Development of an agent-based model to analyse the effect of renewable energy on electricity markets

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Abstract

In this paper we present a bottom-up modelling approach of electric power and CO_2-certificate markets including a detailed modelling of renewables using agent-based simulation: The PowerACE model. It has been developed at the Institute for Industrial Production, the Chair for Information Management and Systems (University of Karlsruhe) and the Fraunhofer Institute for Systems and Innovation Research. The market players of the German electricity market are modelled as independent entities. It is well suited to consider different strategies of market players and testing different market mechanisms.

1. Introduction

Liberalisation of electricity markets, the start of EU-wide emission trading 2005 and the growing contribution of renewable energy sources to the electric system are new challenges for the players in the power markets. The liberalisation process, which started with the directive 96/92/EC (EC 1997) of the European Commission in 2001 led to significant changes in the electricity system. The power generation companies intend to maximise their profits and to increase their market shares instead of minimising costs as before liberalisation in the regulated market. Furthermore, the Kyoto Protocol with its emissions reduction targets and the EU Burden Sharing agreement reduce the allowed amount of emissions. This reduction of the formerly free good “emission right” leads to a price for CO_2-emissions (Fichtner 2004) and will change the merit order curve of power plants as well as long-term investment decisions. Besides the new CO_2 emission trading, the increasing renewable power generation is likely to change the structure of the energy system: the fluctuating character of renewable sources like wind and solar energy will affect the amount of power reserve as well as the electric power grid. The European Commission 2001 has defined target rates for electricity produced from renewable energy sources (i.e. Germany: 12.5% in 2010) in the directive 2001/77/EC (EC 2001). Especially wind energy is, due to its fluctuating character and the enormous growth, relevant for further analysis of the electricity market.

Chapter 2 gives a brief overview about modelling energy systems and about agent-based modelling, chapter 3 an overview over the developed model. Chapter 4 shows the modelling of renewables and chapter 5 gives an exemplary analysis of some aspects of the energy system.

2. Energy models, agent-based simulation and computational economics

The presented model can be placed in the category of bottom-up models. According to (Enzensberger 2003, 47) two main categories of bottom-up-models can be identified: optimising energy system models and market simulation models. Optimising energy system models are mostly based on central optimisa-

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tion. This approach is appropriate for questions that can be examined in a centralised manner. Liberalised electricity markets, however, can be seen as decentralised complex systems in which no participant has complete information about the whole market. The market outcome is a result of local decision making by the participating power generators and traders who interact within the framework of the installed market mechanisms. In agent-based models, belonging to the group of market simulation models, the actors of the examined system are represented by software agents who can communicate and interact with each other. The agents' behaviour and interaction structure can be specified freely; the focus of interest in agent-based simulation is the phenomena that emerge from the local agents' interaction.

As the concept of software agents is used in different contexts, there are several unequal definitions of the term „agent“ (Franklin/Graesser 1997). In the described research project, agents are understood as software units (Java objects) that have the following common characteristics: they are autonomous in the sense that they individually decide which action they choose in order to get a high value of their objective functions (e.g. profit maximisation); they dispose of individual private knowledge on their power plants, emissions or cost structure; they are capable of communication and social interaction, i.e. they can place bids on different markets and they can trade with each other; they are adaptive and can learn to improve their strategies according to their achieved success; and they can dispose of further private variables that can be defined and configured individually (e.g. risk aversion).

The application of agent-based models for the analysis of economic systems is part of the still new research field of Agent-based Computational Economics (ACE). (Tesfatsion 2003) describes ACE as the computational study of economies modelled as evolving systems of autonomous interacting agents. One aim of this project is to better understand the implications of different market mechanisms, with one focus on mechanisms for promoting the use of renewable energy sources for electricity production.

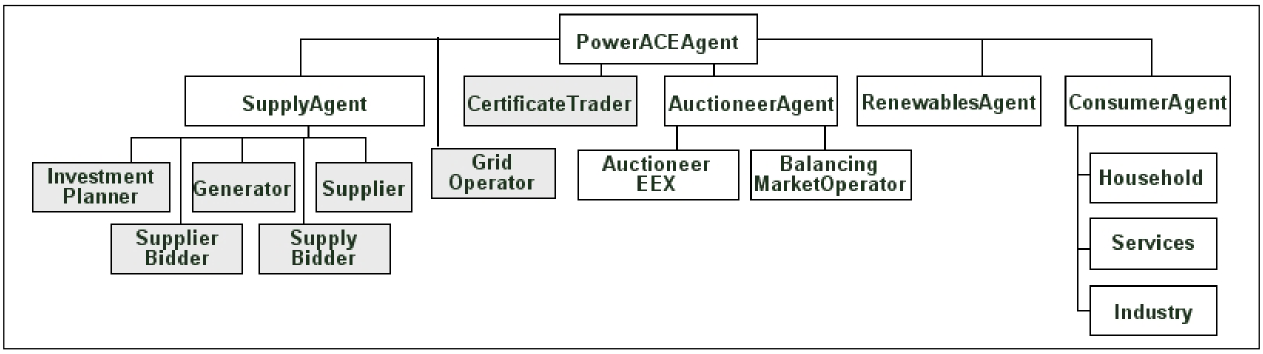

Figure 1
Agent Structure

3. The PowerACE model

The presented work models the German electricity market. Market players, like power generating companies or operators of renewable energy, are split into diverse agents to keep single agents compact, whereby each agent carries out one or more functions. Figure 1 shows a hierarchical tree structure of the agents, where the leafs are concrete instances of the classes. The abstract class *PowerACEAgent* unites methods and variables that are inherited from all agents. Interaction and Communication of agents are shown as flows in figure 2, i.e. the bidding of the agent *supplyBidder* on the power pool.

The player "electricity generating company" is built of the agents {*InvestmentPlanner*, *CertficateTrader*, *Generator*, *Supplier*, *SupplyBidder*, *SupplierBidder*, *GridOperator*}, as shown in figure 1 where the mentioned agents are highlighted.

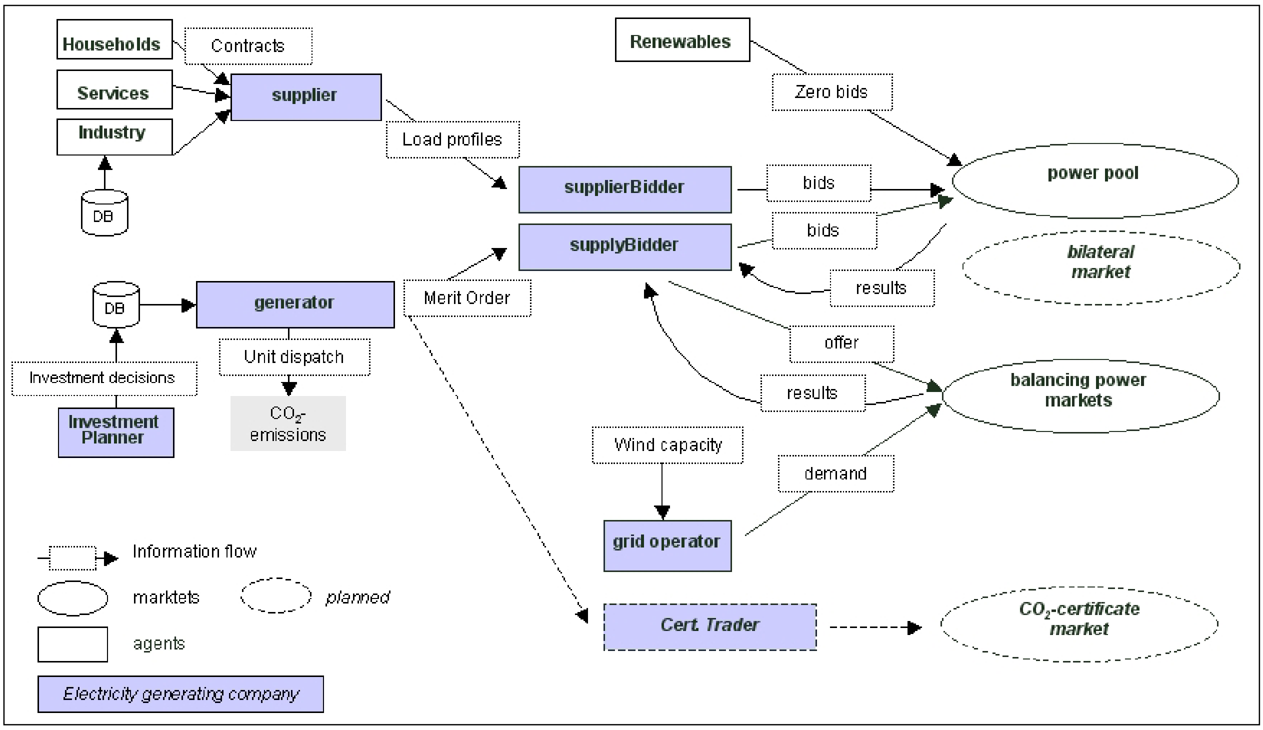

Figure 2
Model structure

The simulation steps can be described as follows: First, the model is built, that means instances of the agents are constructed. Figure 2 gives an overview of the simulation. Each instance of the type *generator*, (belonging to a company with power generation capacities) reads his power plant data from a database. After checking availability (stochastic plant blackout) comparing a uniform random number with the statistical availability of a single unit, a list of available plants sorted by their variable costs, in the following called merit order, is passed to the agent *supplyBidder*. On the demand side, the consumer agents (of type *household*, *services*, *industry*), whose load data is also in a database, negotiate contracts with the agent *supplier*. Result of this negotiation process are load profiles, a characteristic load for each company which has to be bought on the power markets to cover the load. Both the *supplierBidder* (demand side) and the *supplyBidder* (offer side) generate bids according to the load profile and the merit order curve, respectively, and place them on the power pool. The bidding process of renewables as well as the modelling of renewables which is also shown in figure 2 will be discussed in chapter 4. The agent *AuctioneerEEX* matches bids of the bidders and returns the results. Remaining capacities can be sold on the balancing power market. The results of the markets determine the unit dispatch, which is done by the agent *generator*.

For long term analysis, the development of the German power plant capacities is simulated. The power plant database is read once per year to consider new power plants and plants shut down in the model runs. At the moment, capacity extension is realised via a soft link to the PERSEUS-ZERT model (Enzensberger 2003). Endogenous investment decisions will be modelled with the agent *InvestmentPlanner*, which is still under development. Decisions of this agent will modify the power plant database and thus influence i.e. the short-term trading decision.

The model is implemented in Java and uses RePast, the *Recursive Porous Agent Simulation Toolkit*, which is one out of several agent modelling toolkits. The databases used in the simulation model are in MS Access format, the access to which is realised via a JDBC-ODBC bridge.

4. Detailed modelling of renewables in the PowerACE model

An important part of simulating renewable electricity generation is the integration of the load characteristics of renewables. In order to provide a realistic picture of the load characteristics of wind energy the ISI Wind Model has been developed (Sensfuß 2003). The output of the wind model serves as input for the simulation. The load profiles of other renewable sources are based on synthetic load profiles.

A central task of the developed agent-based simulation is to simulate the impact of renewable electricity generation on the conventional power plant portfolio. Based on the (Renewable Energy Sources Act 2004) electricity generated from renewable energy sources has to be bought by the grid operator at guaranteed prices. In the first version of the developed model all renewable electricity is traded on the spot market. In order to simulate the guaranteed grid access renewable agents bid their electricity at the price of zero on the spot market. So, the feed-in of renewables reduces the demand which has to be served with thermal power plants. The feed in tariff is paid by the grid operator agent in compliance with the current rules of the Renewable Energy Sources Act. Another important part of the simulation of renewable electricity generation is the development of the installed capacity. In future versions of the model it is planned to simulate investment in renewable electricity generation within the model under different support schemes in order to analyse the impact of different policies. For the given case study, recent scenarios for the development of different renewable energy sources have been analysed and an own scenario for the capacity development of renewable energy sources has been developed. The grid operator has to ensure the reliability of the electrical grid and thus procures reserve energy on the power reserve markets. The required amount of reserve energy rises with the increasing use of fluctuating energy, values are taken from (DENA 2005). The costs of this additional reserve energy will affect electricity prices, as the grid operators can pass these costs to the end customers.

A comprehensive analysis of the impact of these aspects on the short-term dispatch of power plants as well as the long term development of the structure of the energy system and modelling different strategies of market players are within the focus of this research project.

5. Computation of CO_2-savings by renewable electricity generation and other analysis options

In this chapter, avoided emissions due to the feed-in of renewable energy until the year 2020 are computed to demonstrate the potential of the simulation model. Furthermore other analysis options are shown. First, a reference model run was started with the assumptions of chapter 4 (input of wind model), and the CO_2-emissions were summed up. A second run was started without renewable bidders participating (no feed-in of renewable energy). Emissions were also computed in this run. As above mentioned, the feed-in of renewables leads to a reduced load to be covered by thermal power plants. Every power plant has, depending on the fuel used and its efficiency, specific CO_2-emissions per unit electricity output.

Comparing the total sum of emissions over all periods (2000-2020) of both scenarios shows a theoretically possible CO_2-saving by 21.9% and specific savings of 944 g/kWh electricity in 2004. (Klobasa 2005) shows a CO_2-reduction potential of 943 g/kWh electricity for the same year. Other effects like cost for additional reserve energy are not yet implemented, so that the computed values define a maximum possible amount. I.e. (Rosen 2004) shows that the theoretical reduction potential is about 800 g/kWh CO_2 and the effective reduction is between 300-700 g/kWh CO_2, due to additional reserve energy, depending on the amount of wind energy and considering the shut-down of nuclear power plants in Germany. The replacement of nuclear power plants in Germany depletes the reducing potential of renewables, because other, more emission intensive techniques substitute almost CO_2-free nuclear power plants.

The cost of the feed-in of renewables depending on the guaranteed feed-in tariffs will also be computed in future steps. Together with the avoided emissions the costs for avoiding CO_2-emissions can be computed.

Different feed-in policies (i.e. different tariffs) will also be analysed. Furthermore a method is being developed simulating the wind forecast. The first implementation is to distort each value with a normal distributed random variable. The distortion will be the higher the earlier the forecast moment in the simulation is.

6. Conclusions and outlook

This paper provides a brief overview of the PowerACE model. Next steps will be the implementation of endogenous investment decisions of power plants and renewables. Moreover, emissions trading will be integrated in the model.

It is also planned to enlarge the system boundaries to analyse the effects of the European electricity system on the national electricity and CO_2-certificate prices.

In later experiments different policies for promotion of renewable energy, i.e. the cost and efficiency of green certificates vs. fixed feed-in tariffs could be analysed. Agent-based modelling of short-term electricity markets has shown respectable results. The same can be expected for modelling long-term aspects of the electricity system, such as investment decisions as well as the integration of a growing amount of renewable energy in the electricity system.

7. Bibliography

DENA (2005): Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020. http://www.dena.de. Downloaded 10.06.1005,

Enzensberger, N. (2003): Entwicklung und Anwendung eines Strom- und Zertifikatmarktmodells für den europäischen Energiesektor, VDI-Verlag,

EC (1997): European Commission: Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. Brussels: Commission of the European Communities, 1997,

EC (2001): European Commission: Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market. Brussels: Commission of the European Communities, 2001,

Fichtner, W. (2004): Emissionsrechte, Energie und Produktion, Erich Schmidt Verlag,

Franklin, S.; A. Graesser (1997): Is it an agent or just a program? A taxonomy for autonomous agents. ECAI96 Workshop Proceedings,

Klobasa, M.; Ragwitz, M. (2005): Gutachten zur CO_2 Minderung im Stromsektor durch den Einsatz erneuerbarer Energien, Fraunhofer Institut für System- und Innovationsforschung, Karlsruhe,

Rosen, J., Genoese, M., Fichtner, W., Rentz, O.: Ein Modellinstrument zur Analyse der Auswirkungen einer erhöhten Windstromerzeugung auf den Kraftwerksbetrieb, http://www.energie.de,

Sensfuß, F; Ragwitz, M; Wietschel, M. (2003): Fluktuationen der Windenergie und deren Vorhersagbarkeit bei einem verstärkten Ausbau des Off-Shore Anteils in Deutschland bis 2020, Proceedings der IEWT, Vienna 2003,

Renewable Energy Sources Act (2004): Gesetz zum Vorrang erneuerbarer Energien,

RePast, the Recursive Porous Agent Simulation Toolkit: http://repast.sourceforge.net,

Tesfatsion, L. (2003): Agent-based computational economics. ISU Economics Working Paper No. 1