System LCOE:
What are the costs of variable renewables?

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What are the costs of variable renewables?
Levelized costs of electricity (LCOE) are the full life-cycle costs (fixed and variable) of a technology per generation unit.
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LCOE for plants commissioned in 2015 at 5% discount rate.

Projected Costs of Generating Electricity (IEA, 2010)
When will wind power be competitive? (investor)

→ „As soon as wind LCOE will be fallen below those of conventional plants!“

or equivalently

→ „When LCOE are equal to the average electricity price!“

What is the optimal amount of wind? (modeler/policy maker)

However, this is all wrong!
When will wind power be competitive? (investor)

→ „As soon as wind LCOE will be fallen below those of conventional plants!“
→ Don‘t compare LCOE of different technologies!
or equivalently
→ „When LCOE are equal to the average electricity price!“
→ Don‘t compare generation costs with the average price!

What is the optimal amount of wind? (modeler/policy maker)

![Graph showing the relationship between price ($p$) and wind deployment ($q$)]

$LCOE$ of wind

Average electricity price

$q_0$: wind deployment

However, this is all wrong!
Electricity is a unique commodity

Demand is variable, storage is costly
Demand is uncertain. Ramping of plants is costly
Transmission is costly

The value (price) of electricity varies over time
Short-term balancing is costly
The value of electricity varies between locations

Electricity is a heterogeneous good over time
Heterogeneous w.r.t. lead-time between contract and delivery
Heterogeneous across space

→ Generation of different technologies is no perfect substitute, e.g. „nuclear power“ is not „wind power“
→ Do not compare LCOE
Variable renewables make electricity even more unique

Output is **fluctuating**
- Wind speeds and solar radiation vary over time
- Thus its value depends on **when** it is produced

Output is **uncertain**
- Winds and radiation is uncertain day-ahead
- Forecast errors are costly

Bound to **certain locations**
- Resource quality varies geographically
- Thus its value depends on **where** it is generated

- **„Profile costs“**
- **„Balancing costs“**
- **„Grid-related costs“**

**Integration costs**
(are neglected in LCOE comparison)
System LCOE are defined as the sum of generation and integration costs.
Profile costs: Residual load duration curve shows challenges

- Low capacity credit
- Overproduction
- Reduced full-load hours
- Dispatchable plants
- Variable renewables
- Load duration curve
- Residual load duration curve
Profile costs: Residual load duration curve shows challenges

Wind

Solar

German data
System LCOE are defined as the sum of generation and integration costs.
When will wind power be competitive? (investor)

What is the optimal amount of wind? (modeler/policy maker)

![Diagram showing welfare loss, System LCOE of wind, LCOE of wind, Average price, q*, q0, and wind deployment.](image)
When will wind power be competitive? (investor)

What is the optimal amount of wind? (modeler/policy maker)

Interpretation

- There are two goods “wind” and “power”
- “Power“ is perfectly matching load
- Additional costs needed to transform “wind“ into „power“ → integration costs
- The total costs to cover load with „wind“ are System LCOE
Two perspectives, one framework: System LCOE and market value

Market Value Perspective

- Average electricity price
- Profile Costs
- Balancing Costs
- Grid-related Costs
- Wind Market Value

System LCOE Perspective

- Wind’s LCOE
- Profile Costs
- Balancing Costs
- Grid-related Costs
- Wind’s System LCOE

Integration Costs

Marginal value of „power“  →  Marginal value of „wind“  →  Marginal costs of „wind“  →  Marginal costs of „power“
Profile Costs: The “Cannibalization” Effect

Graph showing the cost profile with a significant drop from 29 €/MWh to 17 €/MWh due to 17 GW wind power addition. The graph compares different energy sources including Nuclear, Lignite, Hard Coal, CCGT, OCGT, and CHP.
Market value of wind decreases with increasing share

Average power price
Integration costs increase
Market value of wind

\[ p \text{ (€/MWh)} \]

\[ q \text{ (wind deployment)} \]

Profile costs
Balancing costs
Grid – related costs
Two perspectives, one framework: System LCOE and market value

System LCOE of wind
\[ p = \text{marginal costs of "power" when produced from wind plant} \]

LCOE of wind = marginal costs of "wind"

Average price = marginal value of "power"

Market value = marginal value of "wind"

Reference system (good)

--- "power"

----- "wind"
System LCOE – magnitude and shape

- From literature: Grid and balancing costs (Holttinen et al. 2011; Gross et al. 2006; Hirth 2012a, dena 2010)
- From a simple model: profile costs.
- Parameterized from German data, representative for thermal systems in Europe

- Caveats that increase integration costs
  - No import/export
  - No demand elasticity
  - No storage
  - Power sector only

• Integration costs of wind power can be in the same range as generation costs at moderate shares (~20%)

• A significant driver of integration costs are profile costs, especially the reduced utilization of capital-intensive thermal plants.

→ Integration costs can become an economic barrier to deploying VRE at high shares.
→ An economic evaluation of wind and solar power must not neglect integration costs.
The market value (here value factor) reduces: Market Data, Model Results, Literature Review

At 30% penetration, the value factor of wind falls to 0.5 – 0.8 of the base price. In Germany, it has already fallen from 1.02 to 0.89 as penetration increased from 2% to 8%.

Conclusions

1. We show that LCOE are a flawed indicator to evaluate power technologies
2. We propose a better metric ‘System LCOE’
3. We present a framework of System LCOE and market value and link it to welfare theory
4. Integration costs of wind power can be in the same range as generation costs at moderate shares (~20%)
5. A significant driver of integration costs are profile costs, especially the reduced utilization of capital-intensive thermal plants.
6. Integration costs can become an economic barrier to deploying VRE at high shares.
7. An economic evaluation of wind and solar power must not neglect integration costs.