Why wind is not coal: on the economics of electricity (generation)

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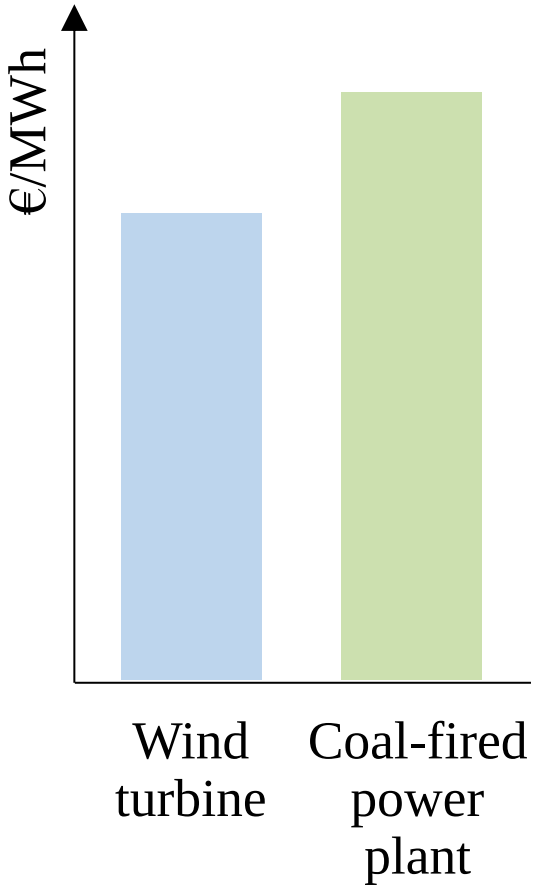
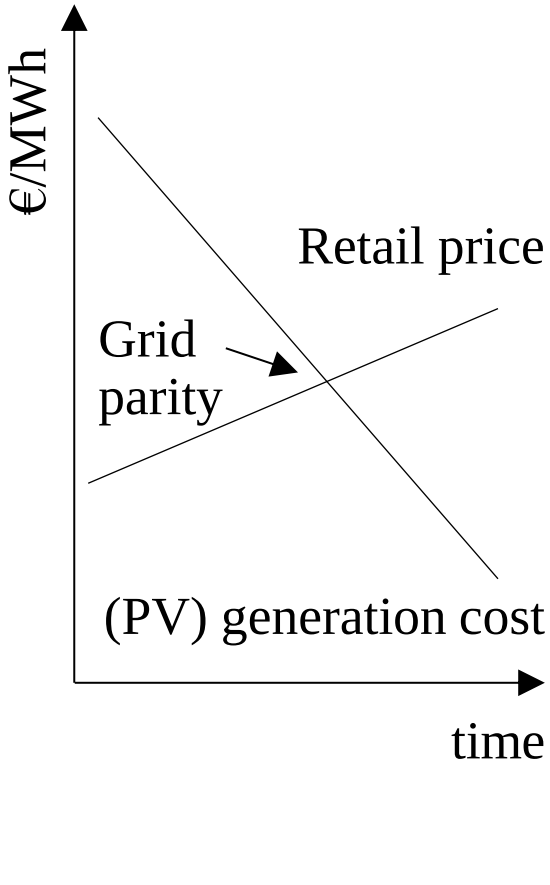
Enerday Dresden | 11 April 2014

Three tools are frequently used to assess the economics of electricity generating technologies…

Levelized cost



Grid parity



Multi-sector models

	(1)	(2)
(1) …		
(2) Power		
(3) …		

Input-output table (IAMs, CGEs, …)

Karlynn & Schwabe 2009, Fischedick et al. 2011, IEA & NEA 2011, BSW 2011, EPIA 2011, Nitsch et al. 2011, IRENA 2012, Kost et al. 2012, EIA 2013; Koch 2013, Fraunhofer ISE 2013; Fischedick et al. 2011, Edenhofer et al. 2013

… often, authors (or readers) draw conclusions on efficiency or competitiveness based on such tools.

These assessments implicitly assume electricity to be *homogeneous* – that is, each MWh to have the same economic value

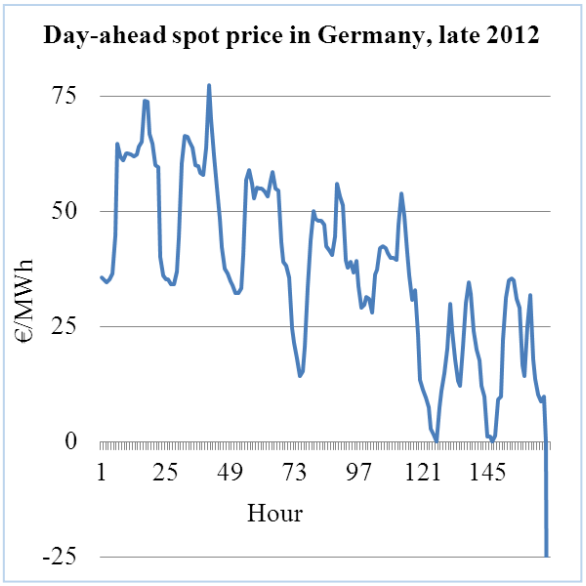
1. *Electricity as an economic good*
2. *The marginal value of a generator*
3. *System LCOE*
4. *Welfare economics in two perspectives*

Electricity is the archetype of a *homogenous* commodity…

- Physics: “an electron is an electron“
- Consumers cannot even distinguish between electricity from different power sources, such as wind turbines and coal-fired plants
- Bilateral power contracts are not fulfilled physically in the sense that electrons are delivers from one party to another, but via an ‘electricity pool’
- Electricity is traded under standardized contracts on power exchanges
- The law of one price applies
- … hence, is the heterogeneity assumption justified?

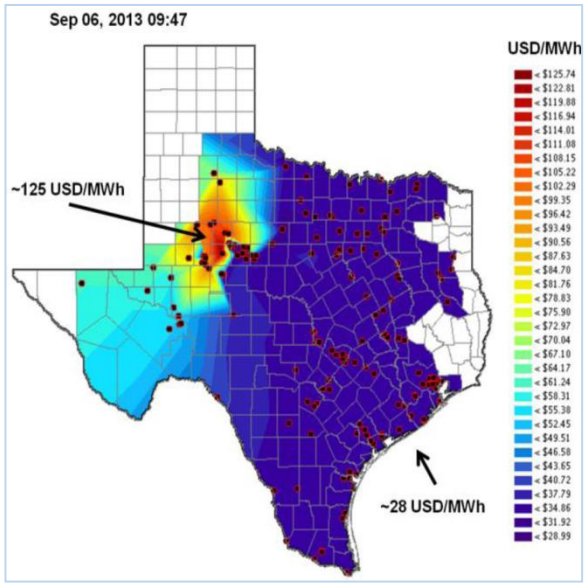
… and *heterogeneous* at the same time

… over time



The electricity spot price varies between hours.

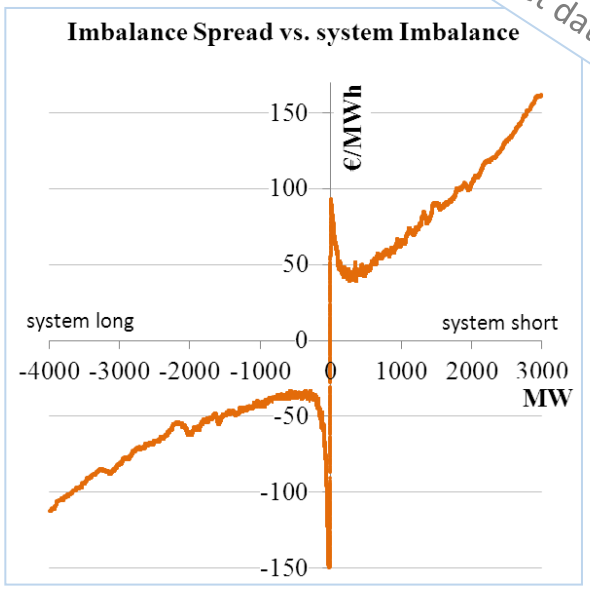
… across space



The price varies between locations.

… over lead-time

Market data



The price varies between real-time and day-ahead.

Heterogeneity is reflected in the real world

- (Complex) “market design”
- Price variability (along three dimensions)
- The development of a variety of generation technologies

Defining heterogeneity

marginal economic value $$v'_p := \frac{\partial W(q_p, \cdot)}{\partial q_p} \qquad \forall p \in P \qquad (1)$$

homogeneous if $$v'_p \cong v'_q \qquad \forall p, q \in P \qquad (2)$$

heterogeneous otherwise

→ this definition does not rely on assumptions about market structure, does not require perfect and complete markets (however, variable prices often indicate heterogeneity)

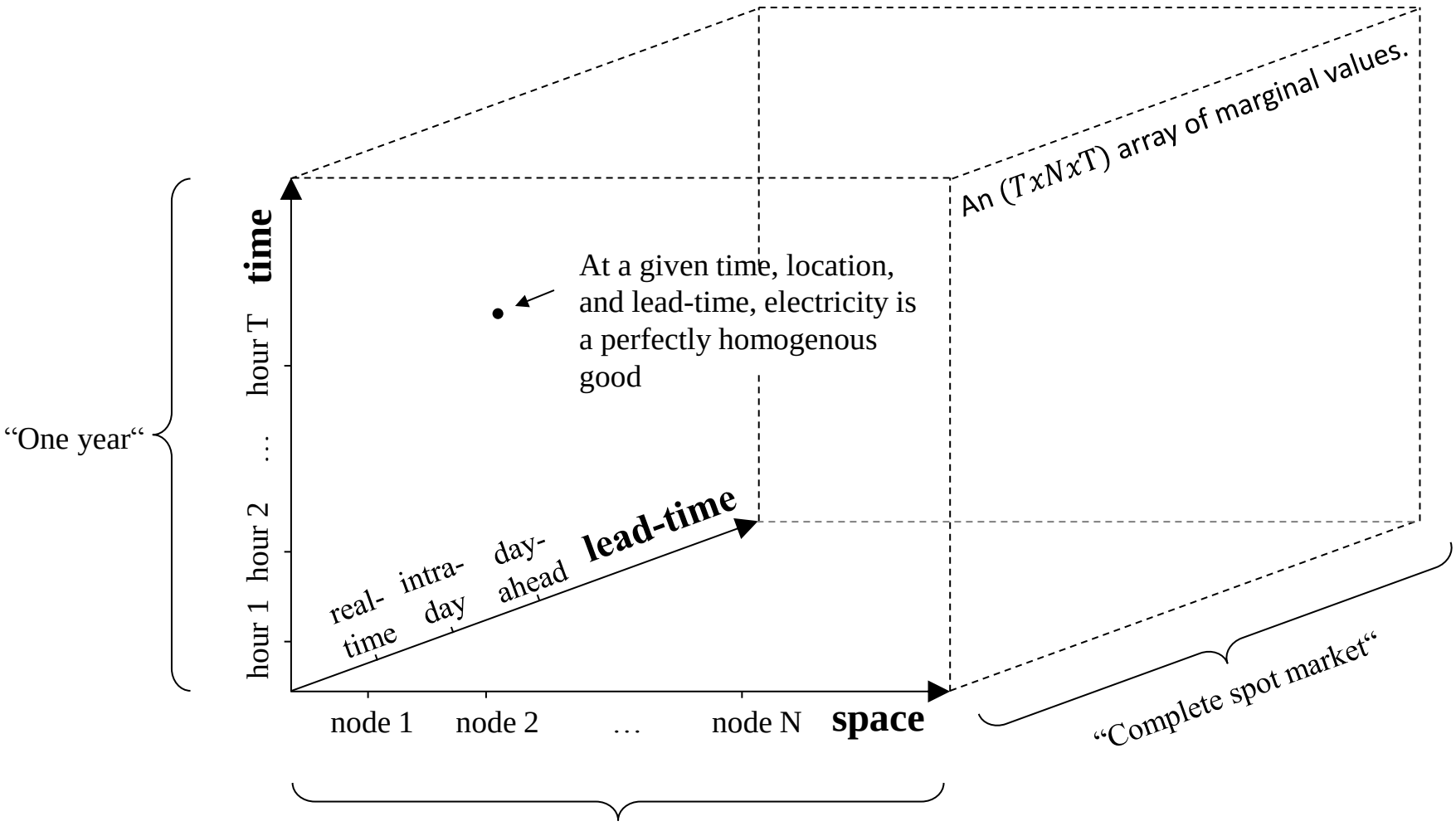
In general, heterogeneity requires three conditions to hold

- arbitrage constrained (otherwise carry trade would wipe out spreads)
- differences in demand or supply conditions (otherwise no differences would arise)
- non-horizontal demand and supply curves (otherwise there would be no price impact)
- → what is special about electricity are the existence of arbitrage constraints

The physics of electricity imposes three arbitrage constraints

Physics	Electrical storage is subject to losses and capex	Electricity cannot be trucked, transmission is subject to thermal losses and Kirchhoff‘s laws	AC power systems require frequency stability
Arbitrage constraint	Storage (storing electricity is costly)	Transmission (transmitting electricity is costly)	Flexibility (ramping & cycling is costly)
Dimension of Heterogeneity	Time (price differs between hours)	Space (price differs between locations)	Lead-time (prices differs w.r.t. to lead-time between contract and delivery)

Electricity is heterogeneous along three dimensions



$$v'_{t,n,\tau} := \frac{\partial W(q_{t,n,\tau},\cdot)}{\partial q_{t,n,\tau}}$$

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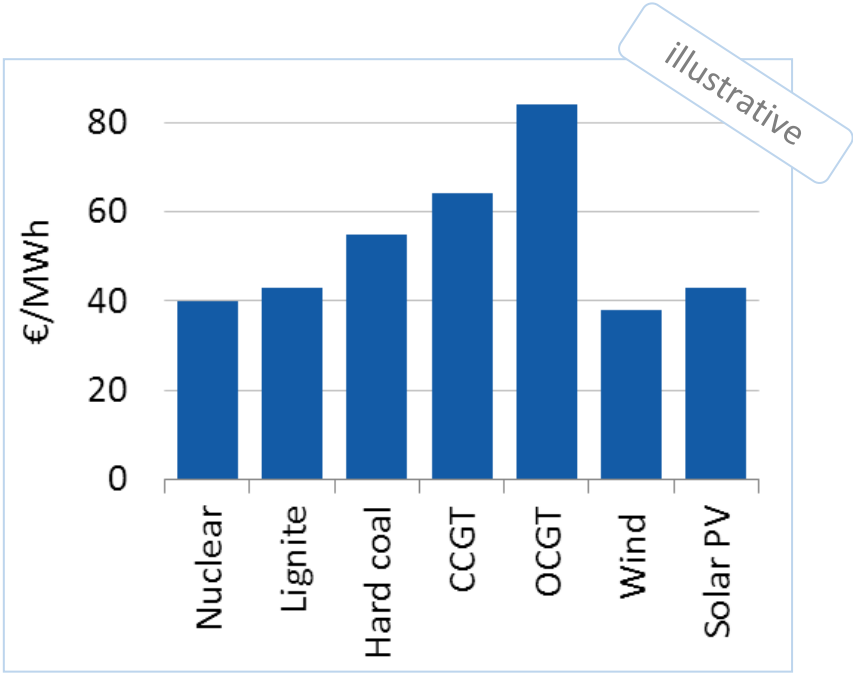
Each generator has a different value

$$\bar{v}'_i = \sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{\tau=1}^{T} g_{i,t,n,\tau} \cdot v'_{t,n,\tau} \qquad \forall i \in I \quad (3)$$

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \sum_{\tau=1}^{T} g_{i,t,n,\tau} = 1 \qquad \forall i \in I \quad (4)$$

$$\bar{v}'_i \neq \bar{v}'_j \qquad \forall i, j \in I \quad (6)$$



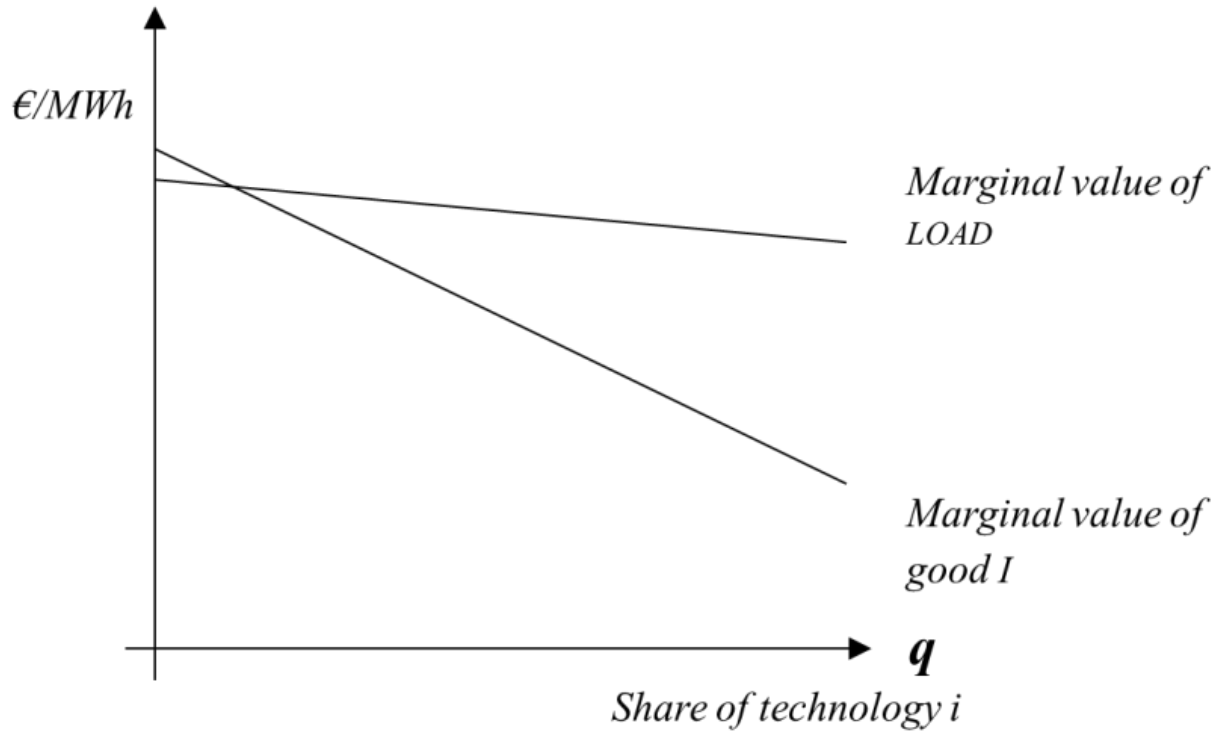
The market value of different technologies is different – also in the optimum/equilibrium.

→ Wind turbines and coal plants produce *different economic goods!*

Different “electricity goods”

- WIND: one MWh that has the same pattern as wind turbines
- COAL: one MWh that has the same pattern as coal plants
- LOAD: one MWh that has the same pattern as consumption
- I: one MWh that has the same pattern as generation technology *I*
- WIND can be produces by wind turbines, but also by any other technology, or any mix of technologies.
- The power system as a whole produces LOAD.

The relative value of any electricity good decreases with supply



The relative price of a good declines with increasing supply.

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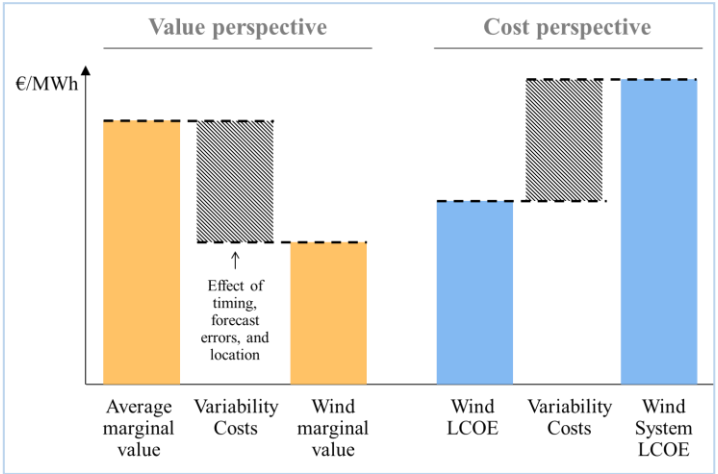
Defining (opportunity) “cost of variability”

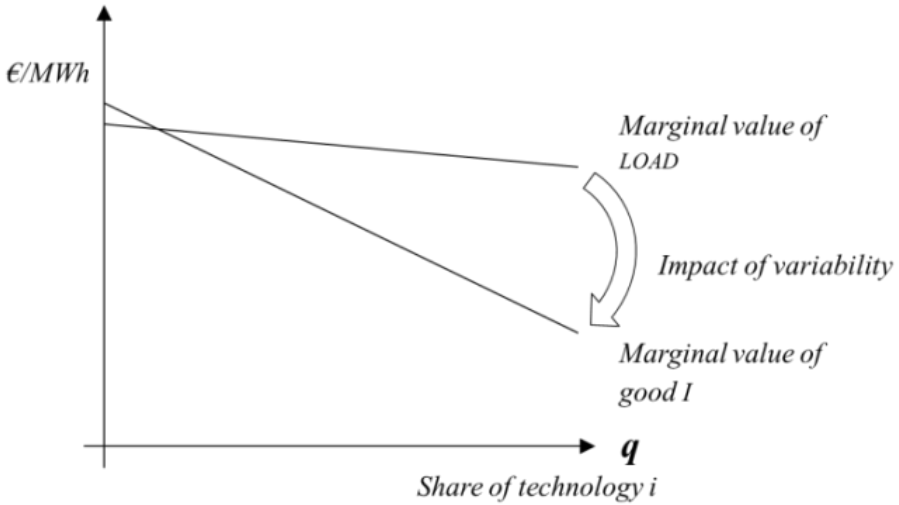
System LCOE $\sigma_i' := c_i' + \Delta_i' \quad \forall i \in I \quad (12)$

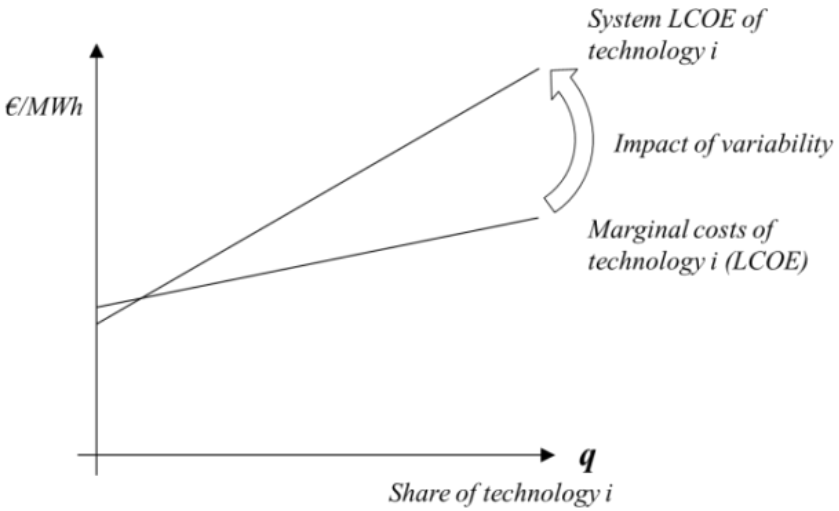
LCOE $c_i' = \sum_{y=1}^{Y} \frac{1}{(1+r)^y} \frac{c_{i,y}}{g_{i,y}} \quad \forall i \in I \quad (13)$

Cost of Variability $\Delta_i' = \bar{v}_{load}' - \bar{v}_i' \quad \forall i \in I \quad (15)$



The impact of variability can be expressed in terms of value or cost





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A simple optimality condition

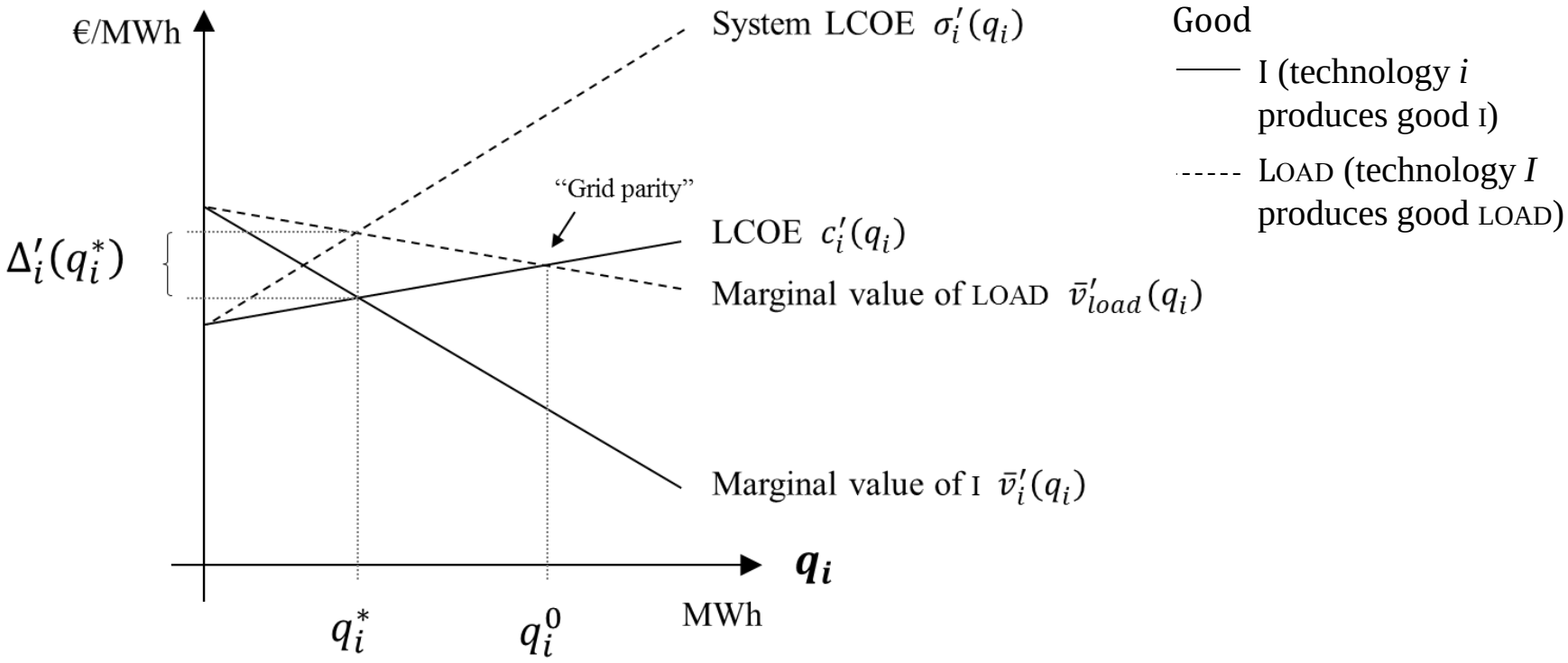
Standard FOC (for any good) $$v'(q^*) = c'(q^*) \quad (16)$$

- this FOC only makes sense if marginal value and marginal cost of *the same good* are compared
- sounds trivial – in the electricity sector it is not: each technology produces a different good
- LEC comparisons, grid parity, multi sector modelling implicity equate marginal cost and benefits of *different goods*!

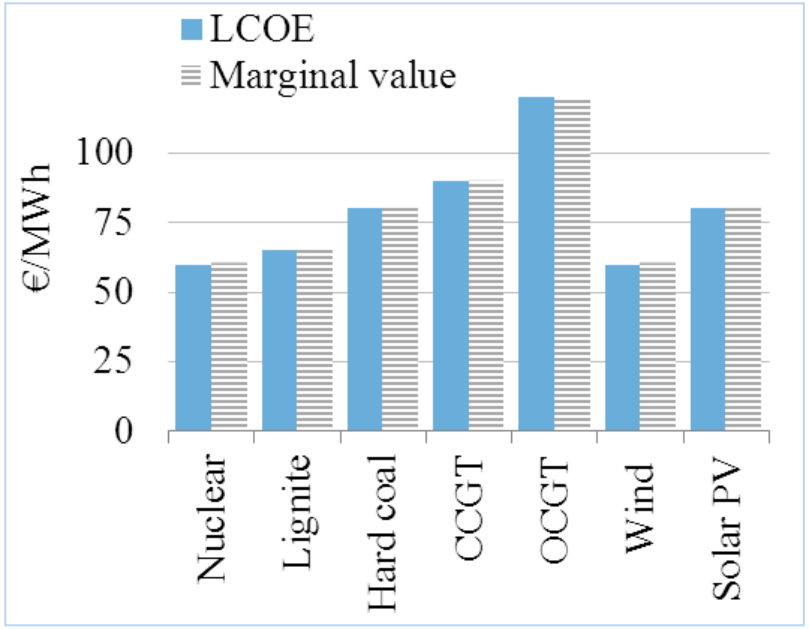
Optimality conditions in the power sector

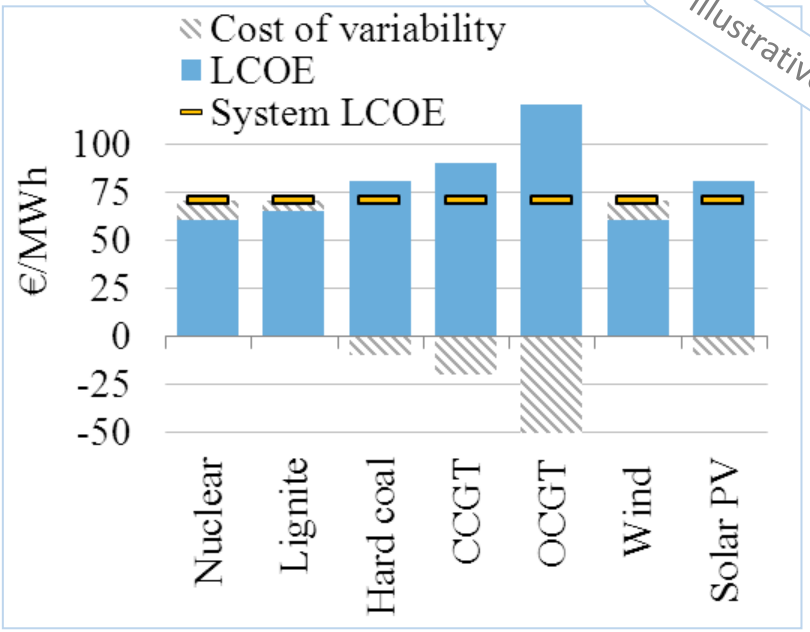
In terms of good I $\overrightarrow{v_i}(q_i^*,\cdot) = c_i'(q_i^*,\cdot) \quad \forall i \in I$ (17)

In terms of good LOAD $\overrightarrow{v_{load}}(q_i^*,\cdot) = \sigma_i'(q_i^*,\cdot) \quad \forall i \in I$ (18)



Global optimum: the cost-efficient generation mix





Either: The LCOE of each technology corresponds to its market value (first-order conditions for optimum)

Or: The System LCOE of all technologies are identical to each other (first-order condition for optimum)

$$\sigma_i'(q_i^*,\cdot) = \sigma_j'(q_j^*,\cdot) \qquad \forall i,j \in I \qquad (19)$$

Summary

- physics shapes the economics of electricity
- constraints on storage / transmission / flexibility cause heterogeneity along time / space / lead-time
- different generators produce different economic goods
- several assessment tools ignore heterogeneity: LCOE comparisons, grid parity, multi-sector modeling
- these tools implicitly equate marginal benefits and costs of different goods
- proposals
  - LCOE comparisons → System LCOE
  - Multi-sector models → Parameterize carefully, couple with sectoral models
  - Grid parity → Don’t use

Policy Conclusions

- None?
  - In principle heterogeneity does not imply any market failures
- Market design: Europeans, price constraints!
  - price grid constraints: locational price signals
  - balancing prices should reflect marginal costs of balancing (Hirth & Ziegenhagen 2013)
- Policy instrument design: transmit price signals to investors

Conclusions on “variable” renewables

- Electricity itself is different from other economic goods
- All generators are different, each generators has a different marginal value – from this perspective, wind and solar are not fundamentally different from others
- Is it sensible to draw a line between dispatchable and “intermittent” generators?

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- A network of (young) professionals in energy
- Bridging gaps between academics, policy makers, private sector
- Monthly workshops and shared email list
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