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Possibilities of Multi-Agent Model of Decentralized Energy Sources

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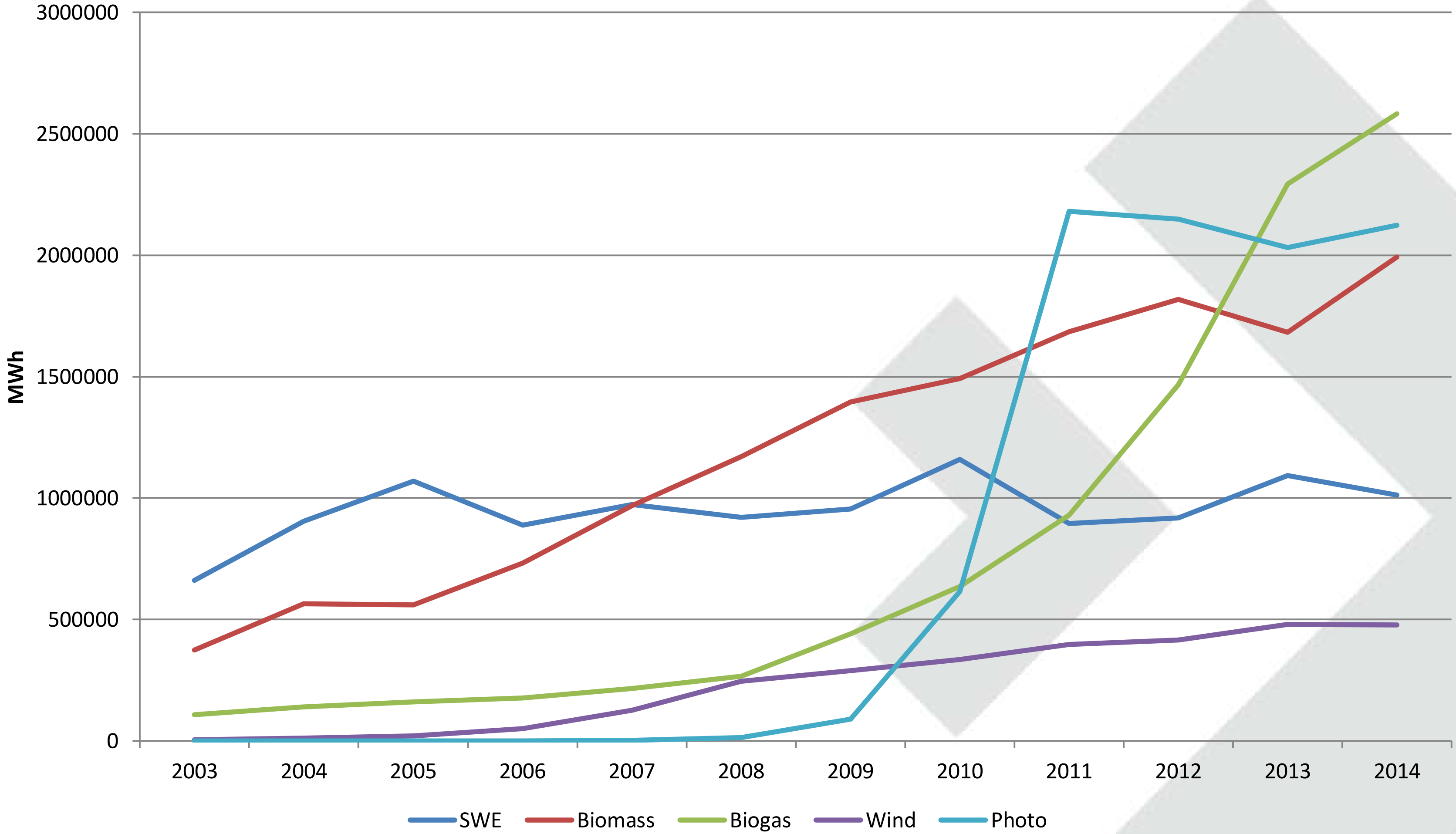
Schedule

- Introduction
- Methodology
- Data
- Preliminary results
- Next steps

Smart Grids

- Ministry of Industry and Trade CR (MIT) - **"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).
- **Schedule of NAP SG implementation in CR:**
  - the period up to 2019 – preparation
  - 2020-2029 - implementation of SG
  - 2030-2040 – finishing implementation
- **Expectations:**
  - development of renewable energy sources
  - development of small sources, including combined heat and power production
  - 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 - to ensure cyber security, privacy and information support provided to the client for his decision (MIT, 2015).

Situation in CR – development of generation of electricity from RES



Agent Based Modelling

- **Real behaviour and decision making of particular economic entities** - can be different in situation with or without **interactions** with other entities
- **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 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).
- Scientific studies based on **financial markets** - AB model with multi-level herding for complex financial systems (Chen et al., 2015), consentaneous AB and stochastic model of financial markets (Gontis and Kononovicius, 2014), AB double auction markets (Cai et al., 2014) and synthesis of AB financial markets and New Keynesian macroeconomics (Lengnick and Wohltmann, 2013).
- Studies in **management -** 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).
- Studies focused on multi-agent models connected with **climate change or carbon emissions reduction -** 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).

The main goal

- **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.
- Question of **uncertainty, unexpected changes and disturbances** in the economic system - we need also methods based on **language rules**.
- **The main goal of our research is create multi-agent model of decentralized energy sources (DES).**
- Our experiences:
  - proposal of multi-agent simulation model application in the emission allowances trading area (Zimmermannová and Čermák, 2014)
  - 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 (1)

- **Multi-agent model of decentralized energy sources (DES) creation** - different methods, including statistical methods, econometric methods and nonconventional methods using fuzzy logic
- Particular agent models will be **tested and validated on the real scenarios**.
- Models on **two different levels:**
  - **micro-level** multi-agent model, representing one household – prosumer
  - **macro-level** multi-agent model, representing the whole economy
- **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 – generation of elektricity (including prediction), Batteries, Distributional network, Consumption of electricity (including prediction).
  - **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.**

Methodology (2)

- Fuzzy rule-based systems - Takagi-Sugeno rules and Mamdani type of rules
- Takagi-Sugeno fuzzy rule-based system is defined as

IF (x_1 is $A_{1,1}$) AND . . . (x_n is $A_{n,1}$) THEN ($y_2 = f(x_1, x_2, x_3, ..., x_n)$)

.

.

IF (x_1 is $A_{1,r}$) AND . . . (x_n is $A_{n,r}$) THEN ($y_r = f(x_1, x_2, x_3, ..., x_n)$)

- Mamdani fuzzy rule-based system is defined as

IF (x_1 is $A_{1,1}$) AND . . . (x is $An_{,1}$) THEN (y_1 is C_1)
IF (x_1 is $A_{1,1}$) AND . . . (x is $A_{n,1}$) THEN (y_2 is C_2)

.

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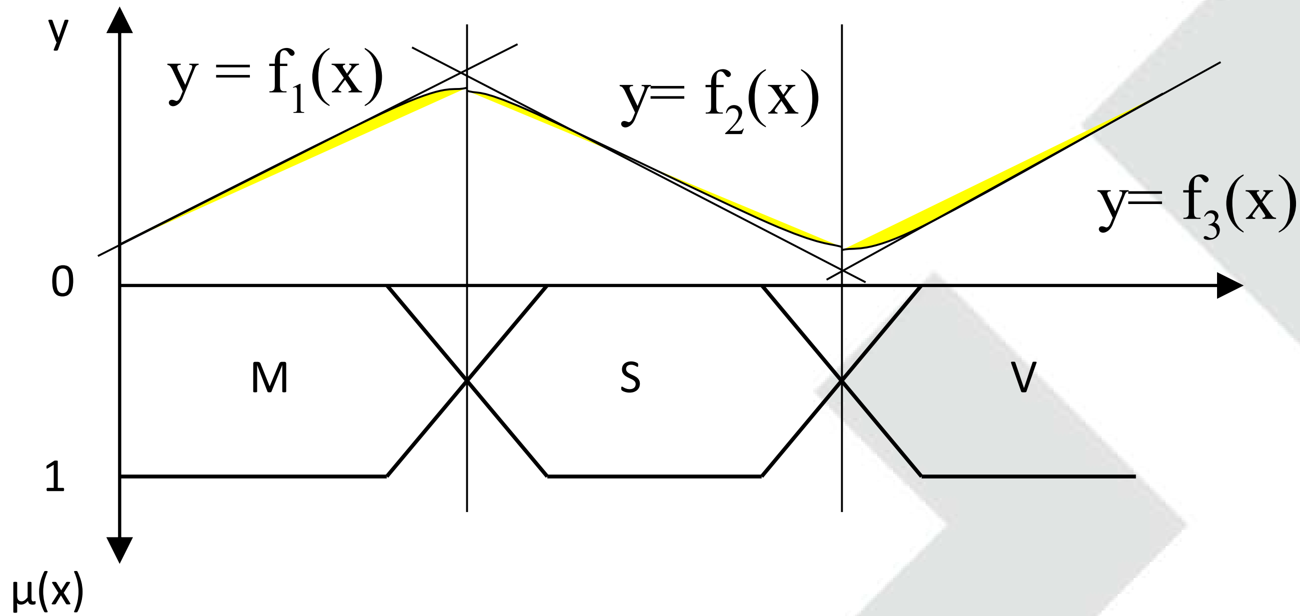
IF (x_1 is $A_{1,r}$) AND . . . (x is $A_{n,r}$) THEN (y_r is C_r)

Takagi Sugeno fuzzy model

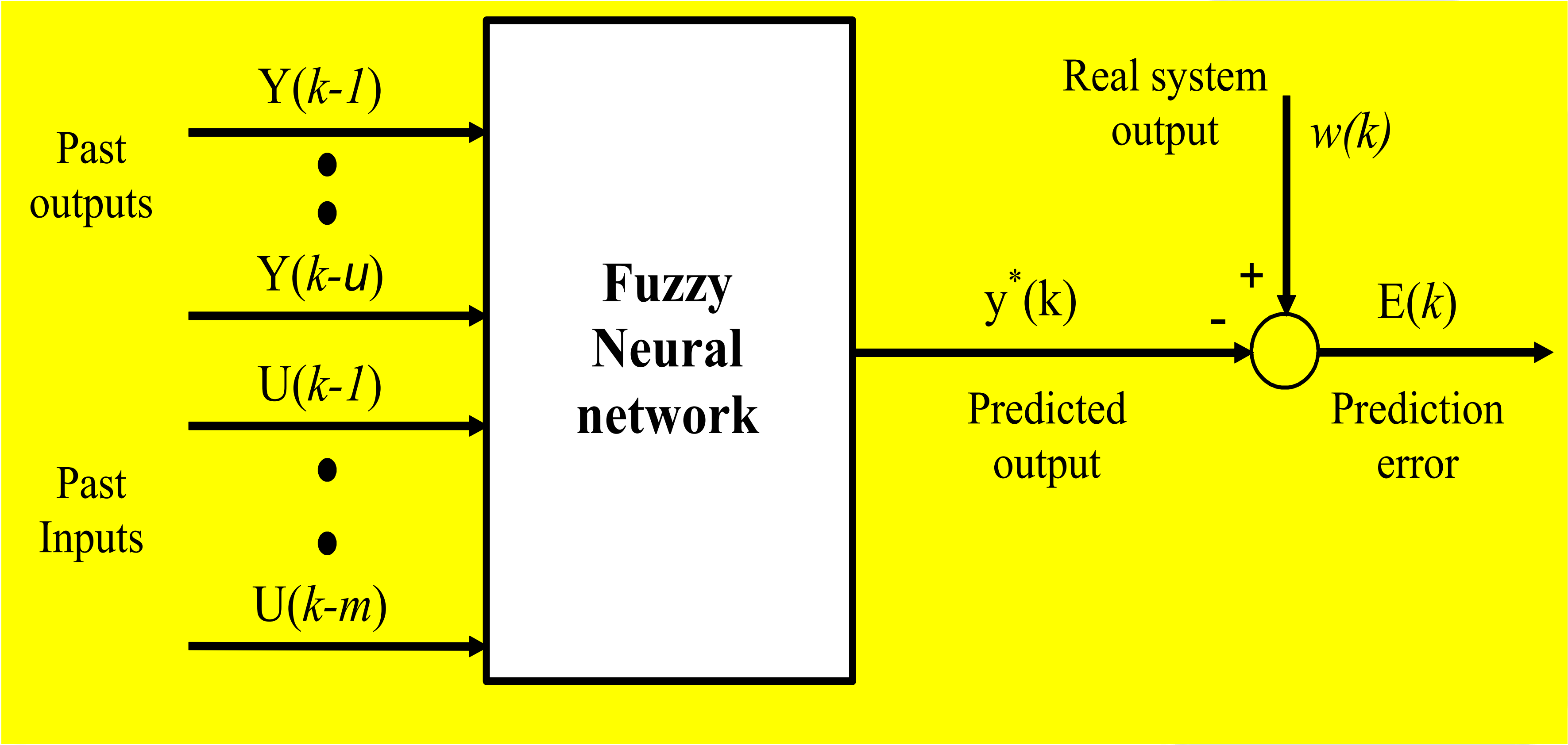


IF x je M THEN $y = f_1(x)$
IF x je S THEN $y = f_2(x)$
IF x je V THEN $y = f_3(x)$

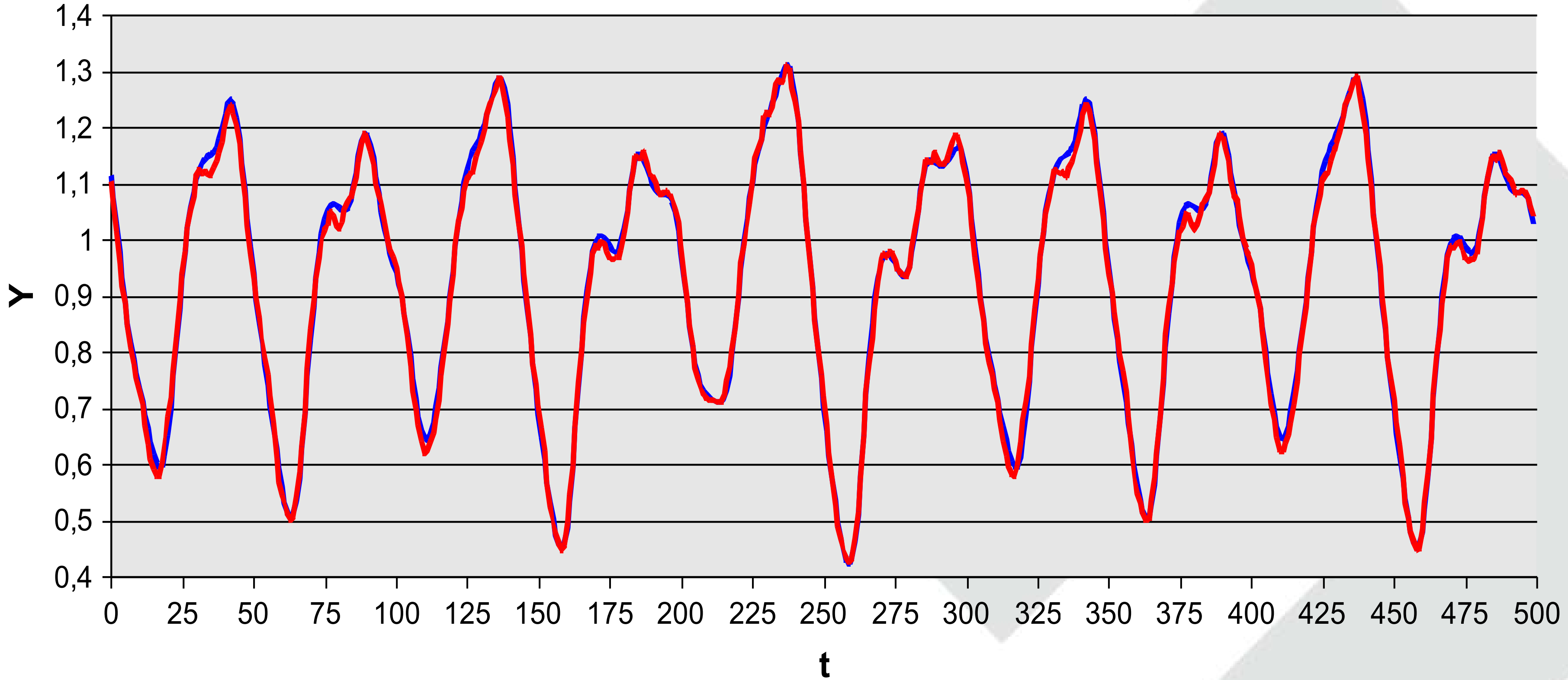
Example of Takagi Sugeno rules

R001: IF (x1 is V11) and (x2 is V21) and (x3 is V31) and (x4 is V41) THEN
y = 1.09469-0.690223*x1 + 1.03483*x2-0.128257*x3 + 0.0996489*x4
R002: IF (x1 is V12) and (x2 is V22) and (x3 is V32) and (x4 is V42) THEN
y = 1.90359-0.805883*x1-1.30222*x2 + 0.543905*x3 + 0.155355*x4
R003: IF (x1 is V12) and (x2 is V22) and (x3 is V32) and (x4 is V41) THEN
y = 1.8211-1.00528*x1-0.750234*x2 + 0.473591*x3-0.0612897*x4
R004: IF (x1 is V12) and (x2 is V22) and (x3 is V31) and (x4 is V42) THEN
y = 2.0326-1.19364*x1 + 0.269845*x2 + 0.283392*x3-0.126903*x4
R005: IF (x1 is V12) and (x2 is V22) and (x3 is V31) and (x4 is V41) THEN
y = 1.82379-1.03537*x1-0.52819*x2 + 0.299011*x3-0.219906*x4
R006: IF (x1 is V12) and (x2 is V21) and (x3 is V32) and (x4 is V42) THEN
y = 1.83692-1.3708*x1 + 0.178394*x2 + 0.213255*x3-0.2576*x4
R007: IF (x1 is V12) and (x2 is V21) and (x3 is V32) and (x4 is V41) THEN
y = 2.01691-1.16742*x1 + 0.261273*x2 + 0.264124*x3-0.194312*x4
R008: IF (x1 is V12) and (x2 is V21) and (x3 is V31) and (x4 is V42) THEN
y = 1.97393-1.16075*x1 + 0.193406*x2 + 0.0245755*x3-0.357652*x4
R009: IF (x1 is V12) and (x2 is V21) and (x3 is V31) and (x4 is V41) THEN
y = 1.68452-1.19928*x1 + 0.0210866*x2 + 0.657662*x3-0.192889*x4
R010: IF (x1 is V11) and (x2 is V22) and (x3 is V32) and (x4 is V42) THEN
y = 1.48979-0.396493*x1-0.961119*x2-0.221355*x3 + 0.698982*x4
R011: IF (x1 is V11) and (x2 is V22) and (x3 is V32) and (x4 is V41) THEN
y = 1.5541-1.3708*x1-0.0272309*x2-0.0585846*x3-0.496947*x4
R012: IF (x1 is V11) and (x2 is V22) and (x3 is V31) and (x4 is V42) THEN
y = 1.68834-1.23168*x1 + 0.0849583*x2 + 0.0739521*x3-0.307045*x4
R013: IF (x1 is V11) and (x2 is V22) and (x3 is V31) and (x4 is V41) THEN
y = 1.81918-1.32262*x1 + 0.134621*x2 + 0.164378*x3-0.267695*x4
R014: IF (x1 is V11) and (x2 is V21) and (x3 is V32) and (x4 is V42) THEN
y = 0.805851 + 0.0747284*x1 + 0.23763*x2-0.173145*x3 + 0.519782*x4
R015: IF (x1 is V11) and (x2 is V21) and (x3 is V32) and (x4 is V41) THEN
y = 1.14531-1.36164*x1 + 0.721637*x2 + 0.0261984*x3-0.686407*x4
R016: IF (x1 is V11) and (x2 is V21) and (x3 is V31) and (x4 is V42) THEN
y = 0.63527 + 0.00234604*x1 + 0.878172*x2-0.413706*x3 + 0.657844*x4

FNRM (Fuzzy Neuro Regression Model) Predictor



Example of prediction



Methodology (3)

- **Fuzzy rule-based system - Mamdani type of rules** is defined as

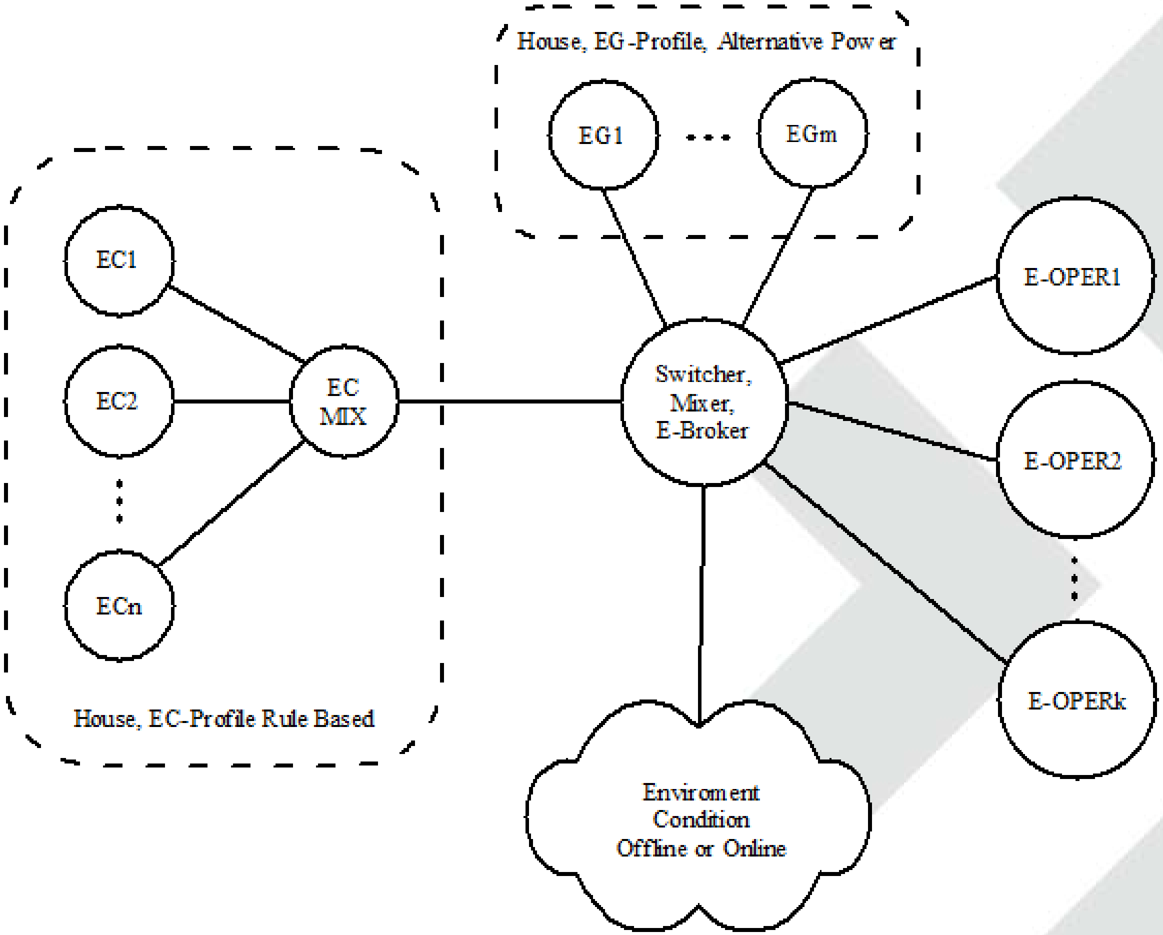
IF (x_1 is $A_{1,1}$) AND . . . (x is $An_{,1}$) THEN (y_1 is C_1)
IF (x_1 is $A_{1,1}$) AND . . . (x is $A_{n,1}$) THEN (y_2 is C_2)
.
.
IF (x_1 is $A_{1,r}$) AND . . . (x is $A_{n,r}$) THEN (y_r is C_r)

- Well suited to develop an expert system, based on definitions of behavior of particular agents [Čermák and Chmiel, 2004].
- The examples of Mamdani rule:
  - **“IF the year season is winter AND the weather is cloudy AND the day time is morning THEN the electricity generation is SMALL.”**
  - **„IF the year season is winter AND the weather is wind AND the day time is night THEN the electricity consumption is SMALL.“**

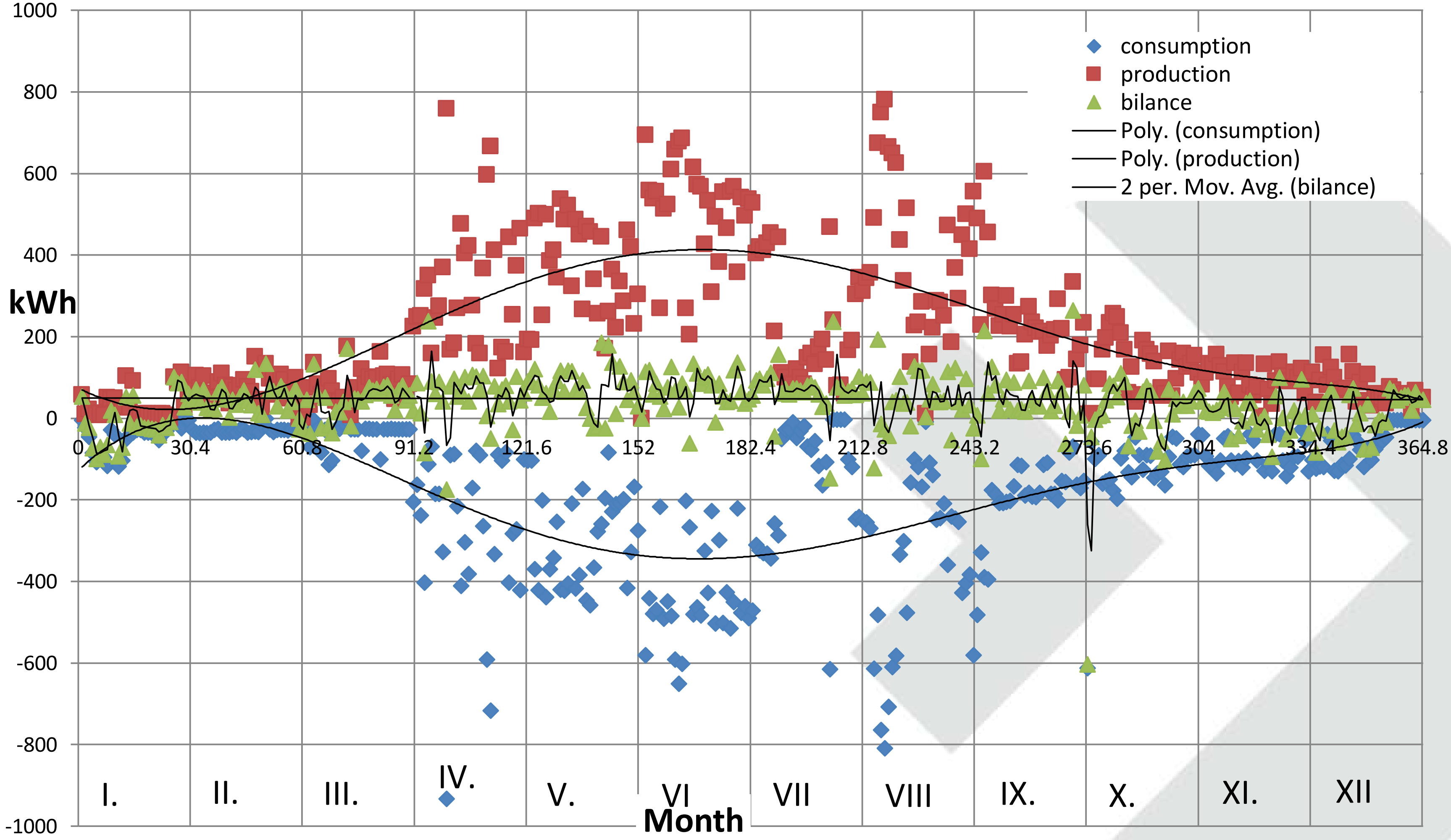
Data

- **Original dataset of daily generation of electricity** from photovoltaic power plant, installed in VSB-TU Ostrava;
- **Original dataset of daily consumption of electricity** in typical household, modelled also in VSB-TU Ostrava;
- **Data from national statistics:**
  – Czech Statistical Office (CZSO)
  – Czech Hydro-meteorological Institute (CHMI)
  – Energy Regulatory Office (ERO) etc.

Results: The structure of multi-agent model of DES for one household



Agent behaviour – generation and consumption of electricity (kWh) – experimental dataset – photovolatic panels 10 kWp



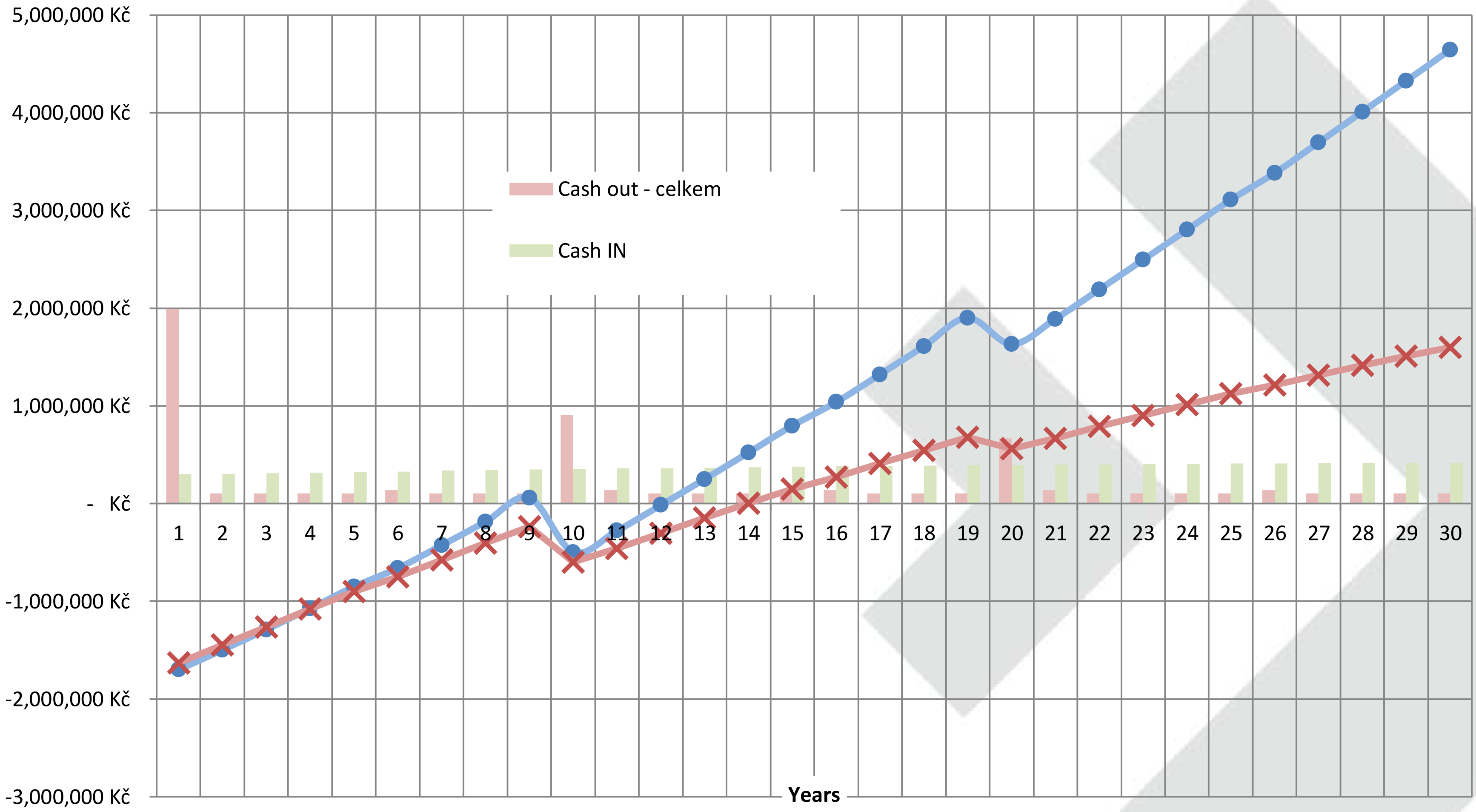
Agent - consumption of electricity

- **Energy consumers - electrical equipment in experimental household**:
  - electric saw, hairdryer, HIFI, air conditioning, refrigerator, microwave, blender, cell phone, freezer, dishwasher, computer, radio, electric kettle, lawn mower, trimmer, tablet, printer, oven, TV, power dril, vacuum cleaner, a light bulbs, energy-saving lamps, iron

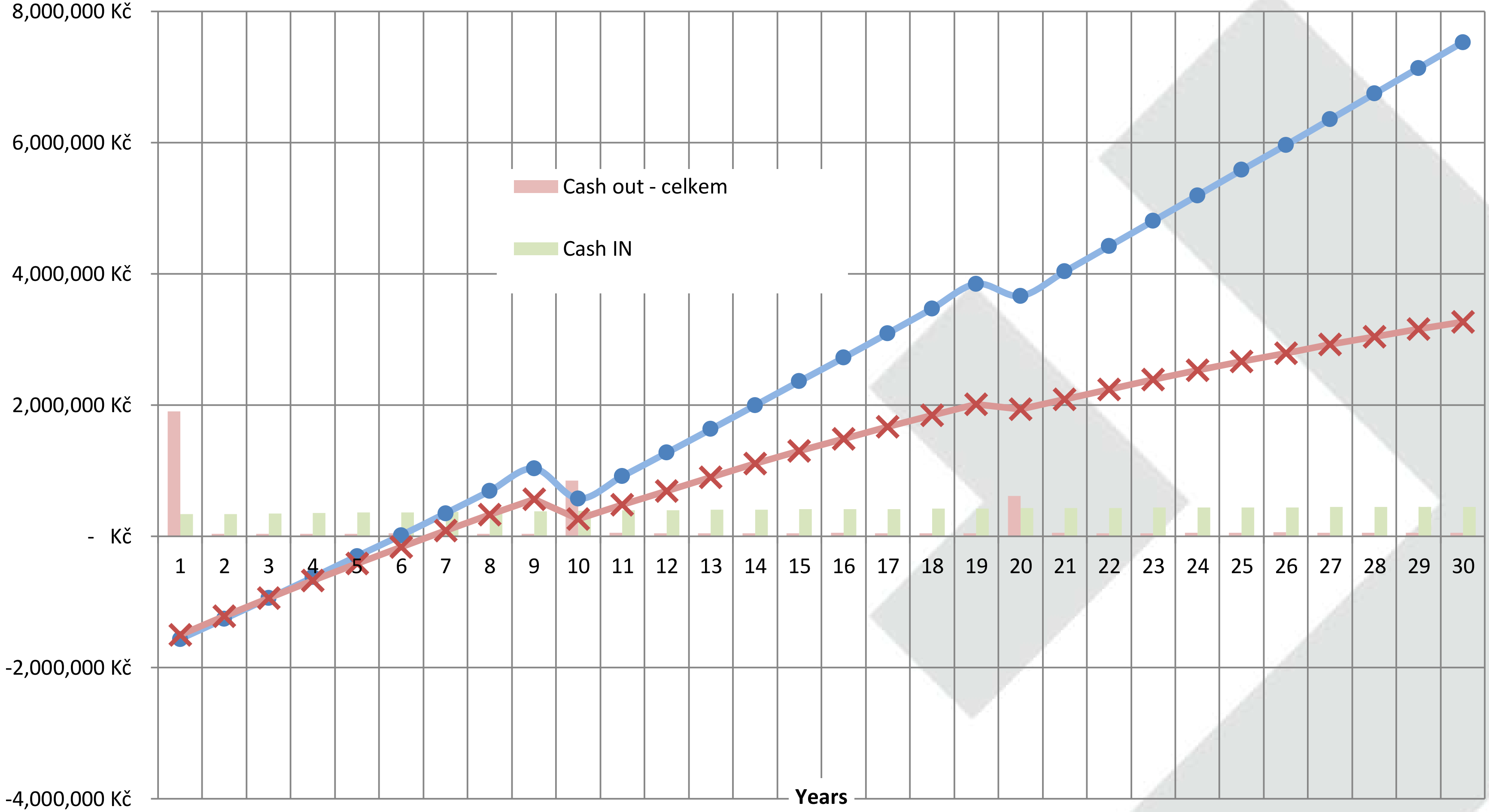
Agent - generation of electricity

- Variations of operating conditions –the base for the rules setting
  - **Weather**
    - Sunny vs. cloudy
    - Wind vs. no wind
    - Rain vs. no rain
    - Heat vs. cold
    - Smog vs. no smog
    - Dustiness vs. no dustiness
  - **Season**
    - Spring
    - Summer
    - Autumn
    - Winter
  - **Day time**
    - Morning
    - Afternoon
    - Evening
    - Night
  - **The need of energy**
    - working days
    - weekends
    - holiday

Off Grid Cash Flow



On Grid Cash Flow



Sensitivity analysis

- Development of electricity prices
  - Demand side
  - Supply side
- Development of discount rates
- Development of battery prices

The following steps

- For the purposes of creation of DES model (micro-level model), the following steps are needed:
  - **Prediction of electricity generation** - based on environmental and natural conditions;
  - **Prediction of electricity consumption** based on week - days consumption of household;
  - **Optimization of energy consumption mix**;
  - **Optimization of energy generator and/or operator selection – based on minimal costs**.

Thank you for your attention.

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