IMPACTS OF PREFERENCE-DRIVEN PEER-TO-PEER ELECTRICITY TRADING ON DISTRIBUTION GRID LEVEL

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Abstract

Until now, the ongoing German Energy Transition primarily takes place on the system's supply-side, while the demand-side remains rather unaffected. This article discusses how consumer behavior can be influenced by flexible electricity prices to align demand with generation. Therefore, a combination of two different approaches is used, (I) The Cellular Approach and (II) Agent-Based Modelling. In a simulated regional energy market area covering a whole distribution grid, all types of consumers are allowed to trade electricity peer-to-peer regarding each consumer's preferences. The results show that energy purchases can be stimulated individually by flexible pricing and met preferences. Moreover, benefits occur for the whole region and potentials arise to smooth the exchange balance to the superordinate grid level.

Keywords

Cellular approach; Agent-based modelling; Regional energy markets; Flexible pricing mechanism; Proactive consumer behavior.

Introduction

To always gain the indispensable equilibrium between generation and consumption, flexibility options are crucial factors for the security of electricity supply. The importance of these options will increase while the German energy transition progresses. Because up to now flexibility is mainly provided by controllable supply-side actors [1]. But due to the dependence on weather conditions, Renewable Energy Sources (RES) cannot be considered controllable.[1] Furthermore, volatility and decentralism become permanent supply-side characteristics. In contrast, the demand-side will hardly change as consumption remains rather inflexible in spatial as well as in temporal sense. Therefore, the organizational effort for gaining the equilibrium increases tremendously [2], [3].

Nevertheless, increasing shares of decentral generation units provide a rising potential for enhanced interconnection of supply and demand on local grid levels. As it is no longer sufficient to only manage supply-side, supply and demand have to be managed and adjusted mutually. Therefore, it is indispensable to create more flexibility on the demand-side [4]. However, still it has not been answered satisfactorily how to change or influence consumer behavior effectively.

As the generation of electricity out of RES is highly weather dependent, technologies allowing the temporal decoupling of generation and consumption are required. Without a doubt, battery storage systems and power-to-x-technologies will be part of the overall solution

[1] The only exceptions are hydroelectric and biogas power plants.

to evade this dependency. Moreover, the so-called demand-side management is an eligible approach for shifting or cutting load peaks to a certain extent [4], [5]. The other part of the overall solution will be the consumers themselves [6].

1 Regional Energy Market Model

1.1 Research Subject

As already described in the introductory part, it will be a matter of making adjustments also on the consumption and not only generation side in future electricity supply systems. While there are already tried and tested technical solutions, it has not been answered satisfactorily yet which contributions financial incentives can make. In order to find out how to change consumer behavior and which effects emerge due to this, a model is set up depicting individual consumer behavior in a regional energy market.

First of all, it has to be stated that this model is not an equilibrium model for minimizing overall system costs assuming perfect foresight, but rather for simulating consumer behavior and investigating possible impacts on the supply system. Therefore, two different methodological approaches are combined: (I) Agent-Based Modelling (ABM) and (II) the so-called "Cellular Approach" (CA). ABM allows to implement individual consumer behavior whereas the CA depicts the technical basis for peer-to-peer electricity trading.

A short note to the Reader: The following sections provide merely a condensed model description. For a full description, the former publication [7] is recommended.

1.2 Research Methods

1.2.1 Agent-Based Modelling

ABM is the method of choice for simulating behavior patterns. These models can portray an economic system in which orderly behavior can emerge as a result of interaction between heterogeneous agents, none of whom has any understanding of how the overall system functions [8], [9]. Furthermore, ABM enables to investigate several system levels in different degrees of abstraction. Especially the interdependency between the microscopic level, where agents act, and the macroscopic level, where system behavior emerges, can be observed [10].

That means, ABM allows to simulate imperfect markets and competition. Therefore, agents represent various market participants acting with strategic behavior based on asymmetrical information.

The REMM is built in NetLogo 6.2.2.[2]

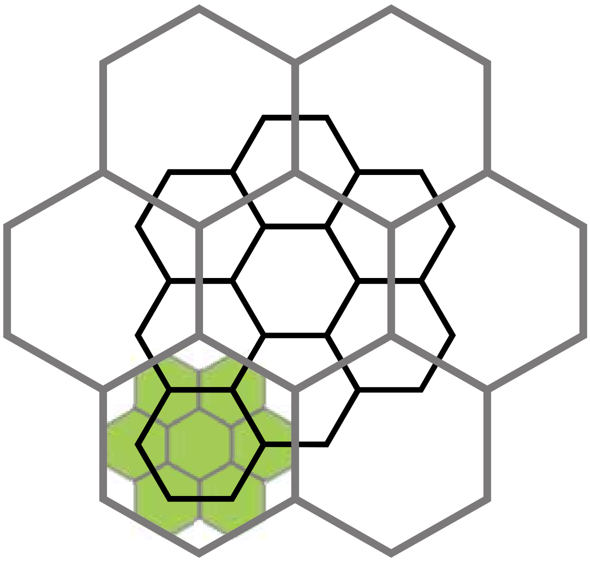
1.2.2 Cellular Approach

As mentioned in the introductory part, Germany's goal is to integrate high shares of fluctuating RES. With regard to the challenge of adjusting supply and demand mutually, this requires new approaches with an increased degree of system control. The CA is such an approach and offers a broad range of potential benefits for integrating RES in local distribution grids, while always balancing supply and demand on the lowest possible level.

Therefore, the CA is based on so-called "Energy Cells". Cells are defined by the ability to generate, consume, and even store energy. Each cell's goal is to reach the equilibrium

[2] For more information about NetLogo, see https://ccl.northwestern.edu/netlogo/.

between generation and consumption by itself. If this goal cannot be reached alone, every cell can connect to other cells and, thereby, build superordinate energy cells in turn, see Figure 1.



Source: Author's own compilation based on [11]

Fig. 1: *Schematic illustration of energy cells*

To rephrase this and give a short example, imagine a private household operating a PV rooftop system. In this example, the household is the lowest possible cell, always trying to fit its own electricity consumption to its own individual generation and vice versa. In case the self-supply by the PV system is higher than its own consumption, this household connects to other cells in the supply system, maybe to another household, and sells its leftover electricity. Or in contrast, buys electricity from other cells if their own demand is higher than the self-supply.

Since the logic of the CA not only provides a technical concept, the feasibility of which is, by the way, confirmed in [12], but also a concept for peer-to-peer trading, the combination of ABM and CA allows to observe emerging consumer behavior in a counterfactual (regional) energy market scenario. Each agent represents one market participant, and accordingly one sub-ordinate energy cell, acting by its own preferences and trying to equilibrate its own generation and consumption.

1.3 Model Structure

1.3.1 Overview

The Regional Energy Market Model (REMM) is set up for a simulation period of one year in a one-hour resolution beginning from January 1st. The modeled electricity system is a typical local distribution grid with its characteristic producing and consuming entities, covering an area of 100 km^2 partitioned as a predefined 10 by 10 mesh with 100 patches each of 1 km^2. The model is set up very variable and, therefore, able to cover and simulate various supply and demand scenarios. For running the model according to the author's purposes, an exemplary scenario is implemented, which is comparable to the supply system of Zittau, a small town in eastern Germany with roundabout 26,500 inhabitants. The supply system of Zittau is operated by the Local Utility Company (LUC), which ties in perfectly with the idea of the CA and the model structure. Once built to supply higher amounts of consumers, the local grid is slightly oversized so that no grid constraints exist in the model.

The REMM covers the three typical representative consumer groups:

- Private Households – model name: Residentials with Standard Load Profile (RSL)
- Trade, Commerce & Service – model name: Business with Standard Load Profile (BSL)
- Industry – model name: Business with Measured Load Profile (BML)

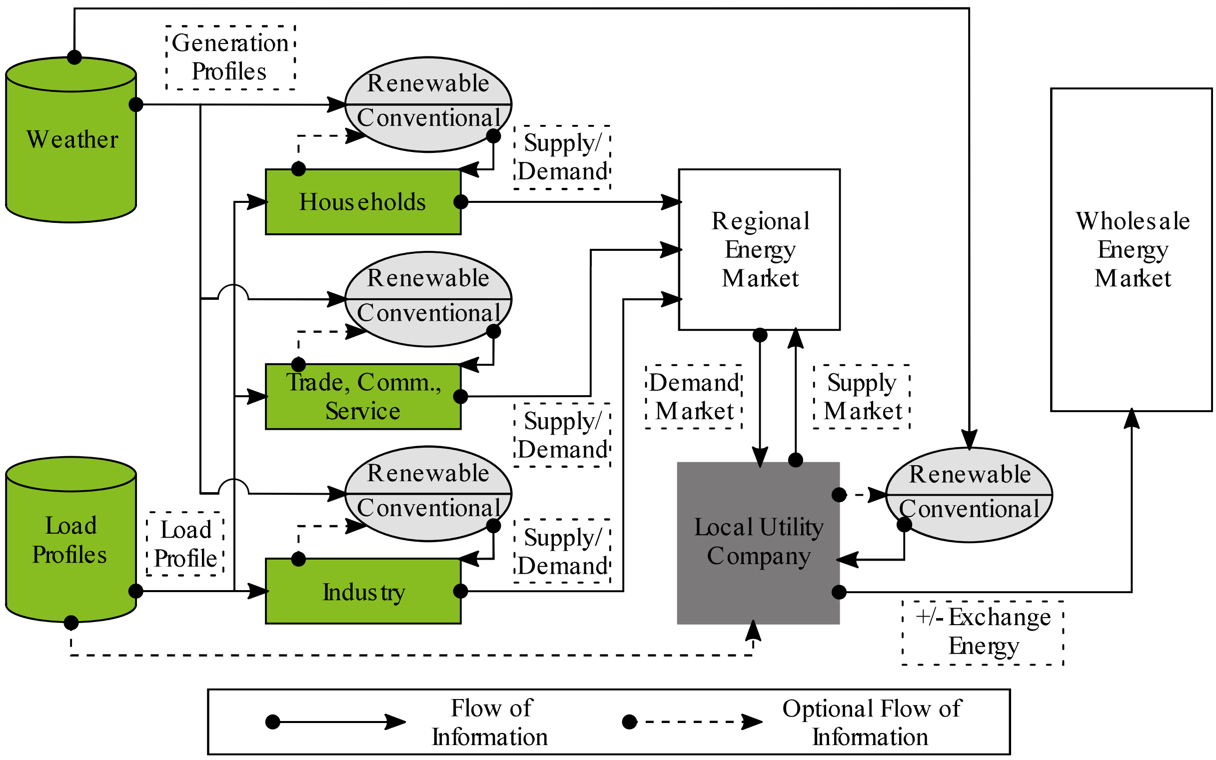
Basically, similar to other economic models, the REMM distinguishes between supply and demand as leading variables. However, particularly in future energy supply systems, the former, relatively solid boundaries between producer and consumer tend to be blurred. More and more so-called “Prosumers” will enter the market, whose role as producers or consumers depends on how high their own energy generation is compared to their consumption. Based on the CA, literally every REMM entity could act as a producer or consumer out of the systems view respectively as a seller or buyer out of the market’s view (see Fig. 3).

As mentioned above, an exemplary simulation scenario corresponding to the supply system of Zittau is implemented in the REMM. In numbers: 15,407 RSL, 1,638 BSL and 108 BML agents.

1.3.2 Local Utility Company

As there is a local market and a local supply system, there consequently has to be a system operator who ensures the regional equilibrium between generation and consumption at any time. In REMM, this is the LUCs responsibility. Therefore, the LUC has various options. One can be to use its own renewable as well as conventional generation units. Another is to sell or buy electricity from the interregional wholesale market depending on regional over- or under capacities respectively.

The LUC is modeled as a passive agent, due to the fact that the model’s observations are all about consumer behavior. Passive means that the LUC acts without any intention of making a profit, maintaining the overall system, and reading the market to meet the consumer’s demand.



Source: Author’s own compilation

Fig. 2: *Schematic overview of the REMM and its entities*

Figure 2 provides an overview over the whole system and entities.

1.3.3 Demand-Side

RSL and BSL agents are characterized by standard load profiles, published by the German Electricity Association.[3] The implemented simulation scenario uses H0 (dynamic) for RSL and G0 for BSL agents. These profiles are standardized to an annual consumption of 1,000 kWh and have to be scaled up to use them in the model. Therefore, each hourly value of the profiles is multiplied by a coefficient randomly chosen out of a domain, which was chosen according to statistical data, and is assigned to each of these agents before the simulation starts.

For BML agents, of course, no standard load profiles exist. Therefore, empirical load profiles were created, which were derived from actually measured profiles of several real existing companies, which are comparable to those companies typically connected to the distribution grid. By this, three load profiles were generated representing different types of companies.

All these entities are consciously modeled out of the systems perspective. That means they are mainly characterized by two attributes, consumption and demand. While consumption describes the total electricity need of an agent per time step, demand describes his hourly electricity purchase from the grid. For most of the agents applies consumption equals demand. However, some agents (prosumers) are able to partially generate their own electricity, so that their demand is smaller than their consumption.

For more detailed information please consult the recommended literature in Sections 1.1 and 1.3.1.

1.3.4 Supply-Side

As already mentioned above, theoretically every demand-side agent could also be a supplier out of the systems perspective as long as he operates a generation unit. Since this is not very probable, the model user can predefine how many of them operate a generation unit via the model's interface. But, which agent becomes a so-called prosumer is still a random decision by the model.

To simulate generation characteristics properly, several possibilities are given. Prosumer can own a PV roof-top system and/or a Combined Heat and Power (CHP) unit, which is operated either with natural gas or biogas (see Fig. 3). Once a generation technology is assigned, the model adjusts its capacity to the annual consumption pattern of the operating agent. By this, different generation characteristics are integrated into the REMM. Volatile feed-in through RES is represented by PV systems, controllable renewable generation by CHP units operated with biogas and controllable conventional generation characteristics by CHP with natural gas.

To determine what amount of electricity can be generated hourly by PV systems, a database with exogenous weather data is linked to the model. CHP units are operated in a heat-controlled mode. Therefore, the daily average temperatures were determined based on the exogenous weather data. If the average temperature of the following day falls below the heating limit, defined in the model's interface, the CHP system is switched on for the next full 24 h and operates on nominal load.

Of course, each prosumer prefers to consume its self-generated electricity prior to cover its own consumption. In times, where generation is greater than consumption, prosumers sell

[3] Verband der Elektrizitätswirtschaft (VDEW)

their leftover electricity at the regional market. If generation is lower than consumption, prosumers will buy the missing electricity at the market, see Figure 3.

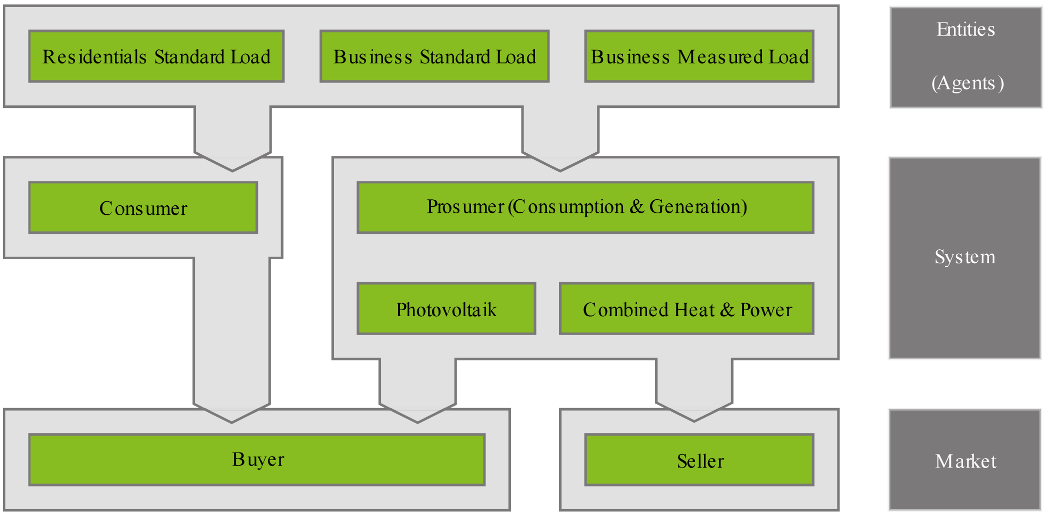


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Fig. 3: *Entities and their roles*

1.4 Market and Pricing

Figure 4 shows the pricing mechanism within the REMM. As in reality – at least in Germany – there are three different price components: (I) generation, (II) transmission and (III) taxes, levies and apportionments. As (III) accrues for all products, it would make no sense to consider them further in the following explanations.

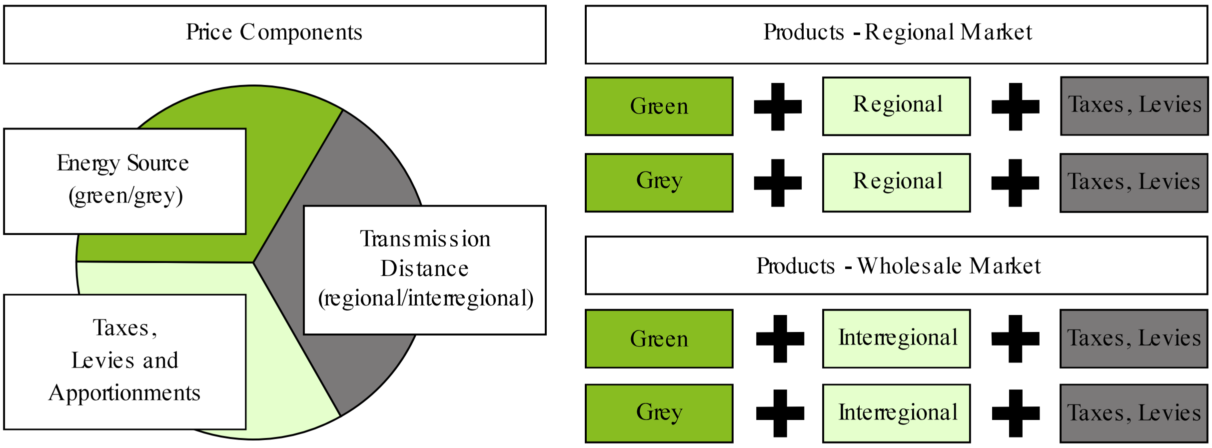

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Fig. 4: *Electricity price components and market products*

Each consumer is free to act according to their own preferences. That means, in every time step each agent is free to choose between electricity generated from conventional sources (grey) or from renewable sources (green). Furthermore, they are free to choose whether they prefer electricity generated in the same region or outside the region. Combining these different possibilities results in four different market products: (I) Green Regional, (II) Grey Regional, (III) Green Interregional and (IV) Grey Interregional.

As Figure 2 shows, agents have only direct access to the regional market section. However, that does not mean that they are only able to buy regional products. As the LUC is the connector between the regional and the wholesale market, interregional products are offered via the LUC. Within the region all prosumers are allowed to offer their self-generated left-over electricity at the regional market, as a regional product.

As there are different price components and several product characteristics to choose, of course the overall electricity price differs from product to product (I – IV). For reasons of simplicity, the simulation works with fixed prices for every time step. That means, neither the regional nor the interregional market owns a further pricing mechanism, like the merit-order approach. In the REMM it is the LUCs responsibility to set the prices.

For purchasing the grey product, consumers only have to pay the so-called "base price", whereas for the green product, an additional price premium for green energy has to be paid. This premium is comparable with the German Renewable Energies Act Levy (known as "EEG-Umlage"). The premium can be treated as a subsidy for RES.

$$p_{source} = \begin{cases} p_{base} & : \ Grey\ product \\ p_{base} + p_{green} & : \ Green\ product \end{cases} \quad (1)$$

By choosing between regional or interregional products, every consumer decides about the height of the grid fee. The model's world is a 10 by 10 mesh with 100 patches. All prosumers located on one of these patches are considered producers offering regional electricity. On the contrary, all electricity generated not within this area is considered interregional. Both, the regional and the interregional grid fee, can be predefined by the user in the model's interface.

$$p_{grid} = \begin{cases} p_{reg} & : \ Regional\ Purchase \\ p_{trans} & : \ Interregional\ Purchase \end{cases} \quad (2)$$

As mentioned, the component for taxes, levies and apportionments accrues for all products. So, the overall electricity price results in dependence of the chosen product as:

$$p_{el} = p_{source} + p_{grid} + p_{tax} \quad (3)$$

1.5 Consumer Behavior and Decision Making

Each Agent in the REMM is parametrized with three preferences, which are the initial point for all decisions made by these agents: (I) environmental awareness, (II) regional awareness and (III) budget, as a marker describing his cost sensitivity. Every preference is a value between zero and one.

Tab. 1: *Domains for consumer preferences*

Awareness	Domain
environmental	$e \in]0;1]$
regional	$l \in]0;1]$
budget	$c \in]0;1]$

Source: Own

Environmental awareness describes each agent's individual esteem for green energy sources. Regional awareness represents each agent's preference for electricity generated in a local context. For both, a value close to one indicates a high preference, a value close to zero a low preference. Budget describes his individual assessment of higher costs. It is directly dependent on one agent's income (RSL), respectively on one agent's earnings (BSL and BML) and expresses in his preference for the price. Here, on the contrary, a value close to one indicates a high sensitivity for higher costs, a value close to zero a low sensitivity, which would mean that these agents are more likely to pay higher prices.

In a two-step decision process, all consumers take a new decision at every time step which electricity product they preferably want to purchase. For this, each agent calculates personal utility values taking into account his own preferences and then compare green and grey in the first step respectively regional and interregional products in the second step. Of course, a product, which provides the biggest utility value, is chosen.

Similar to the approach in [13], the utility values for stage one are calculated as follows. Each agent compares an intrinsic value with the (negative) value of (higher) costs. The intrinsic value is calculated under the estimation that one extra unit of the price premium for green electricity can be converted in exactly one unit of an abstract personal good, which can be interpreted as well-being or moral satisfaction. The intrinsic value results out of the agent's environmental awareness combined with its price sensitivity and the amount of the price premium. By this logic, the intrinsic value for the purchase of grey electricity is 0.

$$u_{intr,i,t} = \begin{cases} 0 & : \ grey \\ e_i \cdot \sqrt{p_{green,t}} \cdot c_i & : \ green \end{cases} \tag{4}$$

The (negative) effect of (higher) costs caused by the base price component and the extra price premium for electricity out of RES results under each agent's price sensitivity and the amount of the price components.

$$u_{cost,i,t} = \begin{cases} c_i^2 \cdot p_{base,t} & : \ grey \\ c_i^2 \cdot \left(p_{base,t} + p_{green,t}\right) & : \ green \end{cases} \tag{5}$$

The overall utility functions for stage one result by combining the intrinsic value with the cost value for the purchase of green or grey electricity.

$$U_{grey,i,t} = 0 - c_i^2 \cdot p_{base,t} \tag{6}$$

$$U_{green,i,t} = e_i \cdot \sqrt{p_{green,t}} \cdot c_i - c_i^2 \cdot \left(p_{base,t} + p_{green,t}\right) \tag{7}$$

Analogous to stage one the utility values for stage II result out of the comparison between the intrinsic values and the values of costs. It is assumed, that the intrinsic value exists only for the purchase of electricity generated in a regional context. The intrinsic value for interregional purchase is 0.

$$u_{intr,i,t} = \begin{cases} l_i^2 \cdot \sqrt{p_{reg}} \cdot c_i & : \ regional \\ 0 & : \ interregional \end{cases} \tag{8}$$

Similar to stage one the functions for the value of costs result considering each agent's price sensitivity and the corresponding price component.

$$u_{cost,i,t} = \begin{cases} c_i^2 \cdot p_{reg} & : \ regional \\ c_i^2 \cdot p_{trans} & : \ interregional \end{cases} \tag{9}$$

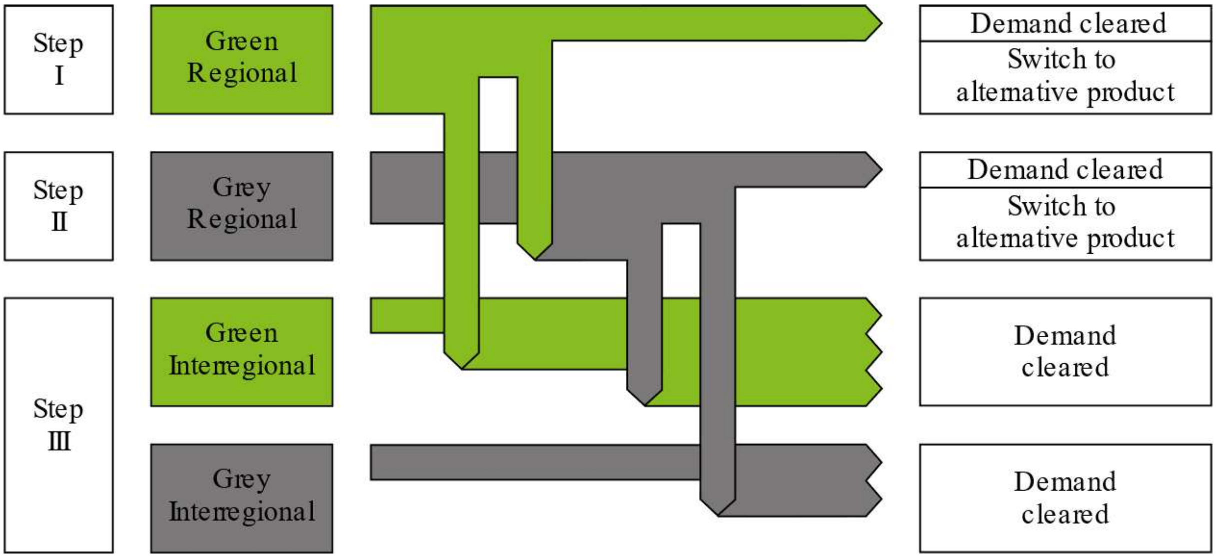
The overall utility functions for stage two result by combining the intrinsic value with the cost value for the regional or interregional purchase.

$$U_{reg,i,t} = l_i^2 \cdot \sqrt{p_{reg}} \cdot c_i - c_i^2 \cdot p_{reg} \tag{10}$$

$$U_{trans,i,t} = 0 - c_i^2 \cdot p_{trans} \quad (11)$$

1.6 Market Clearing

In the REMM it is the LUC's responsibility to clear the market. Due to the inherent characteristics of generation through RES and CHP units, the regional market is highly volatile. Consequently, situations can arise where parts of the preference-driven demand cannot be met. Situations with regional oversupply are not crucial for the simulation, because of the assumption that leftover electricity could be sold at the wholesale market at any time. In contrast, situations with undersupply of both or at least one regional product are challenging. A decision has to be made, who of the applying agents gets served and who has to switch to another product, and on which basis this switching decision happens. In the REMM this decision is based on each agent's Willingness To Pay (WTP). The WTP can be calculated out of the several utility functions. By equating the functions (6) and (7) and converting to p_{green}, the height of the price premium can be calculated at which an agent would just about prefer the green product to the grey one. Analogous this works for the WTP for the regional product by equating the functions (10) and (11) and converting to p_{trans}. The clearing process for regional under capacities is carried out in 3 steps (see Fig. 5).



Source: Author's own compilation

Fig. 5: *Market clearing scheme*

At first, the green regional market section gets cleared. Therefore, all applying agents are listed on the basis of their WTP for green. Agents with high a WTP are served first, and agents with a low WTP last.

$$wtp_{green,i} = \left(\frac{e_i}{c_i}\right)^2 \quad (12)$$

Not served agents switch to an alternative product. Since the initial decision on green and regional is already made, decisive for switching is which of the two predicates the agent would like to keep. Indicators for this decision are the individual preferences for environmental and regional awareness. A weighting for both is already given during the model set-up. If environmental awareness is greater equal regional the agent switches to the green interregional product. If environmental awareness is small the agent switches to grey regional.

In step two all section grey regional is cleared covering all agents who would like to purchase this product right from the beginning and also those who were not served in the first clearing step and subsequently decided on grey regional as their alternative product. Analogous to step one, agents with a high WTP are served preferred.

$$wtp_{reg,i,t} = \frac{l_i^4}{2c_i^2} + \frac{l_i^2}{c_i} \cdot \sqrt{\frac{l_i^4}{4c_i^2} + p_{trans}} + p_{trans} \tag{13}$$

Those agents who cannot be served switch to an alternative product. Since the product green regional is not available any longer, agents are only still free to choose between the interregional green or grey product. For this, the already calculated utility values can be used since it is a decision between green and grey. Consequently, all agents who have already decided to choose grey electricity in the initial decision continue to purchase grey. Only agents who were not supplied with green electricity in clearing step I and switched to grey regional due to a higher regional awareness will switch back to the green but interregional product.

In step three, all agents that were not served yet in the first two clearing steps and all those who initially decided to purchase interregional electricity are regarded and served. It is one of the model assumptions, that the LUC can always meet the demand for interregional products via the wholesale market.

2 Simulation

2.1 Scenarios and Parameters

The parameters for this chapter's simulations, in addition to those already addressed above, are given below in Table 2. This work focuses on the observation of two different pricing strategies within two different levels of RES integration in the supply system.

Tab. 2: *Parameters for simulation scenarios*

	Fix Price		**Flex Price**	
Deviation LP	5%		5%	
Share PV	5%	15%	5%	15%
Share CHP	5%	15%	5%	15%
Share Biogas	33%	50%	33%	50%
p_{base}	7.5 ct / kWh		7.5 ct / kWh	
p_{green}	6.5 ct / kWh		[2; 6.5] ct / kWh	
p_{trans}	7.5 ct / kWh		7.5 ct / kWh	
p_{regio}	10.5 ct / kWh		10.5 ct / kWh	

Source: Own

The first pricing scenario is an ordinary scenario with fixed prices for all price components. The given prices in Table 2 are aligned with the actual level of the real price components in Germany in 2020. The fix price scenario serves as the base case for the observation. In contrast to that, simulations are carried out where the pricing for the extra premium for green energy is flexible. In this given scenario the price premium may vary between 2 and 6.5 ct/kWh. The implemented price mechanism depends on the amount of generated electricity out of RES. The higher the current generation is in comparison to the actual installed capacity, the lower gets the price and vice versa. By this, it can be observed which effects flexible pricing will cause.

Moreover, it will be observed which influence higher shares of RES will have on these effects. For this, two different RES expansion scenarios are simulated. In the first scenario, 5% of the agents of each consumer group operate a PV roof-top system and another 5% with a CHP unit, of which 33% operate their unit with biogas whereas 67% use natural gas. In the second scenario, 15% each operate a PV roof-top system or CHP unit and 50% of the CHP operators use biogas.

The first value in Table 2 is an additional, random value and represents the permitted deviation an agent's electricity consumption is allowed to vary. Since the REMM works with standard load profiles, it is advisable that not all agents of the same group are treated with the same scaling factor and purchase exactly the same amount of electricity per time step.

2.2 Results and Discussion

Since the scenarios explained above refer to the investigation of the effects of flexible green electricity prices, it seems reasonable to focus specifically only on this point in the following. Therefore, the evaluation of the simulation is primarily focused on the product 'green regional'. Furthermore, the following graphs consistently deal with the same four parameters. Firstly, 'generation' that resembles the whole region's generation of green electricity. Secondly, 'Sales Volume' that results out of the fact, that prosumers preferably use their self-generated electricity to meet their demand. Only the left-over electricity is sold at the market. Thirdly, 'Demand fix' that resembles the demand for 'green regional' in the fix price (base case) scenario. And finally, 'Demand flex' representing the demand for 'green regional' in the flex price scenario. All graphs resemble the average results over five full model runs for each scenario.

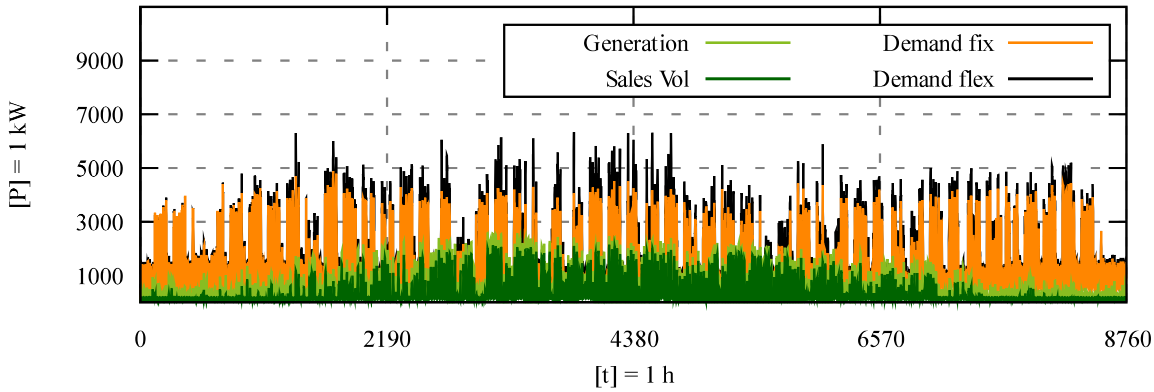


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Fig. 6: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one year*

Figure 6 shows the demand for 'green regional' in the fix and flex price scenario within the 5% RES expansion scenario over one year from January 1st. Although this figure does not provide any details due to the density of the values, several initial results are already included. What hits the eye first is the fact that the available sales volume of 'green regional' is seemingly never enough to meet the overall demand, neither in the fix price nor in the flex price scenario. Moreover, the height of the gap between generation and sales volume (which is equal to the self-consumption) seems not to have a crucial impact on whether the regional demand could be met or not. And last but not least, Figure 6 shows pretty clear that the flexible pricing mechanism causes higher demand for 'green regional' even in low RES scenarios. At this point, it should be noted, that this increase in demand is not an actual, physical change in consumption, since the agents in the model cannot shift their consumption to another time step, but only the electricity's place of origin. It merely shows a potentially increasable absorption of regional willingness to pay, in times with high renewable generation.

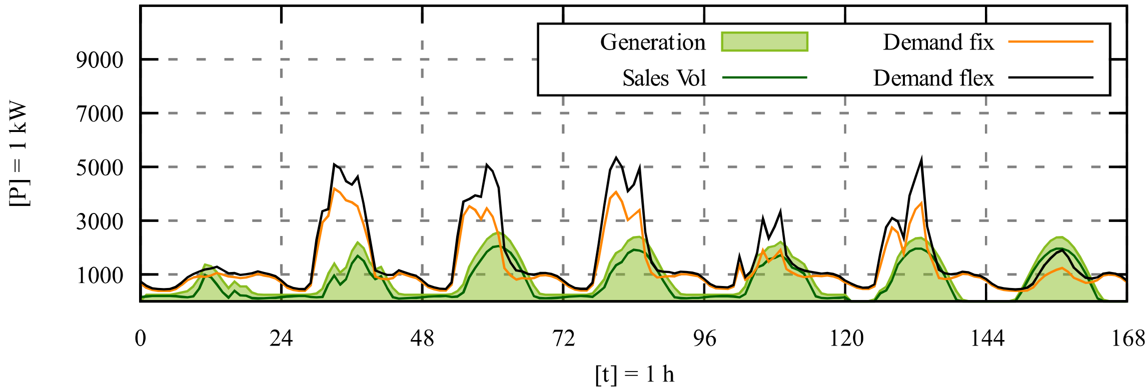

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Fig. 7: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one week in May*

Figure 7 shows the demand for 'green regional' product in the fix and the flex price scenario within the 5% RES expansion scenario over one week in month May. This month is chosen because it belongs to the transitional period between summer and winter and resembles one ordinary, average generation scenario. The impressions provided through Figure 6 are essentially confirmed and, moreover, more details are shown. One of these details is that there are hours, especially in the afternoon, when the sales volume does exceed the demand. On the one hand, it means that the demand for 'green regional' can be met. On the other hand, sales volume exceeds the demand in the fix price scenario, which means the regionally generated electricity is transferred into the transmission grid. But Figure 7 also shows that in the flex price scenario the demand in the afternoon hours could be increased in a manner to nearly match the sales volume.

Another point that is not so obvious at first glance is the different temporal occurrence of the curve's peaks. The several peaks of the demand curves mainly occur a few hours before the generation peaks at noon.

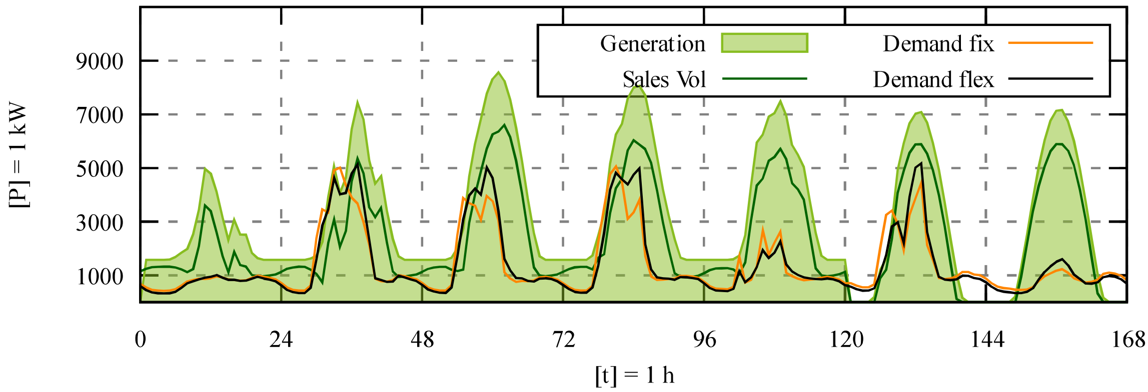

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Fig. 8: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one week in May*

Figure 8 shows the demand for 'green regional' in the fix and flex price scenario over one week in May, but this time within the 15 % RES expansion scenario. What changes to the 5%

RES scenario is, that now most of the time generation respectively sales volume exceeds the regional demand. However, it can be observed that in fix price scenario, the demand curve exceeds the sales volume on most days namely in the forenoon. Even though it is not perfect, the curve of the flex price scenario aligns much better.

As mentioned, while discussing Figure 7, it was noticeable that there was a slight offset between the different curve's peaks. In Figure 8 it seems that this offset is still there, but smaller. According to the current state of verifying these results, this has two reasons. One is that there is indeed a slight shift in demand towards noon due to falling prices. The other is probably an optical reason. Due to the larger and wider form of the curve, it looks like the demand peaks and the generation peak fit better. But in the end, it is more a shift of the generation curve upwards, than a rightward shift of the demand.

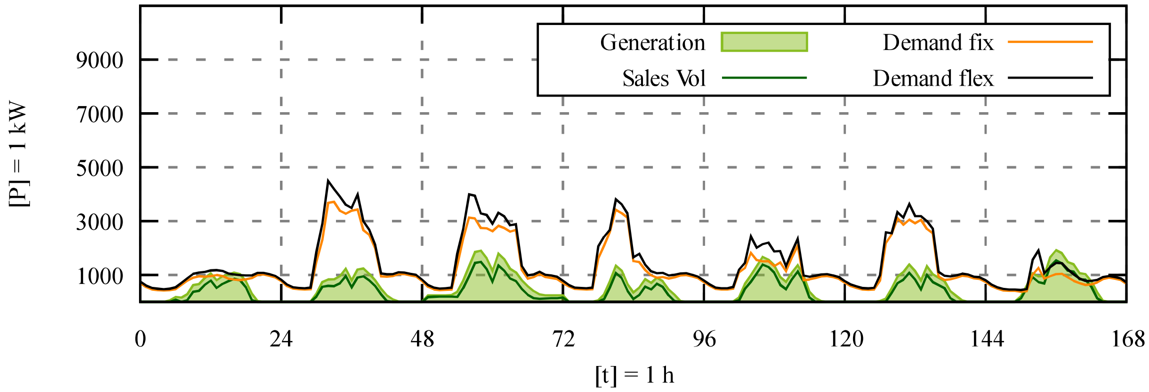

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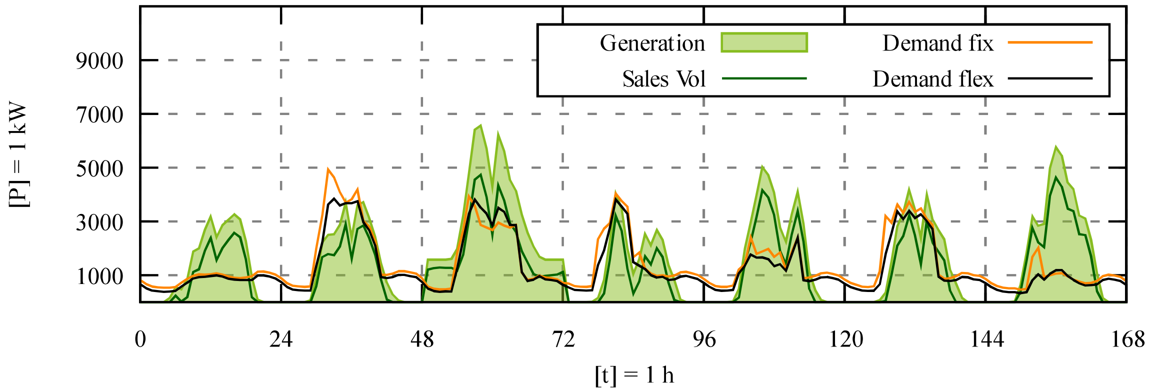
Fig. 9: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one week in July*

Figure 9 shows the demand for 'green regional' in the fix and flex price scenario within the 5% RES expansion scenario, but now over one week in July. In theory, electricity consumption tends to decrease in summer compared to the transitional period, like in the month of May. However, temperatures rise in summer, which means that green electricity generation from CHP units will probably cease, which, in the end, will lower the sales volume. And this is exactly what can be observed in Figure 9.



Source: Own

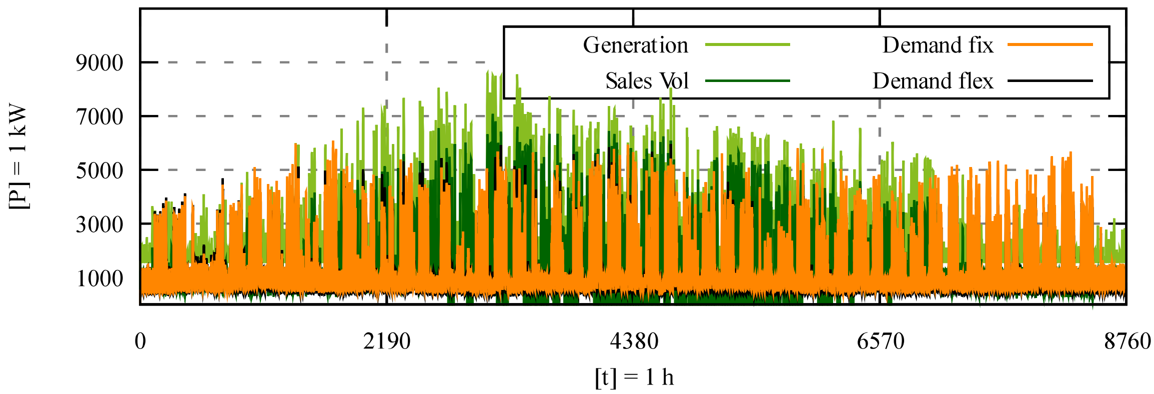
Fig. 10: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one week in July*

Demand in July is significantly lower compared to May. Both curves proceed considerably flatter. Even the effect of increasing the demand due to flexible prices is much less significant.

But of course, since the generation through CHP units ceased and only PV serves the market, the decreasing effect on the price is not given. And this also causes, that the sales volume exceeds the demand only in a very small number of hours.

Figure 10 shows the demand for 'green regional' in the fix and flex price scenario again for the same week in July, but this time within the 15% RES expansion scenario. Generation during nighttime is again zero, which obviously means that CHP units are still not running due to the high temperatures. But at noon generation and sales volume is much higher due to higher shares of PV. With the exception of the first and the last day, it seems that sales volume and consumption match relatively well.

But what hits the eye at the second glance, is that in some hours the demand in the flex price scenario is below the demand of the fix price scenario. According to the current state of verifying these results, this could be caused by randomly chosen model parameters during the set-up of the model before each simulation starts. But also plausible is the following. The LUC sets the price based on the ratio between the amount of the actual generation and the installed capacity. Since all CHP units are switched off and PV systems do not seem to be running at full load either, this ratio is very low, which in turn causes there are only few price incentives and consumers do not buy.



Source: Own

Fig. 11: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one year*

Figure 11 shows the demand for 'green regional' in the fix and flex price scenario within the 15% RES expansion scenario over one year. Compared to Figure 6 (one year within the 5% scenario), it is noticeable that the spreads between the fix and flex price scenario are not as wide. However, demand and sales volume seem to match a little bit better due to the changed face of the generation pattern, however, the figure does not reveal any details.

Conclusion

The results have shown that flexible pricing mechanisms have various advantages and can provide targeted incentives for purchasing at the right time step. For an energy system that is becoming increasingly decentralized anyway, this has a relieving effect and the transferred amount of regionally generated electricity into higher grid levels can be reduced.

However, the results have also shown that the mechanism for setting the price premium based on the ratio of the actual generation to the installed capacity does not always lead to the desired incentives within the selected scenarios. For practical application, therefore, a different approach may have to be taken. And moreover, sometimes no extra pricing mechanism is needed if the generation scenario and the consumption structure basically match.

It must be emphasized again that the current study was only about setting buying incentives and that it was not about the actual shift in the physical purchase of electricity. This approach plays a role in the currently ongoing, further investigations, based on the results shown here.

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ÚČINKY PREFERENČNÍHO OBCHODOVÁNÍ S ELEKTŘINOU PEER-TO-PEER NA ÚROVNI MÍSTNÍ DISTRIBUČNÍ SÍTĚ

Energetická transformace v Německu doposud probíhá primárně na straně nabídky systému, zatímco strana poptávky zůstává spíše nedotčena. Tento článek pojednává o tom, jak lze chování spotřebitelů ovlivnit flexibilními cenami elektřiny, aby se sladila poptávka s výrobou. Proto se používá kombinace dvou různých přístupů, (I) Celulární přístup a (II) modelování založené na inteligentních agentech. V simulované oblasti regionálního trhu s energií pokrývající celou distribuční síť mohou všechny typy spotřebitelů obchodovat s elektřinou peer-to-peer podle preferencí každého spotřebitele. Výsledky ukazují, že nákupy energií lze individuálně stimulovat flexibilním stanovením cen a splněnými preferencemi. Navíc dochází k výhodám pro celý region a vznikají potenciály k vyrovnání směnné bilance na úroveň nadřazené sítě.

AUSWIRKUNGEN VON PRÄFERENZGESTEUERTEM PEER-TO-PEER-STROMHANDEL AUF LOKALER VERTEILNETZEBENE

Bisher findet die deutsche Energiewende vornehmlich auf der Angebotsseite statt und sorgt für teilweise massive Veränderung in diesem Bereich. Die Nachfrageseite hingegen blieb bislang eher unbeeinflusst. In diesem Beitrag wird diskutiert, wie Verbraucherverhalten durch flexible Strompreise so beeinflusst werden kann, dass sich die Nachfrage an die Erzeugungscharakteristika anpasst. Dazu wird eine Kombination aus zwei verschiedenen Ansätzen genutzt: (I) Der zellulare Ansatz und (II) die agentenbasierte Modellierung. In einem simulierten regionalen Energiemarktgebiet, welches ein lokales Verteilnetz umfasst, können die einzelnen Verbraucher der unterschiedlichen Verbrauchsgruppen unter Berücksichtigung ihrer individuellen Präferenzen gleichberechtigt Strom handeln. Die Ergebnisse zeigen, dass Energiekäufe durch flexible Preise und die Berücksichtigung von Präferenzen individuell angeregt werden können. Darüber hinaus ergeben sich Vorteile für die gesamte Region und Potenziale zur Minderung der Austauschenergiemengen mit der übergeordneten Netzebene.

SKUTKI PREFERENCYJNEGO HANDLU ENERGIĄ ELEKTRYCZNĄ W SYSTEMIE PEER-TO-PEER NA POZIOMIE LOKALNEJ SIECI DYSTRYBUCYJNEJ

Transformacja energetyczna w Niemczech odbywa się do tej pory przede wszystkim po stronie podażowej systemu, podczas gdy strona popytowa pozostaje raczej bez zmian. W artykule omówiono, w jaki sposób na zachowania konsumentów mogą wpływać elastyczne ceny energii elektrycznej, dopasowujące popyt do produkcji. Dlatego stosuje się połączenie dwóch różnych podejść (I) Cellular Approach i (II) Agent-Based Modeling. W symulowanym obszarze regionalnego rynku energii, obejmującym całą sieć dystrybucyjną, wszystkie typy odbiorców mogą handlować energią elektryczną w systemie peer-to-peer zgodnie z preferencjami każdego z nich. Wyniki pokazują, że zakupy energii mogą być indywidualnie stymulowane przez elastyczne ceny i zaspokojone preferencje. Ponadto generowane są korzyści dla całego regionu oraz powstaje potencjał w zakresie równoważenia bilansu wymiany z wyższym poziomem sieci.