Valuation of Variability and Unpredictability in Electricity Generation

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Overview

1. Introduction
2. Myths of Wind Energy Integration
3. System-oriented Approach
4. Model-based Analysis
5. Final Remarks

Motivation

- Increasing share of electricity generation from fluctuating renewables in Europe and worldwide
- Especially strong increase in fluctuating, supply-dependent production, namely wind energy (and photovoltaics)

→ Challenges for operation of grids and power plants

→ Value of fluctuating production under these conditions?

→ Or put differently: „Integration cost of wind energy “?

Possibilities for valuation

- Market oriented
  - Use of available prices

  Advantages:
  - Usage of real data
  - Independence from model assumptions
  - Consideration of real scarcities
- **Model based**
  - **Use of electricity system models**

  Advantages:
  - **Independences from real world stochasticities**
  - **Possibilities of a longer-term valuation**
  - **Systematic analysis of interdependences**

Overview

„Shadow power plants“

Basic idea:

- The contribution of wind power to reliable capacity is limited (low capacity factor)
- Therefore increases in wind power production always require availability of additional “shadow” power plants
- Those are used, when wind does not blow
- Corresponding costs have to be taken into account as additional costs of wind energy

Criticisms:

- No system-oriented perspective
- So-called shadow power plants may also be used for other purposes in the system

Merit-Order effect of renewables

Basic idea:

- The variable cost of wind energy are close to zero
- If wind blows, other power plants do not need to produce
- Usually these unused plants will be the most expensive ones
- If power prices are based marginal generation costs, prices will be reduced
- Corresponding cost reductions have to be included as additional benefits of wind energy

Criticisms:

- Short-term perspective
- In the medium to long term, the conventional system will adapt to the wind energy input

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Starting point: system and system costs

Definition:

- An **electrical system *S*** is defined as **triple** {*E*; *Q*; *R*}
- *E* is thereby a set of **elements** *e* including generators, loads, lines and other components
- *Q* is a set describing the **interconnections** between lines and loads, generators etc.
- *R* is a set of relations and characteristics defined over the elements of *E*

Cost are then defined over vectors of characteristics $\mathbf{a}_e$ and $\mathbf{b}_e(t)$

$$C_{Tot}(S) = \sum_e \sum_t C_{Fix,e}(\mathbf{a}_e, \mathbf{b}_e(t), t) + \sum_e \sum_t C_{Var,e}(\mathbf{a}_e, \mathbf{b}_e(t), t)$$

Integration cost

Definition:

- **Difference in the optimal system cost**, which are induced by additional requirements $\mathbf{A}_F$ and $\mathbf{B}_F(t)$

  e.g. **Share of renewable energies**

$$C^*_{Tot}(S; \mathbf{A}_F, \mathbf{B}_F(t)) = \min_{\mathbf{A}',\mathbf{B}'} C_{Tot}(S)$$

$$w.r.t. \quad Q$$
$$R$$

Key Questions

- Difference in comparison to which reference system?
- Which system elements are considered as fix, which as variable?

Key question: What is flexible?

1. Only **demand parameter** (load curves) and the **investment and operating cost** of the different elements are considered as **fix**
2. The **installed capacities** are **also** considered as **fix**
3. Demand is not considered as fully inelastic. Instead **demand flexibility** (e. g. throug DSM) is considered and corresponding cost and utility losses included in the objective function (cf. Ravn 2001).

NB: fixed parameter does not necessarily mean deterministic values. Notably for fluctuating renewables the stochastic production process may be taken as given without being able to forecast precise values ex-ante for each hour.

Key question: What is the reference system?

- Not the system without fluctuating renewables

  → Otherwise integration cost just corespond to the additional system cost

- Nor the additional system cost minus the investment cost of the renewables

  → Otherwise integration costs would be negative most of the time

→ Additional cost when comparing with a reference technology

T1: Technology with same capacity but „normal" availability

T2: Technology with same annual power production but constant output

T3: Technology with same hourly power production

Definition of integration cost

- **Additional cost for system with renewables**

minus

- **Additional cost** for the hypothetical **technology *T2*** with identical output, investment cost and variable cost
- **geographically distributed like conventional power plants** (therefore index *c*).

$$C_{Int} = C^*_{Add,Ren} - C^*_{Add,T2c}$$

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Decomposition of integration cost

$$C_{Int} = C_{Grid,con} + C_{Grid,ext} + C_{Unpred} + C_{Variab}$$

with

- **Grid connection cost**

$$C_{Grid,con} = \left(C^*_{Add,Ren} - C^*_{Add,Ren,r}\right)$$

- **Grid reinforcement cost**

$$C_{Grid,ext} = \left(C^*_{Add,Ren,r} - C^*_{Add,Ren,c}\right)$$

- **Cost of (partial) non-predictability**

$$C_{Unpred} = C^*_{Add,Ren,c} - C^*_{Add,T3,c}$$

- **Cost of variability**

$$C_{Variab} = C^*_{Add,T3,c} - C^*_{Add,T2,c}$$

Overview

Methodological Requirements

Integration cost are defined with respect to **optimal system cost**

→ **Optimizing** energy system model required to assess integration cost

→ **Stochastic approach** necessary,
especially in order to assess the cost of **(partial) non-predictability**

→ But also **costs of variability** may systematically be distorted, if stochastic of infeed is neglected

Peak-Load-Pricing – Optimal power plant park in the long term

- **Basic principle:**
  Prices are formed in a long term market equilibrium
- **Investment and production with different types of power plants**
- In the long term all capacities are variable

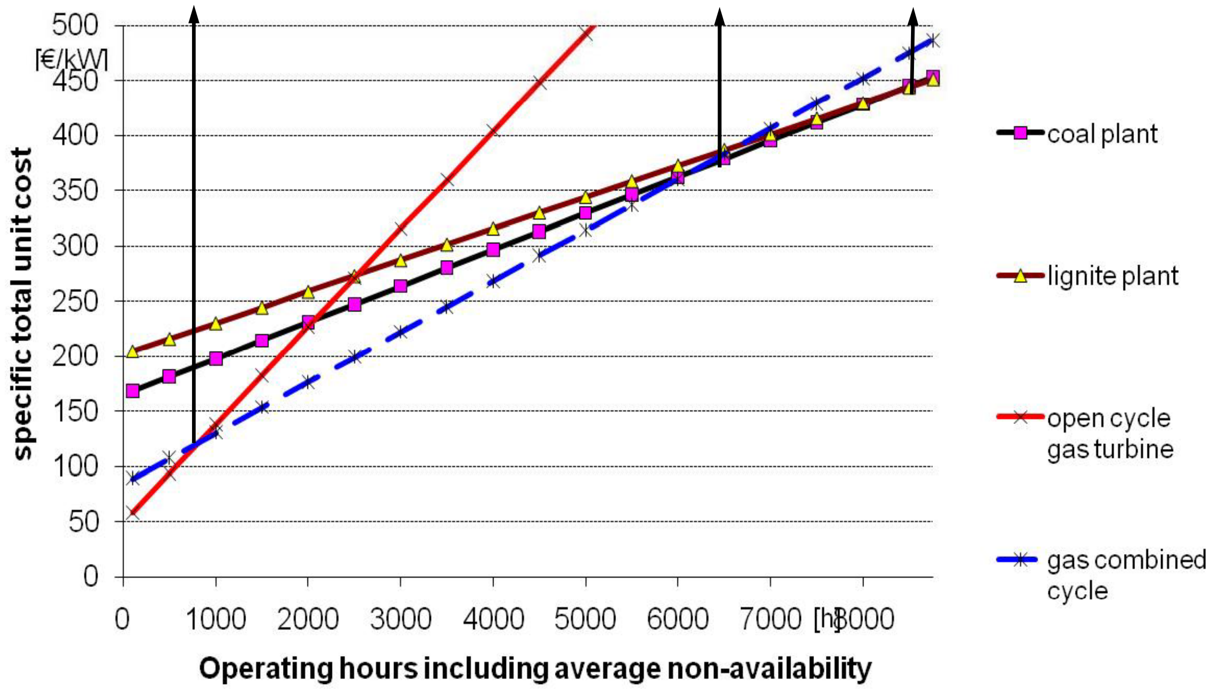
→ As a first approximation consideration of one typical year far in the future is possible

- Each **power plant** respectively each power plant type has to **earn its full cost**
  - Optimal power plant type depends on full load hours
- **Peak-Load-Pricing** not only determines **optimal capacities** but **also prices in equilibrium**

Peak-Load Pricing - Optimization problem

- **Formulation as linear mathematical optimization problem** possible (as approximation)
- **Objective function:** welfare maximization,
  with price inelastic demand **cost minimization** is equivalent
- **Cost**:
  - Variable cost: fuels and others
  - Fix cost: investment annuities + annual fix cost
- Constraint 1: **no load curtailment**
- Constraint 2: **capacity limits**
- Graphical solution for this simple case

Peak-Load-Pricing: Total cost per available capacity as a function of operating hours



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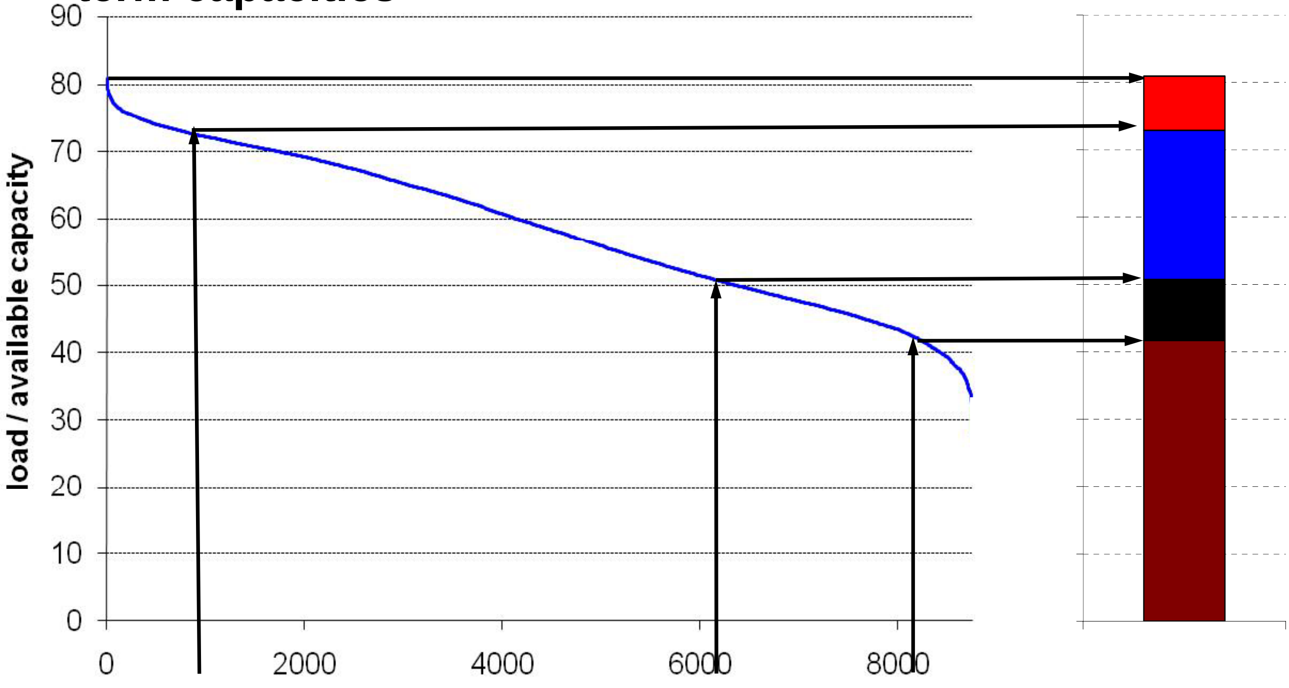
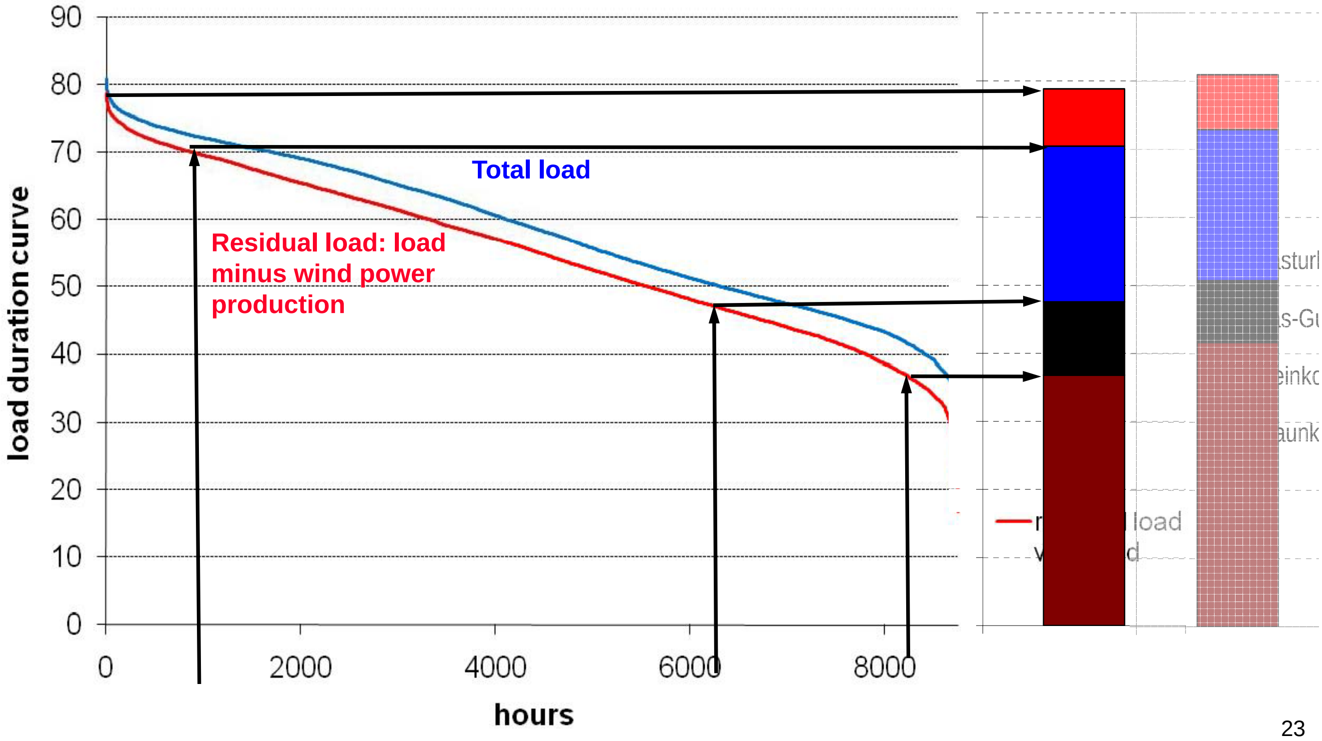
Peak-Load-Pricing: load duration curve and optimal long term capacities



Peak-Load-Pricing: Optimal capacities with 20 GW Wind



Results Peak-Load-Pricing model

- The **capacities** adapt so that all technologies are operated in the range operating hours where they are efficient
- **Total capacities are hardly reduced**
  - **In case of low capacity effect of wind energy**
- **Base load capacities are reduced substantially**
  - **About 5 GW in the example**
- **Peak load capacities are increasing**
  - → **Those are "shadow power plants", but no additional capacities**
- **As long as residual load is above zero, prices** are **unchanged** by wind power infeed
  - → **In the long term** there is **no Merit-Order-Effect** of wind energy
- **Average cost per kWh produced conventionally increase slightly**
  - → **Cost of variability of wind energy, about 6.7 EUR/MWh in the example**

Problems simple Peak-Load-Pricing model

- Only cost of variability may be determined
- No consideration of existing power plant capacities
- No considerations of cost of limited predictability
  → additional reserves
  → increased part load operation
  → more start-ups and shut-dows

→ Stochastisc system model required
  → WILMAR
  → **E2M2s**

Basic concepts of the market model E2M2s

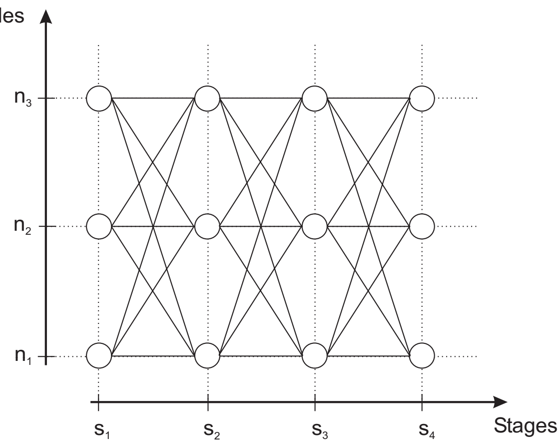
Input: Data on
- existing capacities for conventional power plants, renewables and storage
- fuel price
- efficiencies of power plants
- other technical parameters (availabilities, start-up cost)
- grid connection capacities
- load
- availability
- CO_2-reduction targets and price caps

Methodology: Market results corresponds to system optimization
- use of the cost efficient power plants, DSM or storage to serve demand
- formulation as a cost maximization problem
- LP model encompassing several time steps and all producers

Output:
- marginal system cost = equilibrium level for electricity prices
- investment in power plants and efficiency

Specificities of the market model E2M2s

- Use of recombining trees
- Trade-Off between
  - Taking into account stochastics Wind
  - Modelling of entire years because of hydro reservoir usage
  - Modelling investment decisions



→ Use of recombining trees
  - Approximative approach
  - But good approximation possible

- Endogenous computation of required reserves
  - Taking into account stochasticity wind

Boundary conditions for scenarios

- Modelling for Germany 2000 to 2020
- Increase of electricity demand by around 1% per year

  From 513 TWh in 2004 to 593 TWh in 2020
- Fuel cost & investment cost as of 2004

- Increase of wind energy from 5 % of demand in 2005 to 15 % in 2020

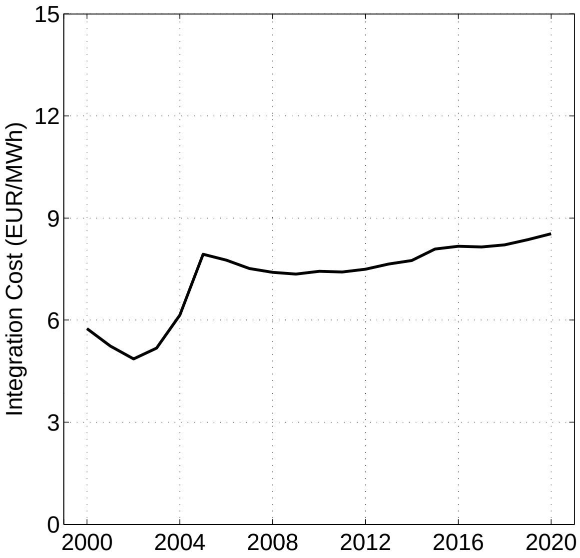
- Scenario low CO_2-price:

  constant price of 10 €/MWh
- Scenario high CO_2-price:

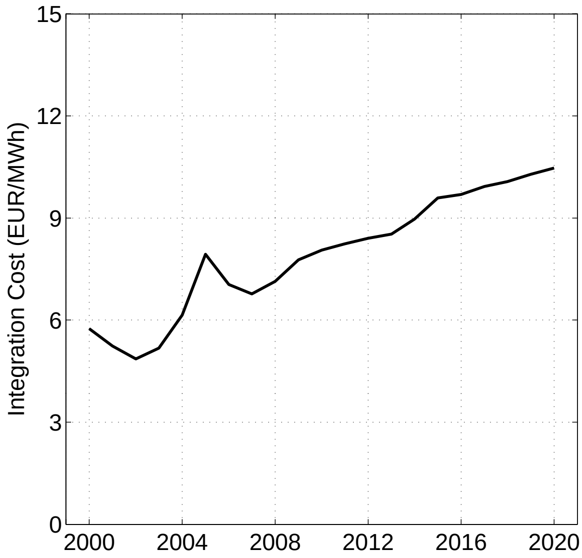
  linear increase from 20 €/MWh in 2006 to 40 €/MWh in 2020

Integration cost wind energy Germany Results E2M2s over time

Low CO_2-cost



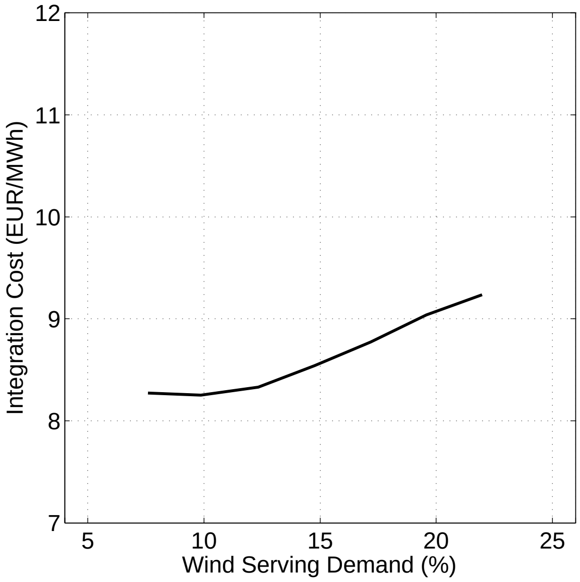
High CO_2-cost



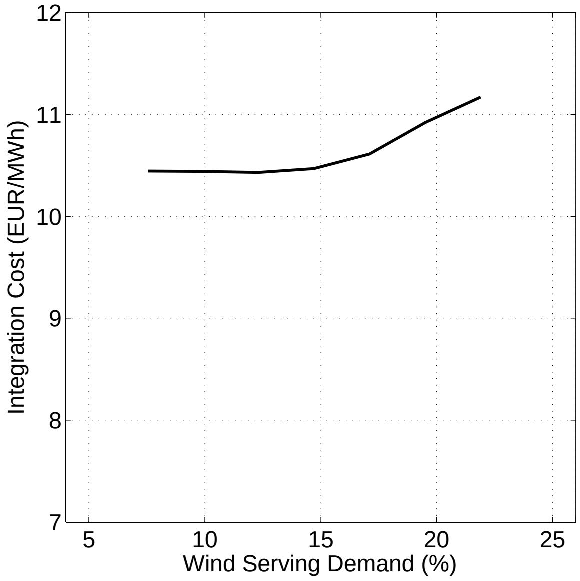
source: Swider, Weber (2007)

Integration cost wind energy Germany Resutls E2M2s depending on wind share

Low CO_2-cost



High CO_2-cost



Source: Swider, Weber (2007)

Overview

Final remarks

Value of wind energy respectively integration cost are depending on

- Methodology of assessment
- Reference technology taken as basis
- Adaptation reactions in the system taken into account
- Specificities of the original system
  - E.g. share of flexible hydro power

→ System oriented, stochastic approach necessary for adequate assessment