**Possibilities of Multi-Agent Model of Decentralized Energy Sources**

***Zimmermannová, Jarmila; Čermák, Petr; Pawliczek, Adam***

***Moravian University College Olomouc***

**Introduction and Literature Overview**

Ministry of Industry and Trade of the Czech Republic prepared the "**National Action Plan for Smart Grids (NAP SG)**”. Smart grids (SG) are defined as the electric networks that are able to effectively link the behaviour and actions of all users connected to them - producers, consumers, prosumers (consumers with their own production) - to ensure the economically efficient, sustainable energy systems operating with low losses and high reliability of supply and safety (MIT, 2015). Regarding the schedule of NAP SG implementation, the period up to 2019 can be characterized as a period of preparation, following period 2020-2029, represents the gradual implementation of SG in order to achieve maximum economic efficiency at the required level of "intelligence" of the SG in the period between 2030 and 2040 in accordance with the needs of the energy system and the existing technological level at that time (MIT, 2015).

As is mentioned in NAP SG, in connection with **the development of renewable energy sources**, the anticipated development of small sources, including combined heat and power production, the development of storage capacities and electro-mobility, increases demand on control systems, protection systems, measuring equipment, automation equipment and other elements of the power system.

An integral part of considerations on the integration of intelligent elements into electricity system of the Czech Republic is to ensure cyber security, privacy and information support provided to the client for his decision (MIT, 2015).

Therefore the importance and necessity of economic models in this area is increasing, especially in case of **models representing the suitable tool for decision making**.

The real behaviour and decision making of particular economic entities can be different in situation with or without interactions with other entities – in other words the rules within a group of economic entities can be different than individual entity rules. The approach, which includes also interaction rules, is called **ABM - agent based modelling**.

The modelling based on the agent based modelling or complex multi-agent modelling has been historically used mainly in the field of engineering and information sciences; however, the importance of this kind of models has been rapidly increasing in the economic sciences and management, mainly in the area of financial markets management, corporate management, water management, waste management, land management, transportation and energy sources management. Applying agent based modelling, the researcher explicitly describes the decision making processes of particular actors at micro level. The structure emerges at the macro level as a result of the actions of the agents and their interactions with each other (Janssen and Ostrom, 2006).

Focusing on scientific studies based on **financial markets**, we can find for example agent-based model with multi-level herding for complex financial systems (Chen et al., 2015), consentaneous agent-based and stochastic model of financial markets (Gontis and Kononovicius, 2014), agent-based double auction markets (Cai et al., 2014) and synthesis of agent-based financial markets and New Keynesian macroeconomics (Lengnick and Wohltmann, 2013).

Regarding interesting studies in **management**, there should be mentioned mainly multi-agent systems for the simulation of land-use and land-cover change (Parker et al., 2003), ecosystem management (Bousquet and Le Page, 2004), urban traffic management and planning (Fiosins et al., 2011) or energy management (Lagorse at al., 2010).

There are also studies focused on multi-agent models connected with **climate change or carbon emissions reduction**, for example the study focused on estimating the impacts of climate change policy on land use (Morgan and Daigneault, 2015) and carbon emissions trading scheme exploration in China (Tang et al., 2015)

Analysis of current scientific studies using agent-based or multi-agent models reveals that there is a lack of agent-based models dealing simultaneously with economic and environmental issues, mainly in the area of sustainable energy development and reduction of greenhouse gas emissions.

Moreover, a dynamic model is needed, since the economic entities have the ability to learn and optimize their behaviour continuously, depending on both external and internal changes in their environment. However, there is also a question of uncertainty, unexpected changes and disturbances in the economic system, therefore we need also methods based on language rules.

Therefore, **the main goal of our research** is create multi-agent model of decentralized energy sources (DES). We can build on our experiences with the proposal of multi-agent simulation model application in the emission allowances trading area (Zimmermannová and Čermák, 2014) and with creation of a pilot model of a single agent – the broker simulation model in the emission allowances trading area, based on fuzzy logic and language rules (Čermák et al., 2015).

**Methodology and Data**

For the purposes of creating of multi-agent model of decentralized energy sources (DES) suitable for decision making, we are going to use different **methods**, including statistical methods, econometric methods and nonconventional methods using fuzzy logic. The particular models will be tested and validated on the real scenarios.

We are going to create models on **two different levels** – **micro-level** multi-agent model, representing one household – prosumer and **macro-level** multi-agent model, representing the whole economy. For the purposes of this abstract, we will present the proposal of micro-level multi-agent agent model of DES suitable for decision making in one household - prosumer. Generally, the particular models will have the following characteristics:

**Micro-level Multi-Agent Model of DES**

* 1 household with own electricity generation (photovoltaic panels or other) - prosumer;
* Particular agents in multi-agent model:
	+ Photovoltaic panels or other sources of energy,
	+ Batteries,
	+ Distributional network;
* The main goal of the agents – to cover electricity consumption in household with minimal costs.

**Macro-level Multi-Agent Model of DES**

* More households with own electricity generation (photovoltaic panels or other), other electricity generators (wind, water, biogas, biomass);
	+ Particular agents in multi-agent model – particular electricity generators;
	+ Distributional network;
	+ Institutional environment.
* The main goal of the agents – to cover electricity consumption in the whole economy with minimal costs and minimal emissions of greenhouse gases and other pollutants.

Regarding data, we have **original dataset** of daily production of electricity from photovoltaic power plant, installed in VSB-TU Ostrava, simultaneously we have also original dataset of daily electricity consumption in typical household, modelled also in VSB-TU Ostrava. Both original datasets are available for the authors within the project TH01020426.

We use also **data from national statistics** of Czech Statistical Office (CZSO), Czech Hydro-meteorological Institute (CHMI), Energy Regulatory Office (ERO) etc.

**Preliminary Results**

The following Figure 1 presents the structure of proposed micro-level multi-agent model of DES suitable for decision making in one household - prosumer.

**Figure 1: The structure of multi-agent model of DES for one household**



Source: authors

Regarding the Figure 1, EC1 - ECn represent particular energy consumers (electrical equipment in household and the rules of electricity consumption for each of them), EG1 - EGm represent individual energy generators and the profile of their electricity generation, E-OPER1 – E-OPERk represent particular energy operators on the market, EC MIX represents energy consumption mix, precisely all rules based on definition of energy consumer devices switching profile (day of week, time), the other variables in the model are Environmental and natural conditions - Online – Sensors and Offline – external Database (Internet, Organization CHI Aladin…). In the middle of the model there we can find the decision-making unit – switcher, mixer which we can define better as E-broker.

For the purposes of creation of the model, **the following steps are needed**:

1. Prediction based on Environmental and Natural conditions;
2. Prediction based on Week - Days Consumption of Household;
3. Optimization of Energy Consumption Mix;
4. Optimization selection of Energy generator and/or Energy operator.

**References**

BOUSQUET, F., LE PAGE, C. 2004. Multi-agent simulations and ecosystem management: a review. *Ecological Modelling*, vol. 176, no. 3-4, pp. 313-332. DOI: 10.1016/j.ecolmodel.2004.01.011.

CAI, K., NIU, J.Z. PARSONS, S. 2014. On the effects of competition between agent-based double auction markets. *Electronic Commerce Research and Applications*, vol. 13, no. 4, pp. 229-242, DOI: 10.1016/j.elerap.2014.04.002.

CERMAK, P., ZIMMERMANNOVA, J., LAVRINCIK, J., POKORNY, M., MARTINU, J. 2015. The Broker Simulation Model in the Emission Allowances Trading Area. *International Journal of Energy Economics and Policy*, vol. 5, no. 1, pp. 80-95. ISSN: 2146-4553.

CHEN, J.J. TAN, L., ZHENG, B. 2015. Agent-based model with multi-level herding for complex financial systems. *Scientific Reports*, vol. 5, article no. 8399, DOI: 10.1038/srep08399.

FIOSINS, M., FIOSINA, J., MULLER, J.P., GORMER, J. 2011. Agent-Based Integrated Decision Making for Autonomous Vehicles in Urban Traffic. Advances on Practical Applications of Agents and Multi-Agent Systems. Edited by: Demazeau, Y., Pechoucek, M. Corchado, J.M., Bajo, J. Book Series: *Advances in Intelligent and Soft Computing*, vol. 88, pp. 173-178. DOI: 10.1007/978-3-642-19875-5\_22.

GONTIS, V., KONONOVICIUS, A. 2014. Consentaneous Agent-Based and Stochastic Model of the Financial Markets. *Plos One*, vol. 9, no. 7, article no. e102201, DOI: 10.1371/journal.pone.0102201

JANSSEN, M. A., OSTROM, E. 2006. Empirically based, agent-based models. *Ecology and Society*, vol. 11, no. 2, art.37.

LAGORSE, J., PAIRE, D., MIRAOUI, A. 2010. A multi-agent system for energy management of distributed power sources. *Renewable Energy*. vol. 35, no. 1, pp. 174-182. DOI: 10.1016/j.renene.2009.02.029.

LENGNICK, M., WOHLTMANN, HW. 2013. Agent-based financial markets and New Keynesian macroeconomics: a synthesis. *Journal of Economic Interaction and Coordination*, vol. 8, no. 1, pp. 1-32, DOI: 10.1007/s11403-012-0100-y.

MIT (Ministry of Industry and Trade of the Czech Republic). 2015. *National Action Plan for Smart Grids (NAP SG)*. Available online at: www.mpo.cz

MORGAN, F.J., DAIGNEAULT, A.J. 2015. Estimating impacts of climate change policy on land use: An agent-based modelling approach. *PLoS ONE*, vol. 10, issue 5, 21 May 2015, article number e0127317.

PARKER, D.C., MANSON, S.M., JANSSEN, M.A., HOFFMANN, M.J., DEADMAN, P. 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. *Annals of the Association of American Geographers*, vol. 93, no. 2, pp. 314-337, DOI: 10.1111/1467-8306.9302004.

TANG, L., WU, J., YU, L., BAO, Q. 2015. Carbon emissions trading scheme exploration in China: A multi-agent-based model. *Energy Policy*, vol. 81, 1 June 2015, pp. 152-169.

ZIMMERMANNOVÁ, J., ČERMÁK, P. 2014. Possibilities of Multiagent Simulation Model Application in the Emission Allowances Trading Area. *Procedia Economics and Finance*, 2014, vol. 12, pp. 788-796. DOI: 10.1016/S2212-5671(14)00406-7.