An Electricity Market Model to Estimate the Marginal Value of Wind in an Adapting System

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Overview

Introduction

Debates on integrating large-scale RES-E in existing systems

- Large amounts of intermittent renewable energy sources for electricity production (RES-E) are expected to be integrated in electricity systems.
- Debates focus on (i) how to estimate the costs of RES-E's intermittency and (ii) how to apportion the costs between RES-E's generators and system operators.

Broad diversity of methodologies to assess integration costs

- Integration costs are due to the influence of intermittent RES-E on the performance of the overall system operation.
- In the literature often static simulation models are applied to assess the additional costs of intermittent RES-E integration.

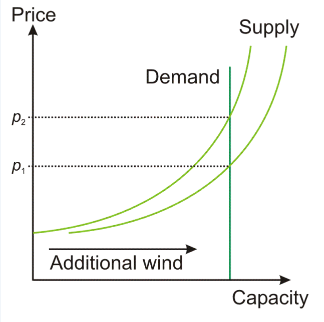
Question: *What are the integration costs of wind assessed with a dynamic stochastic fundamental electricity market model?*

Changes in System Operation

- The characteristics of intermittent RES-E substantially differ from conventional generation mainly due to:
  i. lower controllability,
  ii. higher variability and
  iii. lower predictability.
- Consequently, the system operation becomes more complicated, with a need of a higher flexibility in the overall system to follow load.
- Most import are more start-ups of conventional power plants, a higher fraction of part-load operation and an increased need for reserves.
- These aspects lead to changes in system operation and hence to additional costs due to intermittent RES-E integration.

Induced Additional Costs

What about fuel savings?



- RES-E integration (mainly wind) leads the merit order to shift to the right due to relatively low variable costs.
- Hence, the electricity prices will eventually decrease and high priced plants may have less full-load hours resulting in fuel savings.
- On the other hand the high variability induces additional costs on plant operation and on balancing the system.
- Principally, additional costs of intermittent RES-E integration depend on the considered electricity system and its development.

Fundamental Modelling Approach

The basic idea of a fundamental model is to analyse the power market based on the technical and economical aspects of generation and demand.

In order to analyse intermittency some major challenges arise:

Existing capacities; Thermal and hydro power plant classes.

Unit-commitment; Start-up costs and part-load efficiencies.

Time resolution; Intermittent sources require a fairly high time resolution.

Regional resolution; Interregional transmission may effect market prices.

Investments; System may adapt and change dynamically in the long run.

Stochastic modelling; Fluctuations should be considered most accurately.

Essential Characteristics of the Model

- Linear stochastic fundamental electricity market model.
- Capture of seasonal effects by considering a full year.
- Capture of unit-commitment by dividing the year in typical hours.
- Myopic model with recursive application over longer time horizons.
- Consideration of reduced part-load efficiencies and start-up costs.

In order to analyse intermittency most important are:

- Endogenous investments in new thermal power plants.
- Constant reliability margin to estimate power systems reserve.
- Recombining tree to consider stochastic RES-E fluctuations.

Introduction of Endogenous Investments

- For calculating fix costs $FC_{r,u,t}$ the choice among different investment alternatives with specific irreversible fix costs fc_u^{irr} and the decision variable of newly build capacity $L_{r,u,t}^{\text{new}}$ is endogenously modelled:

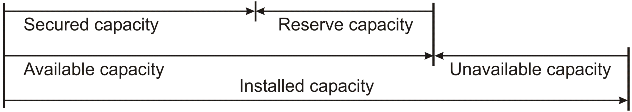
Calculation of fix costs:

$$FC_{r,u,t} = a(i, lt_u)\, fc_u^{\text{irr}}\, L_{r,u,t}^{\text{new}} + fc_u^{\text{rev}}\, L_{r,u,t}$$

- Thereby the investments are discounted by the annuity factor $a(i, lt_u)$ defined by the interest rate i and the lifetime lt_u.
- Finally, also reversible specific fix costs fc_u^{rev} for the total installed power plant capacity $L_{r,u,t}$ are taken into account.
- The decision of investing in new capacity is not binary but continuous.

Introduction of a Constant Reliability Margin

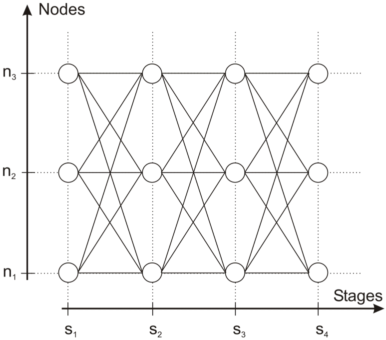
- Power systems reserve (on the supply side) can be defined to be the difference between the available and the secured capacity.



- The secured capacity can be calculated by estimating the probability distribution of the reliability of the given power plant portfolio.
- This distribution can be estimated by sequentially calculating the convolutions of the probability distributions of all power plants.
- Setting the cumulative sum of the probability of the power plant portfolio equal to the reliability margin leads to the secured capacity.

Introduction of a Stochastic Recombining Tree

- Instead of considering one operation mode of the system at each moment in time different stochastic states are considered.
- Any state or node n at a given moment in time or stage s is characterized by a probability $\psi_{s,n}$ and transition probabilities $\tau_{s \rightarrow s+1, n \rightarrow n'}$ between the states.
- For the static equations this leads to add the index for the different nodes and for the dynamic ones also the transition probabilities need to be accounted for.



Stochastic Objective Function

- The model minimizes the total costs TC for system operation in the considered electricity markets (the model can cover interregional transmission but this is not considered in the case study).
- Thereby operating costs OC, start-up costs SC and fix costs FC (subject to region r, unit type u, time segment t and node n) are considered.
- Of special importance in the stochastic model version is that all decision variables are simultaneously indexed over time t and node n; the nodes are considered with their probability $\psi_{r,t,n}$ in the objective function.

Stochastic objective function:

$$TC = \sum_r \sum_u \sum_t \sum_n d_t f_t \, \psi_{r,t,n} \left(OC_{r,u,t,n} + SC_{r,u,t,n} + FC_{r,u,t,n} \right)$$

Calculating Integration Costs

- In order to determine integration costs, differences between systems with and without wind generation have to be looked at.
- Integration costs are defined as the difference in cost savings by wind generation compared to those of some alternative generation.
- Hence, the computation of integration costs always remains dependent on the definition of this alternative generation technology.
- Here the alternative is assumed to have the expected wind energy production with conventional properties (firm and predictable).
- Then integration costs comprise costs for variability and unpredictability due to changed system operation and investment decisions.

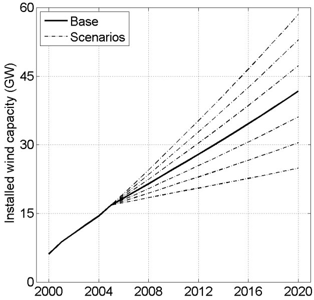
Assumptions I

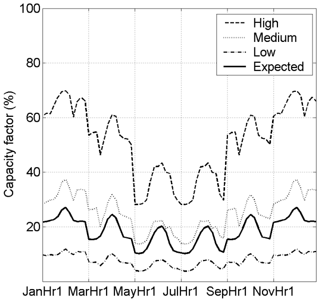
- The case study focusses on large-scale wind integration in Germany.
- Diverse thermal and hydro power plant classes are taken into account.
- Fuel prices and demand are assumed to increase by a constant rate.
- CO_2 allowance prices are assumed to remain low at about 10 €/tCO_2.
- For market-driven investments a discount rate of 8 % is assumed.

Investment opportunities in thermal power plants

Type	Unit	Coal	Lignite	Gas GT	Gas CC
Net capacity	(MW)	750	850	100	800
Efficiency (full load)	(%)	46	42	39	58
Availability (winter)	(%)	96	96	98	99
Reliability	(%)	97	98	94	97
Investment costs	(€/kW)	1100	1350	230	450

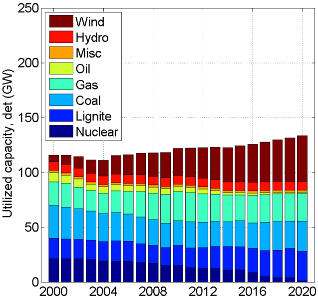
Assumptions II

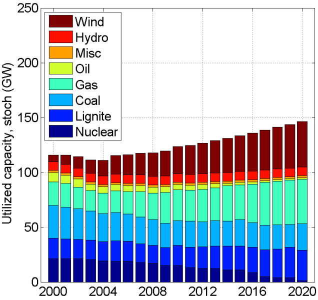




- Several scenarios on installed wind capacities are exogenously given and assumed to be driven by governmental aid.
- Fluctuations of wind are derived for the considered typical hours using historical data of selected weather stations.

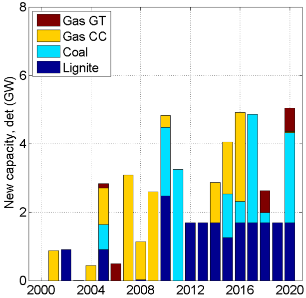
Utilized Capacity

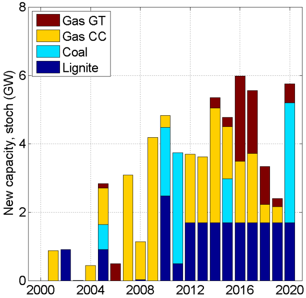




- Investment decisions are highly dominated by the considered CO_2 allowance price paths and hence by energy policies.
- Consideration of wind's intermittency leads to more investments and thereby especially in flexible gas-fired plants.

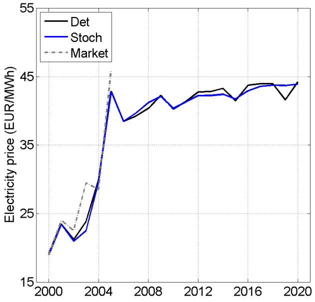
New Capacity

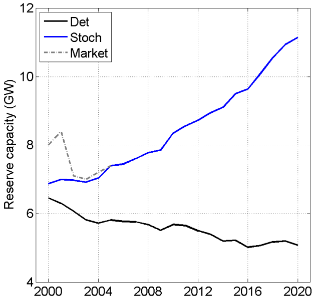




- Due to the nuclear phase-out high investments in base-load plants are necessary; here dominated by lignite-fired plants.
- Considering wind's intermittency higher overall investments and especially in peak-load plants can be seen; notably in gas-turbines.

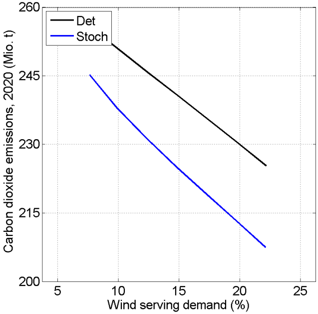
Electricity Price and Reserve Capacity

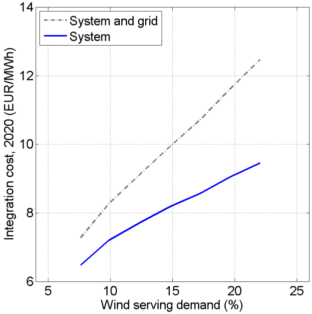




- The development of electricity prices does not significantly change between stochastic and deterministic modelling.
- The reserve capacity is greatly influenced if wind's intermittency is taken into account, mainly due to the reduced capacity credit.

CO_2-Emissions and Integration Costs





- The CO_2-emissions decrease with the fraction of wind serving demand and strongly depend on the adapting conventional system.
- The integration costs due to changed system operation and investments are highly influenced by the wind serving demand.

Disaggregated Integration Costs

Disaggregated integration costs, base case (€/MWh)

Year	Wind serving demand (%)	Operation	Start-up	Sum[1]	Investment	Sum[2]
2005	5	1.9	0.1	2.0	0.0	2.0
2010	8	1.1	0.2	1.3	2.1	3.4
2015	12	-1.1	0.2	-0.9	8.1	7.2
2020	15	2.1	0.2	2.3	5.9	8.2

[1] Integration costs due to changed system operation.
[2] Integration costs due to changed system operation and investment decisions.

- Integration costs are highly dominated by costs due to higher part-load operation and changed investment decisions.
- Disaggregated costs are hard to determine as e.g. investments influence operation and hence depend on the system.

Final Remarks

- A stochastic electricity market model to assess the additional costs of intermittent RES-E integration has been presented.
- The integration costs estimated consider the induced additional costs by wind due to changed system operation and investments.
- Thereby the fluctuations and forecasting uncertainty of intermittent wind are incorporated in the model using a recombining tree.
- The application highlights the need to consider intermittency in a stochastic approach with the system being able to change.
- Estimating integration costs heavily depends on the system and modelling assumptions, hence an unreflected use is misleading.