AN AGENT-BASED SIMULATION MODEL FOR THE ANALYSIS OF MARKET INTEGRATION OF RENEWABLE ENERGY FOR THE GERMAN ELECTRICITY MARKET

Topic: Competition and Investment in Electricity Markets

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Overview

To further ensure a successful integration of renewable energies, technical, financial and organizational aspects of the electricity system have to be redesigned. A main challenge lies in the alignment of generation and demand of energy due to the fluctuating character of renewables. Several possibilities are being discussed to align this imbalance. One possibility is the market integration of renewables by linking the generation of renewable electricity to the price signals of the energy exchange markets. In the year 2012 the German government introduced the market premium for supporting the direct marketing of electricity from renewable energies. The AMIRIS agent-based simulation model allows testing and analysing the impacts of the market premium on the involved market actors (e.g. renewable power plant operators and direct marketers) on the micro level as well as effects on the macro level (energy exchange prices and market structure) of the energy market system.

Motivation

In order to create well defined and reliable political guidelines and regulatory frameworks, it is essential to analyse the market players. Their motivation, strategies and course of action relating to discussed adaptions as well as the impact of their action on the whole market system has to be understood.

For the analysis of complex and multiple linked systems with autonomous actors agent-based models - originating from the research field of artificial intelligence - are particularly suitable [1]. The development of the agent-based simulation model AMIRIS[2] allows to examine the impact of support instruments and changes in the regulatory framework for the integration of renewable energies on the market actors and the market system of renewable energies. The AMIRIS model considers decisions of actors as well as the adaption of their behaviour [2]. Therefore, a reasonable simulation requires an elaborate analysis of relevant

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[2] AMIRIS - Agent-based Model for the Integration of Renewables Into the energy System

actors. This analysis has been carried out with qualitative methods from social science, led by theoretical assumptions of the sociological Neo-Institutionalism [3].

With the help of document analysis and semi-structured interviews with representatives of the relevant actor groups first propositions were formulated. The focus has been set on how various regulation mechanisms would influence actors' goals, strategies and options. The collected propositions and statements were finally discussed and modified in an expert workshop. Further, these results were translated into a formalised model language and implemented into the AMIRIS model, using the simulation platform Repast Simphony 2.0.

Agent-based Modelling and Simulation

For the investigation of complex network systems the approach of multi-agent modelling and simulation is frequently used. In such economic systems the system as a whole follows an evolutionary path. In this it differs significantly from the usual assumption of the omniscient, utility-maximizing individuals of neoclassical economics that result in a series of general equilibriums [4]. The system behaviour in agent modelling results from the behaviour of individual agents - called actors in the real world - and is not centrally determined and controlled.

The agents are situated in and influenced by a dynamic environment, which is simultaneously shape through the actions of the agents - thus creating a complex structure with feedback loops. These heterogeneous agents are modelled having individual states, actions and goals. By implementing tactics and strategies it is also possible to model long-term action strategies. Agents can further be set up having the ability to communicate and cooperate with each other [5], [6]. In addition, the agents can be implemented with learning algorithms [7]. This enables them to improve over the course of simulation by gaining knowledge and, therefore, changing their basis of decision-making.

Agent based approaches to analyse market mechanisms are getting more and more popular in economics. But existing agent based models of the energy sector either focus on the market mechanisms of conventional power systems and electricity markets [8], [9] on certain aspects of the market design of the wholesale market [10], [11], [12], on the evaluation of specific bidding strategies and decision rules [13], [14], [15], or - when dealing with RES - only on market processes, i.e. the influence of the increasing share of renewables on the market price [16]. No one so far has tried to set up an agent based simulation model in order to analyse the policy framework of energy markets and its effect on the actors involved in the process of market integration of RES.

Actor Analysis

In order to set-up the agent based simulation model an actor analysis of the relevant actors was conducted. At its starting point the analysis took assumptions derived from the sociological theory of strategic action fields, as well as concepts from neo-institutionalism of organisational sociology. The theory of strategic action fields [3] offers a specific viewpoint by interpreting activities related to direct marketing as the attempt of competing actors to

shape and design a specific field of action as a new market. Such a new, emergent field typically consists of three types of actors: incumbent actors, challengers, and governance units. In order to understand the competing interests and identities of the respective actors, it could be referred to neo-institutionalist organisational theories. Seen from this perspective, formal institutions, actors, and routines are mutually constitutive and influence each other. In order to understand the behaviour of economic actors, sociological concepts have developed alternative approaches to the typical neo-classical understanding of actors as 'homo economicus'. Typically economic actors' behaviour is efficiency-oriented, but is nevertheless also led by external expectations and sometimes non-economic requests, and is thus shaped by dominant institutions in the specific organisational field [17]. For this reason, different actors from differing backgrounds and environments develop different strategies with regard to goals, as well as with regard to those strategies and measures required to reach their specific goals. For example the actions of new firms with close links to the environmental scene differ from large utility companies traditionally used to centralised structures.
Those general theory-led assumptions and propositions were substantiated according to the objectives, strategies and interaction patterns of the different actors in the new action field of direct marketing. Then they were developed further on the back of document analysis and expert interviews. The assumptions were then tested and reassessed in interviews with representatives from the most important actor-groups, as well as in the context of an actor workshop.
The actor analysis was complemented by further research data relating to trends, forecasts, and price developments. Furthermore assumptions on technological developments according to efficiency or the relevance of new energy technologies were taken into consideration. Finally propositions were formulated on how different actors would react to the new regulatory framework, which actors would profit from the new regulatory incentives, and which would be negatively affected.
In a last step all these results were translated into a formalised model language in order to be integrated into the simulation model AMIRIS.

The AMIRIS Model

The actual structure of the model is shown in Figure 1: Plant operators are characterized by technology - wind, photovoltaic (PV), bio mass -, and the renewable energy FIT remuneration class (RC) as shown in table 1 as well the kind of property ownership (private person, farmer, funds, municipal utilities, utilities, industry/ business).

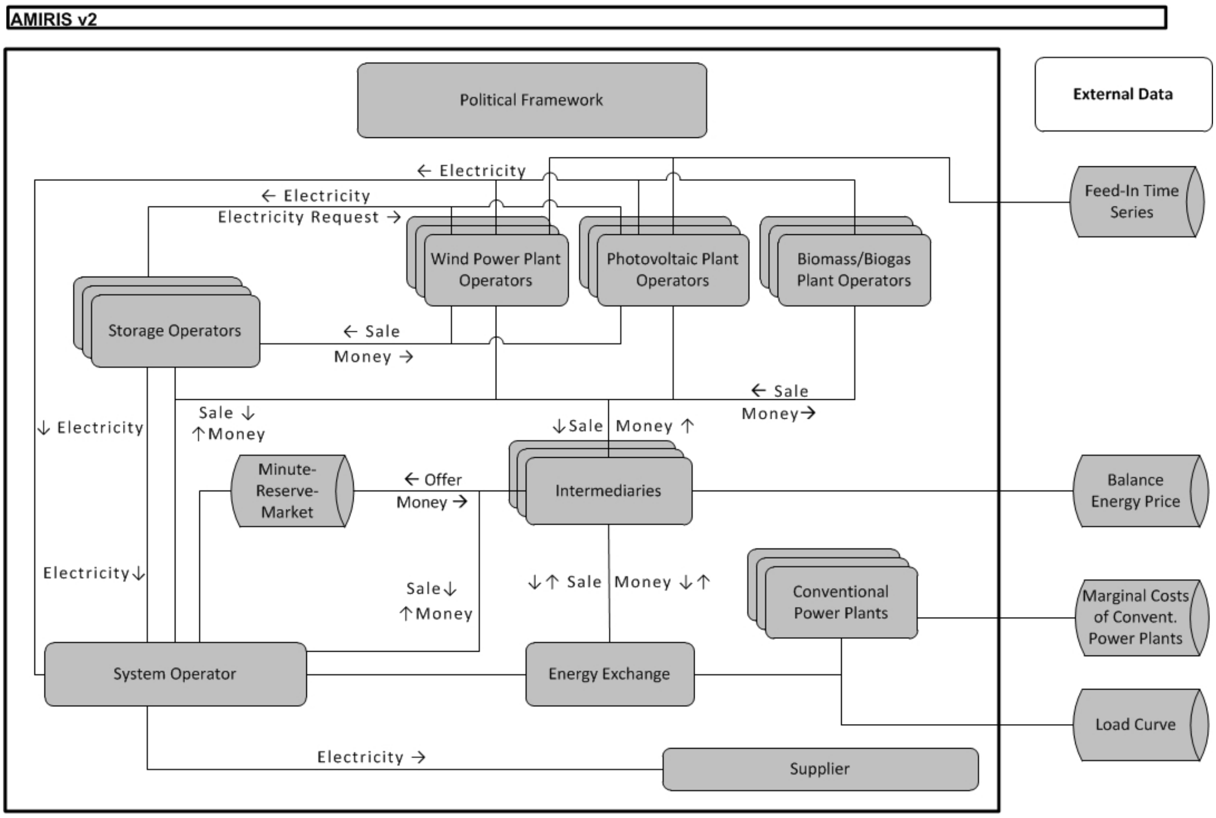

Figure 1 Structure of the AMIRIS model

	Wind (WAB)	PV (PvAB)	Biomass (BmAB)
RC 1	basic FIT	Roof-top < 30 kW, since 2012 < 10 kW	Solid biomass 5-20 MW (matured wood, forest residues)
RC 2	Starting FIT (low average)	Roof-top 30-1000 kW, since 2012 10-1000 kW	wood gasification
RC 3	Starting FIT (high average)	Roof-top > 1000 kW	Biogas 50-350 kW (liquid manure und re-growing resources)
RC 4	Offshore	Conversion and Open space	Biogas > 350 kW (liquid manure, re-growing resources, organic waste)

Table 1: Types of power plant operators in the AMIRIS Modell

They can act in a passive and an active way. Plant operators following the passive way do not participate in direct marketing but sell the generated electricity to the distribution system operator and receive the defined feed in tariff (FIT). The ones acting actively sign a contract with an intermediary (direct marketer) in order to take advantages of the introduced optional market premium. The intermediaries will pay a bonus “X” on top of the FIT; otherwise there would be no incentive to opt for direct marketing. To compensate for the expanses the intermediaries have trough their direct marketing activity, they receive a ‘Management Premium’, which is part of the optional Market Premium support scheme introduced by the German government in January 2012. Regarding to the height of the management premium - which is decrease by law over the years - and their financial success in each accounting year, the intermediaries adjust the bonus paid to the power plant operators.

The analysis of actors revealed, that nine specific intermediaries are to be considered, that use the market premium model as shown in table 2:

	Prototype	Capital resources (million €)	Market premium	Tariff	Output Forecast quality	Price Forecast quality
(1)	**Big national utility**	**100**	**2012**	**FIT+X**	**Good**	**Good**
(2)	**International utility**	**15**	**2012**	**FIT+X**	**Good**	**Good**
(3)	**Big municipal utility**	**15**	**2012**	**FIT+X**	**Medium**	**Good**
(4)	**Municipal utility “Pionier”**	**15**	**2012**	**FIT+X**	**Good**	**Good**
(5)	**Small municipal utility**	**7**	**2012**	**FIT+X**	**Bad**	**Bad**
(6)	**Green electricity trader for households**	**7**	**2012**	**FIT+X**	**Good**	**Medium**
(7)	**Green electricity trader for business/industry**	**7**	**2012**	**FIT+X**	**Good**	**Medium**
(8)	**Specialized intermediary with experience**	**3**	**2012**	**FIT+X**	**Good**	**Good**
(9)	**Specialized intermediary without experience**	**0,1**	**2012**	**FIT+X**	**Medium**	**Medium**

Table 2: Types of intermediaries (direct marketers) in the AMIRIS Modell

In addition, the intermediaries are allowed to offer capacity from biogas plants as minute reserve at the control reserve market. This way extra revenues can be obtained.

The initial compositions of the portfolios of the intermediaries are show in figure 2. Over the time of simulation the structure of the composition of each intermediary does not change, but the overall amount of capacity being in direct marketing increases.

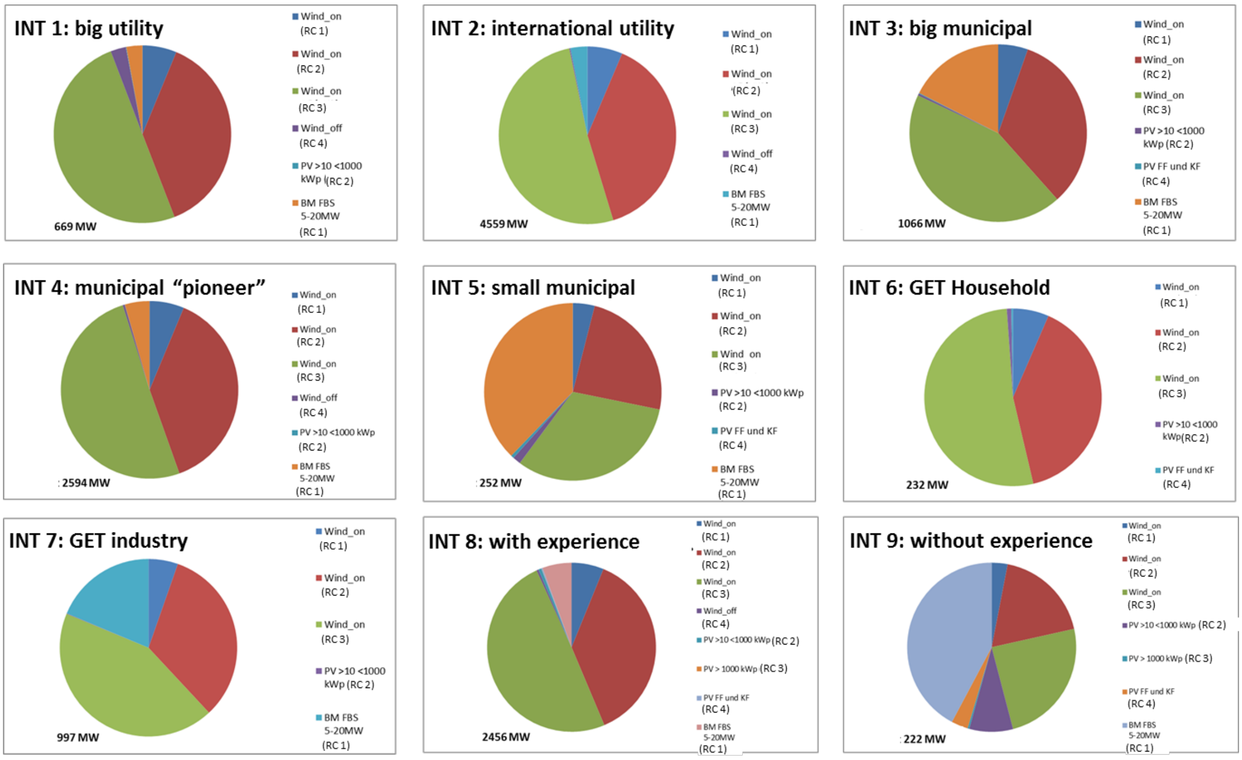

Figure 2: Initial composition of the portfolios of the intermediaries in AMIRIS.

The energy exchange prices are calculated on an hourly basis by a stylised merit-order model of the conventional generation system (nuclear, lignite, hard coal, GTCC and gas turbine). The minute reserve market prices are modelled by a regression model with residual load, wind and PV feed-in as independent variables.

Results

The AMIRIS model is a flexible tool for political consulting as simulations can be configured and parameterized in manifold ways. Among others, it is studied how factors like the quality of forecast, the portfolio composition, cost for profile services etc. affect the market position of intermediaries. Regarding plant operators, it is analyzed which remuneration class profit the most from direct marketing and if there are sufficient incentives to realize a more demand orientated feed-in of renewables. The simulations are run on an hourly basis.

Figure 3 shows overall operation profits[3] per accounting year for intermediaries taking part in direct marketing over the electricity exchange. The development of the overall profit is illustrated for the years 2012 to 2019 assuming a declining management premium (according to [18]). Especially these intermediaries profit from the floating market premium, that have experiences in direct marketing and related activities – mainly energy trading – and which signed contracts with onshore wind plant operators early (INT2/International Utility, INT4/First-Mover municipal utility an INT6/specialized direct marketer with experience). An

[3] The overall profits includes all income and expenses that are accumulated per accounting year and which are directly or indirectly related to direct marketing issues like income from marketing at stock market, income from market premium (floating premium and management premium), income from balancing market, payments to plant operators, expenses for the balancing energy, expenses for fix and variable business costs.

important factor for economic success is the quality of output forecast that directly influences the costs for balancing energy. The declining management premium (the decline was decided in 2012) affects smaller intermediaries with a lower quality forecast and smaller portfolio (INT3/big municipal utilities, INT5/small municipal utilities, INT10/new company without experience). Therefore a market concentration seems likely in the years after full degression (2015 onwards).

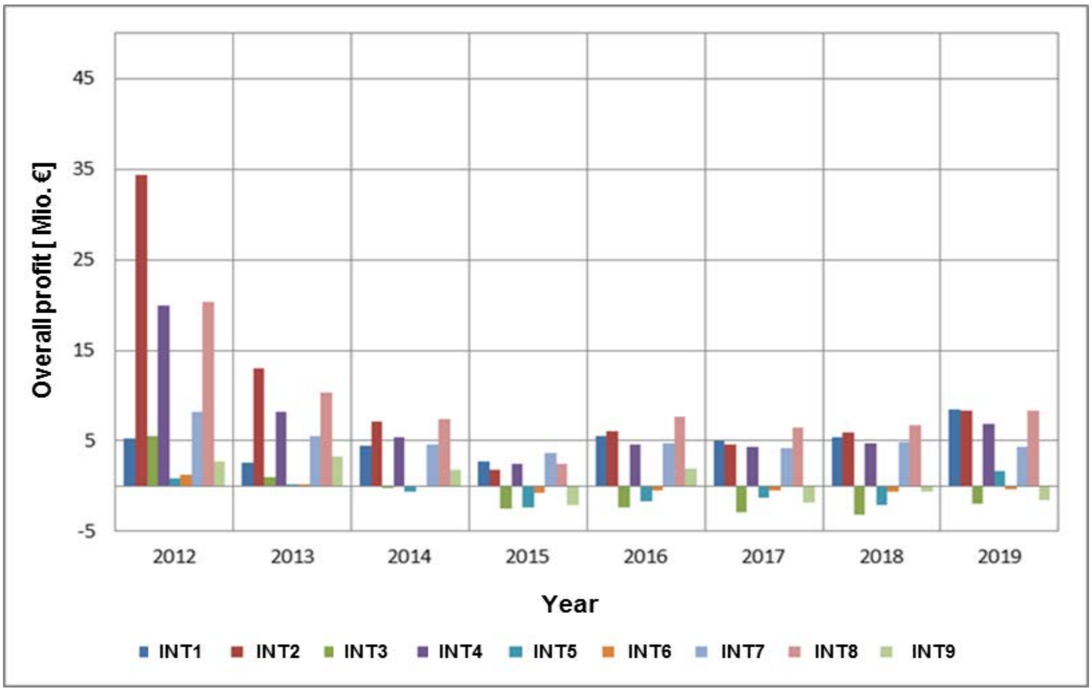

Figure 3 **Development of overall results for the years 2012 to 2019 for the intermediaries participating at the market premium.**

Concerning power plant operators, the wind power plant operators profit clearly from direct marketing and the market premium, as bonus payments of the intermediaries are high due to the relative high management premium for intermitted RES and compared to the corresponding feed-in-tariffs. On-shore power plants gain on average additional revenues of about 2,99 % - 3,35 % for the period between 2012 and 2019. Bio mass power plants, which are actually well suited for demand oriented supply due to their non-volatile feed-in, profit less compared to all other renewables and gain only 1,12 % regarding plants for solid fuels (BmAB1), 0,64 % regarding big biogas plants (BmB4), see figure 4.

It remains unclear, if a more flexible operation with a simplified day-night cycle[4] of the plants with solid biofuels (BmAB1) could generate enough profit in order to refinance investments in heat storage and additional generation capacity as these power plants are by law not allowed to receive the flexibility premium[5] compared to the biogas power plants (BmAB3 und BmAB4).

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[4] The day-night cycle assumes generation of electricity by one and a half times of the original capacity during daytime (8-20h) and semi capacity during nighttime (20-8h).

[5] The flexibility premium was introduced by the government in 2012 to incentivize the modification of inflexible biogas plants to a more demand orientated feed-in.

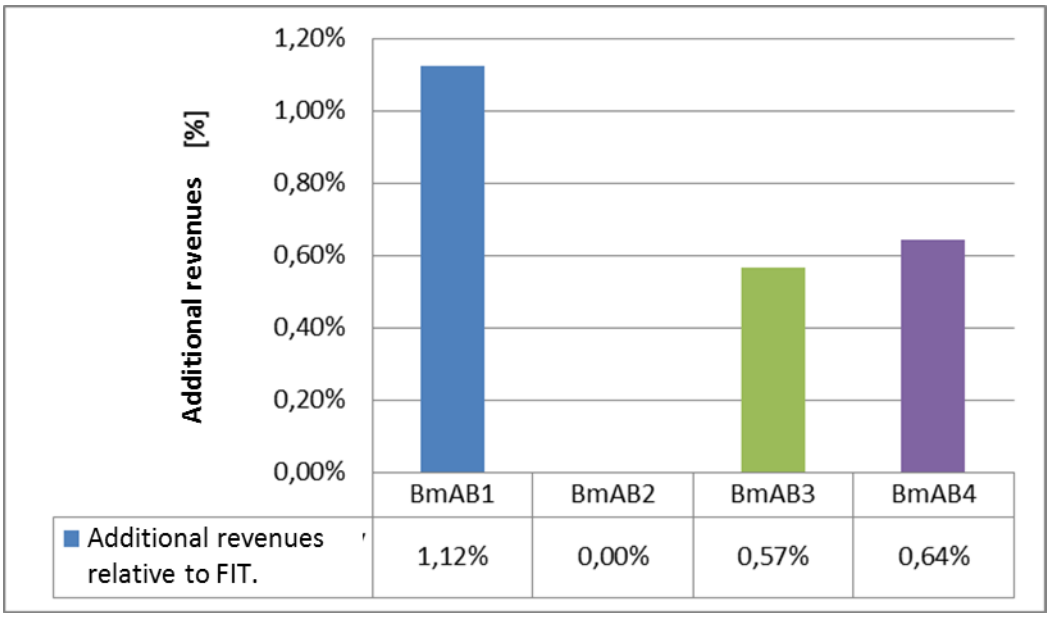

Figure 4 Additional revenues of biomass plants operators from participating at direct marketing compared to the EEG-fedd-in-tariff[6].

By taking part in the balancing power market, the direct marketing becomes lucrative for solid fuel plants (BmAB1) as well as for big biogas plants (BmAB4)[7]. The additional revenues compared to the EEG-feed-in-tariff are shown in figure 5.

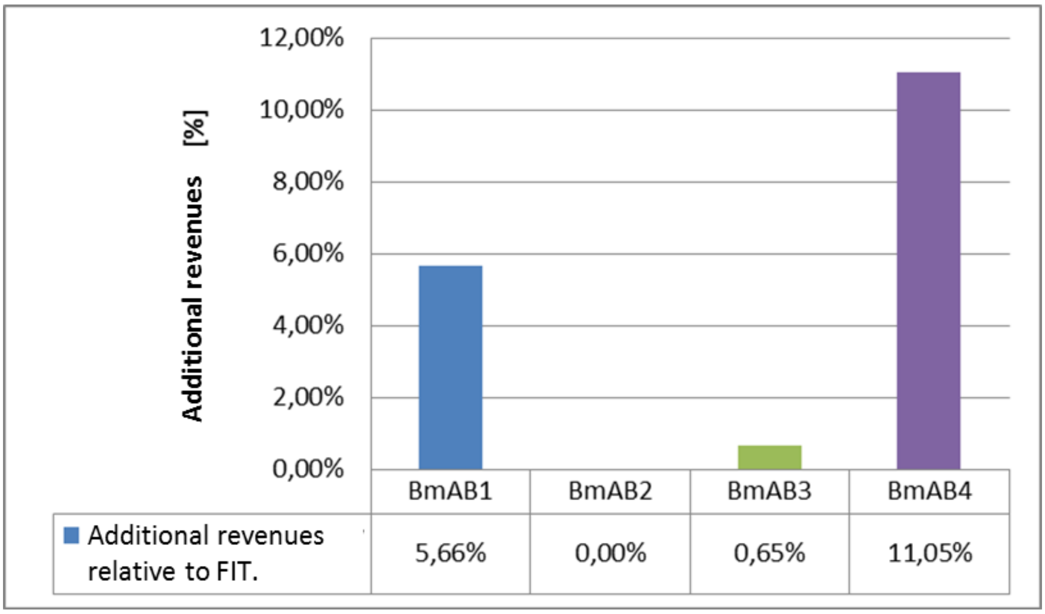

Figure 5 Additional receipts compared to the EEG-fedd-in-tariff for biomass plants operators from participating at direct marketing and balancing power market (negative minute reserve).

The importance of participating at the balancing power market is even raised by the expected degression of the relative market value of biomass plants, as can be seen in figure 6. Assuming an increase of the installed power of PV power plants, peak prices at noon will strongly decrease until 2020, so that the relative market value of biomass plants

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[6] Plants of wood gasifying (BmAB2) do not participate in direct marketing. Class BmAB3 represents small biogas plants.

[7] It is assumed that small biogas plants (BmAB3 < 350kW) do not take part in the minute reserve as they are too costly to handle for the intermediaries.

operating only a simplified day-night cycle falls below 100 %. This effect indicates the importance of considering interdependencies between the feed in of different renewables when analyzing market potentials.

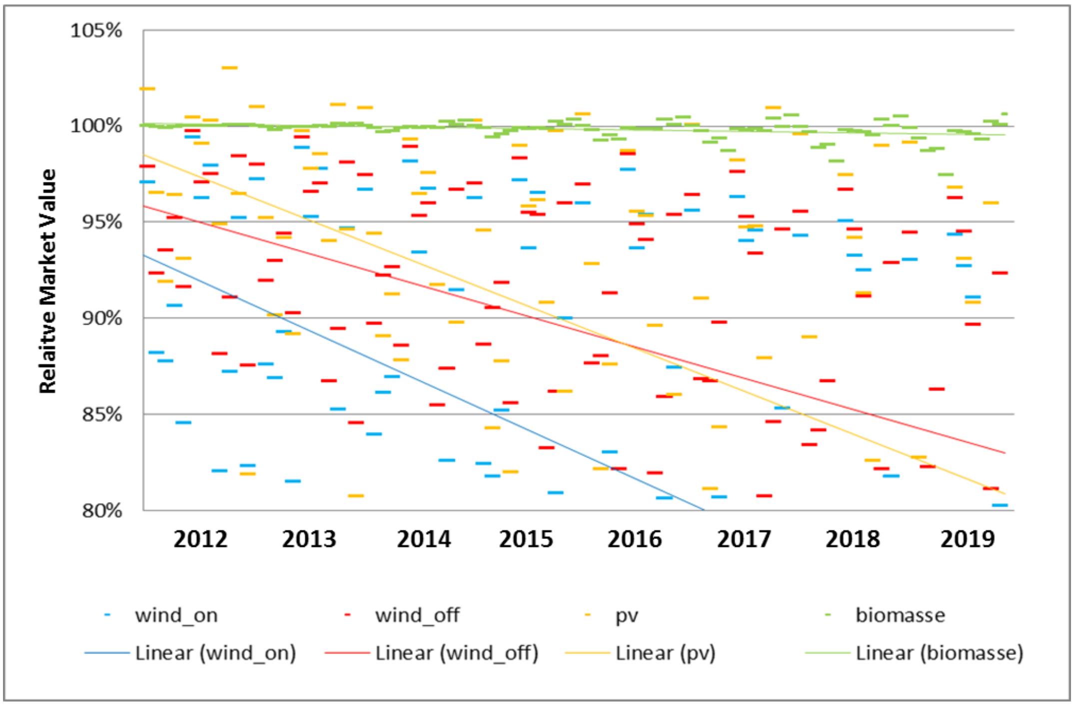

Figure 6 Development of relative market values of RES compared to Phealix base for the years 2012-2019.

An unscheduled degression of the management premium was introduced in mid-2012 after politics have figured that the original management premium has led to excessive over supports. The simulation results also show, that the degression of the management premium leads to the expected savings of support costs of about 110 to 210 Mio. €. Furthermore, calculations of the whole support budget indicate, that additional costs due to the support of renewables via EEG-feed-in-tariff and market premium decrease from 112 €/MWh to 105 €/MWh in 2020 based on the degression of remuneration rates[8]. In consequence of the market premium, the overall support budget increases from about 300 Mio. € in the year 2012 to about 400 Mio. € in the year 2019[9].

Regarding current debates in science and politics about direct marketing of renewables, the effect of an obligatory direct marketing is studied under the premise, that the obligation implicit an avoidance of the management premium. So only the market premium is paid to the direct marketers. This leads to a decrease of intermediaries' profits whereas costs for

[8] The support costs are the difference between the FIT and the realized market revenues for RES. In the indicated simulations runs the average energy exchange prices rise from about 50 €/MWh in the year 2012 to 58 €/MWh in the year 2019.
[9] These numbers do not consider the savings due to the fact, that the marketing costs of the system operators are omitted by the direct marketing.

staff, marketing etc. remain. Simulation results for the intermediaries for the above mentioned premise are shown in figure 7[10].

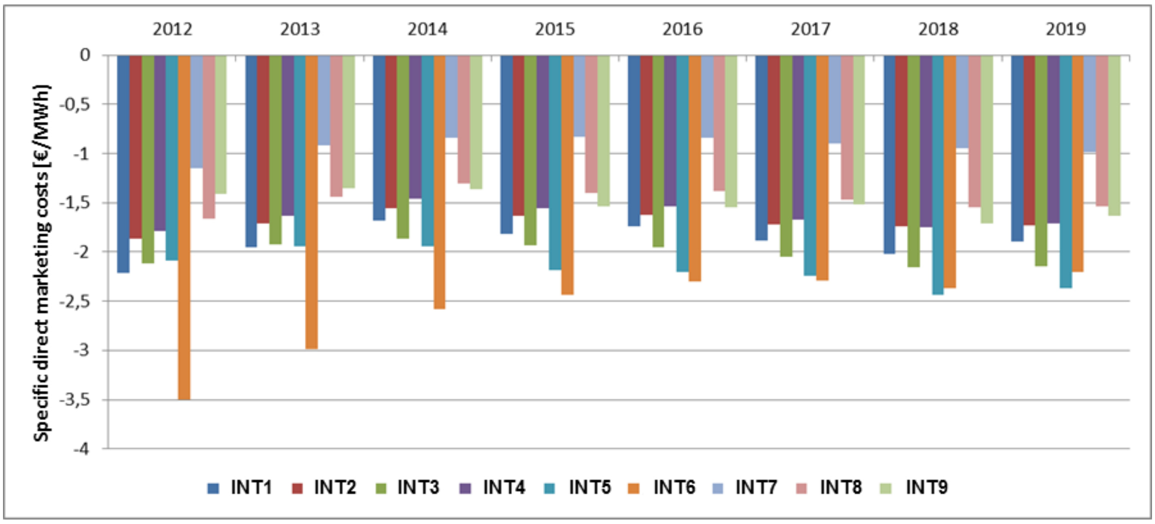

Figure 7 **Specific costs for direct marketing for different types of intermediaries in case of obligatory direct marketing.**

The specific costs for direct marketing are between 1€/MWh and 3,5€/MWh in the years 2012 to 2019 depending on the type of intermediary. These values match quite good the estimation of direct marketers as validations by experts have shown. The costs depend mainly on the portfolio of intermediaries – high shares of volatile renewables result in higher costs due to necessary output forecasts and tend to higher cost for matching the announced schedule with the actual feed-in compared to high shares of controllable renewables. As marketing costs are not compensated by the management premium, intermediaries will possibly charge the power plant operators in order to omit financial losses. Thus, the illustrated specific costs for direct marketing as shown in figure 7 plus n profit margin for the intermediaries of about 1-2 €/MWh can be interpreted as a reduction of remuneration of the plant operators.

The simulation results show possible risks:

- Market concentration: Intermediaries with big diversified portfolios may have lower marketing costs than other intermediaries, as scaling effects for electricity trading as well as spatial distribution of renewable power plants affect the costs positively. This may lead to market concentration und support powerful intermediaries that may use their market power to negatively influence further investments into renewables.
- Rising costs: Todays diversity of intermediaries could be achieved because also small direct marketers with small portfolios can act successfully at the market. In case this diversity is to be preserved, policy instruments must allow the compensation of specific costs for direct marketing by a premium. This premium could imply rising support costs for electricity from renewables.

[10] The configuration of the simulation run is identical to the one used for the optional direct marketing, except that the management premium is set to zero.

- Reduced remuneration: The obligatory direct marketing without management premium is an indirect reduction of remuneration for power plant operators. The amount of reduction equals the specific cost for marketing plus a profit margin for the intermediaries. This weakens the incentives to invest in renewable energies, especially in volatile renewables.

Compared to the impact on volatile renewables, the obligatory direct marketing implies less risk for controllable renewable power plant operators. The participation of controllable renewables at the market would enhance their flexibility potential, as long as financing of necessary technologies is given.

Conclusion

The focus of the investigation is on the one hand on the opportunities of gaining additional revenues through the direct marketing supported by new regulation mechanisms like the 'optional market premium' (§ 33g EEG). On the other hand, additional risks related to direct marketing, to which different actors with different capital backgrounds and energy portfolios are exposed to, are analysed under the paradigm of imperfect knowledge. First simulation runs show that the introduction of the 'market premium' leads to diverse economic effects on the power plant operators as well as on the intermediaries. Even if the 'macro-economic' impact like the overall costs of the support mechanisms of different schemes might not be so diverse, the 'micro-economic' impact on the different actors itself can be huge.

Viewing market integration processes of renewables from an agent based perspective allows for innovative computational analyses of the interdependencies between the relevant actors. It goes beyond standard market structure analysis by attempting to combine actor based and systemic considerations. With the agent-based simulation model AMIRIS influences of different policy-designs on a macro as well as micro scale can be analysed. These kinds of analyses are necessary to be able to construct sound support schemes in order to promote market development on the one hand but prevent windfall profits by certain actors on the other hand.

Future work will concentrate on a more dynamic sampling of the agents and of the model itself. Up to now many parameters of the model and especially of the agents can change over time but are set external. Other aspects to be included deal with the analysis of different market designs for the time when high shares of renewables are already integrated into to the energy system.

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