What are the full costs of variable renewables?

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based on work with
Lion Hirth, Robert Pietzcker, Gunnar Luderer, Robert Brecha, Ottmar Edenhofer
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

Is wind generation competitive or cost-efficient?

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

- \( g_y \): generation in year \( y \)
- \( c_y \): costs in year \( y \)
- \( r \): discount rate

Two perspectives on integration costs

Cost perspective

Value perspective

What are components of integration costs?

Variable renewables (VRE) are special in three aspects:

- **Output is variable in time**
  - Matching of wind and solar with load
  - "Profile costs"

- **Output is uncertain and short-term variable**
  - Short-term balancing of supply and demand is costly
  - "Balancing costs"

- **Output is variable in space**
  - 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)

Must-run

Overproduction

Load duration curve

Residual load duration curve (RLDC)

Load (GW)

Low capacity credit

Variable renewables

Dispatchable plants

Reduced utilization

Hours of one year (sorted)

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

Average summer day

Ueckerdt, Pietzcker, Luderer, Scholz, Stetter, Giannousakis (submitted to energy economics)
Integration costs can become high at high VRE shares (Lit review for wind in OECD power systems)

Profile costs

Balancing costs

Grid costs

- 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


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Integration costs decrease the market value of VRE

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

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)

- Wind/solar 50:50
- Mainly solar 20:80
- Mainly wind 80:20

**Integration cost components**

1. Profile costs
   - Reduced utilization
   - Curtailment

2. Grid costs

3. Storage costs

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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