System integration – a bottom-up taxonomy

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Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies

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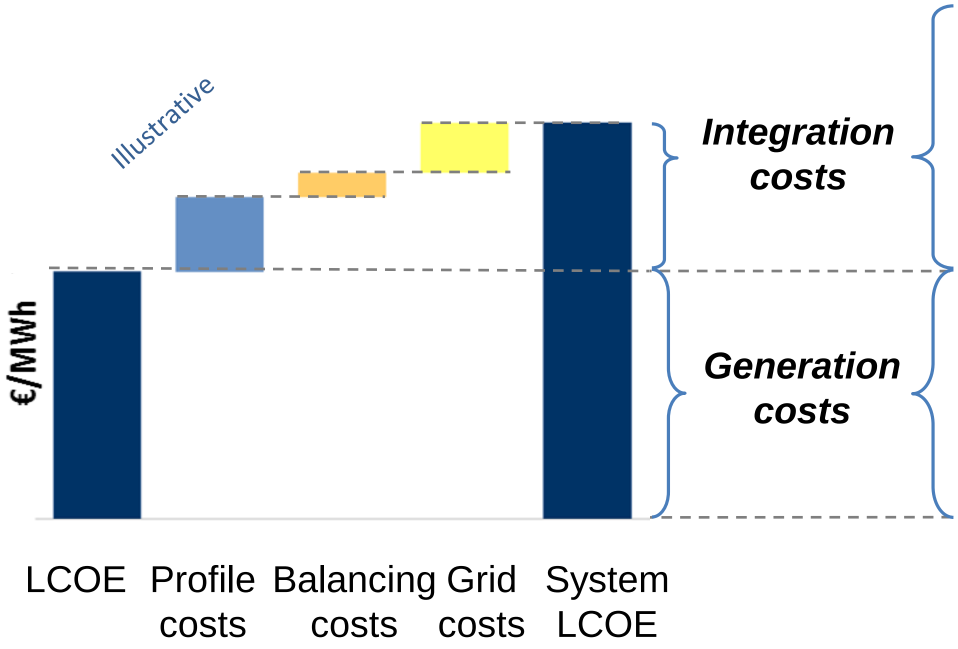
Three properties of variable renewables drive integration costs

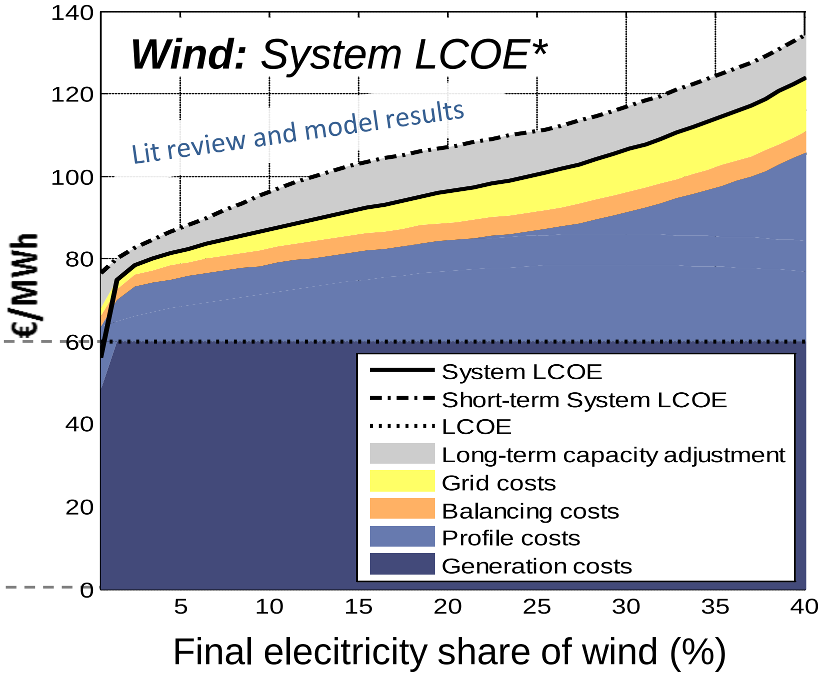
Output is **variable**	Output is **uncertain**	Resources are **location-specific**
• Wind speeds and solar radiation vary • Electricity is not a homogeneous good over time (storage constraints) • Thus its value depends on <u>when</u> it is produced	• Winds and radiation is uncertain day-ahead • Adjusting generation on short notice is costly (operating reserves) • <u>Forecast errors</u> are costly	• Wind and solar resource quality varies geographically • Electricity is not a homogeneous good across space (grid constraints) • Thus its value depends on <u>where</u> it is generated
↓	↓	↓
„Profile costs“	**„Balancing costs“**	**„Grid-related costs“**

Integration costs

Hirth 2012 (submitted), Milligan et al. 2009, IPCC SRREN 2011, Borenstein 2012, Ueckerdt 2013 (submitted)

A decomposition and quantification of integration costs



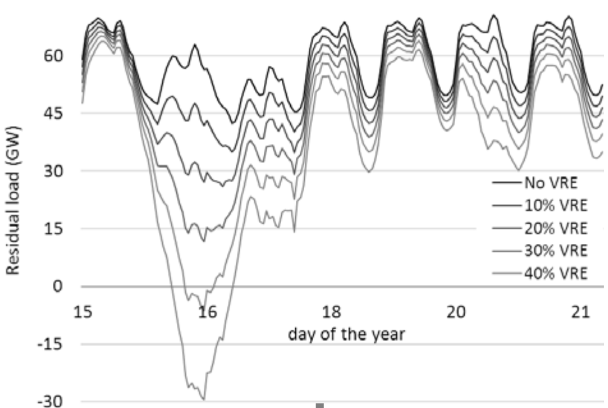


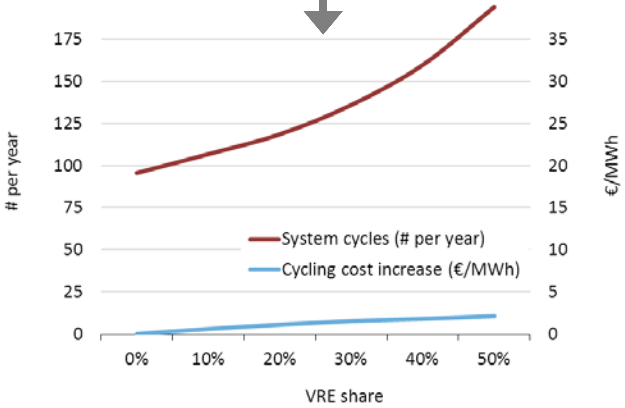
Ueckerdt et al. 2013 (submitted)

*Indicative results for thermal power systems in Europe

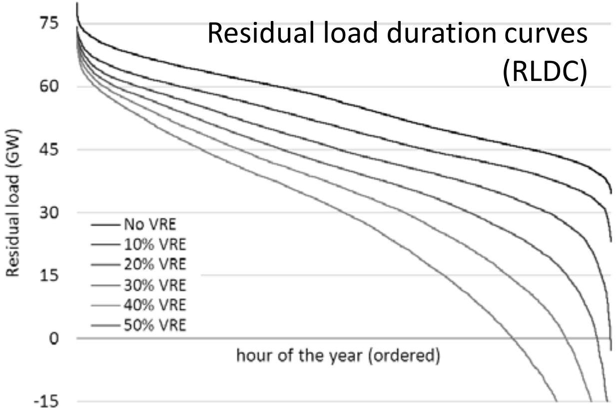
Profile costs are twofold

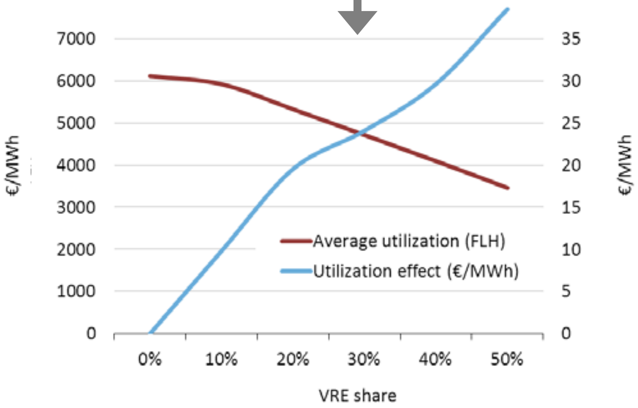
Flexibility Effect





Utilization Effect

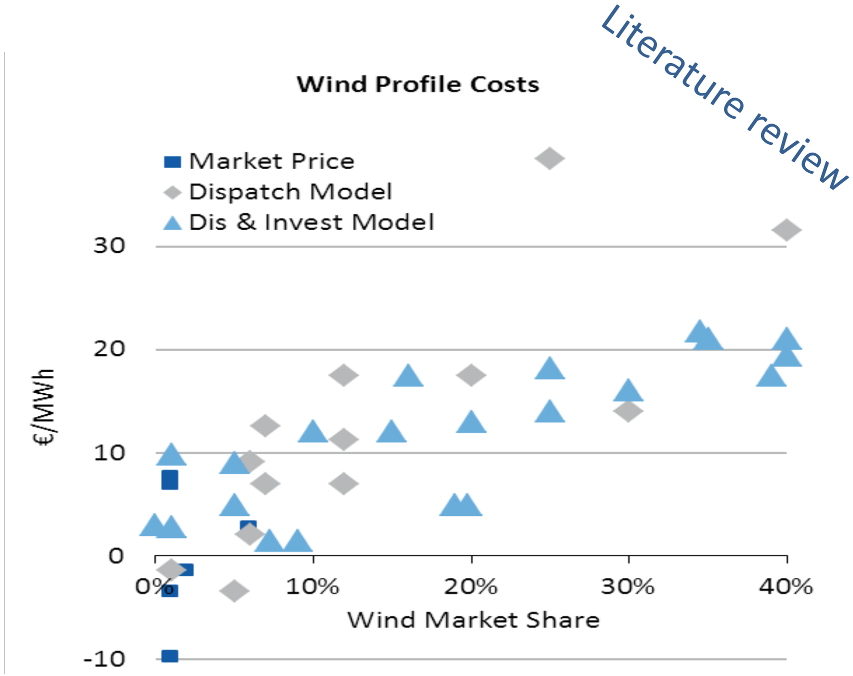


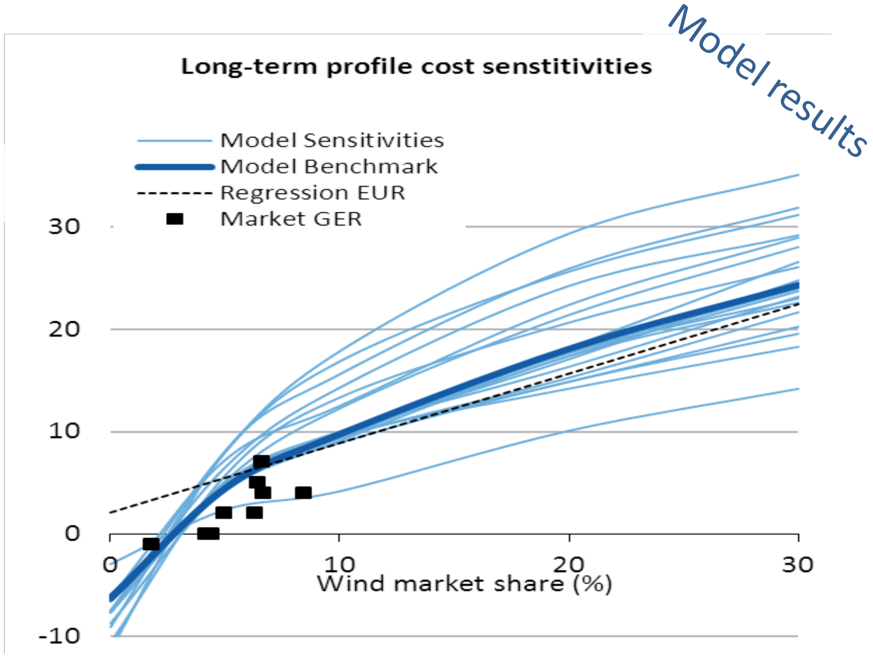


- Profile costs are divided into *flexibility* and *utilization* effect
- Variability has impacts on the
  - Optimal share of variable renewables
  - Capacity mix of the residual system
- Utilization effect is much larger
- Profile costs depend on deployment of storage and grid

Hirth 2012 (submitted), Ueckerdt et al. 2013 (submitted)

Profile costs are substantial





Hirth 2012 (submitted)

Integration options can be structured along the challenges

	Profile Costs	Balancing Costs	Grid-related Costs
Mitigate the Challenge	Increased variability of residual load → Decrease variability with storage, demand response, transmission	Increased forecast errors → Improve weather models; transmission	Geographical mismatch between generation and load → Shift generation/load geographically
Reduce Economic Impact	Reduced utilization increases capital costs → Decrease capital intensity of thermal plant mix	Costly spinning and stand-by reserves → More flexible thermal plants; improve balancing market design	Grid congestion →Grid investments; locational price signals on spot markets

System integration in Advance – the next months

1) Taking stock I: Current situation
   - What approaches are implemented or available?
   - Which parts of the integration challenge are reflected?
   - Experience: Team opinion? Effect on model results? Validation?

2) Taking stock II: Further development
   - Common vision: What integration aspects should be represented?
   - What does each team want to implement?
   - What data is needed?

References

Hirth, Lion (2012): "Integration Costs and the Value of Wind Power. Thoughts on a valuation framework for variable renewable electricity sources", *USAEE Working Paper* 12-150. http://ssrn.com/abstract=2187632

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Thanks!

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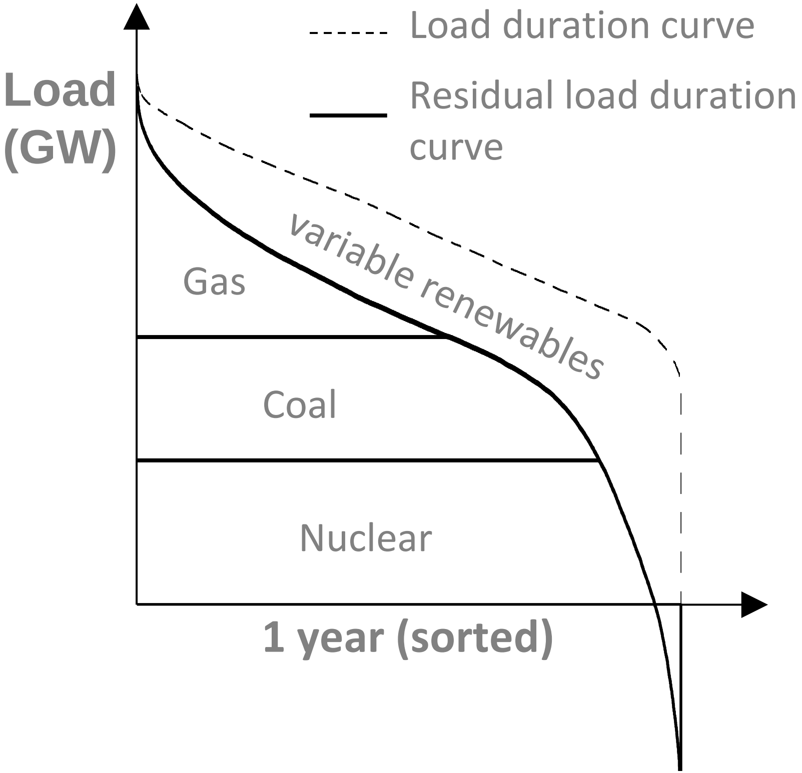
System integration - a possible way forward

- What approaches are implemented or available?
  - Cost penalties
  - Load duration curves
  - Residual load duration curves
  - Flexibility coefficients
  - Storage / Back-up capacities
  - …
- Reflection on the approaches
  - Explicit / implicit representation
  - Which parts of the integration challenge are reflected?
  - Effect on model results? Validation?

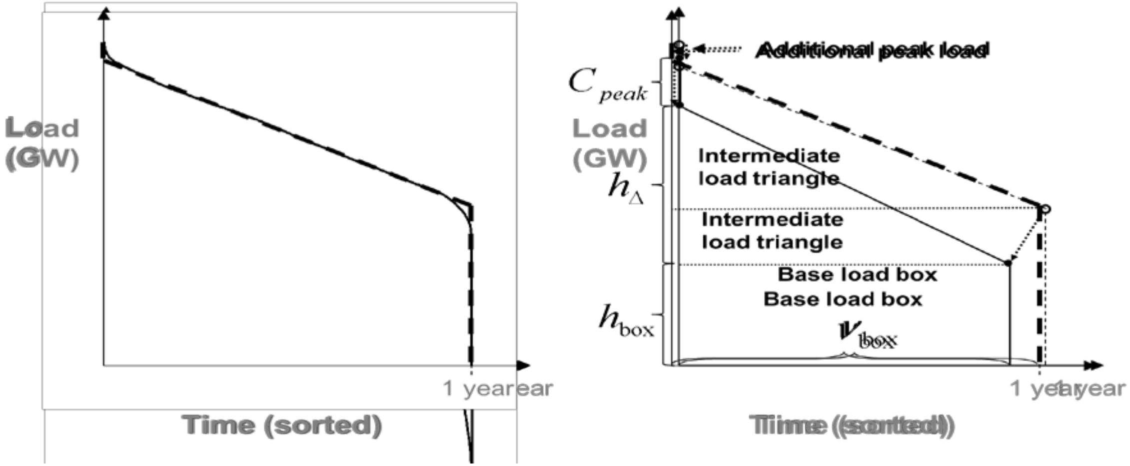
System integration – electricity is not a homogenous good



- Power demand and supply is temporally and spatially variable
- Electricity is a perfectly homogeneous good only for a given point in time and space
- Over the course of a year and in spatial aggregation, electricity from two sources are imperfect substitutes, because …
  - they are generated in different hours
  - they are generation at different locations

  → On a annual average, e.g. "wind power" is not "nuclear power"

System integration in IAMs – the RLDC approach in REMIND-D



- A stepwise linear function approximates the (R)LDC data
- Three parts
  - Base load box
  - Intermediate load triangle
  - Additional peak load

→The RLDC endogenously changes in the REMIND optimization

- 4 parameters describe the RLDC
- Parameters depend on penetration and mix of variable renewables
- Dispatchable power plants cover residual load
- Operation is optimized

→ Capacity factors of dispatchable power plants are endogenous

Investment and operation of the power system are simultaneously optimized considering short-term variability