Models in Models –
On Agent-Based Modelling and Simulation in Energy Systems Analysis

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Agenda

1. Research Case: Energy Systems Analysis
2. Early examples of Agent-Based Modelling and Simulation (ABMS)
3. What is an agent, and how to classify models?
4. What is ABMS for?
5. ABMS in Energy Systems Analysis
Two Modes of Reasoning in Energy Systems Analysis

Projection of technology development and socio-economic change

Forecasting

‘Reference’ future world

Alternative policy options

required interventions and decisions

Backcasting

Normative target world

2000 2010 2020 2030 2040 2050

Cellular Automata: Conway's Game of Life

• Any live cell with fewer than two live neighbours dies, as if caused by underpopulation.

• Any live cell with two or three live neighbours lives on to the next generation.

• Any live cell with more than three live neighbours dies, as if by overpopulation.

• Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.

• Demo: http://arr.gr/playground/life/

https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life
Autonomous ABM: Schelling’s Segregation Model

• Suppose there are two types of agents: Red and Blue.

• A satisfied agent is one that is surrounded by at least \( t \) percent of agents that are like itself. Note that the higher the threshold, the higher the likelihood the agents will not be satisfied with their current location.


What is an agent?

**Agents:**
Attributes + Methods (+ Interfaces)
Central: Behaviors / Decision rules

**Environment:**
Lattice, Network, GIS, „Soup“, …

## Classification

<table>
<thead>
<tr>
<th>Definition</th>
<th>Individuality – agents have diverse set of characteristics</th>
<th>Endogenous, <strong>Autonomous</strong> Behaviours based on the current agent state</th>
<th>Direct <strong>Interactions</strong> between other agents and the environment</th>
<th><strong>Adaptability</strong> - Agents change behaviours / learn during the simulation // Agent population changes over time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual ABMS</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Autonomous ABMS</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Interactive ABMS</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
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<tr>
<td>Adaptive ABMS</td>
<td>Green</td>
<td>Green</td>
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</tbody>
</table>

Macal, 2016 - Everything you need to know about agent-based modelling and simulation Journal of Simulation, 10, 144 - 156
What is Agent-Based Modelling and Simulation for?

Agent perspective allows us to direct our attention to otherwise understudied phenomena, to incorporate decisions and other behavioural aspects into otherwise „cold“ models, and to explore unknown adaptations and emergence.

ABMS is …

• a multi-paradigm method,
• a bridge between different scientific fields,
• a bridge between induction and deduction,
• a way to study disequilibria,
• evolutionary in nature.
What is an agent?

**Agents:**
Attributes + Methods (+ Interfaces)
Central: Behaviors / Decision rules

Decision rules can be based on *any* model

- Logic (if… , then…; else…)
- Machine Learning Algorithm
- System dynamics model
- Dispatch model
- …

Models in Models – ABMS as multi-paradigm simulation

• Proposition: Model coupling can always be depicted as an (abstract) ABMS
• Example:

```
Model 1
  ↓
  Model 2
  ↓
  Model 3
```

„Manual“ model coupling

Explicit ABMS model coupling via mediating agents
AMIRIS

Input Data
Feed-in Renewables, Balance Energy Price, Marginal Costs Conventional Power Plants, Load

ABMS as a container framework

AMIRIS: example of explicit internal model coupling

Input Data
Feed-in Renewables, Balance Energy Price, Marginal Costs Conventional Power Plants, Load

= internal model
Other Example: Investment Decisions in Solar Photovoltaics

Interesting case study, since:
- Stable policy “regime“
- Relatively understudied,
- Magnitude of the effect: ca. 750,000 installations
- Possibility to study investment in RES
Retrospective Analysis of Profitability

Deployment Data

Exponential Utility $u(t)$

Application in Behavioral Economics

- Value not only determined in absolute terms, but also in changes relative to the status quo (i.e. in gains and losses)
- **Value function of Prospect Theory:**

![Diagram of the Value function of Prospect Theory]

Shape parameters determined in choice experiments


Retrospective Analysis of Profitability

Retrospective Analysis of Profitability incorporating Prospect Theory

Induction and Deduction in Energy Systems Analysis

**Induction**

- **Observation // Experiment**
- **Generalization**
- **Paradigm // Theory**

How do energy market and policy instruments work? What are drivers of demand and innovation?

**Deduction**

- **Predictions**

Given \((\Sigma\text{ constraints})\), how does an optimal energy system look like?

ABMS potentially in the middle of the two

Incorporating observation and model logic

Axelrod’s „third way of doing science“
What’s “wrong“ with Equilibrium Theory in the first place?

• Equilibria might exist but are effectively uncomputable
• Equilibrium might not be attained by boundedly rational agents
• Equilibria might be obtained asymptotically but not realized over long periods
• Equilibria might exist but are unstable
• Equilibrium might be less important than fluctuations and extreme events
Inherent Difficulties of ABMS

• There is no „archetypical“ ABMS
• There is 1 way to be rational, but 1000 to be boundedly rational
• Complexity impedes reporting and consulting (there are some standards though (Grimm et al. 2010))
• Complete models of human interactions do not exist, they tend to invalidate themselves
Conclusions

*Agent perspective* allows us to direct our attention to otherwise understudied phenomena, to incorporate decisions and other behavioural aspects into otherwise „cold“ models, and to explore unknown adaptations and emergence.

ABMS is …

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- a way to study disequilibria,
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Literature

- Axelrod, R. M. (1997). *Advancing the Art of Simulation in the Social Sciences*
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Contact: http://www.dlr.de/tt/desktopdefault.aspx/tabid-4074/6449_read-30526/start-k/sortby-lastname/
ACE and Evolutionary Economics

• Compare: Black vs. White Moths during the time of industrial revolution
• ABMS is by definition evolutionary, as it studies adaptations to the environment

See also: [https://www.youtube.com/watch?v=USlJm-2qT2w](https://www.youtube.com/watch?v=USlJm-2qT2w)