SIMULATING THE EXPANSION OF RENEWABLE ELECTRICITY GENERATION IN GERMANY- AN AGENT-BASED APPROACH-

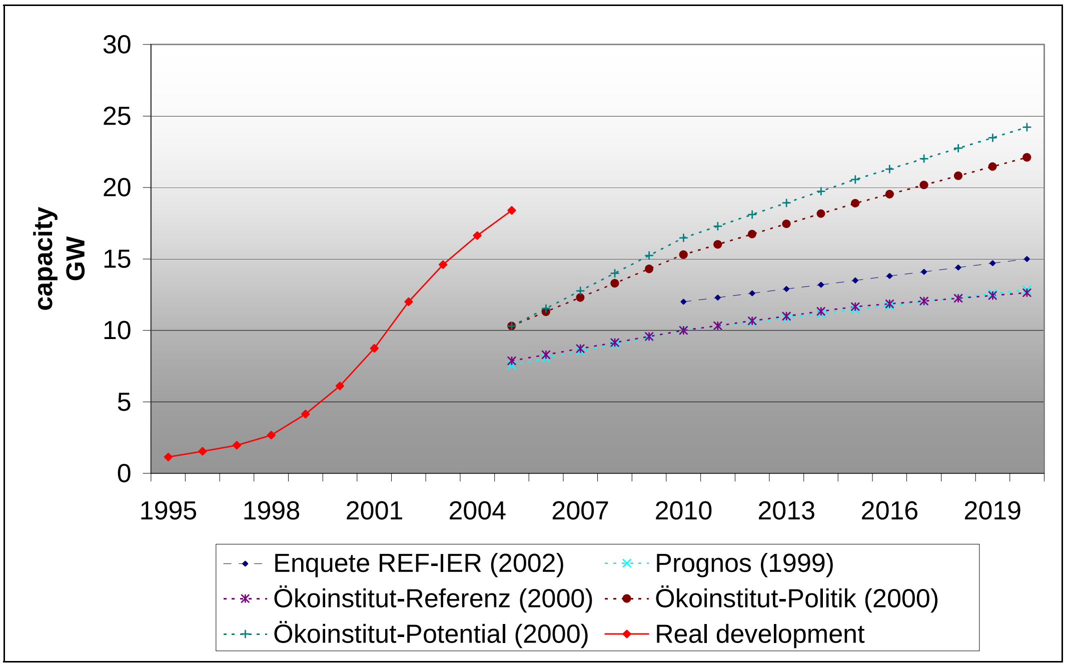
Frank SENSFUSS, Mario RAGWITZ, Massimo GENOESE
Fraunhofer-Institute for Systems and Innovation Research, Breslauer Straße 48, 76139 Karlsruhe, Deutschland
Frank.Sensfuss@isi.fraunhofer.de

The German support for renewable electricity generation has lead to a very dynamic growth of the installed capacity. This paper presents a new approach to the simulation of the development of renewable electricity generation which is based on the concept of agent-based simulation. In a case study a first version of the developed simulation platform is applied to analyse the impact of soft loans on the development of wind energy in Germany.

1 Introduction

The German support scheme for electricity generation based on renewable energy sources has lead to a considerable increase of renewable electricity generation in Germany. The most remarkable example of the success of the German support is the development of wind energy with an increase of the installed capacity from 110 MW in 1990 to 18400 MW in 2005 (Deutsches Windenergie Institut [DEWI], 2006). But the dynamic development of wind energy in Germany also showed considerable weaknesses in the scientific capability to produce reliable projections on the future development of the installed capacity. Even optimistic projections for the development have been overtaken by the real development within one or two years. Due to the dynamic growth of wind energy the actual development of the installed capacity has often been underestimated. A comparison of the real development and the projections of different studies is given in Figure 1.

Figure 1 Different projections for the development of wind energy



(Sources: Prognos, 1999; Ökoinstitut, 2000; Enquete, 2002)

So the central question is why these studies failed to provide an adequate projection of the development of wind energy. Most projections are based on expert judgement of the likely future potential of wind energy. The linear shape of most projections is in strong contrast to the exponential growth seen in the past. In addition to their weak projections this methodology also fails to provide insights into the impact of different support policies on the actual development of wind energy. Are there any other methods available which can provide better information for policy makers? The most common modelling tools used in energy related studies are optimisation models. However, conventional linear optimisation models or even hybrid models such as the Canadian Integrated Modelling System [CIMS] are not suited to produce reliable results concerning the development of renewable electricity generation (Sensfuß, 2004). In the case of the electricity sector these models calculate an optimal power plant portfolio with a given development of electricity demand and other restrictions such as CO_2 emission budgets. Why do these models fail to provide an adequate picture of renewable electricity generation? The central weakness of the given approach is that the optimisation routine assumes that conventional power plant capacity and renewable electricity generation capacity compete on the same market for generation capacity. There are several reasons why this assumption is not adequate. First of all renewable electricity generation in Germany is evolving based on a guaranteed feed in tariff. Apart form technical issues there is no risk concerning the future income. Since risk is also related to the required rate of return the required rate of return for renewable investment is lower than for conventional power plants which are exposed to various risks such as fuel prices, electricity prices and "contract coverage". Based on the given information one could argue that an optimisation model with plant specific interest rate and the possibility to integrate the cash flows of the support scheme could do the job. But the central problem remains that the market for conventional power plant capacity and renewable capacity are entirely different markets. Due to the guaranteed feed-in tariff the renewable electricity generation capacity evolves independently of the development of the conventional power plant portfolio as long as technical restrictions such as available grid capacity are not reached. Consequently it is not adequate to compare the cash value of an investment into gas combined cycle power plants and a wind turbine. As long as the cash value of an investment into a wind turbine is positive it is likely to be realized, if it is not hindered by other issues such as authorization, independently of the cash value of an investment into a gas combined cycle unit. Another issue which has to be taken into account is that the group of investors can be different in the case of renewable energy. This is especially apparent in the case of the development of photovoltaic. Although photovoltaic is not very attractive from an investor's perspective even with the considerable support of the German feed-in system and soft loans with a reduced interest rate it is a fast growing market reaching a total of 1400 MW installed capacity in the year 2005.

Since the development of renewable electricity generation in Germany has reached a considerable volume and with offshore technology there is another technology with huge potential ready to take off it seems to be necessary to consider new approaches to provide adequate estimations of the future development of renewable electricity generation to policy makers and utilities. These new approaches should also be capable to show the impact of different support schemes on the actual development.

The findings stated above argue for separate modelling approaches to the simulation of renewable capacity expansion by taking the investor's perspective into account. One example of a new model developed especially for the simulation of renewable electricity generation is the Green X model. It is a simulation with an algorithm seeking to minimize the cost connected with the achievement of a given renewable electricity generation target. Thereby demand side measures and technology specific investment characteristics are taken into account (Huber et al., 2004).

This paper presents an agent-based approach to the simulation of renewable electricity generation. The development module is part of an agent-based simulation platform seeking to simulate the German electricity markets. The integration into the larger agent-based simulation platform provides the opportunity to analyse different support schemes such as certificate systems and the impact of different developments of renewable electricity generation on the electricity markets. After a short discussion of the methodology of agent-based simulation the model environment is described. Chapter four discusses the module developed for the simulation of investments in renewable generation capacity. In chapter five the developed model is applied to the analysis of the impact of soft loans on the development in Germany. In the last Chapter the main findings are summarized and conclusions are drawn.

2 Methodology

This paper presents an agent-based approach to the simulation of renewable electricity generation. 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 (Wooldridge, 2002). 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, 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).

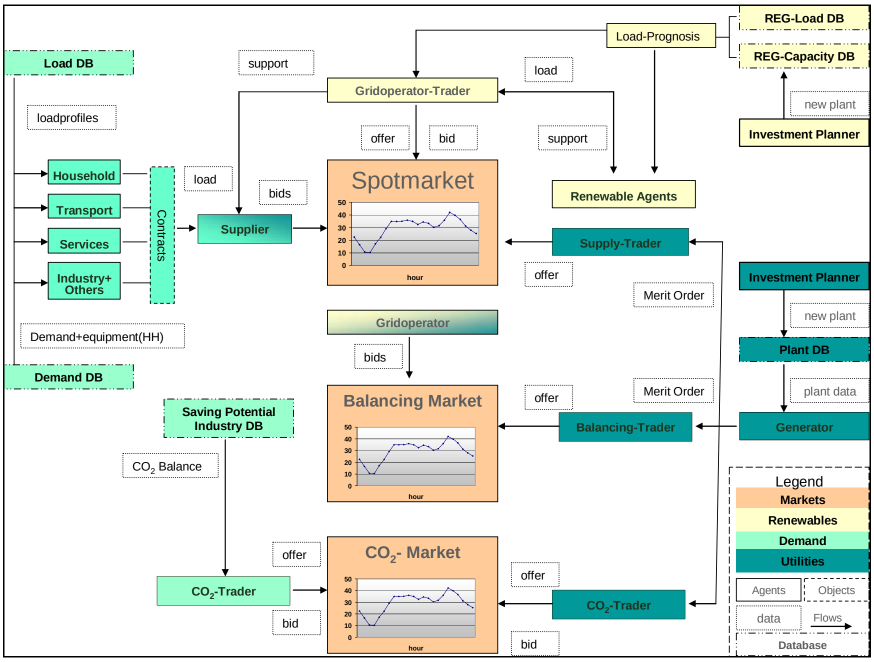
3 Model Environment

The developed module dealing with the expansion of renewable electricity generation is part of an agent-based simulation platform seeking to simulate the German electricity sector and its markets. Since renewable investment decisions are also influenced by market prices the different modules of the PowerACE simulation platform are described in the next section. The module which is developed for the simulation of investments into renewable electricity generation is described in section four.

3.1 Overview

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_2-emssions. Since the goal of this paper is to analyse the investment into renewable electricity generation the balancing power market and the market for CO_2 emissions are deactivated. An overview of the main agents involved in the simulation is given in Figure 2. 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. This chapter concludes with an overview of the timescales of processes within the model.

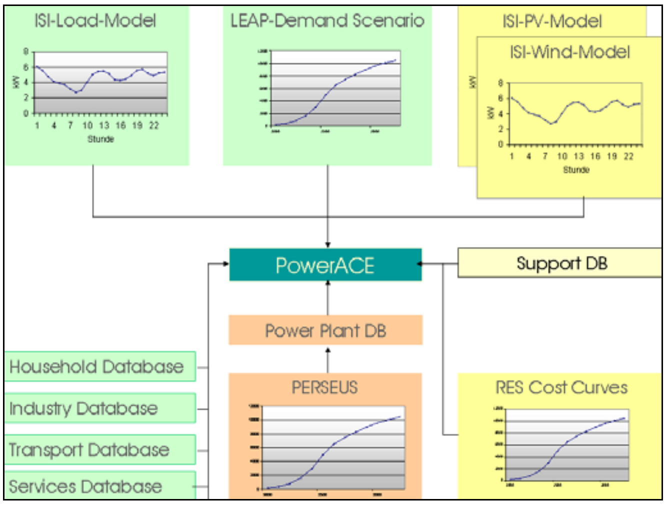
Figure 2 Structure of PowerACE



3.2 Provision of adequate data by soft-links to fundamental models

This model seeks to simulate realistic spot market prices in order to provide an adequate basis for the analysis of renewable capacity development. 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 3. 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, 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 is information on company size, household size and household equipment levels in terms of electric appliances.

Figure 3 Models and databases linked to the PowerACE simulation platform



3.3 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.

3.4 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_2 emissions, which can be balanced by the generator-agents. Certificates needed for these emissions can be traded through the CO_2-Trader at the CO_2-emissions market. The prices of this market change the merit order of power plants (with the beginning of the emission trading in 2005). Another participant in this market is the CO_2 saving potential of the industry. In the given simulation the CO_2 market is deactivated in order to simplify the analysis. A more detailed analyis of the CO_2-savings of renewable electricity generation with the help of PowerACE can be found in Genoese et al. (Genoese et al., 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.

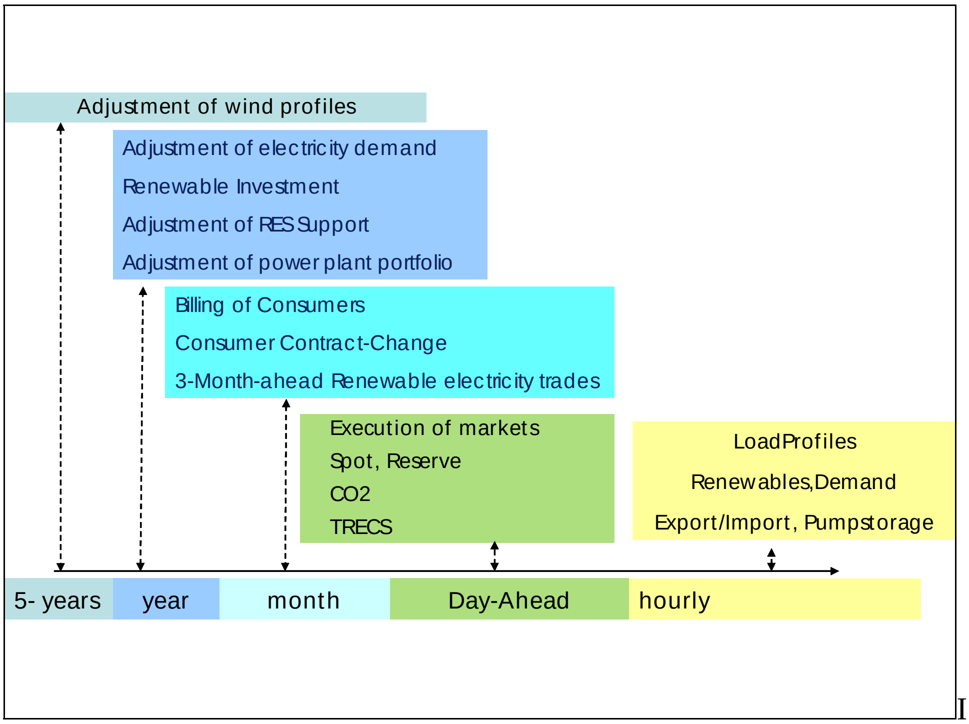
3.5 Simulation of renewable electricity generation

Renewable electricity generation plays a growing role in the German electricity sector. According to the Renewable Energy Sources Act (EEG 2004) the electricity generated from renewable energy sources has to be bought by grid operators at guaranteed feed-in tariffs. The renewable electricity is brought into the market by selling 3-months-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.

3.6 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 4 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_2) takes place on daily level but the spot market allows to place bids for single hours. A more detailed description of the simulation of the German spot market in PowerACE can be found in (Sensfuß and Genoese, 2006).Once per month the consumer-agents are billed and the consumer-agents can change their contract. Every three 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.

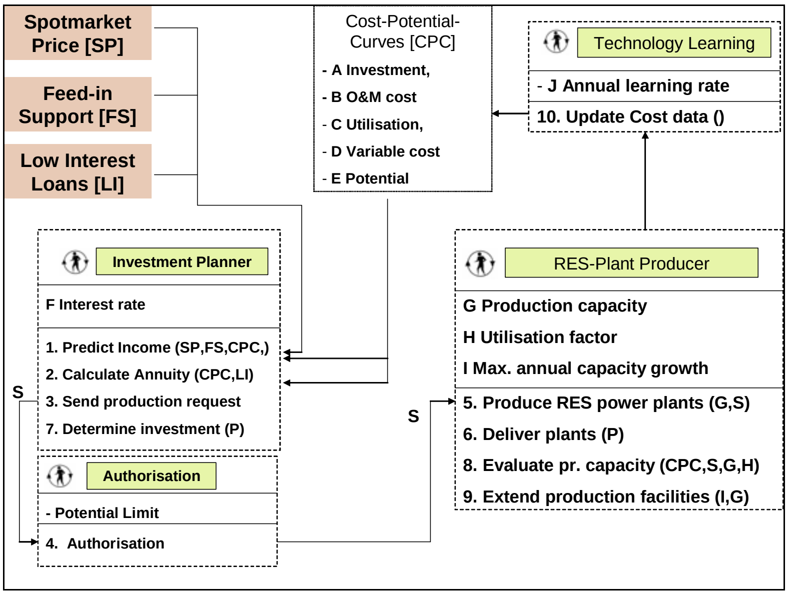
Figure 4 Timescales of the PowerACE simulation



4 The renewable investment module

A central basis for the simulation is a detailed database on cost potential curves of renewable electricity generation technologies in Germany. An overview of the structure of the developed model is given in Figure 5.

Figure 5 Structure of the developed simulation platform



Major players in the given simulation platform are an investment planner which determines the expected income of renewable investment options based on the available potential, the required interest rate and the available support. Based on this information a production request is generated which contains all investment options with a positive annuity. An important parameter for the investment planner is the applied interest rate for the calculation. Based on recent studies and work carried out and a study presented by Held (Held et al., 2005) an interest rate of 6.6% % is assumed for the German feed-in system. Since the German feed-in system is based on nominal support values the impact of inflation has to be taken into account. Based on an analysis of the development of inflation over the past 50 years an inflation rate of 2% is assumed (Sensfuß, 2004).

The Renewable Energy Source-plant producer builds new renewable power plants according to the available production capacity. Requests exceeding the production capacity are not fulfilled. If the requests for new plants exceed the production capacity the plant producer considers to build new production facilities based on the remaining potential for the renewable technology and its own requirements concerning the expected utilisation of new plants. The expansion of production facilities is also limited by a maximum value representing the real world restrictions to the expansion of production facilities. In the case of wind energy the maximum extension of production facilities is limited to 760 MW per year. Thereby the RES-Plant producer of the simulation is used as an aggregate for all the planning and construction capability of a country needed to carry out projects for the construction and operation of renewable power plants. Interaction with construction and planning capabilities of neighbouring countries are not taken into account in the current version of the model.

Two smaller modules seek to integrate the aspect of technology learning and the dampening effect of planning and authorisation procedures. The module for technology-learning simulates the impact by adjusting the cost of renewable power plants by an annual reduction factor of 1.5% reflecting the average annual cost reduction presumed in the Renewable Energy Source Act. In principal a technology learning based on learning curves could also be integrated, but the additional benefit is questionable as the model only simulates the German development. An adequate picture of the learning effects would require a lot of external learning which can only be integrated as external input parameter. The authorisation module reflects the dampening if the installed capacity gets close to the limitations of the available technological potential. In reality it gets increasingly difficult to utilize to the remaining potential if a large part of the generation potential is already utilised. Authorisation procedures last longer and it is more difficult to discover places which are e.g. suitable for wind power plants. In the given version this aspect is integrated by two factors. The first factor determines the possible utilisation of the generation potential which can take place without the dampening effect. The second parameter determines the actual dampening effect in terms of the production effect sent by the investment planner. Both parameters are determined in a calibration procedure.

5 Case Study

In a case study the model is applied to analyse the impact of soft loans with reduced interest rates on the development of onshore wind energy in Germany. The importance of the availability of soft loans for the development of renewable electricity generation is rarely discussed. However, an analysis of the past development shows that a considerable amount of the investment into wind energy has been financed with the help of soft loans. In 2003 ca. 81 % of the capital needed for the construction of new wind energy has been financed by soft loans of the German “KfW promotional bank” (KfW, 2005 found in Held, 2005). In the next section details of the calibration of the model are discussed. Thereafter the results are presented.

5.1 Input parameters and calibration of the model

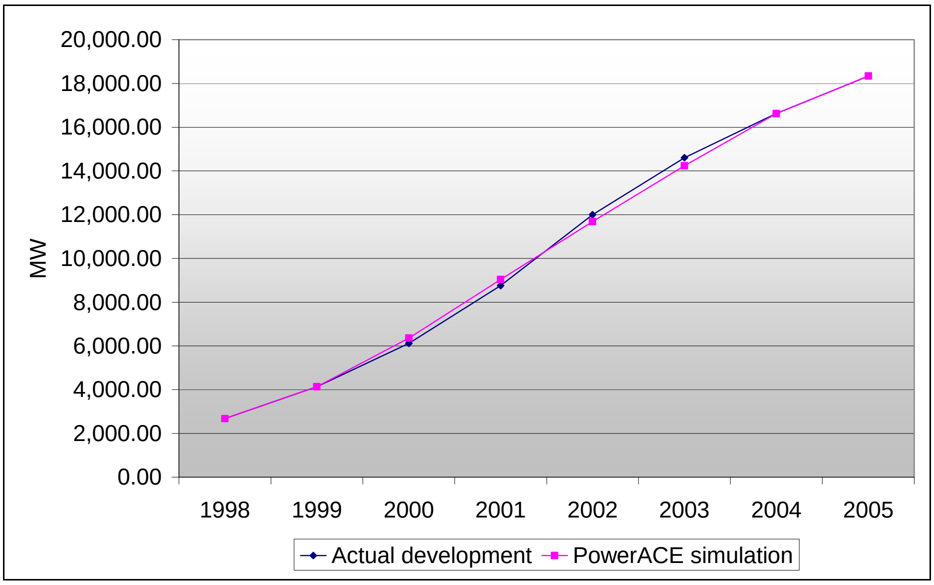
In order to be able to utilize the model for the given task the most important input parameters for the agents involved in the simulation have to be determined. The interest rate of soft loans is assumed to be 4.40 % in accordance with information provided by the KfW-bank. An overview of the parameters of the investment planner is given Figure 6

Figure 6 Parameters of the agent "Investment-planner"

Investment Planner	Value	Source
Required interest rate	6.60%	(Held, 2005)
Inflation	2.00%	(Sensfuss, 2004)
Interest rate of soft loans	4.40%	(KFW, 2005 b)
Share of soft loans	0/81%	(Held, 2005; KfW, 2005a)

The next step is to determine the parameters of the plant producer agent. The capability of the sector to realize new wind projects in the year 1998 is assumed to be 1466 MW in compliance with the new installations of the given year. The maximum possible extension of plant production facilities is assumed to be 760 MW which represents the maximum growth of new installed wind capacity in the period 1990-2005. The required utilisation ratio of new production facilities and remaining potential is determined by a calibration run. In order to calibrate the model the development of wind energy between the period 1998 and 2005 is simulated. This period is selected due to the relatively stable support conditions in this period. All free parameters are adjusted until the simulated development is close to the real development in the given period. An overview is given in Figure 7. The calibration to the period between 1998 and 2005 shows a maximum deviation between the real development and the simulated development of the installed capacity of 370 MW.

Figure 7 Calibration of the simulation



Based on this calibration the required utilisation of new production facilities is assumed to be seven years. An overview of the parameters of the simulation is given in Figure 8.

Figure 8 Parameters of the agent „Plant producer"

Plant Producer	Value	Unit	Source
Initial production capacity	1466	MW	Value of the year 1998
Maximum capacity extension per year	760	MW	Maximum extension seen in the past
Required utilisation of new production facilities	7	years	Calibration

Another important agent within the simulation is the authorisation agent. The parameters of this agent are determined by the calibration run. The potential limit after which authorisation procedures dampen further growth is set to 70%. When this limit is reached all production request sent by the investment planner is damped by the growth-damper-factor of 50%. An overview of the parameters is given in Figure 9.

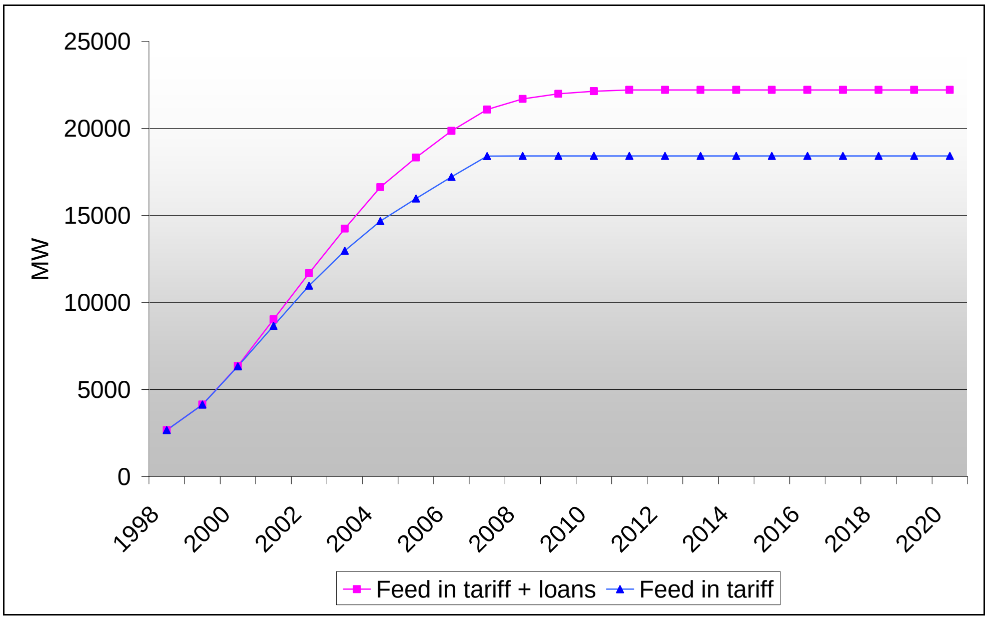
Figure 9 Parameters of the agent „Authorisation“

Authorisation	Value	Source
Potential limit	70%	Calibration
Growth-damper factor	50%	Calibration

5.2 Results

In order to analyse the impact of loans with reduced interest rates provided by the German “KfW promotional bank” is analysed by running the model with feed-in support and a share of soft loans of 81%. In a next step the model is run without soft loans. A comparison of both simulation runs is given in Figure 10.

Figure 10 Simulation results



The results of the simulation run show the considerable impact of the availability of soft loans on the simulated development of wind energy in Germany. After 2002 both simulation runs differ considerably in the development of the installed capacity. At the end of the simulation period the difference between the installed capacities reaches 3800 MW. While the development without soft loans stops at 18.4 GW the development with soft loans reaches 22.2 GW installed capacity. These results underline the importance of the availability of these loans. In addition it has to be taken into account that the availability of low interest loans also helps to attract the additional private capital needed for the investments, an effect which is not yet covered in the simulation. These results might provide some insights for the support of the beginning development of the offshore wind energy in Germany which struggles to take off. Since the offshore wind energy incorporates more technical risks it could be valuable to provide additional support by soft loans in order to attract the necessary private capital.

6 Conclusions

This paper presents a first version of an agent-based approach to the simulation of the expansion of renewable electricity generation in Germany. Although the first version of the model is rather simple it can successfully be calibrated to reproduce the development of wind energy in the period 1998-2005. The described case study on the future development of wind energy with different support conditions shows the considerable impact of the availability of low interest rate loans on the actual development. However, the presented model represents work in progress. Future work will be directed to a better validation of parameters and a more detailed representation of investment decisions. But it has to be taken into account that a detailed agent-based simulation of player decisions requires extensive empirical data which may not be available in many cases. The goal is to develop a simulation platform which can be used to assess the impact of different support schemes on the development of renewable electricity generation. Thereby the impact of a green certificate system and the linkages of renewables to the "conventional" electricity sector and its markets play a major role. The first results presented in this paper show that the selected approach seems to be promising in order to get new insights into the model-based analysis of support policies.

References

Deutsches Windenergie Institut [DEWI] (2006): *Aufstellungszahlen der Windenergienutzung in Deutschland*. http://www.dewi.de/. downloaded 6.3.2006

Drogoul, A.; Vanbergue, D.; Meurisse, T. (2002): *Multi-Agent Based Simulation: Where are the Agents ?* Proceedings of MABS'02 (Multi-Agent Based Simulation, Bologna, Italy, July 2002), LNCS, Springer-Verlag.

Enquete Kommission: Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und der Liberalisierung, (2002) :*Endbericht.* http://www.bundestag.de/gremien/ener/schlussbericht /index.htm download 17.12.02

E.ON (2005): *E.ON Windreport*. http://www.eon-avacon.com/ContentFiles/Internet/ Downloads/E.ON_Netz_Windreport_2005.pdf. downloaded 15.1.2006

Genoese, M., F. Sensfuß, A. Weidlich, D. Möst and O. Rentz (2005): *Development of an agent-based model to analyse the effect of renewable energy on electricity markets*, in: Proceedings of the 19th Conference "Informatics for Environmental Protection" (EnviroInfo). Brno.

Held, A.; Ragwitz, M.; Wietschel, M. (2005): *Evaluation of renewable promotion schemes in the European electricity market.*

Held, A. (2005): *Evaluation von Politikinstrumenten zur Förderung erneuerbarer Energieträger im europäischen Elektrizitätsbinnenmarkt.* Diploma thesis. University Karlsruhe.

Huber, C.; Faber, T.; Hass, R.; Ragwitz, M.; Resch, G. (2004): *Deriving optimal promotion strategies of RES-E in a dynamic European electricity market: The toolbox Green-X.*

Klobasa, M.; Ragwitz, M. (2005): *Simulation der Windeinspeisung in Deutschland und Rückwirkungen auf den Kraftwerksbetrieb*. Wien, Österreich.

Kreditanstalt für Wiederaufbau [KfW] (2005a: *Vergebene Kredite an die Windindustrie in 2003-Gesamtsumme in €.* Information by email 20.01.2005.

Kreditanstalt für Wiederaufbau [KfW] (2005b: *Konditionenübersicht für Investitionskreditprogramme*. http://www.kfw-formularsammlung.de/konditionen/konditionentabelle8.pdf. download 27.02.2004

Möst, D.; Genoese, M.; Rentz, O. (2005): Sensitivitätsanalyse der CO_2 Emissionen im Elektrizitätssektor bei Gas- und Zertifikatspreisvariationen. In: Zeitschrift für Energiewirtschaft, 05 (4), pp. 301-312.

Müller, M. (2005): *Agentenbasierte Modellierung der Privathaushalte im Elektrizitätsmarkt*, Diploma thesis, Universität Karlsruhe.

Öko-Institut (2000): *Energiewende 2020: Der Weg in eine zukunftsfähige Energiewirtschaft*. http://www.oeko.de/bereiche/energie/ docments/ energiewende2020.pdf vom 10.12.02

Prognos AG (1999):*Die längerfristige Entwicklung der Energiemärkte im Zeichen von Wettbewerb und Umwelt.* Schaeffer-Poeschel Verlag, Stuttgart

Sensfuß, F. (2003): *Entwicklung einer Prognose des Lastprofils der Stromeinspeisung erneuerbarer Energien bis 2020,* Praxisarbeit, University of Flensburg.

Sensfuß, F. (2004): *Adapting the Canadian Integrated Modelling System (CIMS) for the simulation of green house gas reduction policies in the German electricity sector,* Diploma thesis, Universität Flensburg, University of Southern Denmark.

Sensfuß, F; Genoese, M. (2006): *Agent-based simulation of the German electricity markets-An analysis of the German spot market prices in the year 2001- Proceedings of the "Symposium Energieinnovationen", Graz, 2006*

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 IEWT, Vienna 2003.

Wooldridge, M. (2002): *An Introduction to MultiAgent Systems*,John Wiley & Sons, Chichester.

Wooldridge, M.; Jennings, N. R. (1995): Intelligent Agents: Theory and Practice. In: Knowledge Engineering Review, 10 (2), pp. 115-152.