Review of developing simulation models for decision-making systems for economical, social and ecological planning

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Agenda

1. **Introduction** (about the Laboratory of Dynamical models of economics & optimisation of CEMI RAS)
2. **Main directions of our researches**
3. **Agent-based modeling for simulation of human crowd behavior**
4. **Agent-based modeling for ecological economics**
5. **Genetic Algorithms for large-scale optimisation**
6. **System-dynamics models for vertically integrated corporations**
7. **Architecture of our decision making systems**
8. **Conclusion**

Introduction

The Laboratory of Dynamical models of economics & optimisation was founded in 1997 in the Central Economics and Mathematics Institute. The Lab staff consists of at least 20 leading scientific researches in the field of mathematical modelling and optimisation in economics. Most of them are PhD holders, some are Dr. Sc. (in Math., Computer Science and Mathematical Economics)

Levon A. Beklaryan
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Full Professor, Dr. Sc.
(Russian Academy of Science)

Andranik S. Akopov
Full Professor,
Chief Researcher, Dr. Sc.
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Nerses K. Khachatryan
Associate Prof., PhD
(Russian Academy of Science)

Fedor A. Belousov, PhD
Candidate
(Russian Academy of Science)

Armen L. Beklaryan
Associate Prof., PhD
(Higher School of Economics)

The most important publications for the last five years

Akopov A. S., Beklaryan L. A., Saghatelyan A. K. **Agent-based modelling of interaction between air pollutants and greenery using a case study of Yerevan, Armenia**. *Environmental Modelling and Software*. 2018. (under Major Revision)

Akopov A. S., Beklaryan L. A., Saghatelyan A. K. **Agent-based modelling for ecological economics: A case study of the Republic of Armenia**. *Ecological Modelling*. 2017. Vol. 346. P. 99-118.

Beklaryan A. L., Akopov A. S. **Simulation of Agent-rescuer Behaviour in Emergency Based on Modified Fuzzy Clustering**, in: *AAMAS'16: Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems*. Richland : International Foundation for Autonomous Agents and Multiagent Systems, 2016.

Akopov A. S., Beklaryan L. **An Agent Model of Crowd Behavior in Emergencies**. *Automation and Remote Control*. 2015. No. 10. P. 1817-1827.

Akopov A. S. **Parallel genetic algorithm with fading selection.** *International Journal of Computer Applications in Technology*. 2014. Vol. 49(3/4). P. 325-331.

Akopov A. S., Hevencev M.A. **A Multi-agent genetic algorithm for multi-objective optimization**, in: *Proceedings of IEEE International Conference on Systems, Man and Cybernetics, 2013*. Manchester : IEEE, 2013. P. 1391-1395.

Akopov A. S. **Designing of integrated system-dynamics models for an oil company**. *International Journal of Computer Applications in Technology*. 2012. Vol. 45. No. 4. P. 220-230.

Main research projects for the last three years

2018 – 2019. Developing decision making-systems aggregating parallel adaptive heuristic algorithms for large-scale multi-objective optimisation for socio-economic and ecological planning
Funding: **RFBR together with Department of Science and Technology (DST), Indian Institute of Technology Mandi (IIT Mandi)**

2018 – 2019. Developing models, methods and software for support of sustainable development of multi-agent ecological-economics system of the city using a case study of Yerevan, Republic of Armenia
Funding: **RFBR together with NAS RA, Center for Ecological Noosphere Studies, Armenia**

2015 – 2017. Traveling and Quasi-traveling waves in complex dynamical systems
Funding: **RFBR, Russian Federation**

2015 – 2017. Development of methods, models and software for optimal control of the agent dynamics of ecological-economics system of the Republic of Armenia
Funding: **RFBR together with NAS RA, Center for Ecological Noosphere Studies, Armenia**

Main directions of our researches

1. Agent-based modelling for complex socio-economics and ecological systems

- **ABM for environmental researches**
- **ABM for human crowd simulation in Emergency**
- **ABM for economical modeling (CGE and DSGE – models)**

2. Developing parallel heuristic (genetic) algorithms and their application

- **Multi-agent genetic algorithm for multi-objective optimisation (MAGAMO)**
- **Real-Coded GAs for large-scale single-objective optimisation**
- **Real-Coded GAs for large-scale multi-objective optimisation**
- **Implementation of GAs on C++, MPI, CUDA**

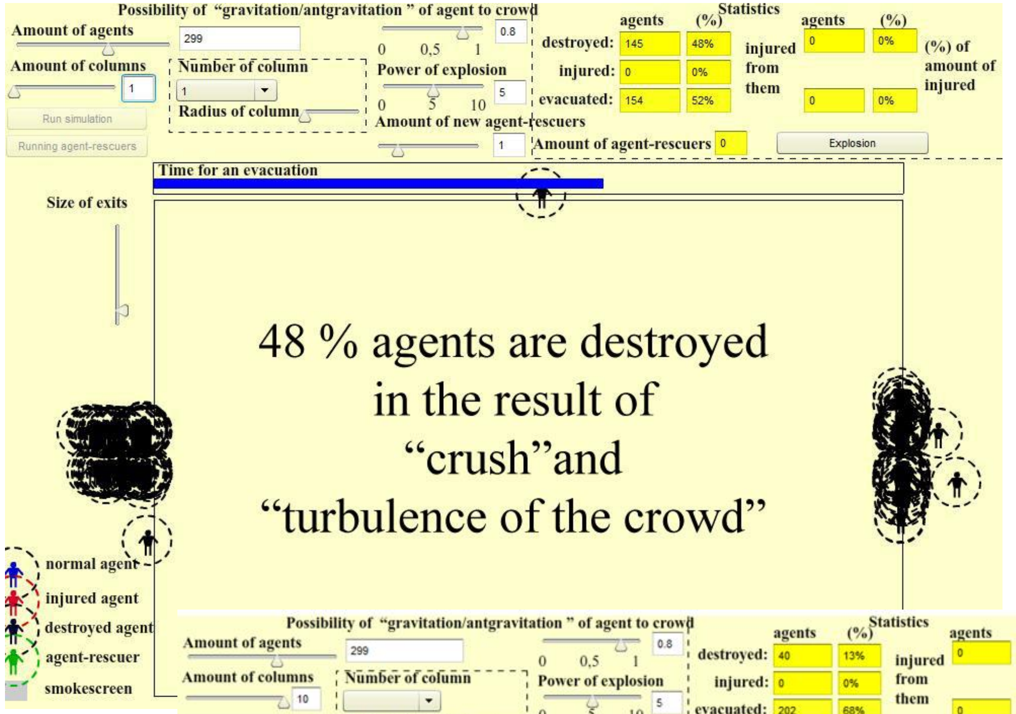
3. Developing System-Dynamics models for vertically-integrated corporations

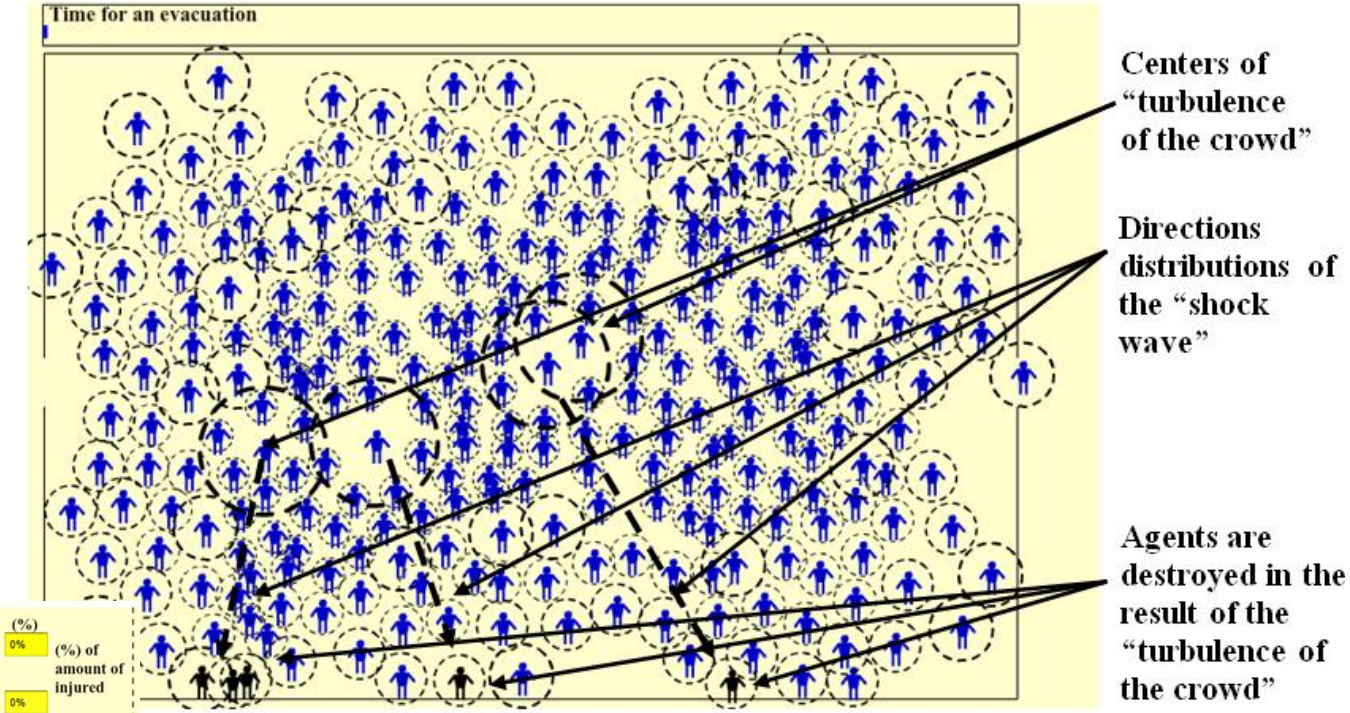
- **SD-modelling for petroleum companies and financial corporations**

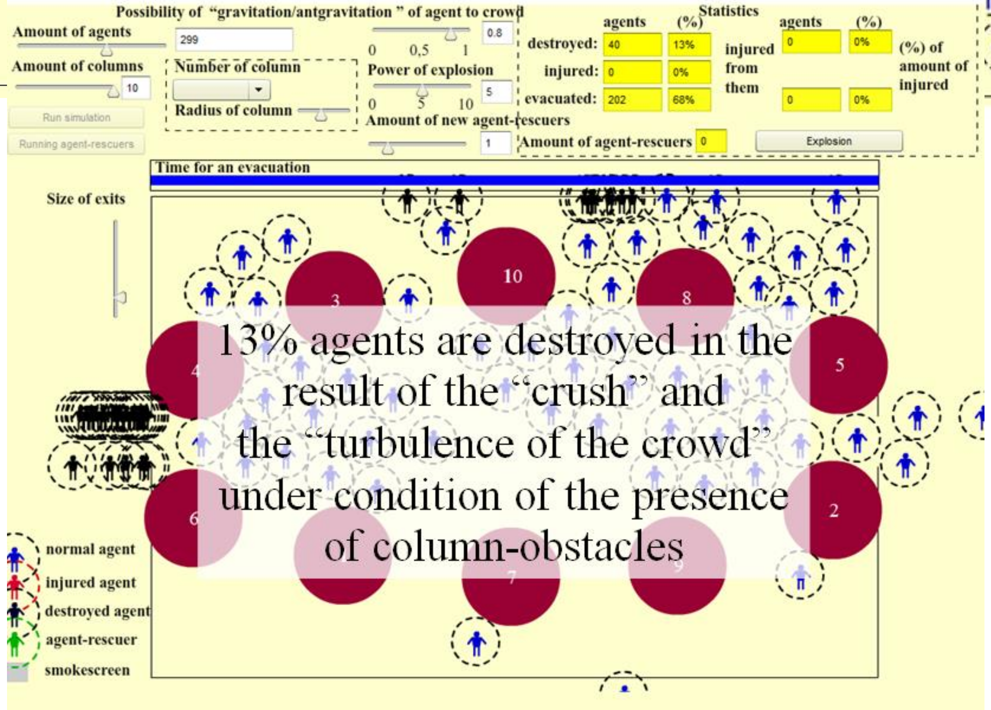
4. Developing methods and algorithms of clustering for complex multi-agent systems

- **Fuzzy clustering for analysis of human behavior**

Agent-based modeling for simulation of human crowd behavior



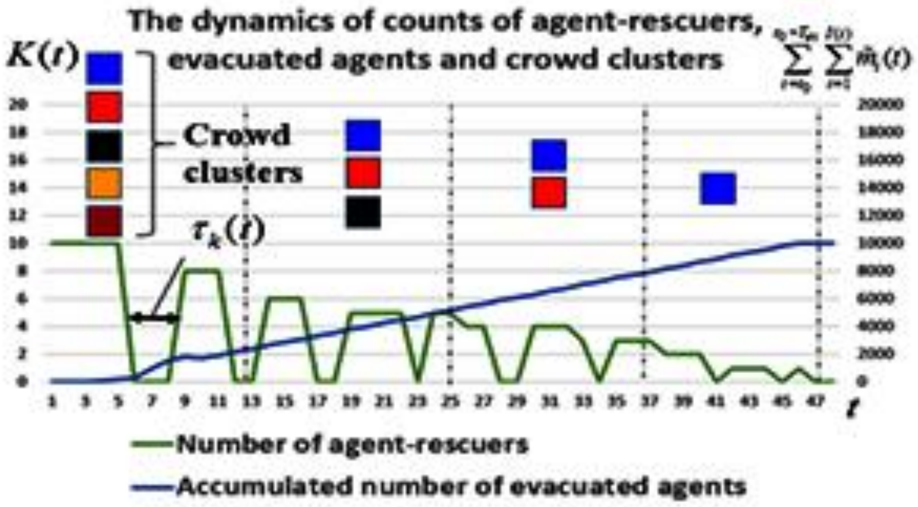




How to use special column-obstacles to minimize the number of destroyed agents (humans) in Emergency?

What configuration of building is optimal in Emergency (exits, walls, obstacles, etc.)?

Agent-based modeling for simulation of human crowd behavior



The developed modified fuzzy clustering algorithm is implemented for each agent. This algorithm is used for recognition of the centers of clusters of crowd by agent-rescuers for the purpose of increase of efficiency of procedure of evacuation through the distribution of agent-rescuer between crowd clusters. The algorithm aims to minimize an objective function:

$$J = \sum_{c=1}^{C(t)} \sum_{i \in I(t)} (m_{ci})^w e^{B\frac{\alpha_{ci}}{\pi}} d(v_c, x_i),$$

where $c = \overline{1..C(t)}$ – indexes of clusters; m_{ci} – degree of belonging of i^{th}-agent to c^{th}-cluster; w – fuzzifier; v_c – c^{th}-cluster center coordinate; x_i – i^{th}-agent coordinate; α_{ci} – angle between the direction of i^{th}-agent movement and the direction from the i^{th}-agent to the c^{th}-cluster center; B – weight coefficient.

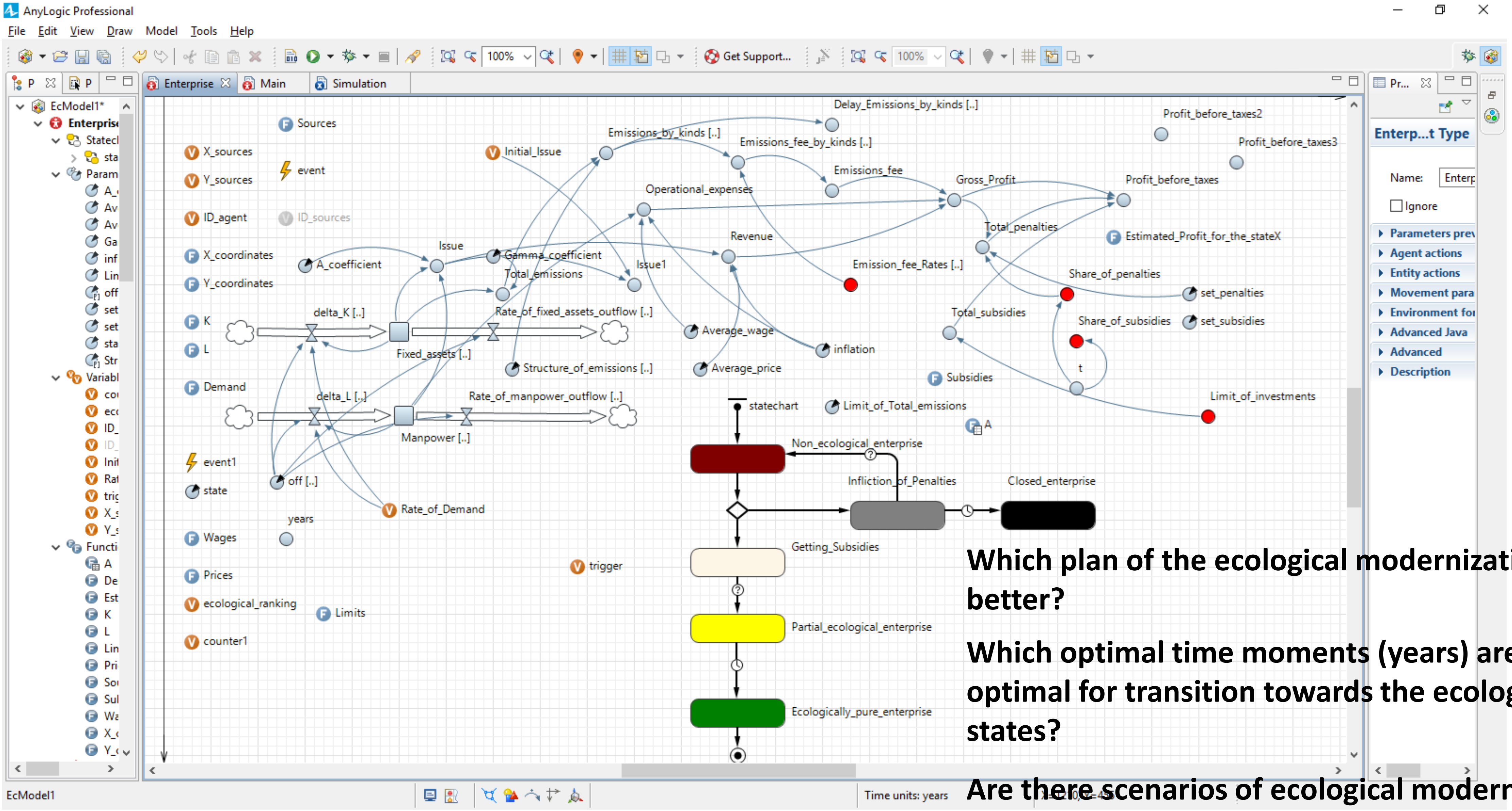
How to identify crowd clusters in order to control of agent-rescuers behavior?

How many agent-rescuers are needed for the fast evacuation?

Which evacuation routs are better in deferent scenarios of emergency?

Agent-based modeling for ecological economics

The agent simulation in AnyLogic for Armenia

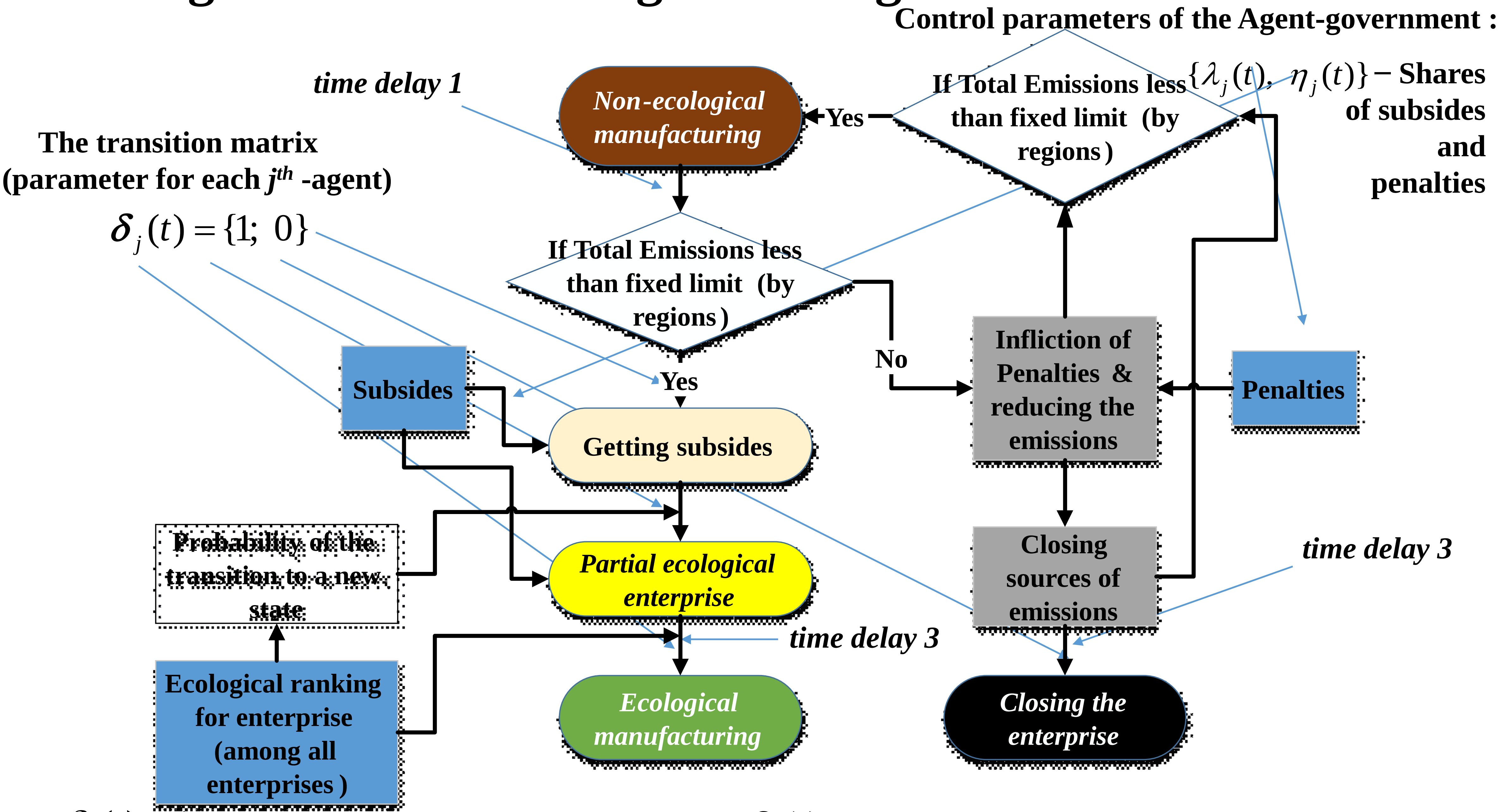


Which plan of the ecological modernization is better?

Which optimal time moments (years) are optimal for transition towards the ecological states?

Are there scenarios of ecological modernization which do not need closing enterprises?

Agent-based modeling for ecological economics



$\delta_j(t) = 1$ – the transition to a new state is allowed; $\delta_j(t) = 0$ – the transition to a new state is blocked

Agent-based modeling for ecological economics

The Web Interface of decision-making system

http://localhost:5020/index1.xhtml

localhost

Back to Models

Agent-based modelling for ecological economics: A case study of the Republic of Armenia

What-if Experiments | Optimization experements | Graphs | Maps | User Manual

(http://www.smartersim.com/ecmodel)

Exogenous variables

Limit of investments on subsidies (mln. dram) 1000000

Years (2016 - 2025)	Rate of Dust em. decr.	Rate of Heavy metals em. decr.	Rate of SO2 em. decr.	Rate of CO em. decr.	Rate of NOx em. decr.	Rate of Carbonates em. decr.	Rate of VOC em. decr.	Rate of Others em. decr.	Share of subsidies in costs (%)	Share of penalties in profit (%)	Emissions utilization coeff. (from 0 to 1)
0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	20.0	5.0	0.05
1	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	25.0	10.0	0.1
2	1.3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	15.0	20.0	0.1
3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	10.0	30.0	0.15
4	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	5.0	40.0	0.15
5	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	5.0	50.0	0.2
6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	5.0	60.0	0.2
7	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	3.0	70.0	0.25
8	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	2.0	80.0	0.3
9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	90.0	0.3

Calculate | Restore | Save scenario | Name of scenario | Instruction

Calculation progress

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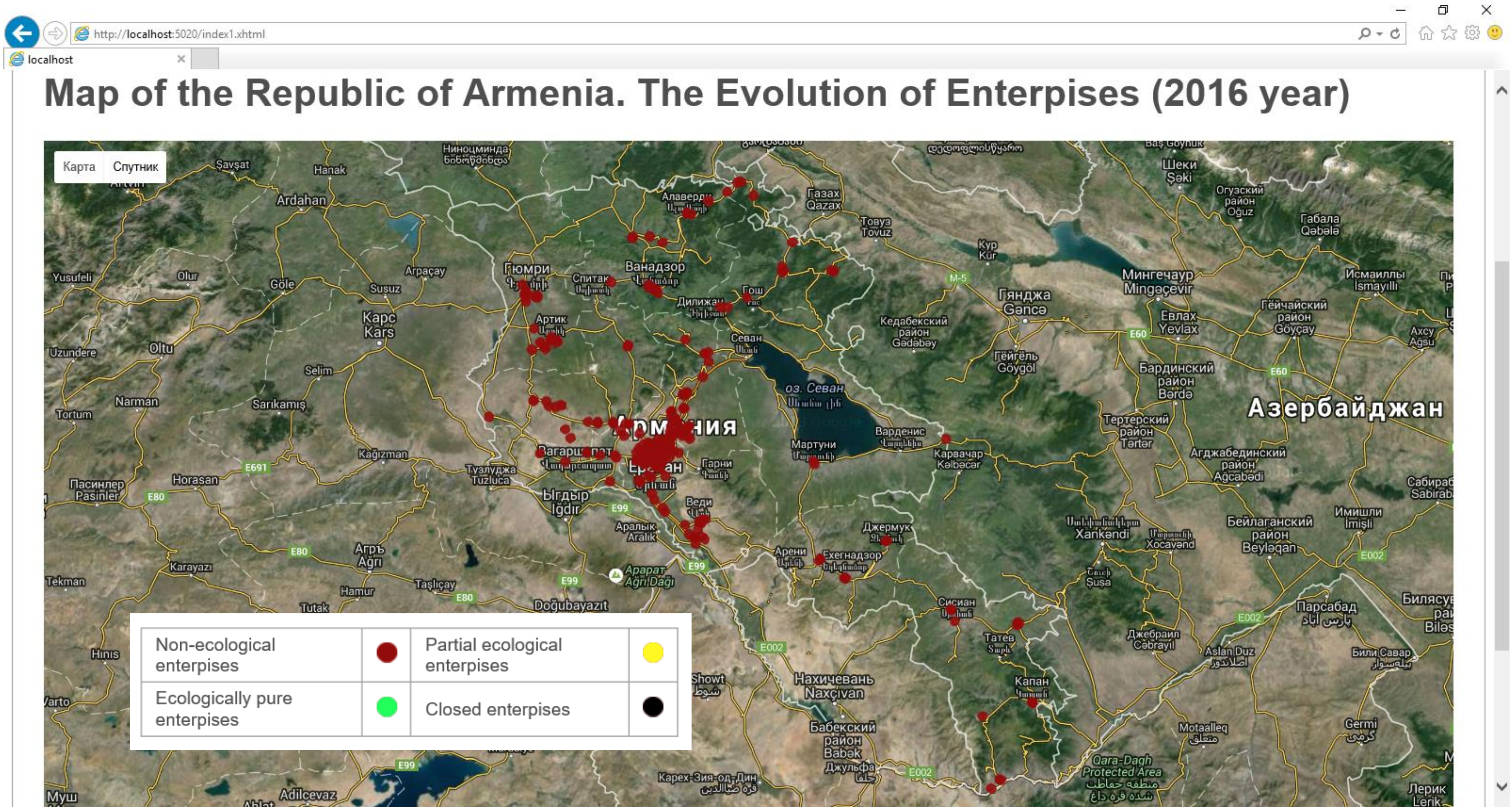
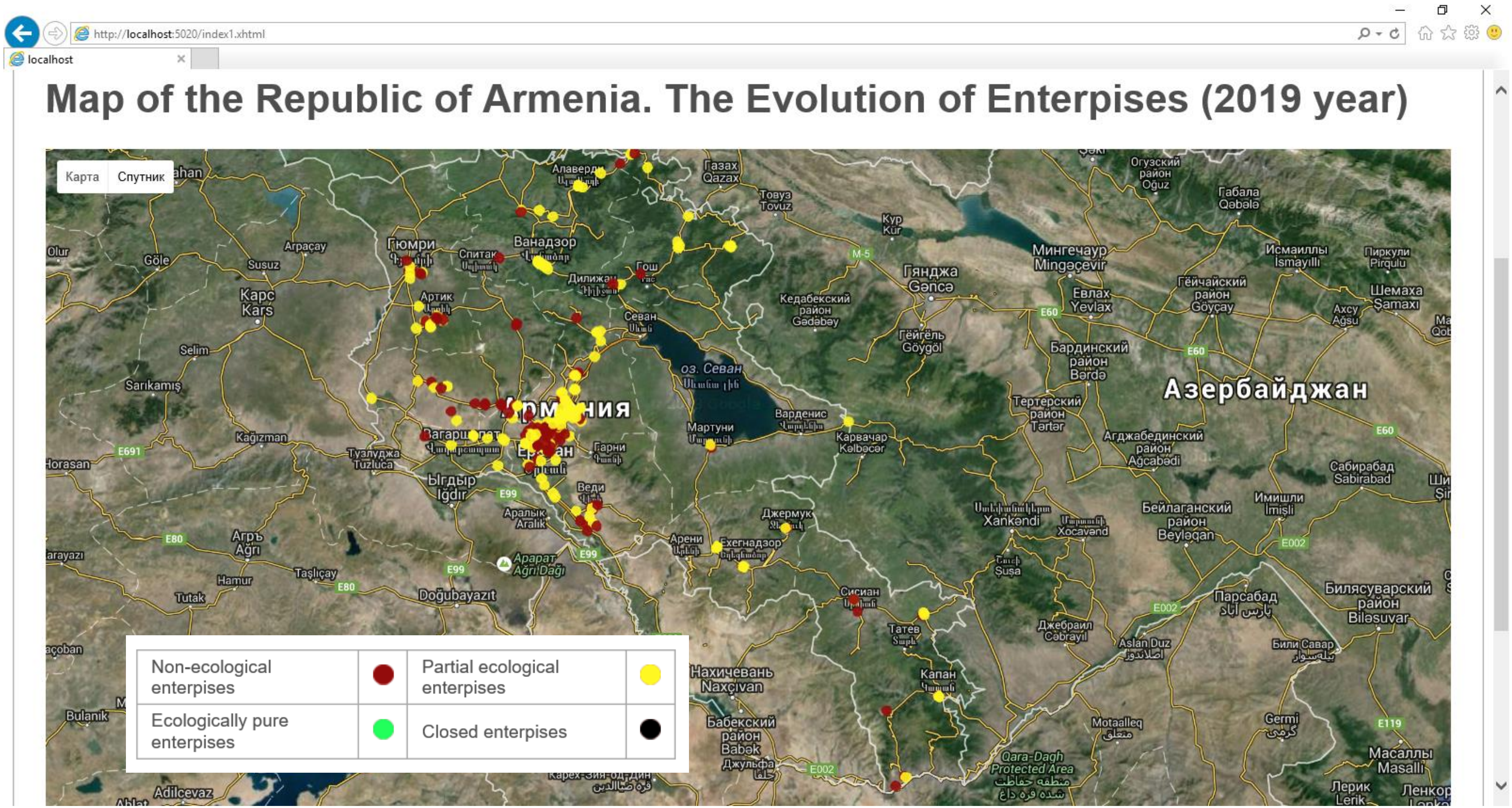
Agent-based modeling for ecological economics

The visualization of agents evolution on the Maps



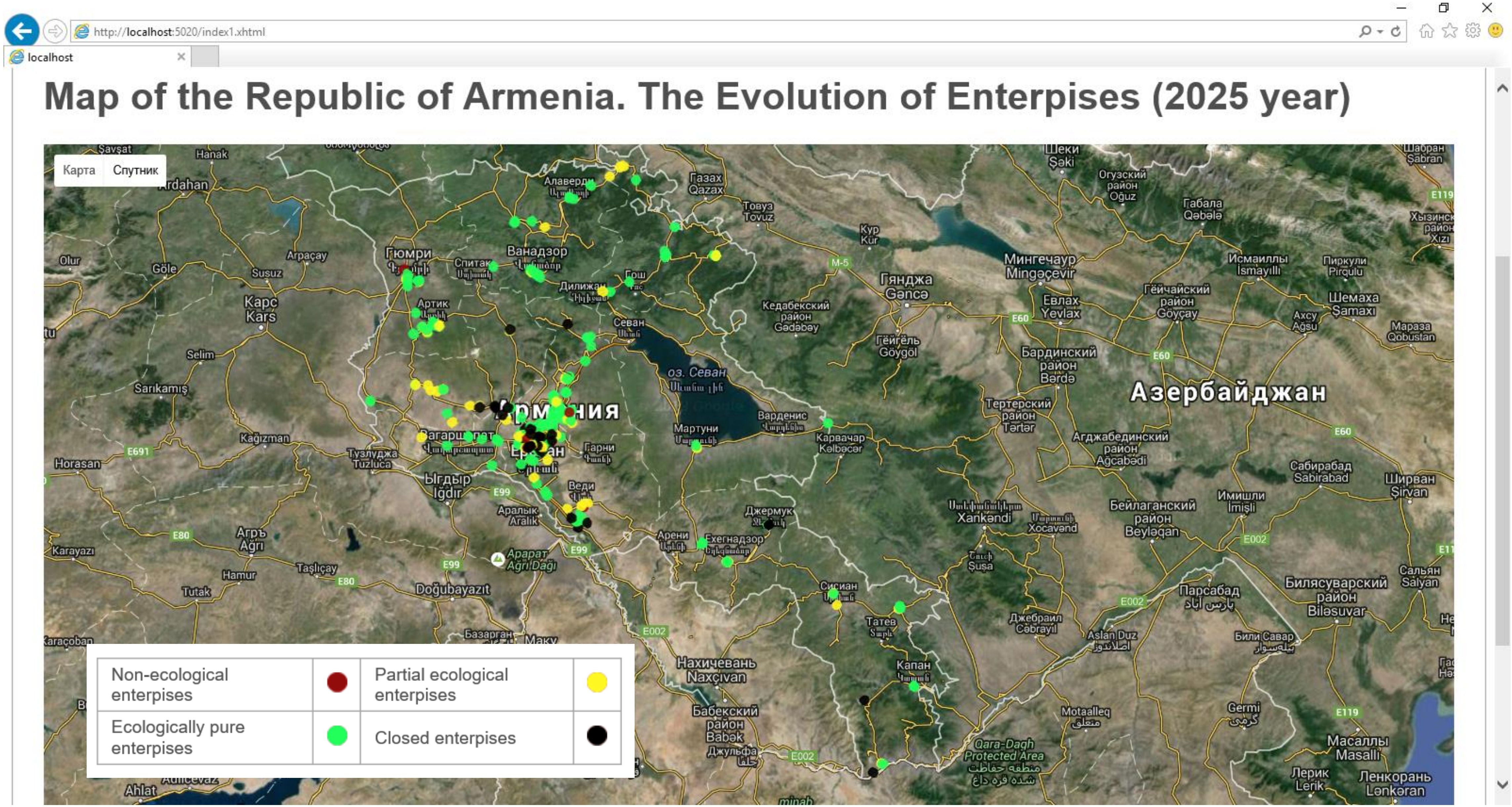
Agent-based modeling for ecological economics

The visualization of agents evolution on the Maps



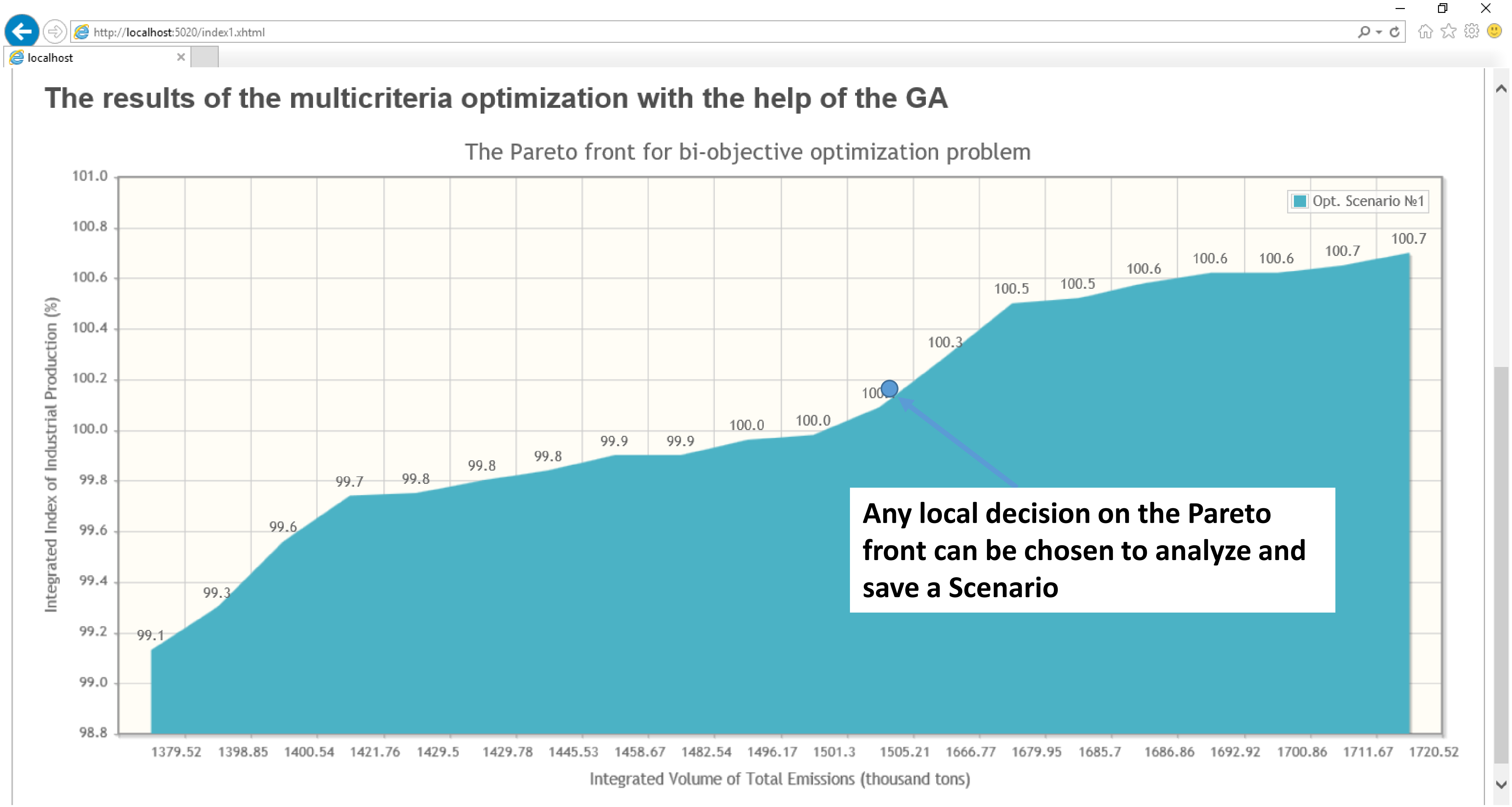
Agent-based modeling for ecological economics

The visualization of agents evolution on the Maps



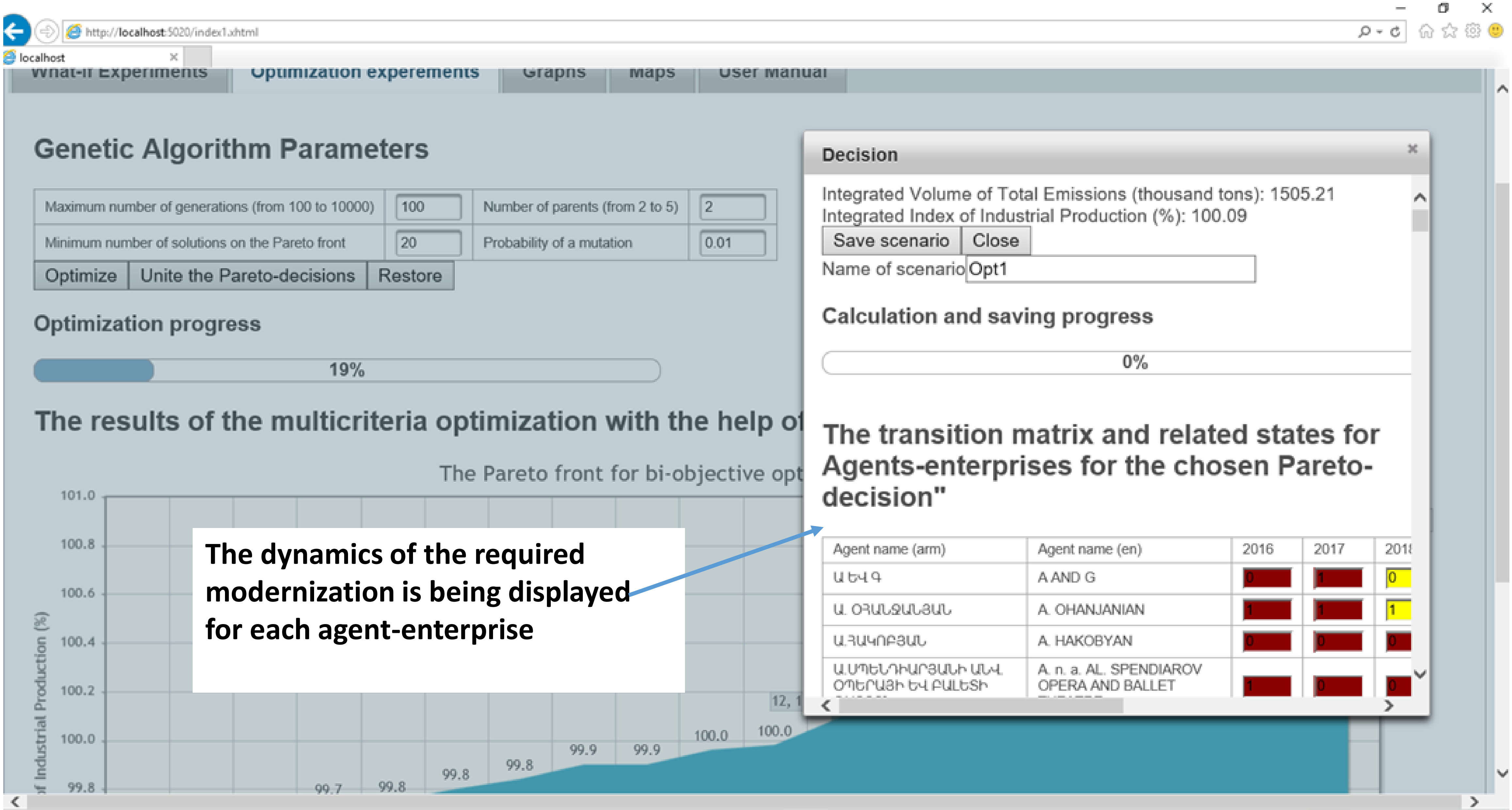
Agent-based modeling for ecological economics

Optimization experiments



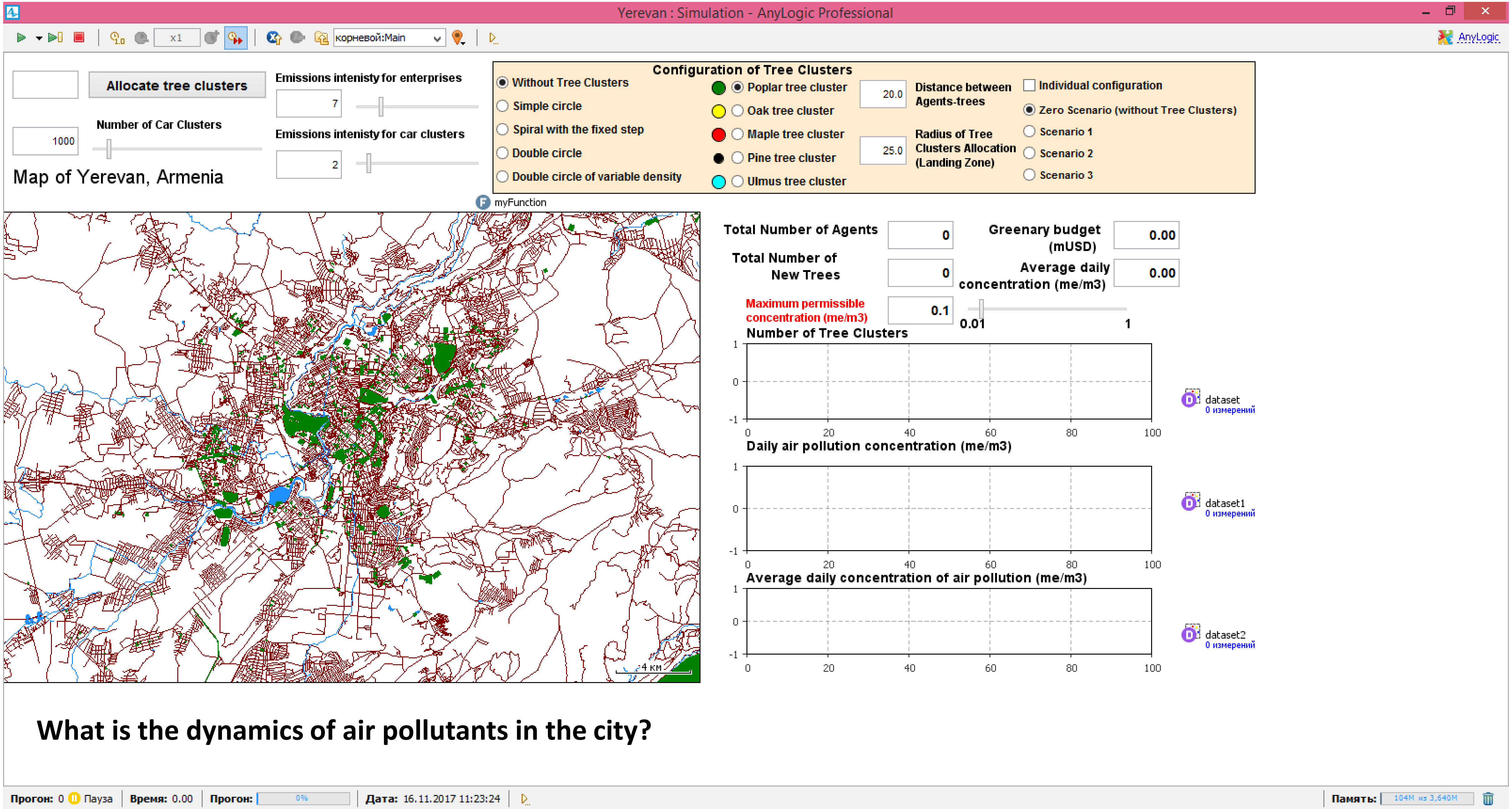
Agent-based modeling for ecological economics

Optimization experiments



The dynamics of the required modernization is being displayed for each agent-enterprise

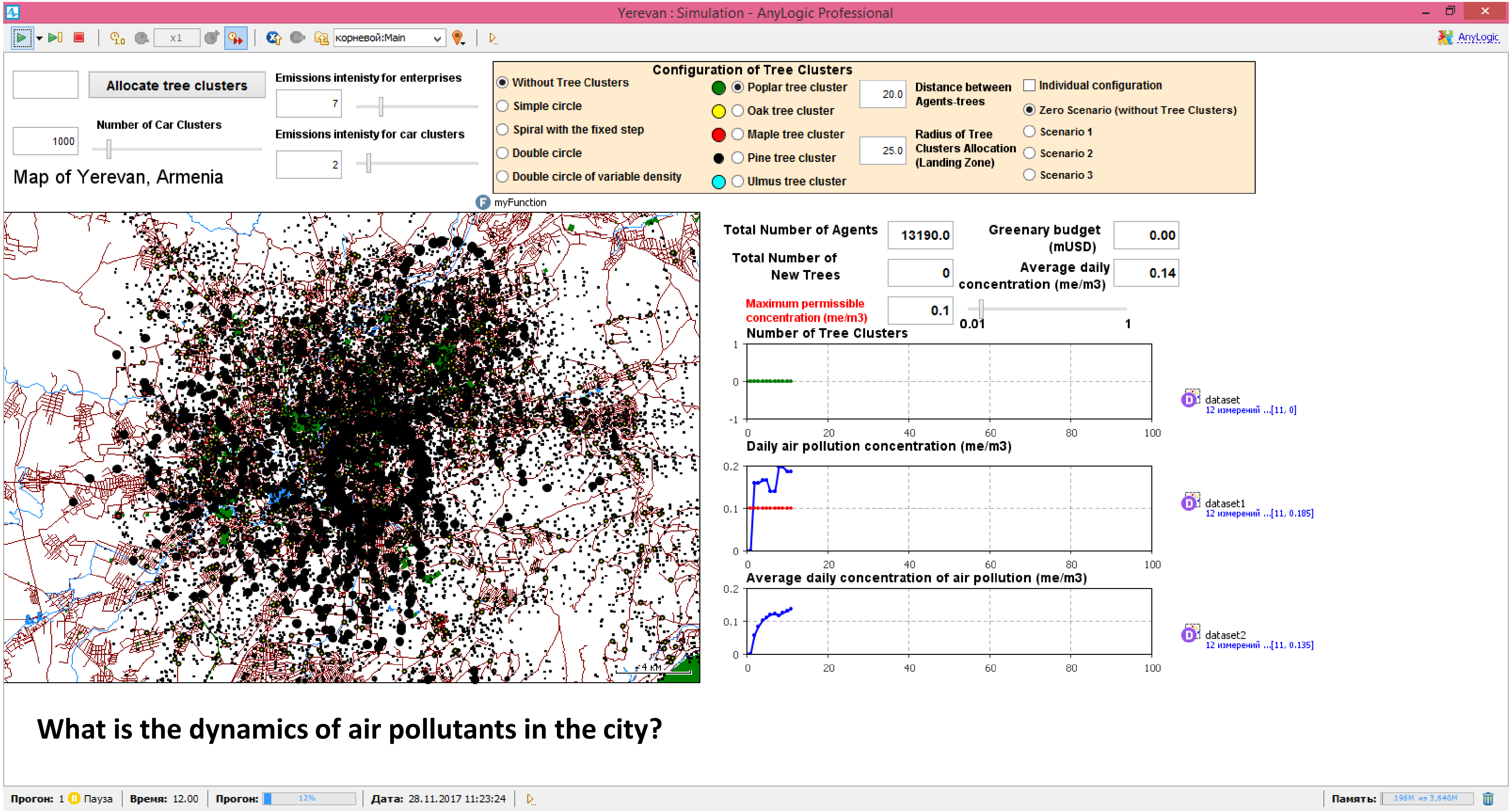
Agent-based modeling for ecological economics



What is the dynamics of air pollutants in the city?

Agent-based modeling for ecological economics

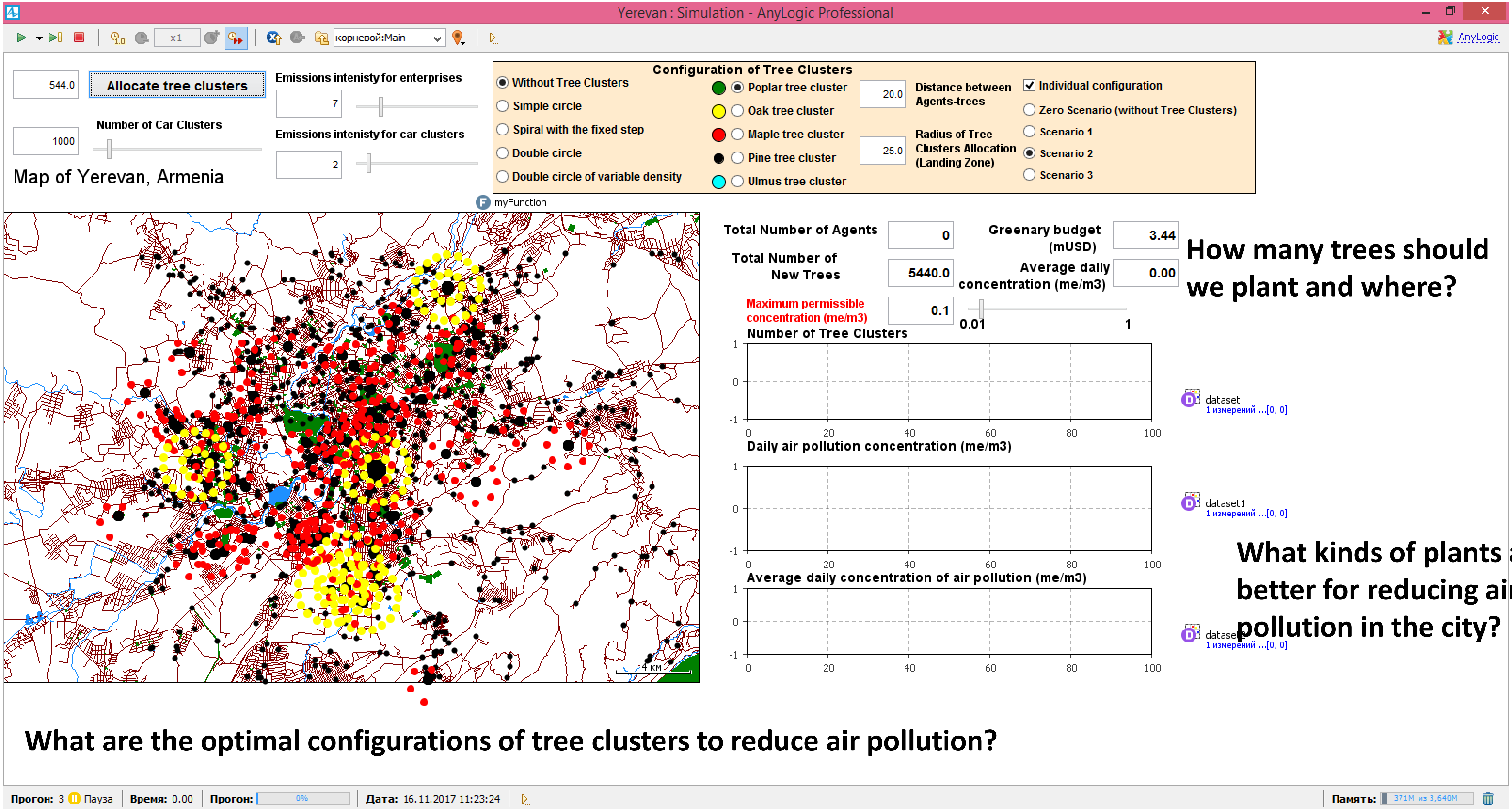
The zero scenario - without three clusters



What is the dynamics of air pollutants in the city?

Agent-based modeling for ecological economics

Scenario 2. *Compromise greenery:* relatively simple configurations of tree clusters that maintain a high impact on emissions.



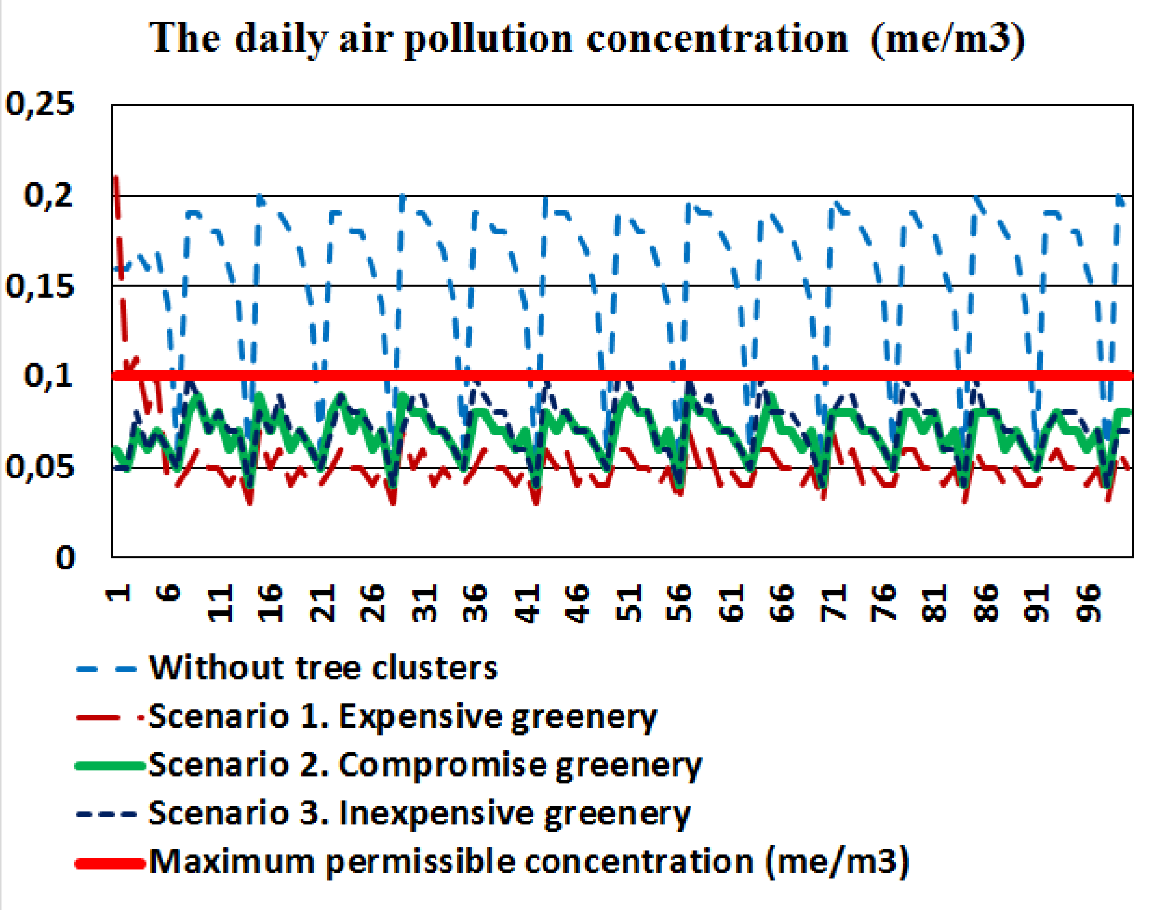
How many trees should we plant and where?

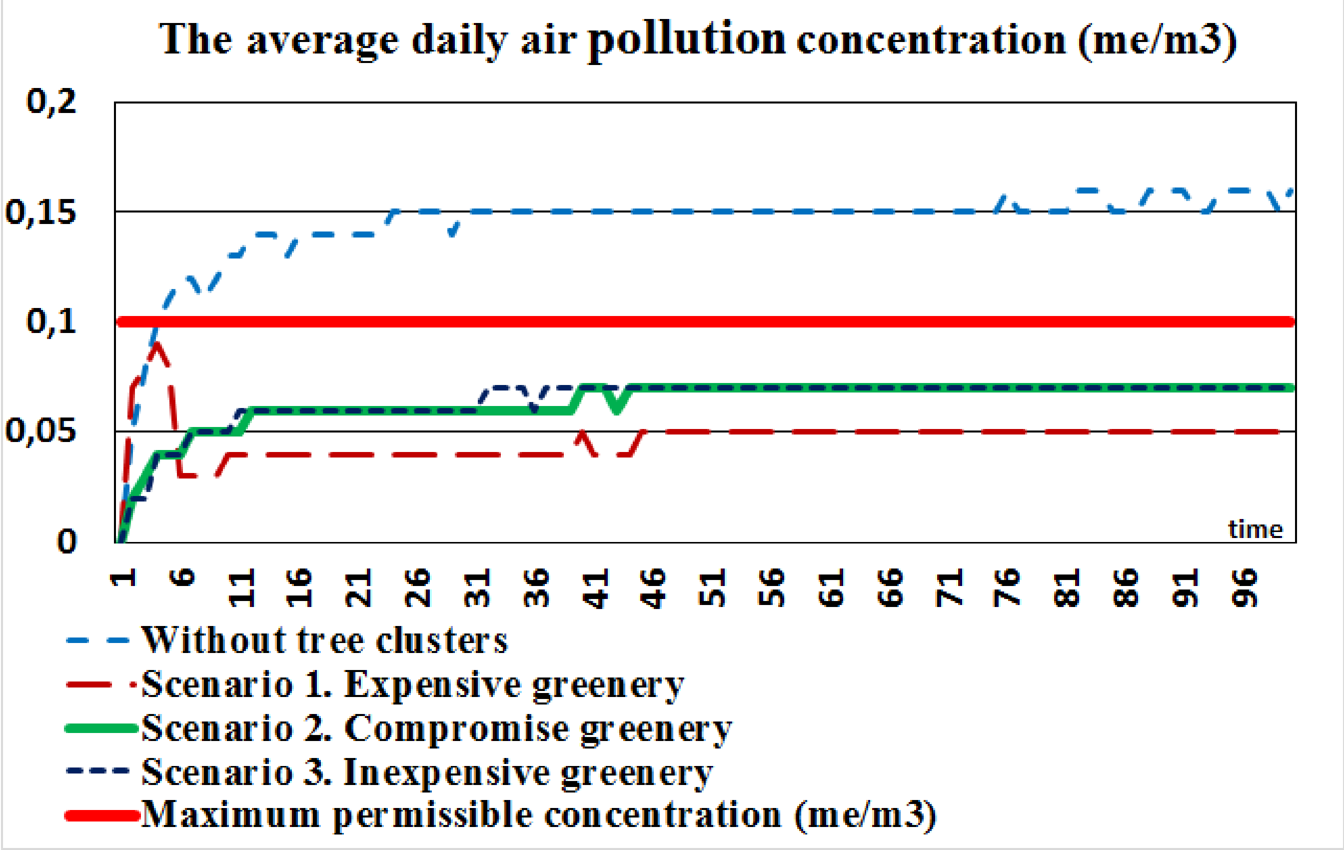
What kinds of plants are better for reducing air pollution in the city?

What are the optimal configurations of tree clusters to reduce air pollution?

Agent-based modeling for ecological economics

Scenarios	Number of agent-trees	Number of trees	Greenery budget (mUSD)
Scenario 1. *Expensive complex greenery.*	720	7 200	6.32
Scenario 2. *Compromise greenery.*	544	5 440	3.44
Scenario 3. *Inexpensive greenery.*	337	3 370	2.95





Genetic Algorithms

The following large-scale box-constrained single-objective optimization problems (LSOPs) is considered:

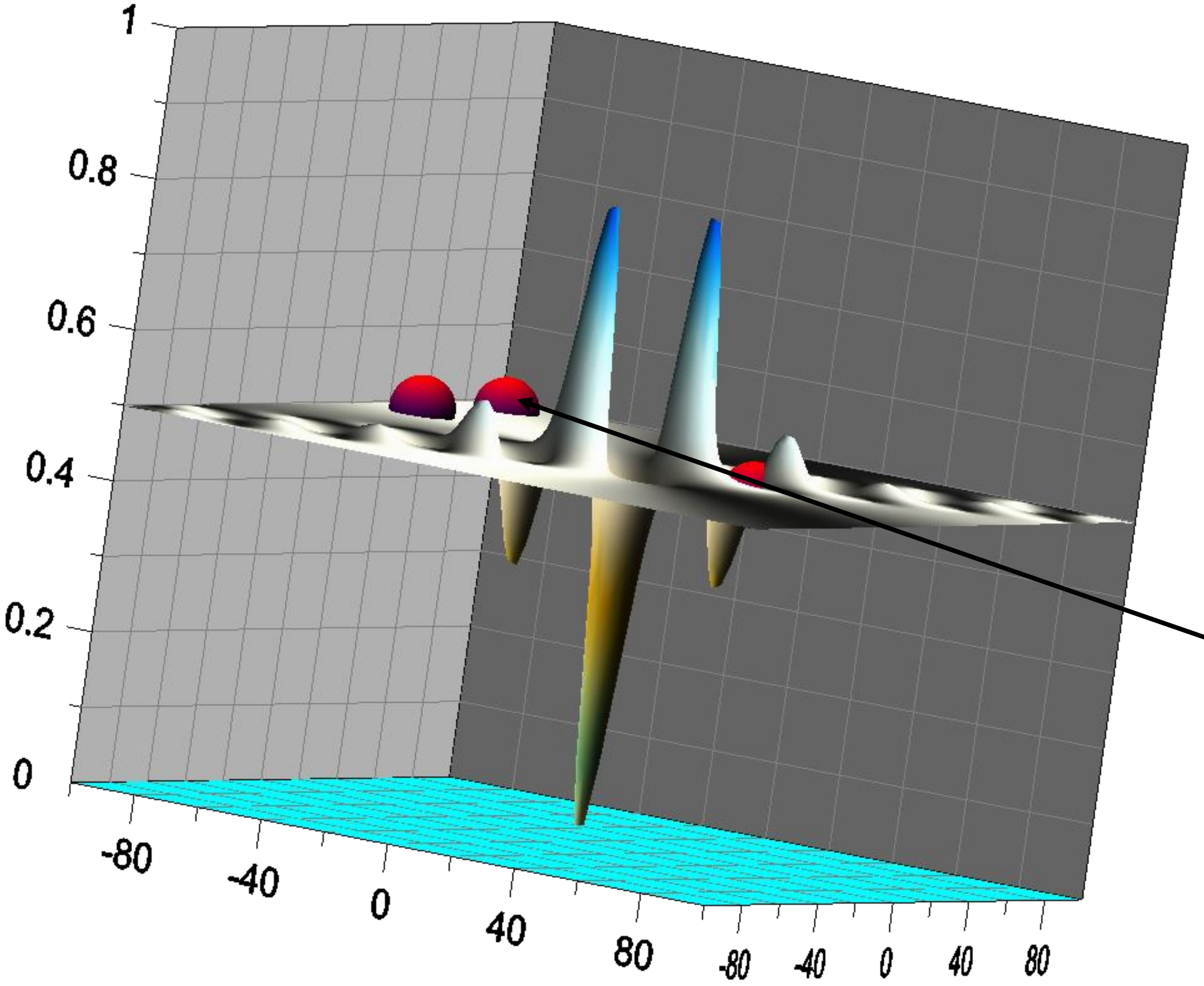
$$\min F(\mathbf{x}),$$
$$\text{s.t. } \mathbf{x} = (x_1, x_2, \ldots, x_n)' \in \Omega \qquad (1)$$

where $\mathbf{x} = (x_1, x_2, \ldots, x_n)'$ is a decision variable vector with a large-scale dimension n, $\Omega = \prod_{i=1}^{n} [a_i, b_i]$ is the feasible region of the search space ($i = 1, 2, \ldots, n$ is the index of decision variables), $F : \Omega \to \mathbb{R}$ is the objective function that is computed in the result of the simulation modelling.

The objective functions are the results of simulation modeling.

There are many decision variables in the optimisation problem (100 and more)

Genetic Algorithms



The Schaffer's F6 function as a sample

$$F(\mathbf{x}) = 0.5 + \frac{\sin^2\left(\sum_{i=1}^{n}\sqrt{x_i^2}\right) - 0.5}{\left(1 + 0.001\sum_{i=1}^{n} x_i^2\right)^2},$$

$$x_i \in [-100,\ 100] \quad i = 1,\ 2,\ \ldots,\ n$$

$$F(0, 0, \ldots, 0) = 0$$

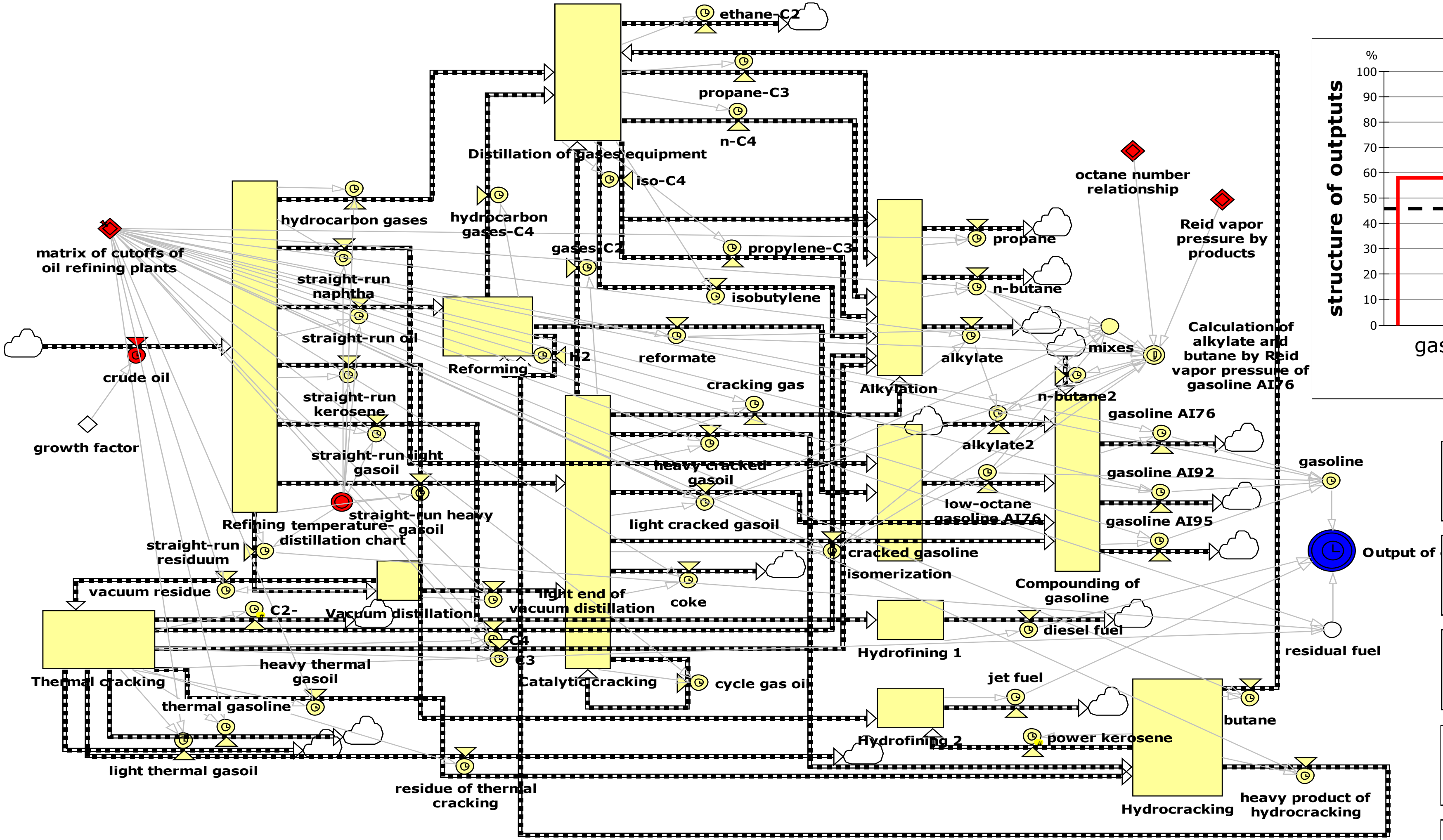
Agent-process

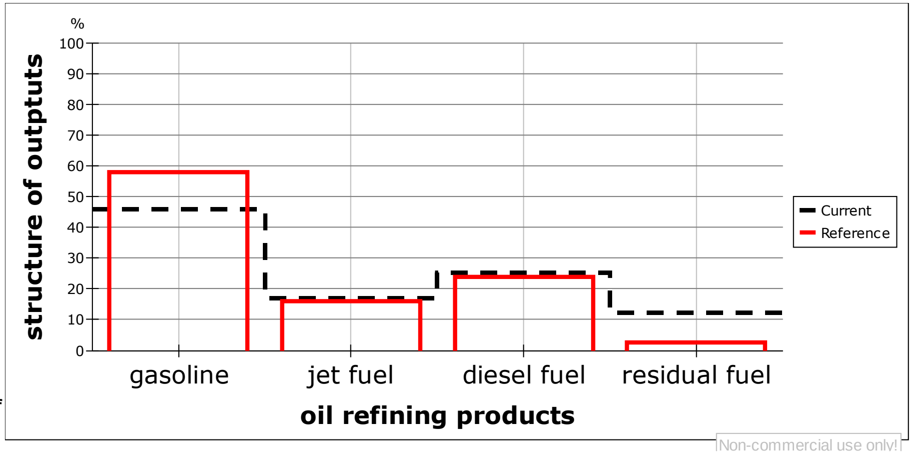
How many agent-processes are need for LSOPs?

Which combinations of heuristic operators are better?

What optimal frequency of exchanging by the best potential decisions between agent-processes should be?

System-dynamics models for vertically integrated corporations



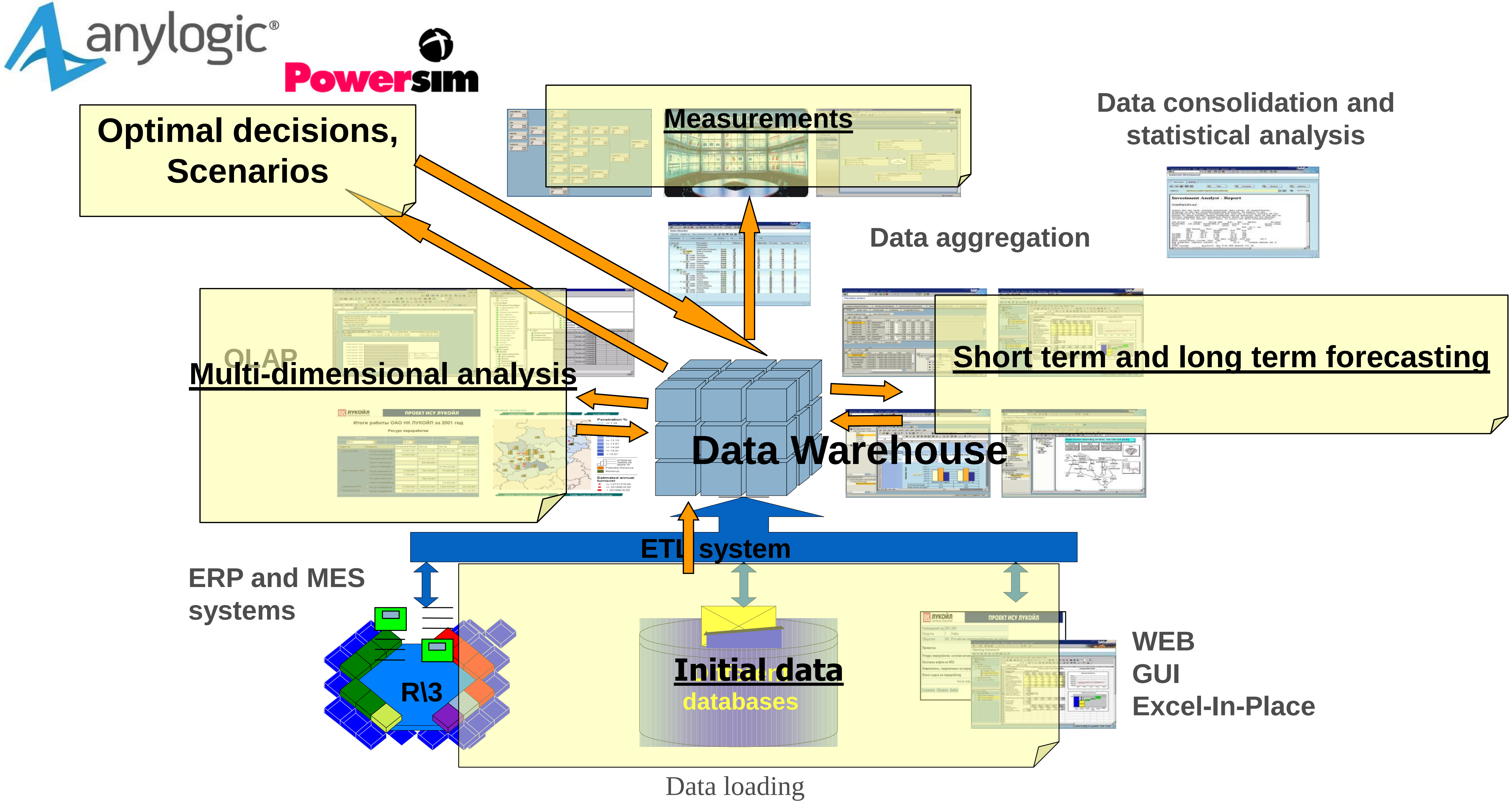


- ☐ Alkylation
- ☑ Compounding
- ☐ Hydrocracking
- ☑ Catalytic cracking
- ☑ Thermal cracking

What is the optimal configuration of the oil refining plant?

What is the optimal structure of the set of investment projects for the petroleum company with taking into account interconnections between oil production and refining?

Architecture of our decision-making systems



Thank you very much!

Questions?

Contact information

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