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Agent Based Simulation Model of Virtual Power Plants for greener Manufacturing

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Abstract

Green energy supply can play an important role for manufacturing companies. To achieve this, companies can support their energy supply with renewable energies (RE). For designing and planning a Virtual Power Plant, the PREmdeK simulation can be used. Realized with the AnyLogic© software, PREmdeK 3.0 simulates combinations of RE sources, energy storages and consumers as a multiagent system (MAS). In this MAS, every member of the local energy system is represented by an agent. The agents negotiate to reach a balanced energy state. The negotiation is based on operating data (energy production and/or demand) and sustainability criteria. The simulation is set up in a generic way, able to reflect changes in the constellation of the energy system. New agents can easily be implemented into the generic MAS through inheritance. In this paper, the implementation of this MAS to handle energy balancing of local energy system including sector coupling is presented.

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Keywords: Green Factory; Multiagent System; Virtual Power Plant; AnyLogic Simulation

1. Introduction

The energy revolution is driven by several reasons, such as the finite nature of fossil energy, the dependence of energy imports on other countries, and the increase of greenhouse gases (GHG) emissions. Until 2050, Germany plans to increase the electrical RE to at least 80% and decrease the emission of GHG by 80% [1]. It is intended to reach this goal by advancing large projects, wind parks and solar parks, but in addition by implementing decentral power systems for small and middle-sized manufacturers (SME). SMEs are a central part of economies worldwide, comprising 99% of enterprises, providing about 60% of employment and being responsible for at least 13% of total energy consumption [2]. Environmental awareness in German SMEs is already an important factor, one in four German SMEs has implemented sustainability measures with energy saving aspects and CO2-emission reduction as driving factors [3]. An interesting option to improve sustainability indicator and decreasing energy costs is the installation and use of a Virtual Power Plant (VPP). A disadvantage of this option is the complex design of the best fitting solution for a local, company owned energy system.

The technical and legal feasibility to install and operate one or more RE producers has been verified, the question of the optimal RE system fitting the SMEs' energy demand and profile has to be decided [4]: Does it consist of one producer or of different ones? In which combination and of which size? To what extent is the energy demand satisfied by the RE? How is an overproduction handled? Is it suitable to store it, or can it be injected into the grid? Under which conditions?

To support decision maker in SMEs to design a suitable VPP, the PREmdeK simulation has been developed at the University of Applied Science Emden / Leer [5]. In German, the word PREmdeK stands for "prognostics and realization of the energy supply through decentral energy plants". The PREmdeK simulation helps to design a VPP that is able to

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cover a specified energy demand, e.g. of certain consumers like production companies. It visualizes and simulates different scenarios through the representation of above mentioned energy producers and consumers. The current PREmdeK version (3.0) allows for the user to quickly design and combine different scenarios for comparison. To achieve realistic results, consumers' historic load profiles and local weather data are used for the calculations.

The distributed nature of this problem makes it perfect for the MAS paradigm, according to the definition of Wooldridge and Jennings [6]. In the case of the PREmdeK 3.0 simulation, an agent represents an element of the local energy system, such as a consumer, RE producer/prosumer or an energy grid. The agent is situated in the simulation environment and is capable to act autonomously for balancing its energy. In most cases, this task cannot be completed by an agent alone. Rather, the agent needs to cooperate with other agents to achieve its objective and the objective of balancing the entire energy system.

This paper presents the architecture and communication concept of a self-organizing and generic multiagent system. The simple architecture with its generic design allows an easy integration of new agents into the system with all its interoperability functions. For this reason, different basic agent types and a suitable communication phase for the energy exchange are defined.

To create the PREmdeK 3.0 Simulation, a multi method simulation platform called AnyLogic© was used [7]. It supports agent-based simulations, system dynamics, and process-centric (discrete event) modeling [8]. Various studies have already compared AnyLogic© to other agent platforms [9–11]. The Java based program supports the concept of inheritance, which is a key factor for our MAS realization. Additionally, the flexibility through the agent based and state chart based modeling led to the decision of using AnyLogic©.

After discussing related work in section 2, the theoretical background of the PREmdeK Project, the AnyLogic© Software, and the MAS with its IEEE standard on Foundation for Intelligent Physical Agents (FIPA©) related realization shall be explained. Section 3 contains the theoretical background of the PREmdeK project, the simulation software and the FIPA© reference architecture. Section 4 covers the concept of the PREmdeK MAS with its architecture, agent design and negotiation approach and the simulation itself. Finally, section 5 presents the conclusion and gives an outlook on further potentials of the PREmdeK simulation.

2. Related Work

Typically, many applications of MASs have been devoted to the management and operation of micro or smart grids. The focus can lie on the optimization of energy distribution [12], the design of an MAS for an easy implementation of VPP [13] or the energy resource scheduling of an islanded power system with distributed energy resources (DER) [14]. The MAS paradigm is mainly used to represent the autonomic members of a grid and achieve the best method to balance the energy. In our case, the focus lies on finding the best design for a local energy system. An energy balancing behavior is needed, but getting a balanced energy system is not mainly achieved through management or operation, but through changing the composition until the intended balancing level can be achieved.

For operation and coordination of DER in grids, the contract net protocol (CNP) is often used. The paper "Multi-agent coordination for DER in MicroGrid"[15] uses it to establish a communication and coordination structure for a scalable system. In "An Intelligent Multiagent System for Autonomous Microgrid Operation"[16] the CNP was used in a modified way to implement the function of announcing a new task, bidding, and awarding a contract. Both use the CNP for the same reason we do: to select the most suitable service provider for a task among several possible service providers.

The PREmdeK 3.0 simulation model approaches the topic from another direction, not designing a MAS for a local energy system, but designing a local energy system with the help of MAS and the focus on specific user scenarios.

3. Theoretical Background

Before discussing the implementation of the MAS architecture, the Negotiation Phase (NP) or the simulation, focus will be put on the project PREmdeK itself, the AnyLogic© software and the specifications from which this MAS is based off.

3.1. The Project PREmdeK

The current version of the PREmdeK Simulation is 3.0. Its predecessors, version 1.0 and 2.0 (see Figure 1), are implemented in AnyLogic© and follow the same energy concept: a simulation for prognostics and realization of the energy supply through decentral energy plants. PREmdeK balances local energy production with energy demands of (industrial consumers) in intervals of 15 minutes for up to a year time frame. The PREmdeK 1.0 simulation started off as a monolithic simulation with a hybrid power plant, grid connection and one main consumer as static and centralized control architecture. The simulation was not scalable and hardcoded without generic setup which made it difficult to change or expand the simulation. The following version – PREmdeK 2.0 – allowed access to databases that include historic weather data and load files. In PREmdeK 3.0, the simulation is implemented as generic MAS.

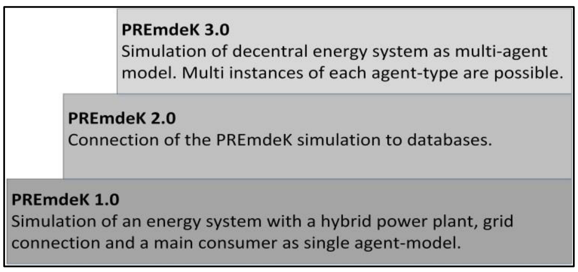

Fig. 1. The evolution of the PREmdeK Simulation

3.2. Simulation Software AnyLogic©

The AnyLogic© simulation software was created in the year 2000 by the AnyLogic Company. The simulation tool supports agent-based, discrete event and system dynamic modeling methods and provides the opportunity to combine these modeling methods (Multimethod Simulation Software and Solutions). AnyLogic© is a commercial (not open source) multimethod simulation platform. Its graphical interface, tools, and library objects allow quick modeling of diverse application fields. The object-oriented model design paradigm provides for modular, hierarchical, and incremental construction of large models. It already has a message exchange platform with pre-defined syntax for communication between agents. AnyLogic© is a popular software with high scalability and good learnability [9].

3.3. FIPA© Reference Architecture

The built MAS Architecture for PREmdeK is partly based on the FIPA© Specifications. The FIPA© is an organization that is dedicated to promoting agent-based technology and the interoperability of its standards with other technologies. These standard specifications contain definitions of architectural elements, such as basis classes and their relationships, guidelines for instantiations and interoperability guidelines [17]. Some of these specifications were used in the PREmdeK realization. Based on the Agent Management Specification [18], a component to find other agents in the agent platform and providing a yellow page service with agent IDs & service entries in form of a Directory Facilitator was installed. The Communicative Acts Library Specification [19] was used for a standardized communicative act between agents. In addition, NP interactions are based on the Contract Net Interaction Protocol (IP) Specification [20].

4. The Multiagent System Architecture of PREmdeK

For the PREmdeK 3.0 simulation, the following subsections present the agent architecture with the agent design itself, an agent management system and a communication method for the NP.

4.1. The Multiagent System Architecture

In this section, the focus of our MAS Architecture (see Figure 2) lies on the agent management and the agent design. The architecture consists of six basic agent types which are handled in AnyLogic as a Java Class Type: Directory Facilitator-, SCADA-, Grid-, Producer-, Consumer- and Prosumer- Agent type. The functions and methods realized in the respective type are explained in the following section.

The Directory Facilitator (DF) agent type is needed for the agent management inside the platform and it is based on the FIPA© Agent Management Specification [18]. The DF manages the agent registrations and de-registrations, generates individual agent IDs for every agent and provides yellow page services to other registered agents. The agent is a unique component inside the simulation platform. Its address is deposited as a *service_root* variable inside every other agent. The yellow pages contain agent services, agent names and agent addresses. Every agent is required to register their services at the DF. For the NP it is important that every agent can be found inside the agent platform or can find other agents by searching for specific agent services.

The next unique component inside the simulation platform is the SCADA agent type. It collects a defined set of information from all participating agents in the platform and saves the data in tables for a later analysis of the simulation results.

To represent the electrical or thermal grid in the simulation, a Grid agent type is defined. It can have an infinite amount or a defined amount of energy capacity and may represent a connection to another micro grid in the simulation.

The Consumer agent type represents an electrical and/or thermal consumer with an energy demand inside the platform. A consumer agent can be added and configured in three different ways: Configured as consumer, dispatchable consumer, and dispatchable consumer with integrated Demand Side Management (DSM). A dispatchable Consumer represents a consumer that can, but is not forced to, consume or store energy. A dispatchable DSM Consumer is able to control his energy demand to a specific range and does not need to be supplied completely.

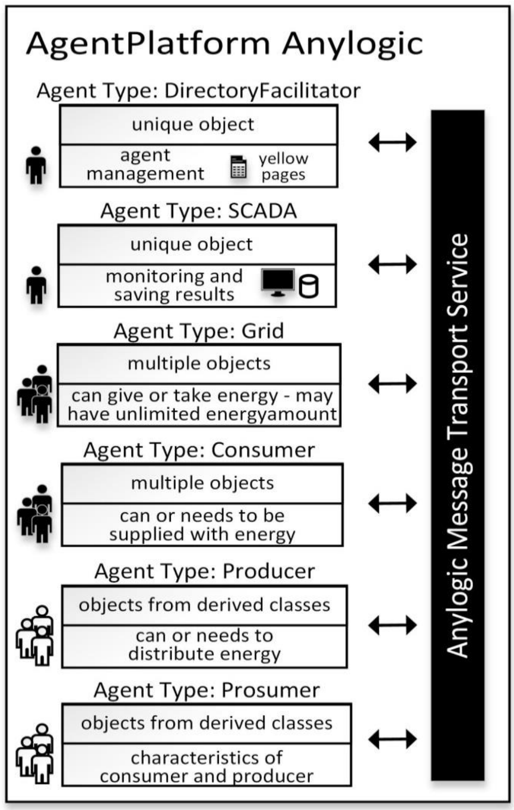

Fig. 2. MAS Architecture

The Producer agent type is needed for the implementation of an energy producer, for example a wind turbine (WT). The WT agent can be programmed with its internal functions and methods for a realistic representation of the physical process. It inherits the needed functions for the agent interoperability from the agent type producer. Analog to the consumer agent type, the producer can also represent an electrical and/or thermal energy producer and can be implemented as a dispatchable unit.

The Prosumer agent type represents a consumer and producer at the same time and shares the same specifications as both. For example, an Accumulator agent can be programmed and inherit from this base class. This gives him the needed interoperability und function to participate in the agent platform.

When using this agent types in the simulation, all types except the DF and the SCADA require extra steps. DF and SCADA are unique types that are permanently integrated in the Simulation. Grid and Consumer types can be used with a configuration beforehand. This configuration involves settings for the kind of type (electrical, thermal or dual) and agent specific setting. For a consumer for example, the historic load file for the energy consumption and the consumer type (normal, dispatchable or DSM and electrical, thermal or both) is needed. Producer and Prosumer agent types need a configuration too, but they can only be used inside a derived agent type like a wind turbine. This Concept makes it easy to implement new prosumer and producer agents. The agent type derivations that are planned for implementation have already been mentioned in the section 1.

4.2. Communication and Negotiation Phase

Interoperability for the agents of a MAS requires a method to exchange information. In this Simulation all agents reside on the same AnyLogic© agent platform. It provides a Message Transport Service (MTS) for an information exchange via messages between agents. By using this service, the agent can send a message with the integrated *sent* function and the use of the respective parameters for content and the agent address. The content is delivered within a self-defined message class. AnyLogic© uses its own self-generated addresses to transport a message to the correct receiver. The target agent can receive a message through a specific "Message-Arrival" Transition and save the content with the use of the AnyLogic© interface variable *msg*. The simulation runs on one computer system, cross platform communication is not intended, which means all agents share the same ontology and the use of an Agent Communication Language is not necessary.

For the communication, the MTS of AnyLogic© and the FIPA© Communicative Acts [19] are used. A communicative act defines a message type and the way it should be interpreted. In addition to the messages exchange, the NP defines the information of the messages to realize an energy exchange. The NP is split into three sub phases in which different participants communicate with each other. These phases were defined in the framework of a master thesis by Aitor Casado Garcia [21]. Every 15 minutes in the simulation, a new NP is started. The start of the NP begins with a call for proposal (based on FIPA© CNIP [20]) of the initiating agents for every sub phase. The initiating agents are looking for different partners depending on the actual phase. Participating agent types are the grid, consumer, producer and prosumer.

Figure 3 shows the different sub phases from the NP without an explicit listing of the prosumer because they participate as a producer or consumer depending on their energy balance. In sub phase one, all producing agents, which are required to sell their energy (not the dispatchable ones) to a consumer, are selling to the consumer agents. For the selling of the energy, several sustainable indicators are used, such as energy price, CO2 emission, and image of the factory. The values and the weighting of the indicator are specified by the user of the simulation. In case not all consumers can be provided with enough energy, the grid agent can support with the rest amount of energy. For this case, the NP has already finished. If the producers were not able to sell all their energy, they can sell their energy to dispatchable DSM consumer in sub phase 2.

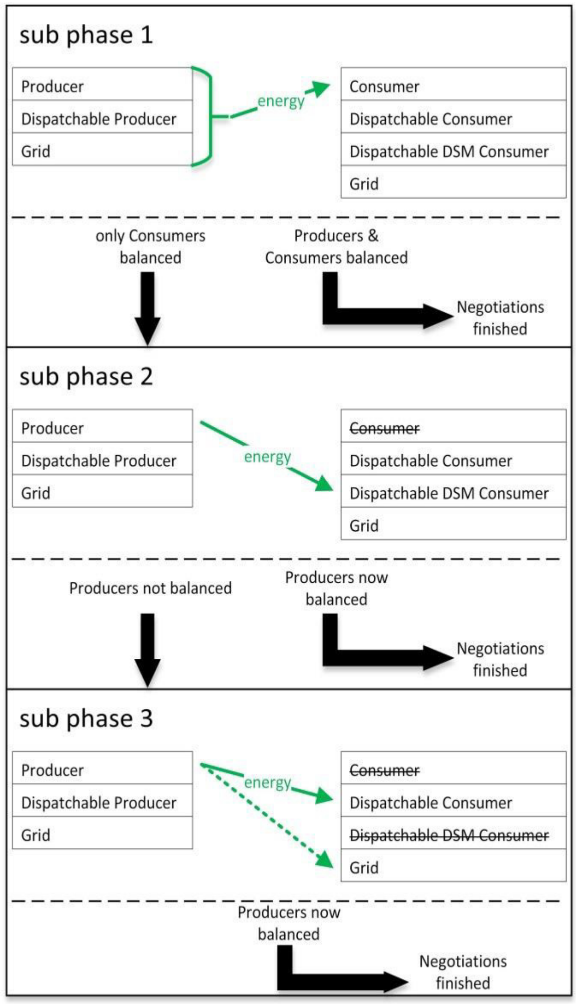

Fig. 3. Negotiation Phase with its three sub phases

If the producers were still not able to sell all energy, they can offer it to the dispatchable consumer and the grid to finally sell it in phase 3. These three phases leave the participating agents in a balanced energy state.

4.3. The PREmdeK 3.0 Simulation

This section shows the different features of the PREmdeK 3.0 simulation, and how it can be used by giving an example. When starting the simulation (available as a standalone version or via AnyLogic©), the user must configure the scenario he wants to simulate. An exemplary scenario is the following:

- Two consumers with specific load profiles
- One photovoltaic (PV) agent
- One grid agent to represent the electrical grid

For ease of explaining, the scenario considers the exchange of electrical energy only. For the example, Figure 4 shows the implemented agents and its origins. The DF and the SCADA agent origins are not explicitly shown in the figure, because they are unique objects which appear in every simulation.

The configuration of the scenario begins with an input mask in which the user must set the overall configuration setting. These are the settings for the time base and the simulation duration. The time base defines the time the NP reoccurs (in this example 15 min), and the simulation duration sets the simulation time (for example: one year). Another input masks are for the individual agent type setting. All agent type settings have one common input – the number of agents the user wants to create of a specific subtype. Every agent type has been given a limited number of subtypes to create to improve the clarity and usability of the input mask (the limitation can be removed). For example, the input mask of the PV agent is limited to five different subtypes, which means you can configure five different versions of PV agents, but as many of these versions as you want. For our example scenario, one subtype of the PV agent type, with a reference to a table with weather data, two subtypes for the two consumers, with references to tables with the historic load files for the electrical energy and an electrical grid agent with an infinite amount of energy capacity are configured. Then, a last setting for the simulation scenario has to be made.

A Pricing Matrix (PM) input mask shows producing agents on the horizontal axis and the consuming agents on the vertical as you can see in Figure 5. The PM represents the different pricing relations between the producer and consumer. For example, the photovoltaic agent can sell its energy to the first consumer for a different price than to the second consumer. This would usually be the case if the consumer 1 and the photovoltaic agent are from the same company and consumer 2 is from a different company, which results in different pricing conditions.

With the setting of the PM, the scenario settings are completed, and the simulation model starts. All configured agents as well as the DF and SCADA agents are added automatically and register themselves at the DF agent. They receive an identifier from the DF and an agent address from the MTS. The internal functions of the PV agents calculate the energy generation based on the weather data. When the first 15 minutes are simulated, the NP starts and the participating agents begin to act according to their CNP based state charts. In each of the sub phases the agents search their respective partners with the help of the DF and start a negotiation according to the CNP procedure. They exchange their energy based on the price and the CO2 amount. The simulation now runs until the set simulation time is finished. The time it takes to run the simulation depends on the computer and the number of agents that are added. The time for the reference PC (Intel i7-6820HQ, 2.7GHz, 32GB Ram, Win7-64Bit) for this simulation scenario is under 16 minutes for a one-year simulation period split in 15 min. intervals.

Finally, the user can export the simulations results as Excel format for further analysis or directly have a look at the developed results visualization.

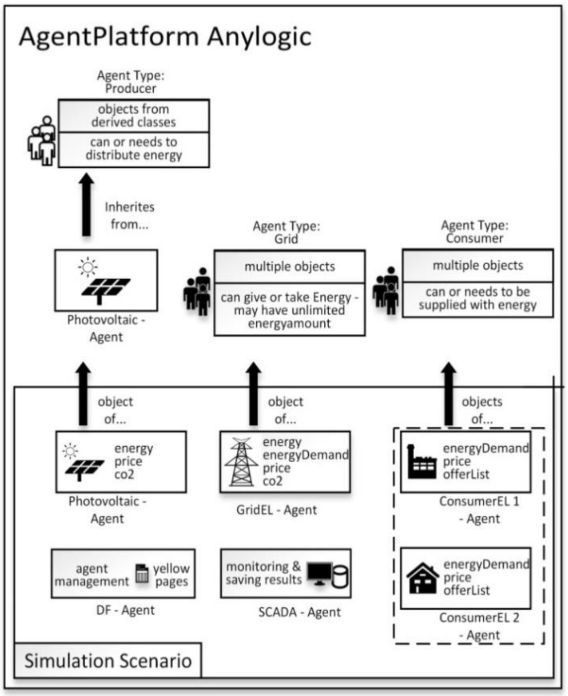

Fig. 4. Simulation Example Scenario

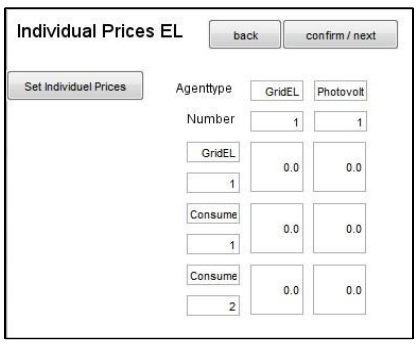

Fig. 5. Price Matrix for Example Scenario

5. Conclusion

This paper describes the design and implementation of the PREmdeK 3.0 simulation. It uses the MAS technology to represent the participants of a local energy system of a green factory with a VPP. For the implementation of the MAS, the AnyLogic© Agent Platform is used. We designed an agent architecture with an easy way to add new RE plants into the simulation. New producer or prosumer derivations can get all interoperability functions of the agent platform through the inheritance of one of the basic classes. The simulation is able to realistically present the RE plants (weather data, complex physical models). It simulates models from small sized to medium sized VPP. Simulations for a time interval of many years can be performed in which the agent structure is able to alter the composition of the participants while running (joining and leaving agents). A PM enables different prices between every participant in the energy system. In addition to the producing, consuming and prosuming agents, a grid agent has been implemented. This enables a guaranteed balanced energy state or represents an uplink to another micro grid. The SCADA agent automatically collects, visualizes and saves all the relevant data from the simulation. The management of the MAS from registration of agents to giving out address information to the agents is implemented in the DF agent. A NP based on the CNP guarantees the optimal energy exchange and an updated energy status of the local energy system. The first simulation of small VPPs with two consumers, a photovoltaic and a grid agent was tested and demonstrated the functionality of the system. The previous PREmdeK versions biggest limitation were the centralized program structure resulting in high amount of engineering work when implementing new RE plants. Due to the concept of inheritance and the generic character of the agent architecture, the implementation of new producer or prosumer derived agents can be performed without deep knowledge of the MAS itself.

This flexible and generic simulation model will help decision makers to evaluate the potential to change from a classical energy supply (often fossil energy) to a self-supply by own RE plants. It gives reliable information thanks to the use of real energy demand profiles and historic weather data and lays the groundwork for a feasibility study to develop towards green manufacturing.

Additionally to the already implemented producer agent derivations (wind turbines, photovoltaics, calorific boilers) the developments of more producer agent derivations (combined heat and power, geothermal energy, solar panels, batteries, hydrogen accumulators, thermal accumulators) are planned in the future. A test phase has yet to show the functionality of more complicated and larger grid sizes. The usability of the agent configuration, for example the input method of the PM, must be improved for larger numbers of agents in the simulation. The simulation could even be extended to an autonomous testing of different VPP combinations to determine the optimal composition of the VPP without any complex pre-configuration. These measures could not only improve the results but also extend the application area of the software to larger companies.

References

[1] Presse- und Informationsamt der Bundesregierung, Bundesregierung | Energiewende: Was sind die Kernpunkte/Ziele der Energiepolitik der Bundesregierung? [Online] Available: https://www.bundesregierung.de/Webs/Breg/DE/Themen/Energiewende/Fragen-Antworten/1_Allgemeines/1_warum/_node.html. Accessed on: Sep. 28 2017.

[2] International Energy Agency, Accelerating Energy Efficiency in Small and Medium-sized Enterprises. [Online] Available: https://www.iea.org/publications/freepublications/publication/SME_2015.pdf.

[3] KfW Bankengruppe: Abteilung Volkswirtschaft, KfW-Wettbewerbsindikator 2016: Deutscher Mittelstand muss seine Wettbewerbsposition verteidigen - und dazu seine Energieeffizienz weiter verbessern. [Online] Available: https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-Wettbewerbsindikator/KfW-Wettbewerbsindikator_2016.pdf.

[4] A. Pechmann and M. Zarte, "Economic Analysis of Decentralized, Electrical- and Thermal Renewable Energy Supply for Small and Medium-Sized Enterprises," Procedia CIRP, vol. 61, pp. 422–427, 2017.

[5] H. Emden/Leer, PREmdeK. [Online] Available: http://www.hs-emden-leer.de/forschung-transfer/projekte/premdek.html. Accessed on: Oct. 07 2017.

[6] M. Wooldridge, An introduction to multiagent systems, 2nd ed. Chichester: Wiley, 2009.

[7] The AnyLogic Company, Multimethod Simulation Software and Solutions. [Online] Available: https://www.anylogic.com/. Accessed on: Sep. 28 2017.

[8] A. Borshchev, The big book of simulation modeling: Multimethod modeling with AnyLogic 6. Chicago: AnyLogic North America, 2013.

[9] K. Kravari and N. Bassiliades, "A Survey of Agent Platforms," JASSS, vol. 18, no. 1, 2015.

[10] S. Abar, G. K. Theodoropoulos, P. Lemarinier, and G. M.P. O'Hare, "Agent Based Modelling and Simulation tools: A review of the state-of-art software," Computer Science Review, vol. 24, pp. 13–33, 2017.

[11] C. Macal and M. North, "Introductory tutorial: Agent-based modeling and simulation," in Winter Simulation Conference (WSC), 2014: 7 - 10 Dec. 2014, Savannah, GA, Savanah, GA, USA, 2014, pp. 6–20.

[12] R. Brehm, S. Top, and S. Matefi-Tempfli, "A distributed multi-agent linear bi-objective algorithm for energy flow optimization in microgrids," in Proceedings of 2015 IEEE International Renewable and Sustainable Energy Conference (IRSEC'15), Marrakech, 2015, pp. 1–6.

[13] L. Hernandez et al., "A multi-agent system architecture for smart grid management and forecasting of energy demand in virtual power plants," IEEE Commun. Mag., vol. 51, no. 1, pp. 106–113, 2013.

[14] T. Logenthiran, D. Srinivasan, and A. M. Khambadkone, "Multi-agent system for energy resource scheduling of integrated microgrids in a distributed system," Electric Power Systems Research, vol. 81, no. 1, pp. 138–148, 2011.

[15] T. Logenthiran, D. Srinivasan, and D. Wong, "Multi-agent coordination for DER in MicroGrid," in IEEE International Conference on Sustainable Energy Technologies, 2008: ICSET 2008 ; Singapore, 24 - 27 Nov. 2008, Singapore, Singapore, 2008, pp. 77–82.

[16] H.-M. Kim, Y. Lim, and T. Kinoshita, "An Intelligent Multiagent System for Autonomous Microgrid Operation," Energies, vol. 5, no. 12, pp. 3347–3362, 2012.

[17] FIPA Abstract Architecture Specification, SC00001L.

[18] FIPA Agent Management Specification, SC00023K.

[19] FIPA Communicative Act Library Specification, SC00037J.

[20] FIPA Contract Net Interaction Protocol Specification, SC00029H.

[21] A. Casado Garcia, "PREMDEK 3.0: A multi-agent simulation software for the analysis of virtual power plants," Master Thesis, Faculty of Technology, University of Applied Sciences Emden/Leer, Constantinplatz 4, 26723 Emden, 2016.