02	0.00	-0.01	0.01	-0.03	0.00	-0.02	-0.02	0.01	0.01	0.01	-0.04	-0.01	0.01	0.01	0.37	0.37	0.39	0.34	0.35	0.40	0.40	0.36	0.36	0.36	0.30	0.31	0.35	0.37	0.38	0.37
Offshore wind	DKe	-0.02		0.01	-0.05	0.01	0.02	0.03	0.03	0.04	0.25	0.12	0.00	0.01	0.00	0.01	0.00	-0.01	0.01	0.02	0.02	0.00	0.01	0.01	0.05	0.13	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03	-0.04	-0.03	-0.03	-0.04	-0.03	-0.03	-0.03	-0.04	-0.04	-0.04
	DKw	0.05	0.01		-0.01	0.08	-0.03	0.04	0.02	0.02	0.16	0.22	0.00	0.00	-0.01	0.00	-0.02	-0.01	0.00	0.05	0.07	0.02	0.00	0.01	0.05	0.12	-0.04	-0.05	-0.04	0.01	0.01	0.00	-0.04	-0.04	-0.04	-0.04	-0.09	-0.08	-0.04	-0.04	-0.04	-0.04
	EE	-0.07	-0.05	-0.01		0.00	0.01	0.06	-0.02	-0.04	-0.01	0.00	0.19	0.03	0.07	0.06	0.12	0.00	0.01	-0.01	0.00	0.01	0.02	0.03	0.05	0.01	-0.08	-0.08	-0.07	-0.09	-0.10	-0.10	-0.08	-0.08	-0.07	-0.08	-0.05	-0.05	-0.07	-0.08	-0.08	-0.08
	FI	0.03	0.01	0.08	0.00		0.03	0.09	0.05	0.01	0.01	0.01	0.07	0.32	0.25	0.04	0.03	0.00	0.01	-0.01	0.00	0.00	0.09	0.07	0.05	0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02	-0.01	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01
	LT	-0.03	0.02	-0.03	0.01	0.03		0.07	-0.03	0.03	-0.01	-0.02	0.08	0.02	0.02	0.33	0.22	0.00	0.01	-0.01	-0.01	-0.01	0.02	0.02	0.05	0.02	-0.09	-0.10	-0.09	-0.08	-0.08	-0.09	-0.09	-0.09	-0.08	-0.09	-0.09	-0.09	-0.08	-0.09	-0.09	-0.09
	LV	-0.04	0.03	0.04	0.06	0.09	0.07		-0.01	0.00	-0.02	-0.01	0.09	0.00	0.02	0.16	0.30	0.00	0.00	-0.01	-0.01	-0.01	0.00	0.01	0.04	0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.02	-0.03	-0.03	-0.01	-0.02	-0.02	-0.02
	NO	0.01	0.03	0.02	-0.02	0.05	-0.03	-0.01		0.02	-0.02	-0.01	-0.02	0.00	-0.02	-0.02	-0.01	0.14	0.05	0.04	0.00	0.08	-0.01	-0.01	-0.02	-0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	0.00	0.00
	SE	-0.01	0.04	0.02	-0.04	0.01	0.03	0.00	0.02		0.09	0.04	0.02	0.03	0.05	0.01	0.02	0.02	0.01	0.02	-0.02	-0.01	0.05	0.15	0.16	0.11	-0.05	-0.05	-0.06	-0.07	-0.07	-0.06	-0.06	-0.05	-0.06	-0.05	-0.03	-0.04	-0.06	-0.06	-0.06	-0.06
Onshore wind	DKe	0.03	0.25	0.16	-0.01	0.01	-0.01	-0.02	-0.02	0.09		0.48	-0.01	0.01	0.04	0.00	0.00	-0.01	0.00	0.09	0.09	0.02	0.00	0.05	0.16	0.39	-0.01	-0.01	0.00	-0.04	-0.05	-0.05	0.00	0.00	0.02	0.00	0.05	0.06	0.00	0.00	0.00	-0.01
	DKw	0.02	0.12	0.22	0.00	0.01	-0.02	-0.01	-0.01	0.04	0.48		0.02	0.01	0.02	0.01	0.02	-0.01	0.01	0.15	0.21	0.06	-0.01	0.04	0.16	0.26	0.01	-0.01	0.01	-0.03	-0.04	-0.04	0.01	0.01	0.03	-0.01	0.05	0.05	0.02	0.01	0.00	0.00
	EE	0.00	0.00	0.00	0.19	0.07	0.08	0.09	-0.02	0.02	-0.01	0.02		0.08	0.23	0.18	0.28	-0.01	-0.01	0.00	0.02	0.01	0.06	0.07	0.10	0.04	-0.11	-0.11	-0.10	-0.14	-0.15	-0.13	-0.09	-0.12	-0.10	-0.10	-0.06	-0.07	-0.09	-0.10	-0.10	-0.10
	FIn	-0.01	0.01	0.00	0.03	0.32	0.02	0.00	0.00	0.03	0.01	0.01	0.08		0.40	0.05	0.04	0.00	0.03	0.01	0.00	0.01	0.25	0.11	0.07	0.04	-0.08	-0.08	-0.07	-0.12	-0.11	-0.10	-0.07	-0.09	-0.09	-0.08	-0.05	-0.06	-0.09	-0.08	-0.08	-0.08
	FIs	0.01	0.00	-0.01	0.07	0.25	0.02	0.02	-0.02	0.05	0.04	0.02	0.23	0.40		0.08	0.10	-0.01	0.01	-0.01	-0.01	0.00	0.23	0.19	0.14	0.08	-0.05	-0.06	-0.03	-0.12	-0.12	-0.10	-0.03	-0.07	-0.05	-0.05	0.02	0.01	-0.04	-0.05	-0.05	-0.05
	LT	-0.03	0.01	0.00	0.06	0.04	0.33	0.16	-0.02	0.01	0.00	0.01	0.18	0.05	0.08		0.48	0.00	0.03	0.02	-0.01	0.00	0.06	0.07	0.14	0.09	-0.11	-0.12	-0.11	-0.14	-0.15	-0.16	-0.12	-0.13	-0.10	-0.11	-0.06	-0.07	-0.10	-0.11	-0.11	-0.11
	LV	0.00	0.00	-0.02	0.12	0.03	0.22	0.30	-0.01	0.02	0.00	0.02	0.28	0.04	0.10	0.48		0.00	0.01	0.00	0.00	0.00	0.03	0.06	0.16	0.08	-0.03	-0.04	-0.03	-0.08	-0.09	-0.08	-0.03	-0.05	-0.02	-0.03	0.02	0.01	-0.02	-0.03	-0.03	-0.03
	NMI	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.14	0.02	-0.01	-0.01	-0.01	0.00	-0.01	0.00	0.00		0.14	0.13	-0.02	0.00	-0.02	0.06	0.05	0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.02	-0.04	-0.04	-0.02	0.00	-0.01	-0.03	-0.04	-0.03	-0.02
	NNO	-0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.05	0.01	0.00	0.01	-0.01	0.03	0.01	0.03	0.01	0.14		0.05	0.00	0.01	0.04	0.08	0.04	0.03	-0.04	-0.04	-0.04	-0.05	-0.05	-0.05	-0.04	-0.05	-0.06	-0.04	-0.02	-0.03	-0.05	-0.05	-0.05	-0.04
	NOS	0.01	0.02	0.05	-0.01	-0.01	-0.01	-0.01	0.04	0.02	0.09	0.15	0.00	0.01	-0.01	0.02	0.00	0.13	0.05		0.05	0.08	0.03	0.11	0.20	0.13	-0.05	-0.06	-0.03	-0.07	-0.07	-0.06	-0.04	-0.08	-0.04	-0.08	-0.05	-0.06	-0.05	-0.06	-0.06	-0.05
	NSY	0.01	0.02	0.07	0.00	0.00	-0.01	-0.01	0.00	-0.02	0.09	0.21	0.02	0.00	-0.01	-0.01	0.00	-0.02	0.00	0.05		0.24	-0.02	-0.05	-0.03	0.03	0.02	0.01	0.02	0.01	0.00	0.01	0.03	0.03	0.03	0.01	0.02	0.03	0.03	0.02	0.02	0.02
	NVE	0.01	0.00	0.02	0.01	0.00	-0.01	-0.01	0.08	-0.01	0.02	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.08	0.24		-0.01	-0.05	-0.03	0.00	-0.01	-0.01	0.00	-0.03	-0.03	-0.02	0.00	-0.02	-0.01	-0.02	0.00	0.00	-0.01	-0.01	-0.01	-0.01
	SE1	-0.04	0.01	0.00	0.02	0.09	0.02	0.00	-0.01	0.05	0.00	-0.01	0.06	0.25	0.23	0.06	0.03	-0.02	0.04	0.03	-0.02	-0.01		0.26	0.09	0.03	-0.13	-0.14	-0.12	-0.17	-0.16	-0.15	-0.12	-0.14	-0.14	-0.14	-0.11	-0.12	-0.15	-0.15	-0.14	-0.14
	SE2	-0.01	0.01	0.01	0.03	0.07	0.02	0.01	-0.01	0.15	0.05	0.04	0.07	0.11	0.19	0.07	0.06	0.06	0.08	0.11	-0.05	-0.05	0.26		0.29	0.11	-0.14	-0.14	-0.12	-0.17	-0.18	-0.16	-0.12	-0.15	-0.13	-0.14	-0.09	-0.10	-0.13	-0.15	-0.15	-0.14
	SE3	0.01	0.05	0.05	0.05	0.05	0.05	0.04	-0.02	0.16	0.16	0.16	0.10	0.07	0.14	0.14	0.16	0.05	0.04	0.20	-0.03	-0.03	0.09	0.29		0.33	-0.13	-0.13	-0.11	-0.16	-0.17	-0.17	-0.11	-0.13	-0.10	-0.13	-0.05	-0.06	-0.11	-0.13	-0.14	-0.14
	SE4	0.01	0.13	0.12	0.01	0.02	0.02	0.01	-0.03	0.11	0.39	0.26	0.04	0.04	0.08	0.09	0.08	0.02	0.03	0.13	0.03	0.00	0.03	0.11	0.33		-0.10	-0.10	-0.06	-0.11	-0.12	-0.12	-0.06	-0.08	-0.06	-0.09	-0.02	-0.02	-0.07	-0.08	-0.09	-0.10
Solar PV	DKe	0.37	-0.04	-0.04	-0.08	-0.01	-0.09	-0.02	0.00	-0.05	-0.01	0.01	-0.11	-0.08	-0.05	-0.11	-0.03	-0.02	-0.04	-0.05	0.02	-0.01	-0.13	-0.14	-0.13	-0.10		0.92	0.84	0.75	0.75	0.78	0.85	0.83	0.82	0.86	0.77	0.78	0.82	0.85	0.90	0.92
	DKw	0.37	-0.04	-0.05	-0.08	-0.01	-0.10	-0.02	0.00	-0.05	-0.01	-0.01	-0.11	-0.08	-0.06	-0.12	-0.04	-0.02	-0.04	-0.06	0.01	-0.01	-0.14	-0.14	-0.13	-0.10	0.92		0.83	0.76	0.76	0.78	0.85	0.84	0.82	0.88	0.79	0.79	0.82	0.86	0.90	0.90
	EE	0.39	-0.04	-0.04	-0.07	-0.01	-0.09	-0.02	0.00	-0.06	0.00	0.01	-0.10	-0.07	-0.03	-0.11	-0.03	-0.02	-0.04	-0.03	0.02	0.00	-0.12	-0.12	-0.11	-0.06	0.84	0.83		0.79	0.81	0.81	0.96	0.83	0.86	0.82	0.75	0.77	0.86	0.88	0.88	0.86
	FIn	0.34	-0.03	0.01	-0.09	-0.03	-0.08	-0.01	0.00	-0.07	-0.04	-0.03	-0.14	-0.12	-0.12	-0.14	-0.08	-0.03	-0.05	-0.07	0.01	-0.03	-0.17	-0.17	-0.16	-0.11	0.75	0.76	0.79		0.93	0.86	0.79	0.80	0.84	0.76	0.56	0.59	0.84	0.83	0.80	0.77
	FIs	0.35	-0.03	0.01	-0.10	-0.03	-0.08	-0.01	0.00	-0.07	-0.05	-0.04	-0.15	-0.11	-0.12	-0.15	-0.09	-0.03	-0.05	-0.07	0.00	-0.03	-0.16	-0.18	-0.17	-0.12	0.75	0.76	0.81	0.93		0.88	0.80	0.78	0.79	0.76	0.55	0.58	0.79	0.82	0.81	0.77
	LT	0.40	-0.03	0.00	-0.10	-0.02	-0.09	-0.01	0.01	-0.06	-0.05	-0.04	-0.13	-0.10	-0.10	-0.16	-0.08	-0.03	-0.05	-0.06	0.01	-0.02	-0.15	-0.16	-0.17	-0.12	0.78	0.78	0.81	0.86	0.88		0.85	0.79	0.78	0.77	0.57	0.60	0.77	0.80	0.81	0.79
	LV	0.40	-0.04	-0.04	-0.08	-0.01	-0.09	-0.02	0.00	-0.06	0.00	0.01	-0.09	-0.07	-0.03	-0.12	-0.03	-0.02	-0.04	-0.04	0.03	0.00	-0.12	-0.12	-0.11	-0.06	0.85	0.85	0.96	0.79	0.80	0.85		0.85	0.87	0.84	0.76	0.79	0.86	0.89	0.90	0.87
	NMI	0.36	-0.03	-0.04	-0.08	-0.02	-0.09	-0.02	-0.01	-0.05	0.00	0.01	-0.12	-0.09	-0.07	-0.13	-0.05	-0.04	-0.05	-0.08	0.03	-0.02	-0.14	-0.15	-0.13	-0.08	0.83	0.84	0.83	0.80	0.78	0.79	0.85		0.87	0.88	0.75	0.82	0.85	0.90	0.88	0.84
	NNO	0.36	-0.03	-0.04	-0.07	-0.02	-0.08	-0.01	-0.01	-0.06	0.02	0.03	-0.10	-0.09	-0.05	-0.10	-0.02	-0.04	-0.06	-0.04	0.03	-0.01	-0.14	-0.13	-0.10	-0.06	0.82	0.82	0.86	0.84	0.79	0.78	0.87	0.87		0.82	0.75	0.78	0.93	0.90	0.86	0.84
	NOS	0.36	-0.04	-0.04	-0.08	-0.01	-0.09	-0.02	0.00	-0.05	0.00	-0.01	-0.10	-0.08	-0.05	-0.11	-0.03	-0.02	-0.04	-0.08	0.01	-0.02	-0.14	-0.14	-0.13	-0.09	0.86	0.88	0.82	0.76	0.76	0.77	0.84	0.88	0.82		0.81	0.82	0.83	0.90	0.93	0.88
	NSY	0.30	-0.03	-0.09	-0.05	-0.01	-0.09	-0.03	0.00	-0.03	0.05	0.05	-0.06	-0.05	0.02	-0.06	0.02	0.00	-0.02	-0.05	0.02	0.00	-0.11	-0.09	-0.05	-0.02	0.77	0.79	0.75	0.56	0.55	0.57	0.76	0.75	0.75	0.81		0.93	0.75	0.78	0.81	0.78
	NVE	0.31	-0.03	-0.08	-0.05	-0.01	-0.09	-0.03	-0.01	-0.04	0.06	0.05	-0.07	-0.06	0.01	-0.07	0.01	-0.01	-0.03	-0.06	0.03	0.00	-0.12	-0.10	-0.06	-0.02	0.78	0.79	0.77	0.59	0.58	0.60	0.79	0.82	0.78	0.82	0.93		0.78	0.81	0.82	0.79
	SE1	0.35	-0.03	-0.04	-0.07	-0.02	-0.08	-0.01	-0.01	-0.06	0.00	0.02	-0.09	-0.09	-0.04	-0.10	-0.02	-0.03	-0.05	-0.05	0.03	-0.01	-0.15	-0.13	-0.11	-0.07	0.82	0.82	0.86	0.84	0.79	0.77	0.86	0.85	0.93	0.83	0.75	0.78		0.93	0.87	0.83
	SE2	0.37	-0.04	-0.04	-0.08	-0.02	-0.09	-0.02	-0.01	-0.06	0.00	0.01	-0.10	-0.08	-0.05	-0.11	-0.03	-0.04	-0.05	-0.06	0.02	-0.01	-0.15	-0.15	-0.13	-0.08	0.85	0.86	0.88	0.83	0.82	0.80	0.89	0.90	0.90	0.90	0.78	0.81	0.93		0.93	0.87
	SE3	0.38	-0.04	-0.04	-0.08	-0.01	-0.09	-0.02	0.00	-0.06	0.00	0.00	-0.10	-0.08	-0.05	-0.11	-0.03	-0.03	-0.05	-0.06	0.02	-0.01	-0.14	-0.15	-0.14	-0.09	0.90	0.90	0.88	0.80	0.81	0.81	0.90	0.88	0.86	0.93	0.81	0.82	0.87	0.93		0.94
	SE4	0.37	-0.04	-0.04	-0.08	-0.01	-0.09	-0.02	0.00	-0.06	-0.01	0.00	-0.10	-0.08	-0.05	-0.11	-0.03	-0.02	-0.04	-0.05	0.02	-0.01	-0.14	-0.14	-0.14	-0.10	0.92	0.90	0.86	0.77	0.77	0.79	0.87	0.84	0.84	0.88	0.78	0.79	0.83	0.87	0.94	

The colouring is based on how beneficial the correlations are for achieving a lower residual load 1st difference variance

Correlations between VRE generation and aggregate load 1st differences (2/2)

	Offshore wind	Onshore wind	Solar PV
Correlation with aggregate load's 1st difference	-0.01	0.00	0.36

- Wind generation 1st differences are much less correlated than the wind generation time series themselves
  - Wind ramping is thus expected to experience more geographical smoothening than is seen in wind generation itself
- Solar generation ramps are positively correlated with load ramps
  - Can reduce residual load ramp rates



Example of solar PV ramps and aggregate load ramps

A modified 2050 scenario

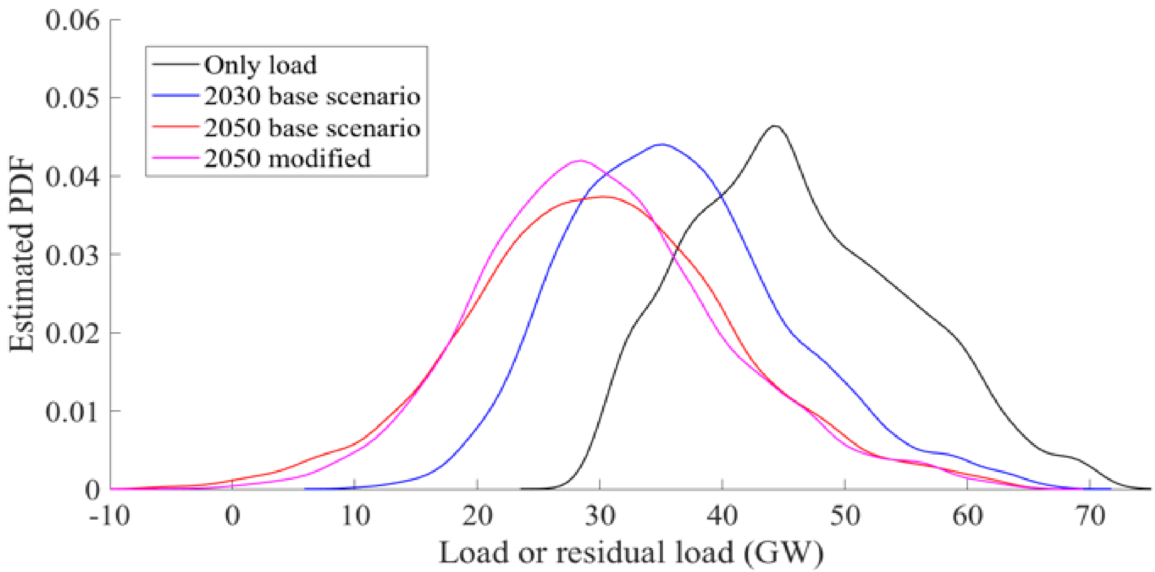
- Modifications were tested for the base 2050 scenario
  - Expected yearly VRE energy generation was kept constant in all test scenarios
- Increasing the low offshore wind share in the baseline scenario up to 50 % resulted in a small reduction of the residual load SD (up to 2 %)
- Increasing the overall geographical distribution of wind decreased the residual load SD about 4 %
- A final modified 2050 scenario:
  - 30 % of wind energy from offshore, and solar share 10 %
  - Installations geographically more dispersed

Percentages of expected yearly energies coming from the different VRE types in the different scenarios

	Offshore wind	Onshore wind	Solar PV
2030 base scenario	15%	83%	2%
2050 base scenario	9%	90%	1%
2050 modified	27%	63%	10%

Resulting residual loads

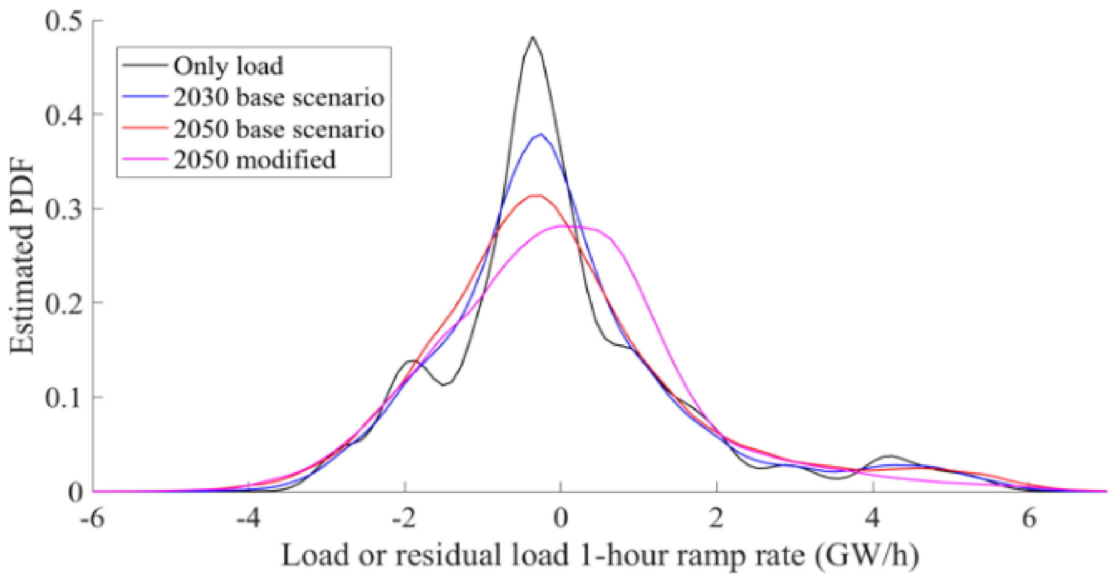
- SD of the residual load increases only by a few percentages compared to only load in the 2030 base scenario
  - but notably in 2050 (22 % higher than the SD of load only)
- As the mean of residual load decreases at the same time, the RSD increases very significantly
- The modified 2050 scenario shows about 7% lower SD in residual load than in the base 2050 scenario



Scenario	Mean (GW)	SD (GW)	RSD	5th percentile (GW)	95th percentile (GW)
Only load	46.3	9.0	0.19	32.6	62.0
2030 base scenario	36.3	9.2	0.25	22.7	52.9
2050 base scenario	30.1	11.0	0.37	12.3	48.8
2050 modified	30.1	10.2	0.34	14.5	48.3

Resulting residual load ramp rates

- Hourly ramp rates in residual load increase only moderately
  - In the 2050 base scenario, the SD of the residual load ramp rate is 10% higher than in load only
- The modified scenario shows a much lower ramp rate SD compared to the base 2050 scenario
  - Especially the 95th percentile value is much lower
  - This is explained by the increased solar PV share, as solar up-ramping happens often at the same time as load up-ramping



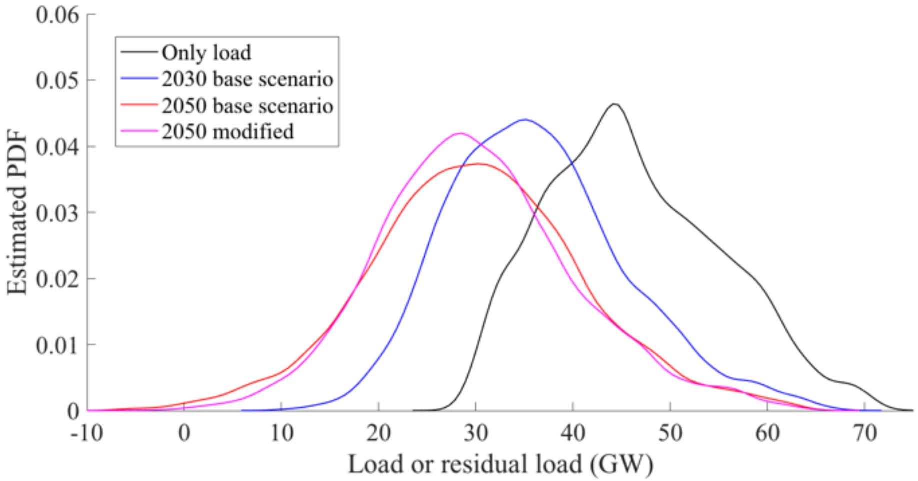
Scenario	Ramp rate SD (GW/h)	5th percentile (GW/h)	95th percentile (GW/h)
Only load	1.59	-2.24	3.54
2030 base scenario	1.62	-2.26	3.52
2050 base scenario	1.75	-2.42	3.64
2050 modified	1.57	-2.38	2.87

Future work

- Creating more years of load time series
  - To get different meteorological years into the analysis (e.g., very cold winters)
  - Either by acquiring more historical load data,
  - or by building stochastic time series models of load for the different countries and using past meteorological data to simulate load time series
  - VRE simulations are already available for 35 past meteorological years
- VRE technology development in the future
  - Changes, e.g., in hub heights and specific power will be implemented to model the capacity factors of future wind generation
- Optimizing the geographical distribution and VRE generation mix
  - E.g., by minimizing residual load variance

Conclusions

- SD of residual load in the 2050 base scenario expected to be 22 % higher than in load only
  - Mean decreases at the same time -> RSD increases significantly
  - There will be thus less energy to be generated by non-VRE generation types, but with higher needs of flexibility
- In the 2050 base scenario, the residual load ramp rate is expected to be 10% higher than in load only
- A modified scenario for 2050:
  - 7% lower SD in residual load than in the base 2050 scenario
  - Residual load ramp rate SD is expected to be even slightly lower than in load only
- During some high load hours of the year, there is only little VRE generation available in all scenarios



Extra material

Offshore wind

	DKe	DKw	EE	FI	LT	LV	NO	SE
Mean	0.43	0.45	0.29	0.31	0.35	0.30	0.41	0.34
SD	0.34	0.31	0.30	0.27	0.32	0.30	0.29	0.26
RSD	0.77	0.70	1.04	0.88	0.91	1.01	0.71	0.76
1st difference SD	0.10	0.08	0.11	0.08	0.10	0.10	0.07	0.08

Onshore wind

	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
Mean	0.25	0.26	0.26	0.27	0.25	0.24	0.26	0.30	0.35	0.32	0.29	0.23	0.24	0.22	0.27	0.35
SD	0.25	0.24	0.24	0.26	0.22	0.24	0.26	0.29	0.25	0.24	0.30	0.25	0.22	0.20	0.22	0.28
RSD	1.00	0.95	0.93	0.98	0.87	1.00	1.00	0.95	0.70	0.75	1.03	1.09	0.90	0.89	0.83	0.81
1st difference SD	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.03	0.02	0.05	0.04	0.03	0.02	0.03	0.04

Solar PV

	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
Mean	0.11	0.12	0.12	0.09	0.09	0.12	0.12	0.10	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11
SD	0.18	0.18	0.19	0.14	0.14	0.18	0.18	0.15	0.14	0.16	0.16	0.16	0.17	0.17	0.17	0.17
RSD	1.54	1.55	1.57	1.64	1.63	1.54	1.54	1.61	1.63	1.60	1.60	1.59	1.65	1.61	1.57	1.56
1st difference SD	0.06	0.06	0.06	0.04	0.04	0.06	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Offshore wind

Scenario	DKe	DKw	EE	FI	LT	LV	NO	SE
2030 base scenario	573	1443	250	1206	0	180	0	215
2050 base scenario	573	1443	250	1206	0	180	0	215
2050 modified	1000	2000	1000	1206	1000	950	3000	1500

Onshore wind

Scenario	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
2030 base scenario	990	4219	635	533	1067	1677	2979	330	5033	124	1410	126	424	5488	4396	1206
2050 base scenario	1520	6480	400	533	1067	7046	2409	5033	5033	124	1410	126	5488	5488	10975	1206
2050 modified	990	4000	635	2100	1067	1677	2979	2000	5033	124	1410	126	5000	5000	4396	1206

Solar PV

Scenario	DKe	DKw	EE	FIn	FIs	LT	LV	NMI	NNO	NOS	NSY	NVE	SE1	SE2	SE3	SE4
2030 base scenario	268	624	0	0	40	750	2	0	0	0	0	0	0	0	0	79
2050 base scenario	268	624	0	0	40	740	2	0	0	0	0	0	0	0	0	79
2050 modified	1500	2000	1000	0	1500	1000	1000	0	0	1000	1000	1000	0	0	2000	2000

	Offshore wind							Onshore wind							Solar PV						
Year	**DK**	**EE**	**FI**	**LT**	**LV**	**NO**	**SE**	**DK**	**EE**	**FI**	**LT**	**LV**	**NO**	**SE**	**DK**	**EE**	**FI**	**LT**	**LV**	**NO**	**SE**
2014	1271	0	26	0	0	0	212	3603	303	607	279	62	819	5220	602	0.2	11	68	1.5	0	79

VRE installation in 2014 in total around 13 GW

Load TWhs

	DK	EE	FI	LT	LV	NO	SE	Aggregate
Annual TWh	33	8	83	10	7	128	137	405

VRE (all) annual TWhs

Scenario	TWh
2030 base scenario	87.57
2050 base scenario	141.80
2050 modified	141.78