

# Agent-based simulation of the German electricity markets-An analysis of the German spot market prices in the year 2001-

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Summary: This paper presents a first version of the agent-based simulation platform PowerACE for the simulation of the German electricity sector. In a case study the PowerACE model is used to simulate the development of market prices on the German spot market in the year 2001. In order to analyse the capability of the model the results are compared to the official spot market results of the LPX (EEX) in the year 2001.

Keywords: agent-based simulation, electricity markets, spot market, market analysis

## 1 Introduction

The German electricity sector has undergone considerable changes throughout the past few years. Main developments are the liberalisation of electricity markets, the evolving European CO<sub>2</sub> emissions trading scheme and the promotion of renewable electricity generation. Policy makers and market players have to deal with new aspects like market power, bounded rationality and the appearance of fluctuating energy sources. In the given environment the complex interactions between different markets and environmental policy instruments like CO<sub>2</sub> emissions trading become an issue of increasing importance. Conventional modelling approaches such as optimisation models or top down models are not very suited to deal with these issues. A promising and novel approach for the scientific analysis of these new developments is the field of agent-based simulation.

The concept of agent-based simulation seeks to overcome some of the weaknesses of conventional modelling approaches by building a simulation from a player's perspective which helps to integrate aspects like player strategies or imperfect information. The approach of agent-based simulation draws on the concepts of several disciplines such as economy/game theory, social sciences and software engineering (see also Wooldridge, 2002, p.7 ff). The variety of approaches to agent-based simulation has led to a variety of definitions concerning the term "agent". One definition which is often quoted in the field of multi-agent systems or distributed artificial intelligence is given by Wooldridge and Jennings (Wooldridge and Jennings, 1995) stating that agents are characterized by autonomy (ability to operate on its own), social ability (ability to interact with other agents), reactivity (ability to respond to a perceived environment) and pro-activeness (ability to act on its own initiative in order to reach envisaged goals). However, a review of agent-based simulation platforms shows that the agents used in these simulations in many cases apply weaker definitions of the term "agent" (Drogoul et al, 2002).

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This paper presents a basic version of the simulation platform PowerACE which seeks to simulate the German electricity sector with special consideration of the renewable electricity generation and the evolving European CO<sub>2</sub> emissions trading system. The project is funded by the Volkswagen Stiftung and developed in a cooperation of the Fraunhofer Institute for Systems and Innovation Research, the Institute for Industrial Production and the Chair for Information Management and Systems at the university of Karlsruhe.

The goal of the PowerACE platform is to provide a simulation tool for politics and players which can be used to analyse the impact of different market settings, policies and player strategies. Thereby a central goal is to produce valid quantitative results wherever possible thus combining the strength of conventional modelling techniques with the flexibility of the agent-based approach. However, the goal to produce valid quantitative results in an agent-based simulation of the German electricity sector leads to extensive requirements regarding the required data and calibration of the model.

In a case study the developed simulation model is applied to analyse the German spot market prices in the year 2001. Thereby the comparison of model results and real world prices serves two different purposes. The first goal is model calibration and development. Since the developed model is going to be used to assess the impact of CO<sub>2</sub> emission trading and different ways to integrate renewable electricity generation it is essential to analyse the capability of the model to produce reliable spot market prices. These prices will play a central role in future analyses e.g. of policy measures. Before the development of additional features such as additional bidding algorithms the quality of the applied fundamental algorithms and the enormous amount of data required for the simulation is analysed in a basic simulation run. In a first extension of the basic model an additional algorithm to integrate start-up cost is applied and analysed.

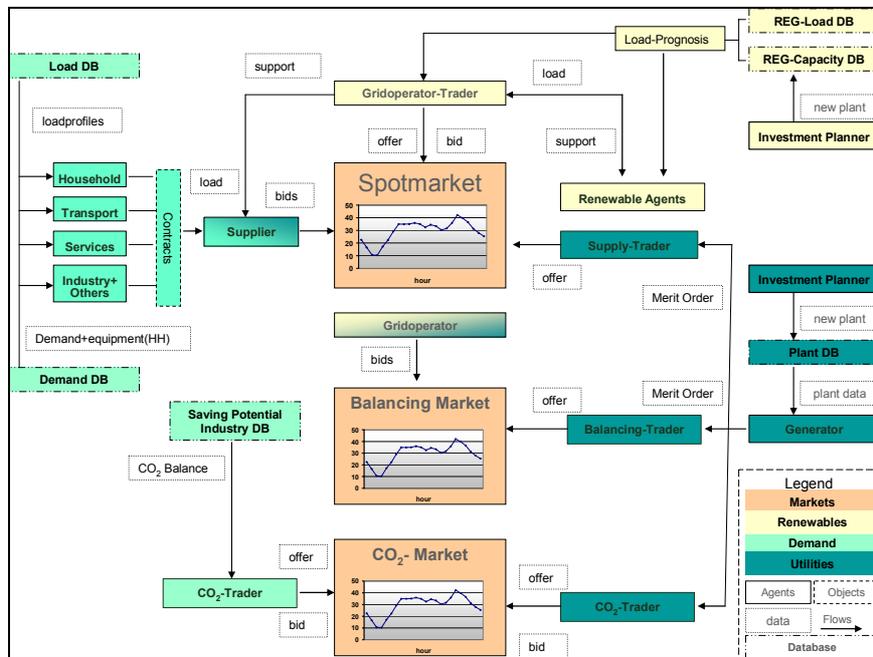
In addition the analysis also allows to get some insights into fundamental aspects such as integration of unit commitment constraints, market behaviour and the likely profit margins which have been reached by utilities on the spot market. This paper is structured as follows. In section two the current version of the PowerACE simulation platform is described. Section three describes the simulation settings applied for the simulation of the German spot market. Section four deals with the comparison and analysis of the German spot market prices in the year 2001. In the last section the main insights gained from the case study are summed up, conclusions are drawn and an outlook on the future development is given.

## **2 Model description**

The PowerACE simulation platform simulates important players within the electricity sector as computational agents. Among these are agents representing consumers, utilities, renewable agents, grid operators, government agents and market operators. Some players like utilities are modelled using several computational agents representing different functions within the company like trading or generation. The current version of the PowerACE model incorporates a spot market for electricity, a market for balancing power and a market for CO<sub>2</sub>-emissions. Since the goal of this paper is to analyse the general capability of PowerACE to produce reliable spot market results all other markets are deactivated for the simulation runs. An overview of the main agents involved in the simulation is given in Figure 1. In general the simulation platform can be categorized in four modules dealing with: markets, electricity demand, utilities and renewable electricity generation.

These modules are described within the next section after a short overview of the databases utilized for the PowerACE simulation. Finally the timescales of processes within the model are summarized in a last section of this chapter.

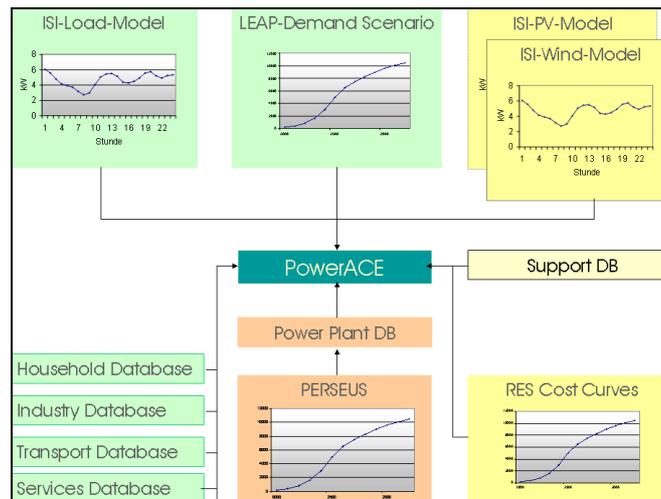
Figure 1 Structure of PowerACE



## 2.1 Provision of adequate data by soft-links to fundamental models

This paper seeks to analyse the capability of the model to simulate spot market prices in order to provide an adequate basis for future analysis. Therefore a central part of the simulation is to provide realistic data on electricity demand, renewable electricity generation and the stock of power plants in Germany. The agents' fundamental decisions are based on this data. An adequate dataset for the PowerACE simulation platform is provided by soft-links to various models. These linkages are visualized in Figure 2. The ISI Load Model and the Leap Demand Scenario provide load profiles and a long term development of the electricity demand. Due to the increasing importance of renewable electricity generation the provision of adequate load profiles for renewable electricity generation is crucial. The ISI-PV (Sensfuß, 2003) and ISI Wind model (see also Sensfuß et al., 2003; Klobasa and Ragwitz, 2005 ) generate these data for photovoltaic and wind energy on the basis of extensive meteorological data and assumptions on the regional distribution of wind turbines. The PERSEUS model (Möst et al., 2005) can be used to provide a scenario for the future development of the German power plant portfolio and to calculate load profiles of electricity imports and exports. Additional information on the support of renewable electricity generation and different sectors of electricity demand is stored in databases. Among these are information on company size, household size and household equipment levels in terms of electric appliances.

Figure 2 Models and databases linked to the PowerACE simulation platform



## 2.2 Simulation of electricity demand

On the demand side, the consumer agents representing the sectors household, industry, transport and service negotiate contracts with the supplier-agents representing the sales department of utilities. There are several suppliers in the model offering contracts to the consumer agents. These agents can choose from a set of contracts based on a contract change algorithm which considers aspects like limited market information or emotional barriers of consumers. Since this part of the model does not influence the market analysis carried out in this paper it is not described in all details (for more information see also Müller, 2005). The supplier-agents are learning agents seeking to maximize their profits on the consumer market. In the given version of the model they purchase the entire electricity required by their consumers on the spot market. Thereby the supply-agents are modelled as price takers.

## 2.3 Simulation of electricity supply

The Supply Traders get a daily updated list of available power plants which is based on a detailed power plant database containing the most important parameters of power plants (capacity, costs, availability, technology, fuel). Based on this information the traders can sell electricity generated by their power plants on the spot market, on the balancing market or on both markets. They calculate their offers according to a merit order, considering variable costs (mainly fuel costs). In the current version remaining capacities which are not considered in the spot market can be traded on the balancing power market, which represents the total German demand of reserve energy. The availability of power plants is determined by a comparison of independent uniform distributed random numbers to the average availability of the given plant. The dispatch of power plants causes CO<sub>2</sub> emissions, which can be balanced by the generator-agents. Certificates needed for these emissions can be traded through the CO<sub>2</sub>-Trader at the CO<sub>2</sub>-emissions market. The prices of this market change the merit order of power plants (with beginning of the emission trading in 2005). Another participant at this market is the CO<sub>2</sub> saving potential of the industry. In the given simulation of the year 2001 the CO<sub>2</sub> market is deactivated since it started in 2005.

The power plant database can be modified through the agent Investment-planner. Thereby investment planning can be either integrated by a soft-link to PERSEUS or an internal decision process.

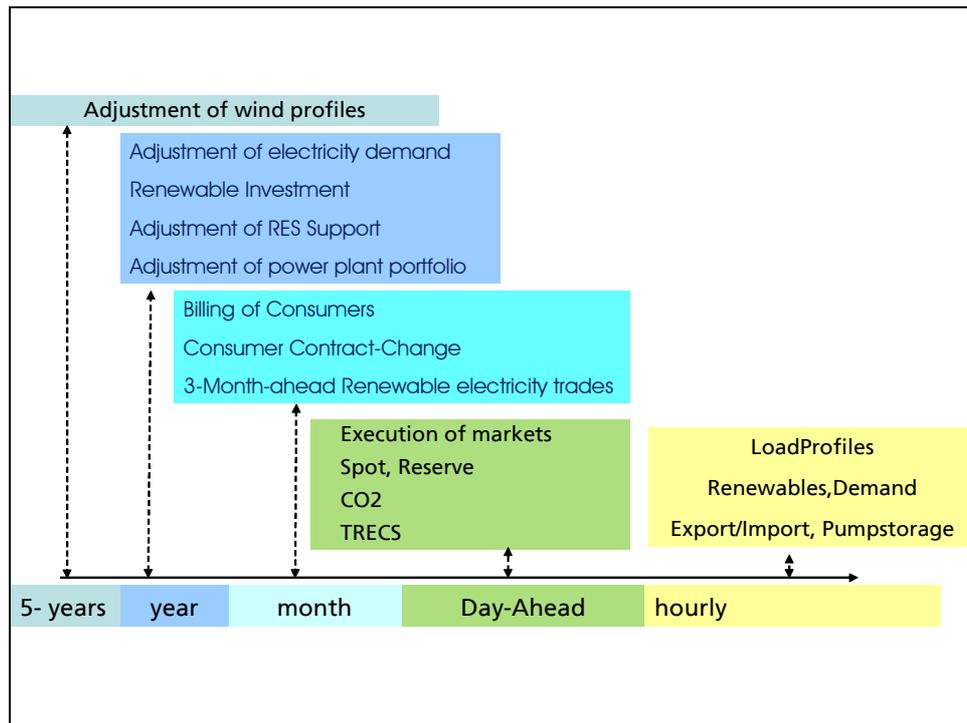
## **2.4 Simulation of renewable electricity generation**

Renewable electricity generation plays a growing role in the German electricity sector. According to the Renewables Energy Sources Act (EEG 2004) the electricity generated from renewable energy source has to be bought by grid operators at guaranteed feed-in tariffs. The renewable electricity is brought into the market by selling 3-month-ahead base load blocks based on a prognosis of renewable electricity generation which is sold to supplier-agents at the price of the feed-in tariffs. On day-ahead basis a new prognosis of renewable electricity generation is calculated and the differences between the sold base-load block and the new day ahead hourly prognosis is traded on the spot market (E.ON, 2005). This task is carried out by the Gridoperator-Trader in the PowerACE simulation. In order to decrease the complexity of the market analysis envisaged in this paper the prognosis error of the projection of renewable electricity generation is set to zero, which means that the day-ahead prognosis matches the actual generation. Future analysis will take typical forecast errors into account. Another aspect is the simulation of the expansion of renewable electricity generation based on a given support scheme. PowerACE offers the possibility to integrate renewable capacity expansion by a scenario or by an endogenised investment planning which is carried out by the Investment-Planner-agent. For the given analysis the installed capacity is set to the known values for the year 2001.

## **2.5 Timescales**

Since PowerACE seeks to simulate interaction decisions of different agents within the electricity sector the timescales of different developments have to be taken into account. Figure 3 summarizes the processes and timescales within the model. The shortest time step within the simulation is a single hour. Load profiles of electricity demand, renewable electricity generation, production of pump storage power plants and the profile of import/export of electricity are provided on hourly basis. The execution of the markets (spot, reserve, CO<sub>2</sub>) takes place on daily level but the spot market allows to place bids for single hours. Once per month the consumer-agents are billed and the consumer-agents can change their contract. Every 3 months the grid-operator-trader sells a base-load-block of renewable electricity to the supplier. Yearly simulation steps contain the adjustment of electricity demand which is based on an expected growth of electricity consumption and possible energy savings, the investment into new renewable generation capacity, the adjustments of RES-Support according to the Renewable Energy sources act and the adjustment of the power plant portfolio. Furthermore every five years the wind profile is adjusted reflecting the tendency to build higher wind turbines leading to higher utilization rates.

Figure 3 Timescales of the PowerACE simulation



### 3 Setting up the simulation of the German spot market

A central goal of this paper is to assess and calibrate the capabilities of the PowerACE simulation platform to generate realistic spot market prices. In order to simulate realistic market prices in an agent-based simulation the data requirements are extensive. This chapter discusses the basic assumptions and settings of the simulation.

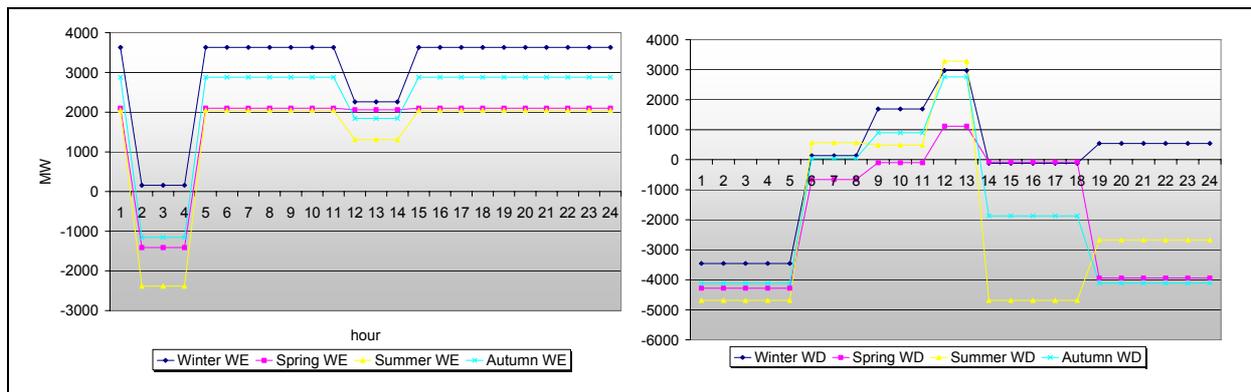
#### 3.1 Selection of the base year

The central basis for the simulation is the provision of adequate fundamental data. Among these are: 1. the power plant portfolio 2. an hourly load curve of electricity demand 3. an hourly load curve of electricity generation from renewable energy sources. In order to provide these data the PowerACE simulation is linked to several other models and databases. The most important models in the given context are the ISI-Load model providing a synthetic hourly load profile for the electricity demand in Germany and the ISI-Wind model which generates an hourly load profile of the German electricity generation from wind energy. In order to be as detailed as possible these models require extensive meteorological data such as local wind speed or temperature. Since all the necessary data is available for 2001 in high quality this year is selected for the case study in order to minimize errors that might be caused by the underlying dataset. However, it has to be stated that the German spot market which went into operation in June 2000 (EEX, 2000) was still very young in the year 2001. Trading volumes and market experience of the involved player have been considerably lower than in recent years such as 2004. This aspect has to be taken into account in the analysis. Therefore the spot market prices for the years 2002-2004 are also analysed with regard to main indicators in order to assess the spot market prices for 2001.

### 3.2 Integration of electricity imports and exports

The essential fundamental basis for the price generation is the remaining system load that has to be covered by German power plants. Since PowerACE focuses on Germany imports and exports of electricity have to be integrated as external input into the simulation. This external input is provided by the PERSEUS linear optimisation model, a European energy system model where Germany and all border countries are modelled. In view of the transmission capacities, cost, electricity demand and supply, export/import flows between these countries are computed and used as a fixed load flow for the PowerACE model runs. The resulting seasonal profiles are presented in Figure 4.

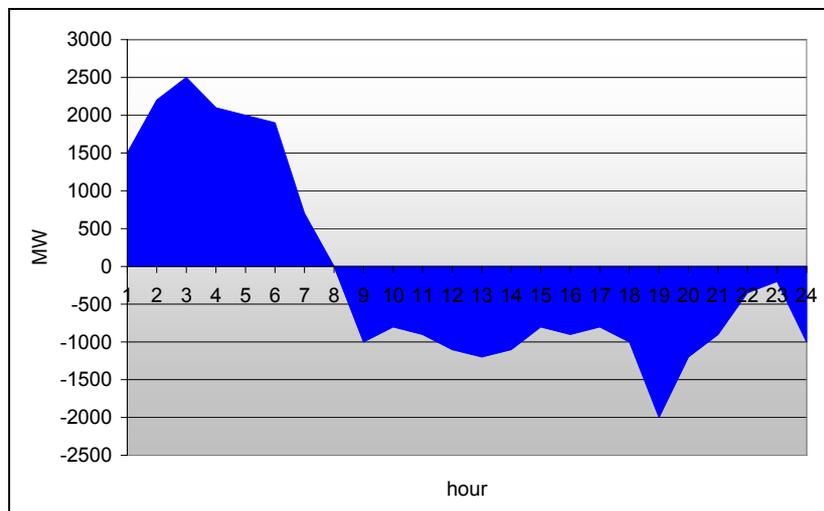
Figure 4 Import and Export of electricity for working days [WD] and weekend [WE]



### 3.3 Integration of pump storage

Another aspect is the use of pump storage power plants. Pump storage power plants can be used to levelize electricity demand and for the provision of reserve energy. In the given simulation the use of pump storage power plants is integrated as an exogenous load curve which is based on the available information. An overview of the pump storage profile applied for every simulation day is given in Figure 5. One future improvement of the model could be the integration of dynamic dispatch of pump storage power plants within the model.

Figure 5 Pump storage load profile



(based on: VDEW, 1998)

### **3.4 Simulating the availability of power plants**

Another important aspect for the generation of market prices is the availability of power plants. In order to integrate scheduled and unscheduled outages of power plants a random generator is integrated into the simulation. In the case of nuclear power plants an average monthly availability based on the known electricity production of nuclear power plants in the year 2001 (UCTE, 2004) is used as input for the random generator. In a calibration procedure the average availability of fossil fuel fired power plants on weekdays is set to 98.5%. A crucial issue is the availability of power plants on weekends. The available information on power plant dispatch and market prices indicates that scheduled maintenance work is preferably scheduled at weekends due to the lower demand and market prices. Since details on the dispatch of power plants on weekends are unknown the average utilisation of fossil fired power plants is set to 93% based on a calibration procedure. Thereby the availability is determined on hourly level for every single plant. One possible improvement is to take out single plants for longer periods such as 2 days. However, as the results are generated as an average of 20 simulation runs a similar effect can be reached.

## **4 Simulation of the German spot market**

This section discusses the simulation of the German spot market with PowerACE. The first simulation shows market results without unit commitment constraints. In a second step an algorithm for the integration of unit commitment constraints is discussed and the results are analysed.

### **4.1 Basic simulation**

The basic simulation is structured as follows. The entire German electricity generation and demand are traded on the spot market on hourly basis. Electricity generation companies bid their merit order curves based on the variable electricity generation cost of their power plants. Unit commitment constraints like cost concerning the warm-up times of power plants or imports and exports of electricity are not taken into account in a simulation run. A random generator is used to integrate scheduled and unscheduled plant outages. Electricity demand is represented by suppliers which purchase electricity and sell it to consumers. In the given simulation the suppliers are modelled as price takers with inelastic electricity demand.

A first comparison between the time series of hourly prices of the German spot market in 2001 and the average simulated prices of 20 simulation runs with the PowerACE model shows a low correlation and a considerable underestimation of the annual average price. However, a closer look at the actual spot market prices in 2001 shows that market prices of up to 998 Euro/MWh are reached which indicate extensive gaming on the market during few hours throughout the year. In order to reduce these effects 53 hours with market prices above 90 Euro are excluded from further analysis. The Pearson's correlation coefficient between both time-series rises to approx. 0.704 and the average underestimation of the market prices reaches 2 Euro/MWh. A comparison of both time series for the month Oktober and as ordered curves is given in Figure 6 and Figure 7. The correlation shows that the underlying datasets concerning electricity demand, renewable electricity generation and power plant portfolio are adequate to provide a basis for the analysis of market developments. Besides the underestimation of peak market prices two other phenomena can

be discovered. In times of low demand actual market prices can fall below the simulated generation cost expected by the PowerACE model. A possible explanation of this effect can be that generation companies want to keep their plant online due to technical restrictions or start up cost. Another aspect is the fact that the model results fail to explain the volatility of market prices at the weekend. This aspect needs further investigation in order to improve the model. Possible explanations could be low liquidity on the market or preferred scheduling of plant maintenance at the weekend leading to a considerable reduction in the available capacity.

Figure 6 Comparison of market prices for Oktober 2001

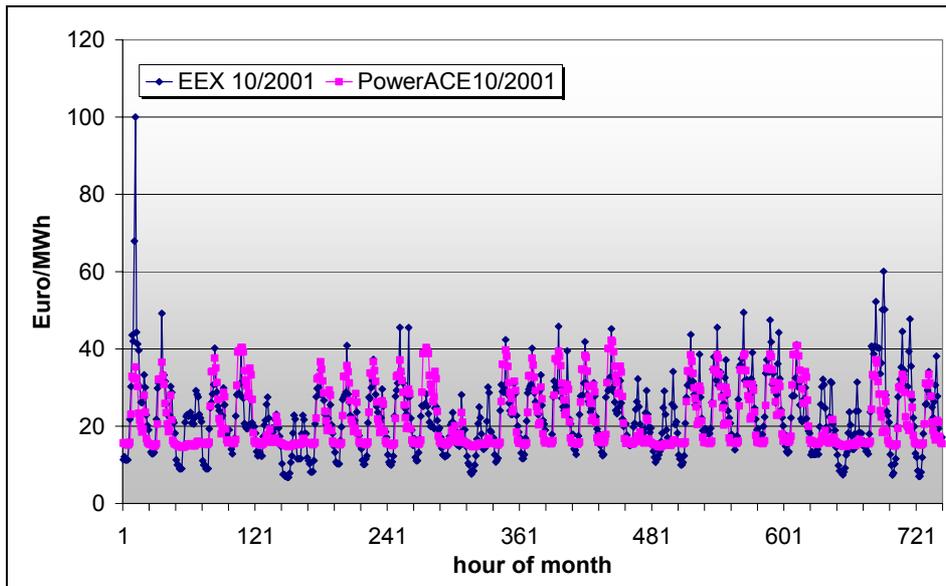
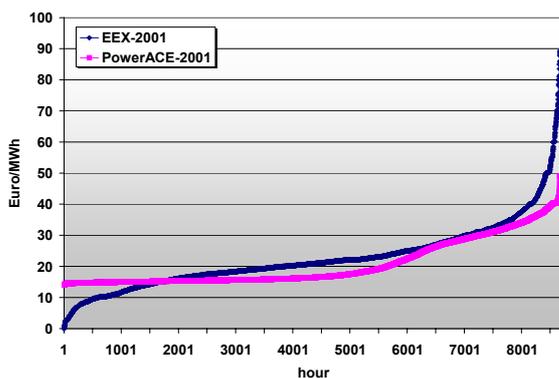


Figure 7 Comparison of ordered market curves for the year 2001 (filtered)



	EEX (filtered)	PowerACE (filtered)
Ø-Price(€/MWh)	22.76	20.76
Min-Price(€/MWh)	0	13.96
Max-Price(€/MWh)	89.19	49.03
Standard-deviation	10.83	7.42

(Prices provided by European Energy Exchange [EEX], 2005)

## 4.2 Integration of start up cost

As the basic simulation run shows that EEX prices are lower in some hours than variable cost used in PowerACE a new algorithm is developed which integrates the start up costs in the bidding process in periods of low prices. In a first step the generator creates a price forecast for the next day which is based on a forecast of renewable electricity supply demand and the merit order of the next day. If the situation occurs that the variable generation cost of a generation unit are higher than the expected market price for a given period the generator

calculates a new minimum price by subtracting the start up cost divided by the length of the period and the capacity of the generation unit. The formula is given in Formula 1.

Formula 1 Calculation of minimum bid price

$$MinCost = VarCost - \frac{StartupCost}{h * capacity}; h = \text{unscheduled hours in one period}$$

For oil and gas fired units the start up cost is added to the bid price for the hours when the plants are expected to be in operation (see Formula 2).

Formula 2 Integration of start-up cost for oil and gas fired peak units

$$Cost = VarCost + \frac{StartupCost}{h_s * capacity}; h_s = \text{scheduled hours}$$

A new series of 20 simulation runs for the year 2001 shows that the new algorithm has some impact on the results. The Pearson's correlation coefficient for the filtered EEX prices and the PowerACE simulation rises to 0.713. The average price is reduced by 0.3 Euro/MWh to 20.46 MWh. The maximum price shows a slight increase to 50.66 Euro/MWh and the standard deviation rises by 0.19 Euro/MWh. An overview of the market results is given in Figure 8 and Figure 9. The minimum price is reduced by 1.14 Euro/MWh. Although the new algorithm shows a remarkable improvement of the results there is still a considerable time period where market prices are below the minimum level that can be simulated by the PowerACE model. Likely reasons for the remaining differences may be lower generation cost or aspects related to forecast or trading errors. The interpolation algorithm applied in the EEX closed auction for single hours can lead to prices below the cost of the marginal generation unit if some units such as nuclear plants bid at zero cost to avoid shut down. Another aspect which has to be taken into account is that not the entire electricity demand is traded on the real world spot market. Other markets like the OTC/Future market might have an additional impact on the spot market. However, a comparison with the spot market prices of the years 2003 and 2004 shows that the time periods with prices below the 12.82 Euro/MWh are decreasing which might be caused by increasing trading volumes and trading experience. Another aspect which can be shown in the simulation is that the market participants are capable to raise market prices considerably above the level which can be explained by underlying cost data. Despite the limitations of the model to simulate extreme market results with very low and very high prices the considerable correlation between PowerACE results and EEX prices shows that PowerACE is a promising model for the analysis of the electricity market.

Figure 8 Comparison of market prices for Oktober 2001

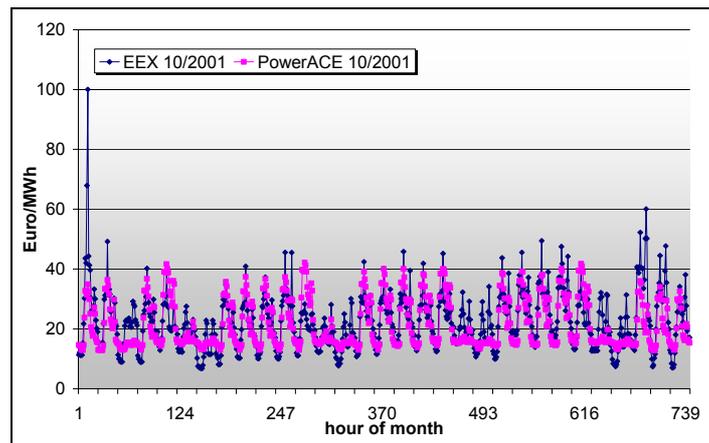
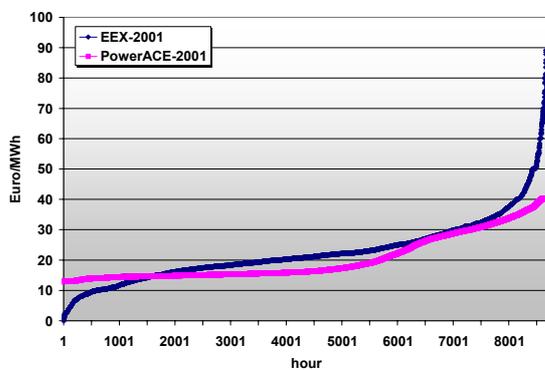


Figure 9 Comparison of ordered market curves for the year 2001 (filtered)



	EEX (filtered)	PowerACE (filtered)
Ø-Price(€/MWh)	22.76	20.46
Min-Price(€/MWh)	0	12.82
Max-Price(€/MWh)	89.19	50.66
Standard-deviation	10.83	7.61

(Prices provided by European Energy Exchange [EEX], 2005)

## 5 Conclusions

This paper presents a basic version of the agent-based simulation model PowerACE and applies it to the simulation of the German spot market in the year 2001. After a basic simulation run an additional algorithm is developed in order to integrate the start-up cost of power plants into bidding strategies. The comparison of the simulation results to the spot market prices shows considerable correlation between spot market prices and the simulation runs throughout a broad price range. However, periods with prices far below the variable cost of the marginal generation unit and extremely high prices reached at the German spot market cannot be explained by the simulation platform. However, the general tendency of the PowerACE model to underestimate the average market prices shows that utilities are capable to reach market prices above marginal cost, especially in hours of peak demand. In general it can be stated that the developed simulation platform is capable to produce results which show considerable correlation with the price development of the German spot market which indicates that the market is still driven to significant extent by fundamental data like marginal cost of generation units. The results of the simulation platform are promising. Future work will be directed to a better integration of bidding strategies and additional markets such as the CO<sub>2</sub> markets into the simulation platform.

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