What are the full costs of variable renewables?

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based on work with

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P I K

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What are the full costs of variable renewables?

Policy makers: “What is the optimal share of wind and solar?“

Investors: “When are renewables competitive?“

Modelers: “Does our model consider the relevant cost aspects of renewables?“

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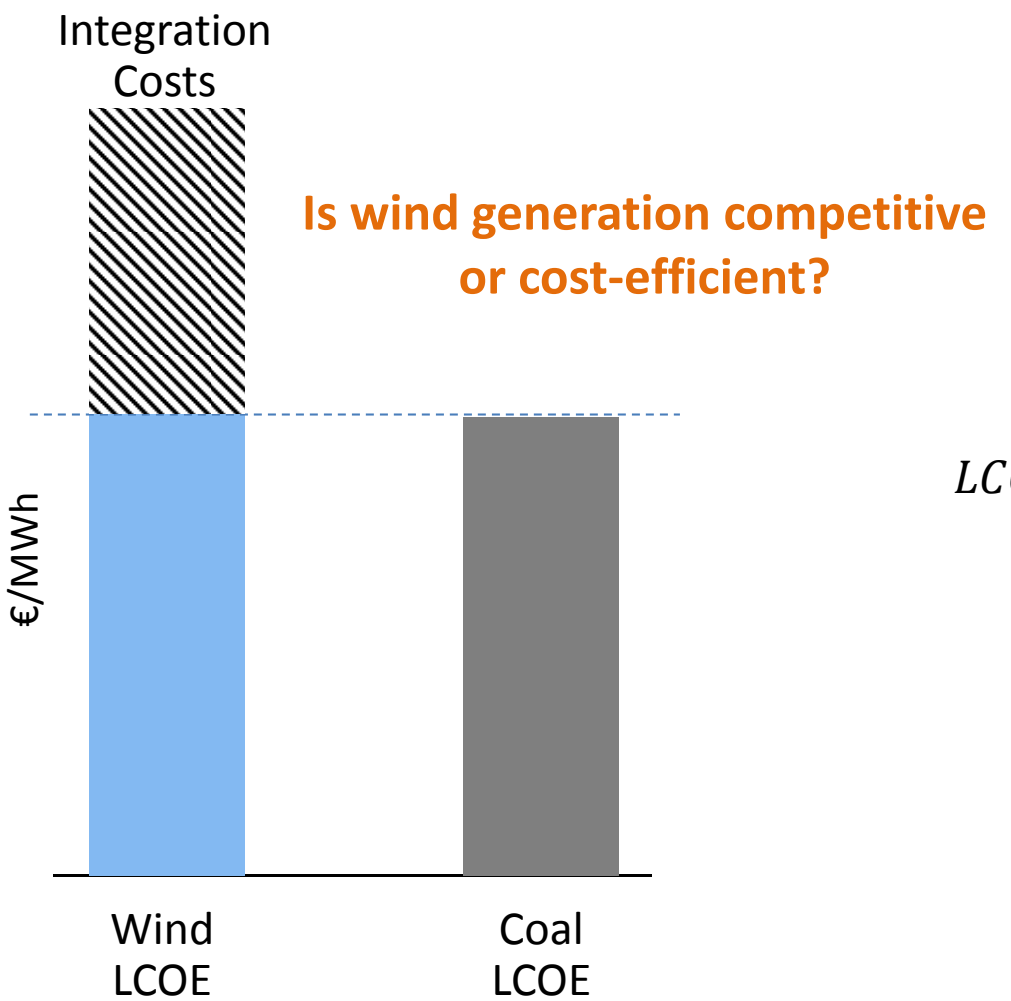
LCOE are a common approach to compare technologies



$$LCOE := \frac{\sum_{y=1}^{lifetime} \frac{c_y}{(1+r)^y}}{\sum_{y=1}^{lifetime} \frac{g_y}{(1+r)^y}}$$

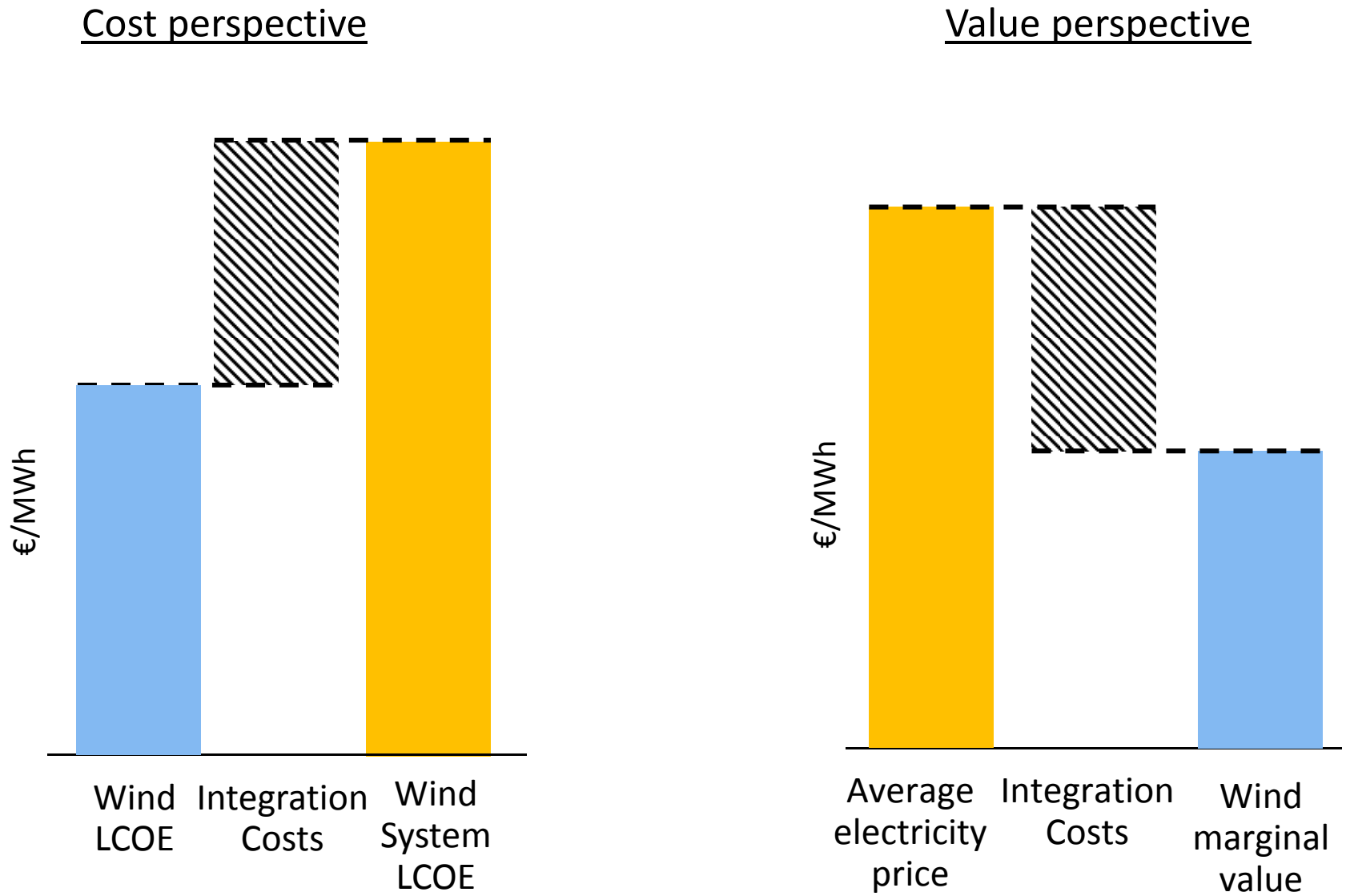
g_y: generation in year y

c_y: costs in year y

r: discount rate

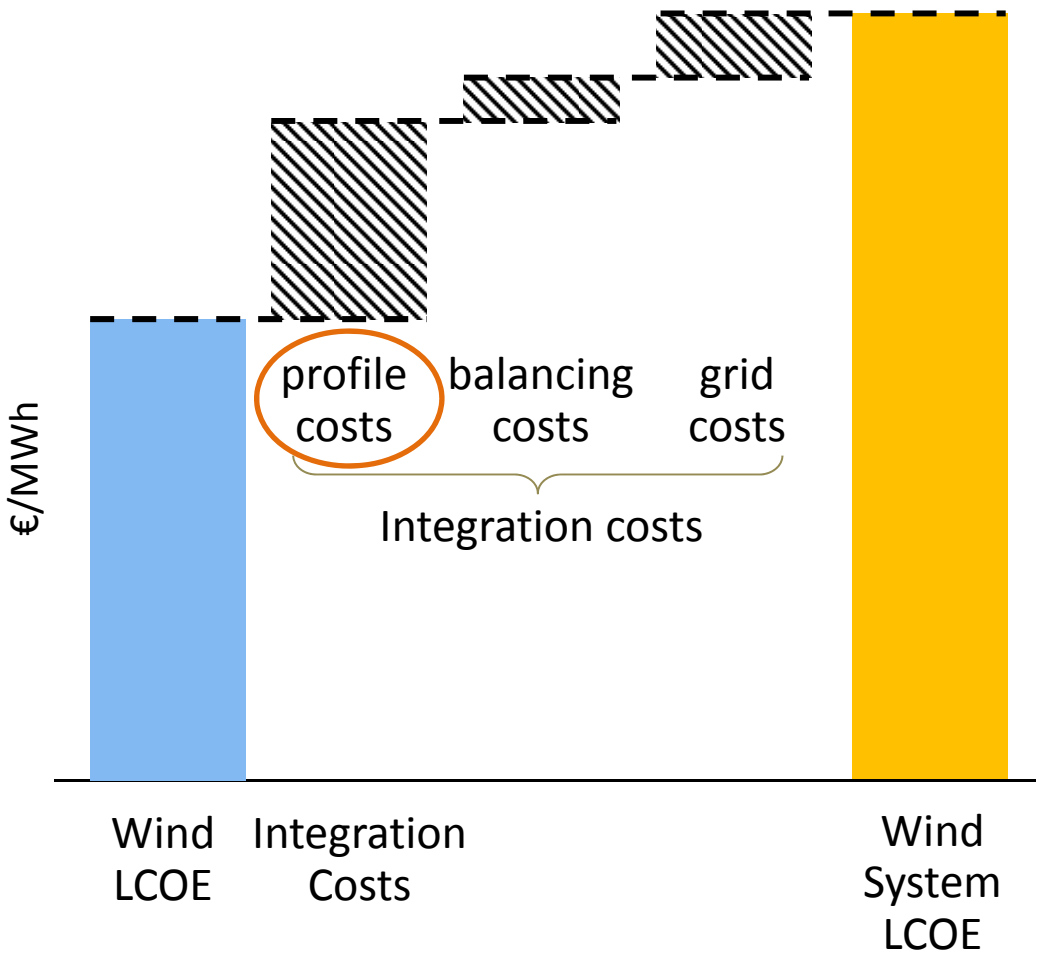
IEA & NEA 2011, EIA 2013, IRENA 2012, IPCC 2011, Nitsch et al. 2011, Kost et al. 2012, Karlynn & Schwabe 2009, …

Two perspectives on integration costs



Ueckerdt et al. 2013. System LCOE: What are the costs of variable renewables? Energy 63, 61–75.

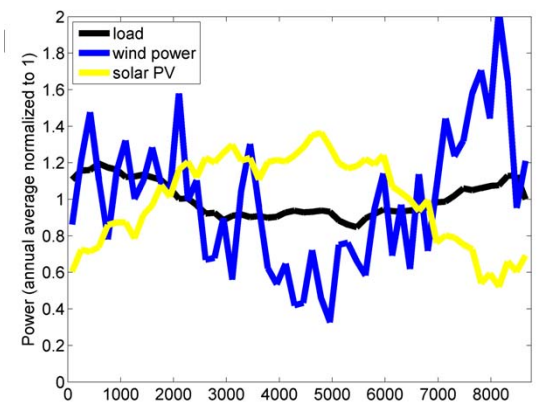
What are components of integration costs?



Ueckerdt et al. 2013. System LCOE: What are the costs of variable renewables? Energy 63, 61–75.

Variable renewables (VRE) are special in three aspects

Output is **variable in time**

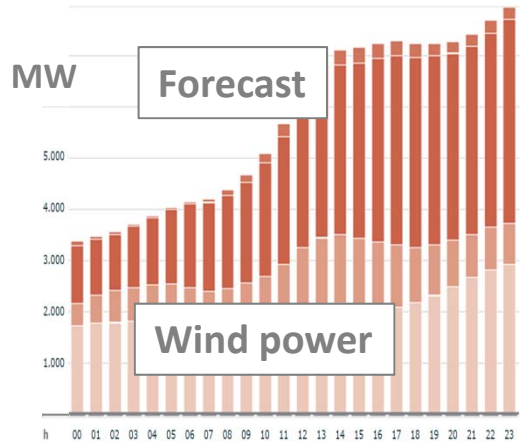


1 year

→ matching of wind and solar with load

„Profile costs“

Output is **uncertain** and **short-term variable**

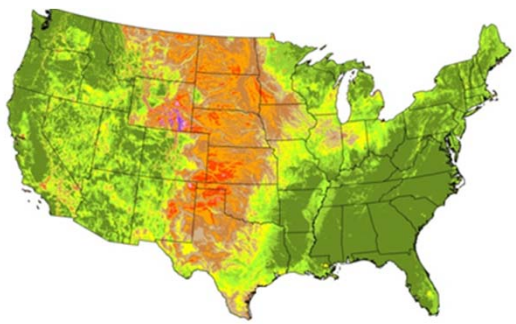


1 day

→ short-term balancing of supply and demand is costly

„Balancing costs“

Output is **variable in space**



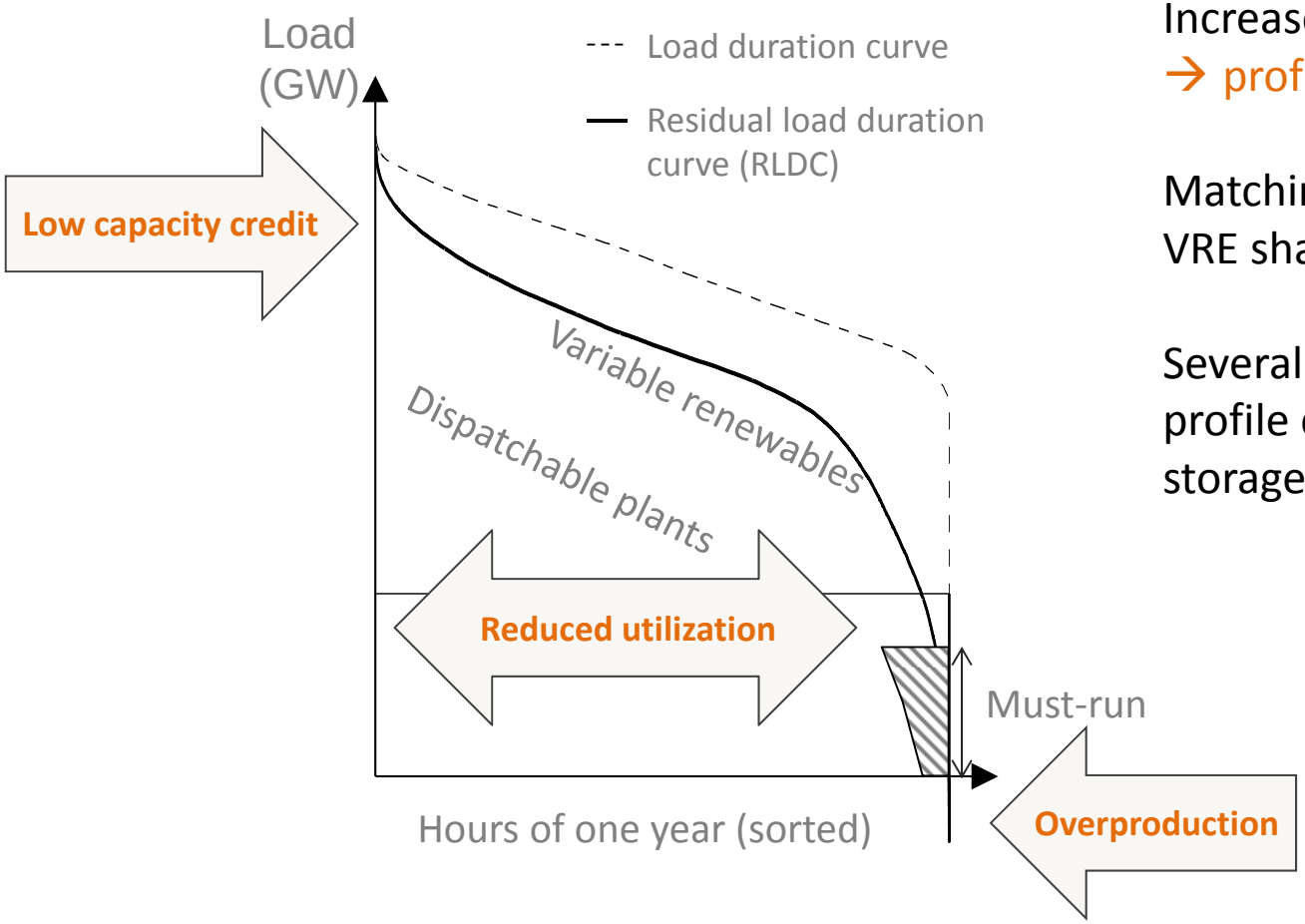
US wind speeds, NREL

→ transmission is costly

„Grid costs“

Additional system costs = “integration costs“

Total system costs depend on temporal matching of VRE supply with demand



Increase in total system costs
→ profile costs

Matching gets worse as VRE shares increase

Several options can decrease profile costs (large grids, DSM, storage, more mid/peak plants)

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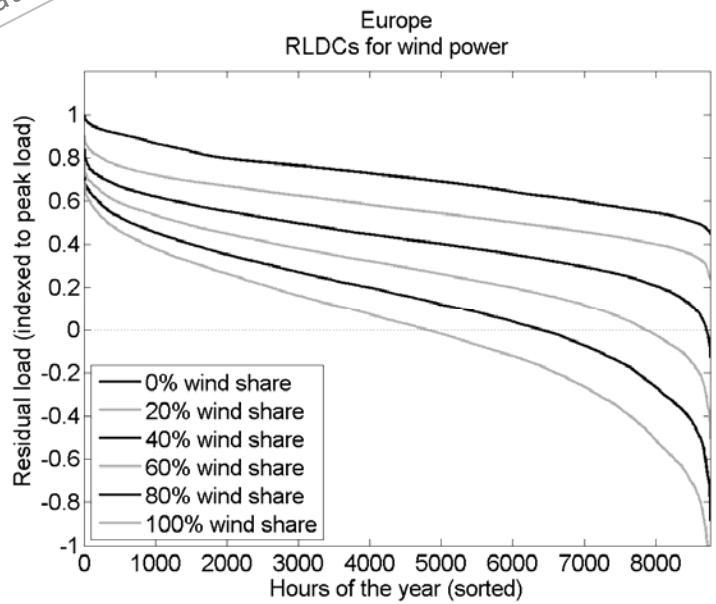
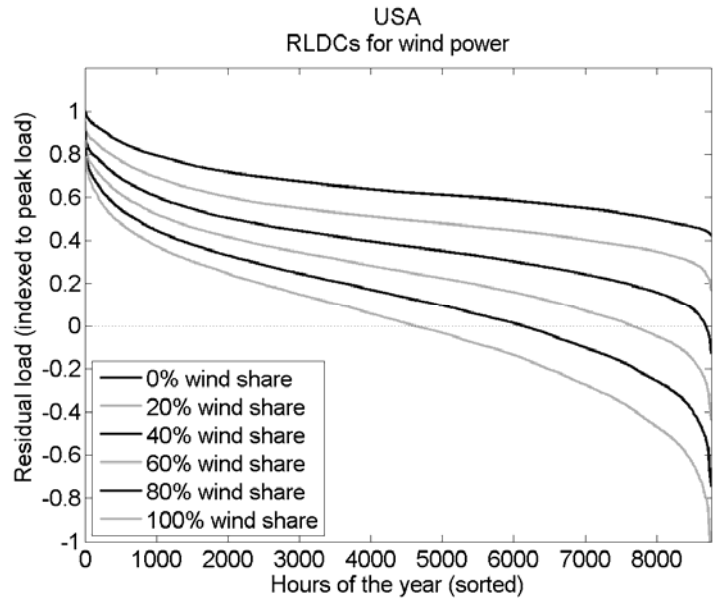
Full spatial aggregation

Europe

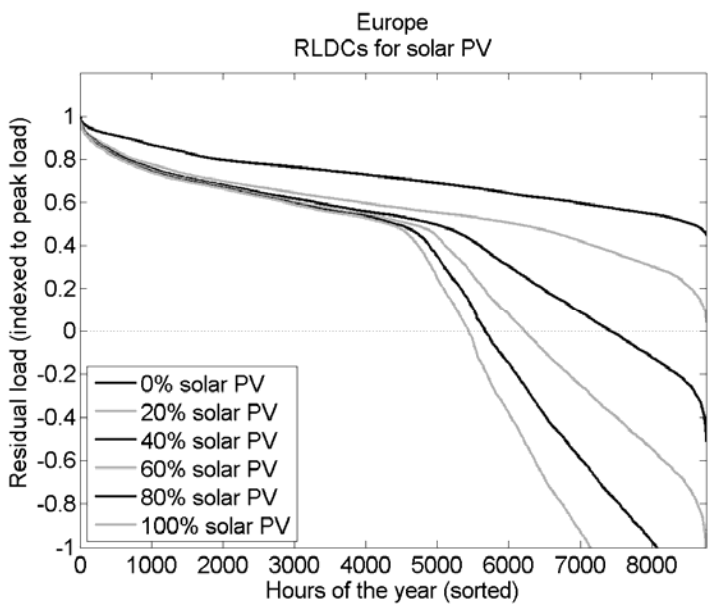
USA

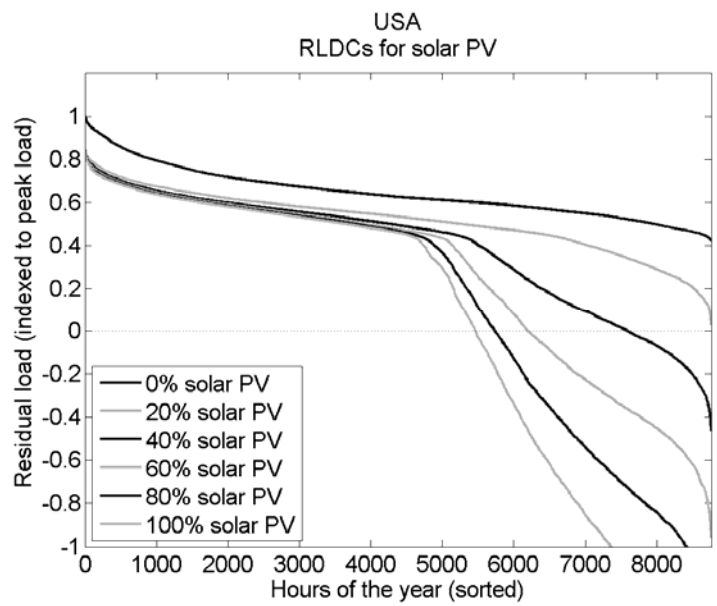
Wind



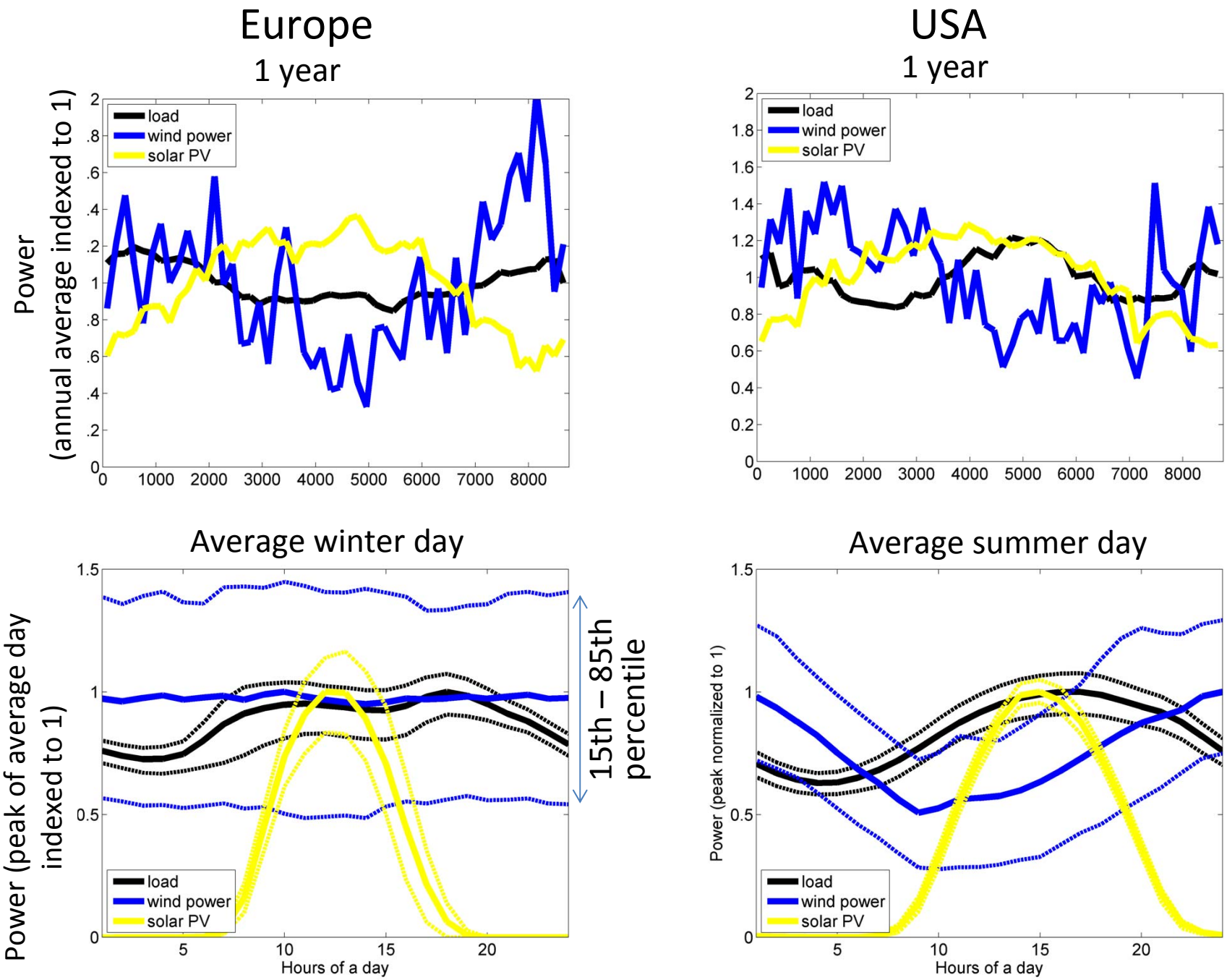


Solar PV





Ueckerdt, Pietzcker, Luderer, Scholz, Stetter, Giannousakis (submitted to energy economics)



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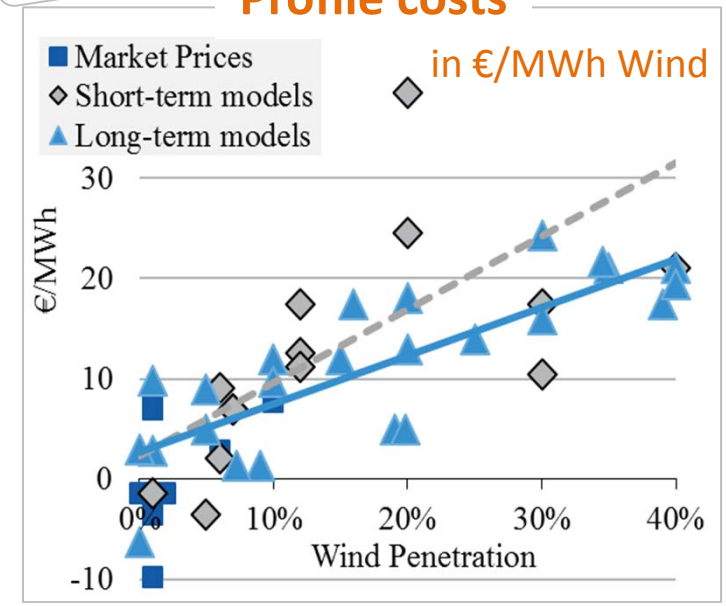
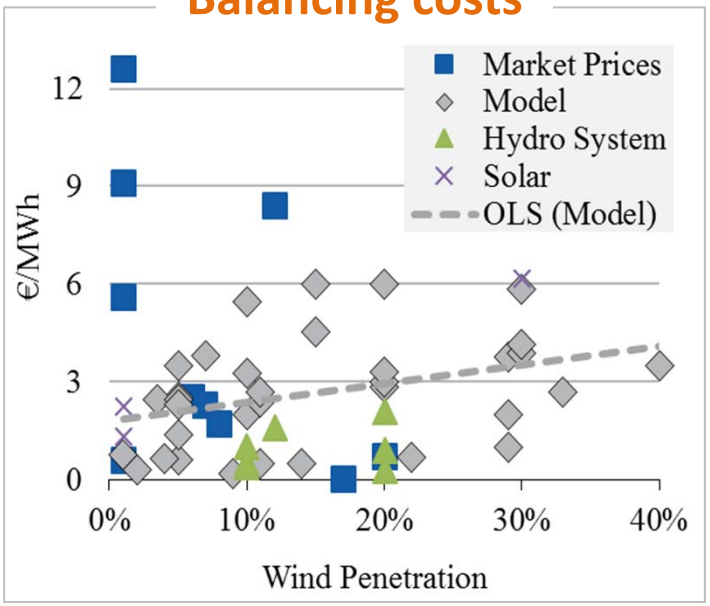
Integration costs can become high at high VRE shares
(Lit review for wind in OECD power systems)

Hardly flexibility options considered

Profile costs



Balancing costs



Grid costs

- **2-13 €/MWh wind** (at 15-40% wind,)
- Scarce and partly inconclusive data

- Integration costs increase with VRE and can become high (~30€/MWh VRE at 40% wind)
- Profile costs are the largest cost component (at high shares in thermal power systems)
- Flexibility options and a shift towards peak/mid-load plants reduces integration costs

L. Hirth, F. Ueckerdt, and O. Edenhofer, “Integration costs revisited – An economic framework for wind and solar variability,” *Renew. Energy*, vol. 74, pp. 925–939, Feb. 2015.
Ueckerdt, O. F. Hirth L. Luderer G. Edenhofer, 2013. System LCOE: What are the costs of variable renewables? Energy 63, 61–75.

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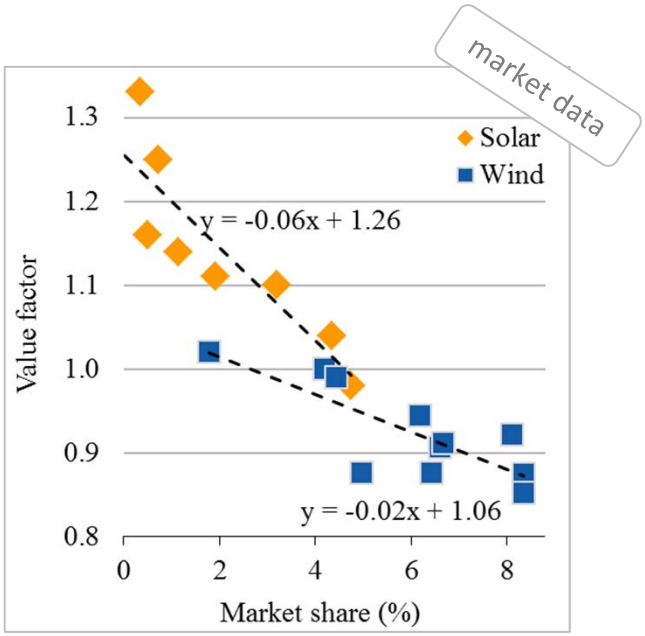
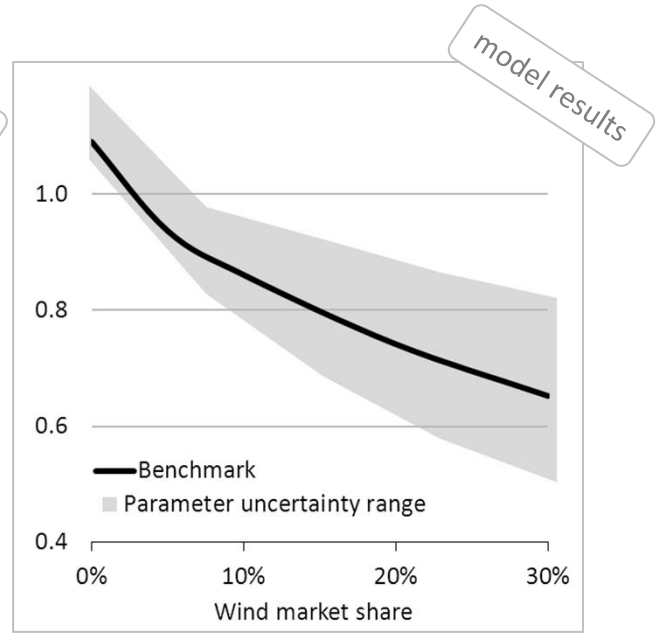
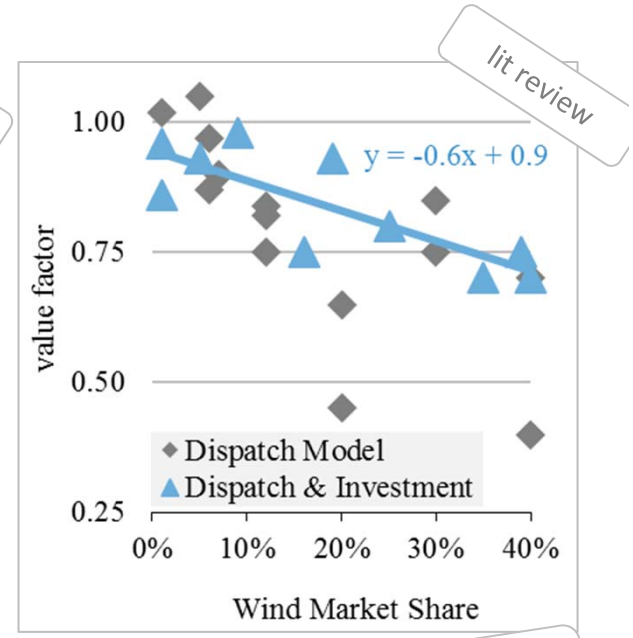
Integration costs decrease the market value of VRE



German price data



German price data



Hardly flexibility options considered

- Value factor := market value / base price
- Value drop shown in empirical results, model runs and literature

L. Hirth, “The market value of variable renewables: The effect of solar wind power variability on their relative price,” Energy Econ., vol. 38, pp. 218–236, Jul. 2013.

Ueckerdt, Falko, Müller, Simon, Hirth, Lion, Nicolosi, Marco: “Integration Costs and Marginal Value: Connecting two perspectives on the economics of variable renewables”. (2013 conference paper)

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Integration costs can be reduced by large grids and storage
(Model analysis with the REMix model for Europe)

REMix model
(German Aerospace Centre, DLR)

- Minimizes total system costs
- Linear optimization of hourly dispatch and investment (based on annuities)
- Represents Europe in 15 regions
- Endogenous DC transmission grid and storage (redox flow battery, pumped hydro and hydrogen storage)

Scholz, Gils, Pietzcker "Application of a high-detail energy system model to derive power sector characteristics at high wind and solar shares" *(submitted to energy economics)*.

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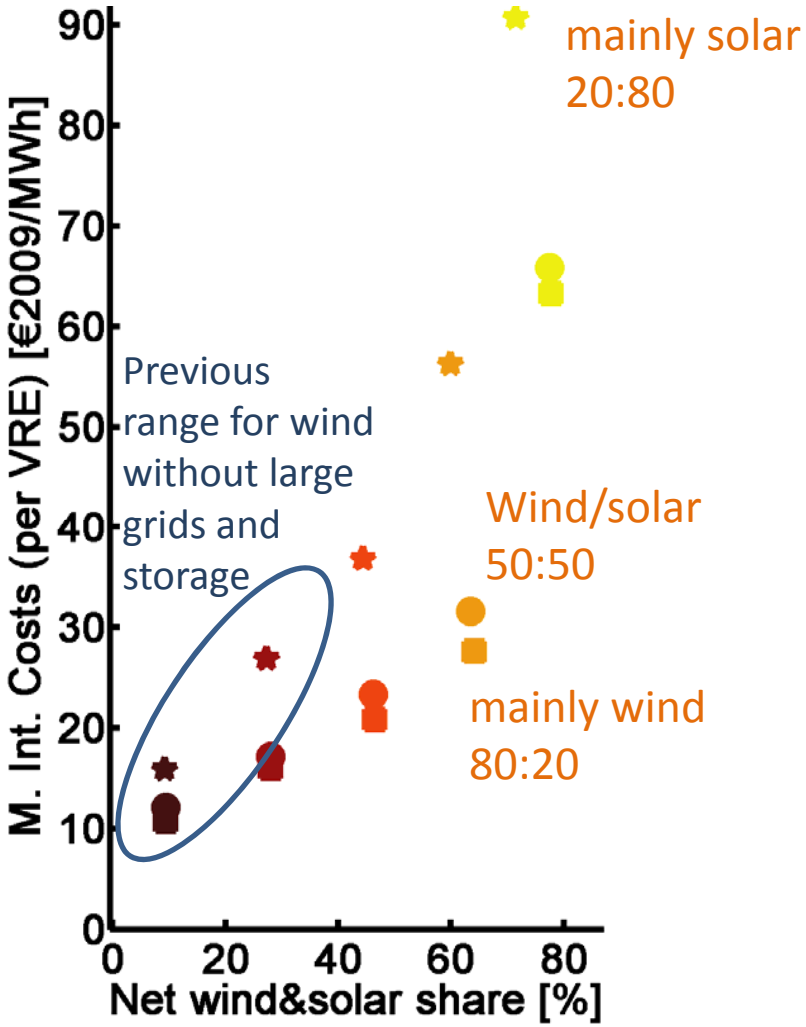
Integration costs can be reduced by large grids and storage

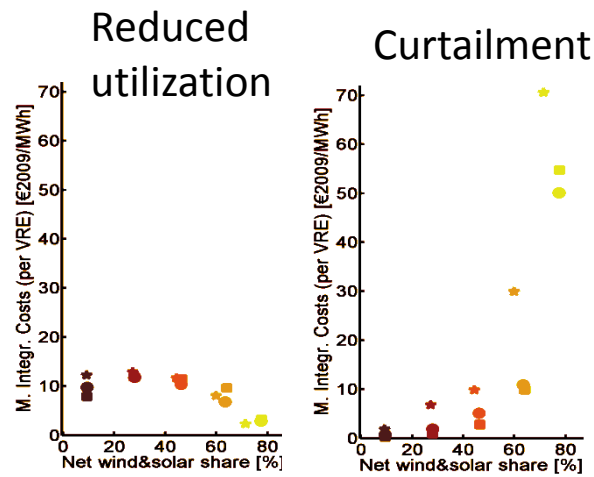
Integration costs with large grids and storage

(€/MWh VRE, marginal)

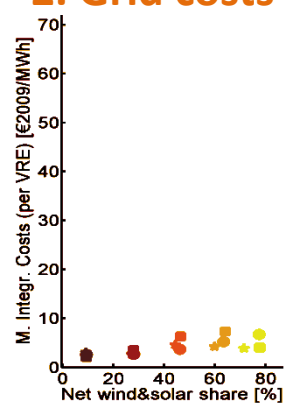


Integration cost components

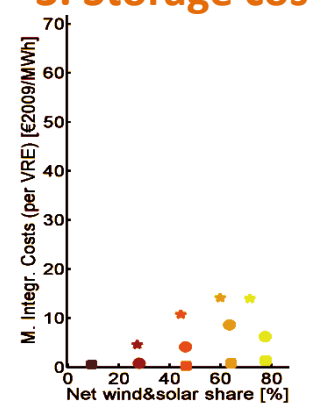
1. Profile costs



2. Grid costs



3. Storage costs



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