"Agent-based modelling and simulation in the energy transition"

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Social Innovation in the Energy Transition webinar series
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Utrecht University

My background

- BSc. Mechanical Engineering

University of Tehran, Iran

- MSc. Environmental and Energy Management (MEEM)

University of Twente, the Netherlands

- PhD candidate at Technology, Policy and Management faculty

Delft University of Technology, the Netherlands

- Lecturer in Copernicus Institute of Sustainable Development

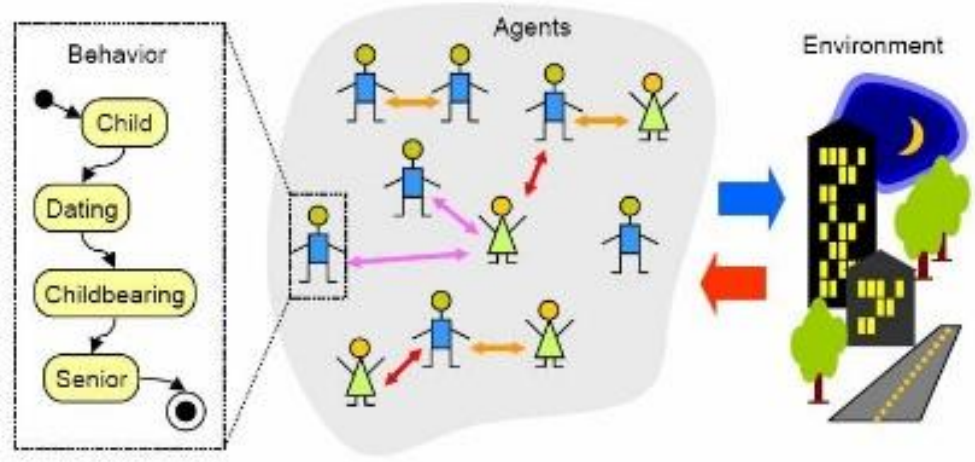
Utrecht University, the Netherlands

Overview

Goal: Elaborating on agent-based modelling (ABM) as an approach to study the energy transition

- Introduction to ABM
- Why ABM?!
- Examples of ABM
- Specific ABM for formation of thermal energy communities
- Results and recommendations
- Further discussions and reflection on using ABM for studying the energy transition

Introduction to ABM



A research approach/ learning approach:

Conducting experiments

But, not always possible in real-world

- **Time;**
- **Cost;**
- **Not necessarily beneficial impacts, …**

Computational simulation (computer models)

Computational social simulation:

The cross-road between technical design, social sciences, computer sciences, and mathematics

Agent-based modelling (ABM)!?

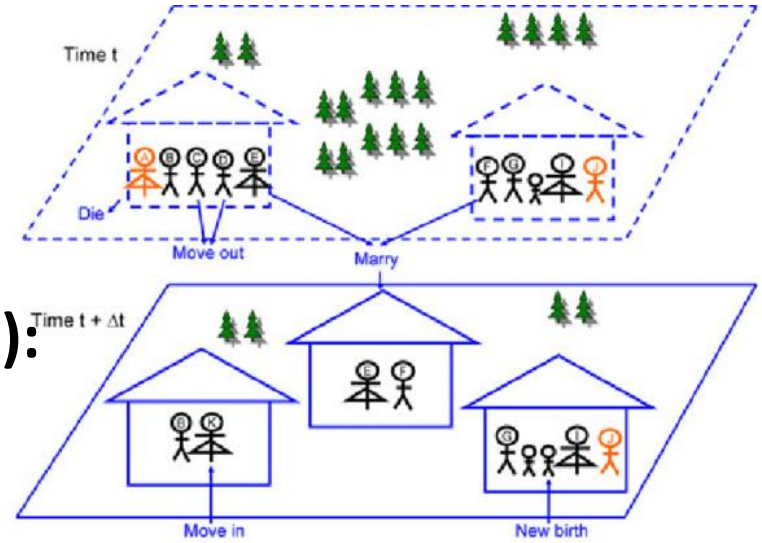
Agent-based modelling (ABM) is a **computational modelling approach** for simulating the **actions and interactions of autonomous agents** (both individual or collective entities such as organizations or groups) in order to understand the **behavior of a system and what governs its outcomes**.

U. Wilensky and W. Rand, An Introduction to Agent-Based Modeling. The MIT Press, 2015.
E. Bonabeau, "Agent-based modeling: Methods and techniques for simulating human systems," Proc. Natl. Acad. Sci. U. S. A., vol. 99, no. SUPPL. 3, pp. 7280–7287, 2002, doi: 10.1073/pnas.082080899.
V. D. K. H. K. K.H., "Agent-based Modelling of socio-technical systems," Agent-Based Model. Socio-Technical Syst., 2013
Complexities explorer, series of lectures in YouTube ☺

Why ABM?!

ABM as a research tool:

- Heterogeneously of actors (agents);
- Capturing motivations and interactions;
- Trade-offs of decision-making;
- Collective action of actors (agents);
- Ability to adopting and learning from each other;
- Adding time variable;
- ….



Purpose of using a computer model (ABM):

- Explanation!?
- Prediction!?
- Exploration!?
- ….

Different modelling purposes:
https://www.scopus.com/record/display.uri?eid=2-s2.0-85071223267&origin=resultslist&sort=r-f&src=s&sid=d1c0340e2f5c2fca8fb48efcf5f3efaf&sot=b&sdt=b&sl=43&s=TITLE-ABS-KEY%28Different+Modelling+Purposes%29&relpos=0&citeCnt=27&searchTerm=

Examples of ABMs in the energy transition

- The renewable energy technology adoption

V. Rai and S. A. Robinson, "Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors," Environ. Model. Softw., vol. 70, pp. 163–177, 2015, doi: 10.1016/j.envsoft.2015.04.014.

- Role of leadership in energy communities

A. Ghorbani, L. Nascimento, and T. Filatova, "Energy Research & Social Science Growing community energy initiatives from the bottom up : Simulating the role of behavioural attitudes and leadership in the Netherlands," Energy Res. Soc. Sci., vol. 70, no. March, p. 101782, 2020, doi: 10.1016/j.erss.2020.101782.

- Value conflicts and social acceptance of renewable energies

T. E. De Wildt, A. R. Boijmans, E. J. L. Chappin, and P. M. Herder, "An ex ante assessment of value conflicts and social acceptance of sustainable heating systems An agent-based modelling approach," Energy Policy, vol. 153, no. March, p. 112265, 2021, doi: 10.1016/j.enpol.2021.112265.

- Scaling-up district heating systems

J. Busch, K. Roelich, C. S. E. Bale, and C. Knoeri, "Scaling up local energy infrastructure; An agent-based model of the emergence of district heating networks," Energy Policy, vol. 100, no. October 2016, pp. 170–180, 2017, doi: 10.1016/j.enpol.2016.10.011.

- The effect of group decisions in heat transitions

G. del C. Nava-Guerrero, H. H. Hansen, G. Korevaar, and Z. Lukszo, "The effect of group decisions in heat transitions: An agent-based approach," Energy Policy, vol. 156, no. April, p. 112306, 2021, doi: 10.1016/j.enpol.2021.112306.

An ABM repositories:

https://www.comses.net/

A detailed example:

Simulating thermal energy community formation: Institutional enablers outplaying technological choice

Thermal Energy Communities (TEC) (1)

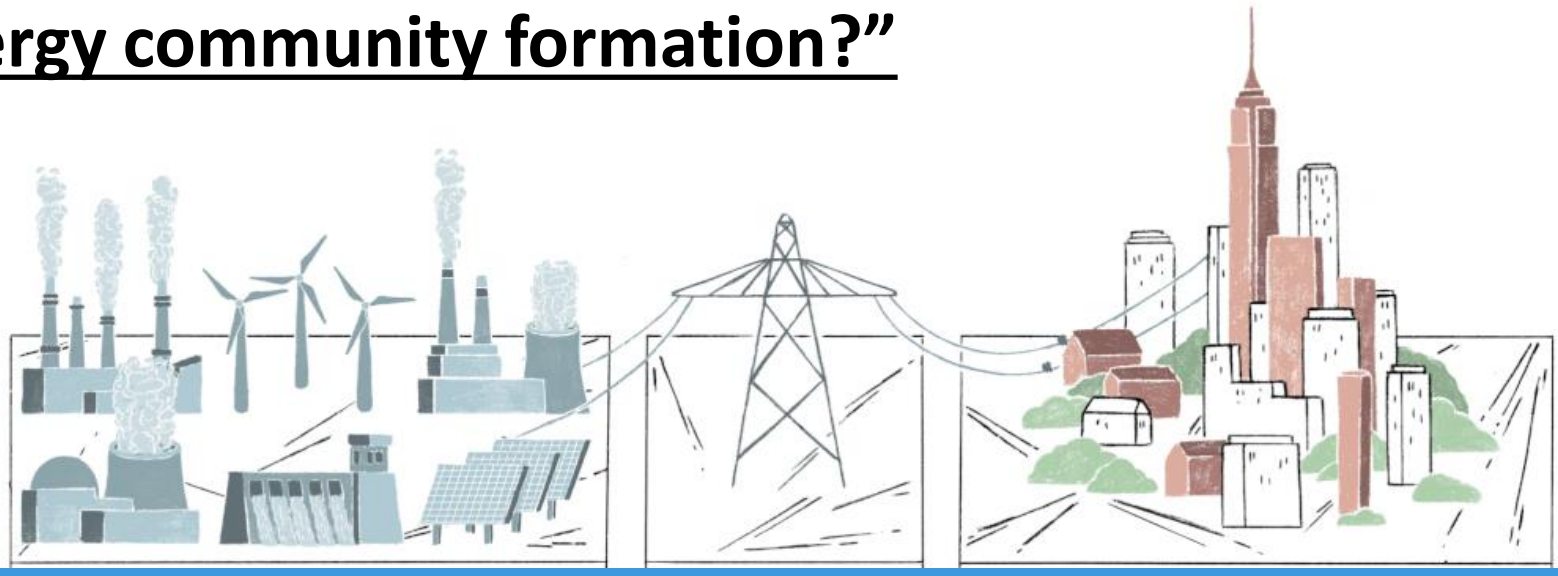
Local Energy Transition

Thermal energy communities

"people in a neighbourhood, who invest in renewable thermal energy technologies jointly and generate the energy they consume"

Characteristics: distributed thermal **RETs** and **collective action**

"What technical and institutional conditions influence thermal energy community formation?"

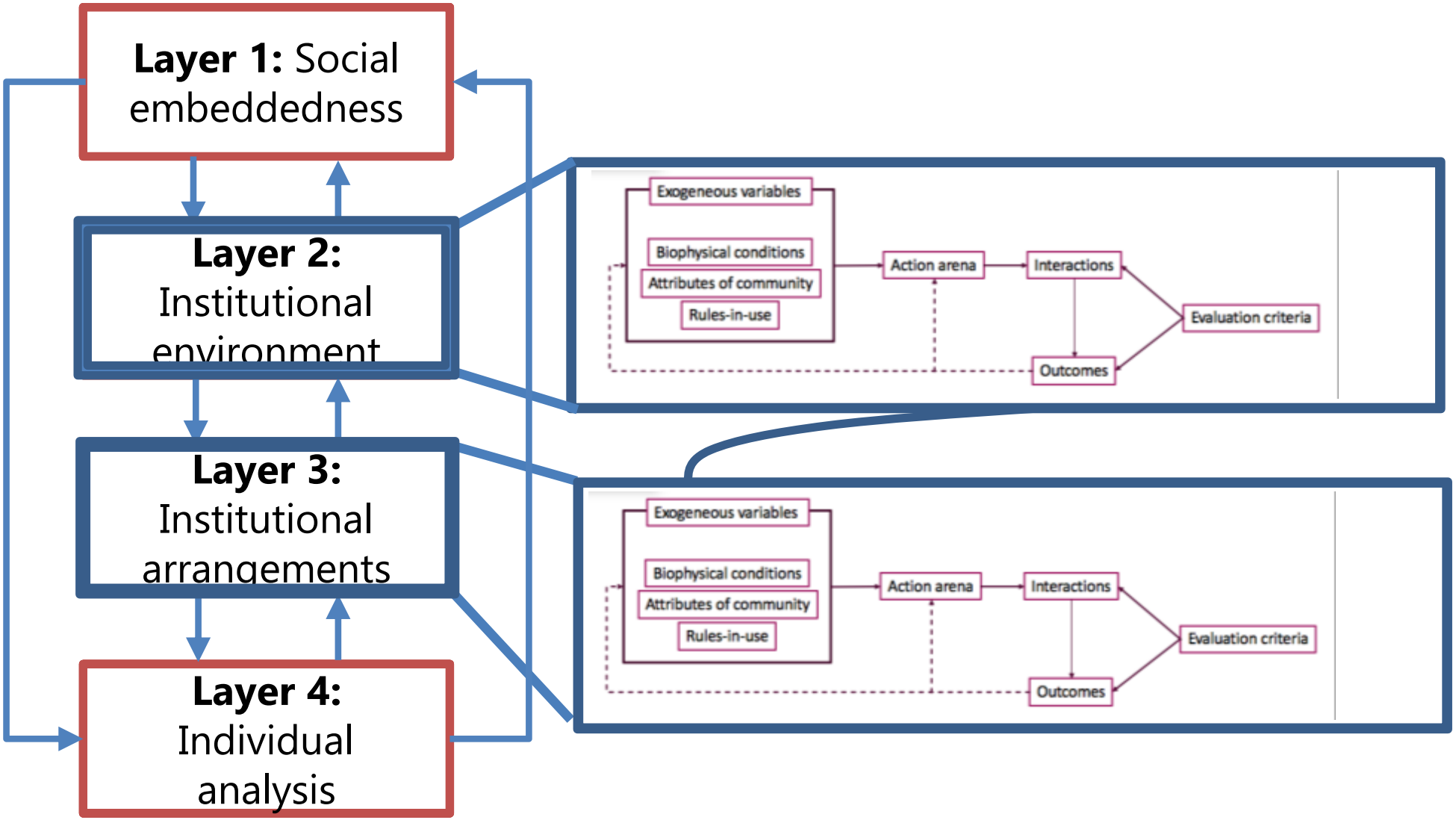


Thermal Energy Communities (TEC) (2)

Why using ABM for studying formation of TEC?

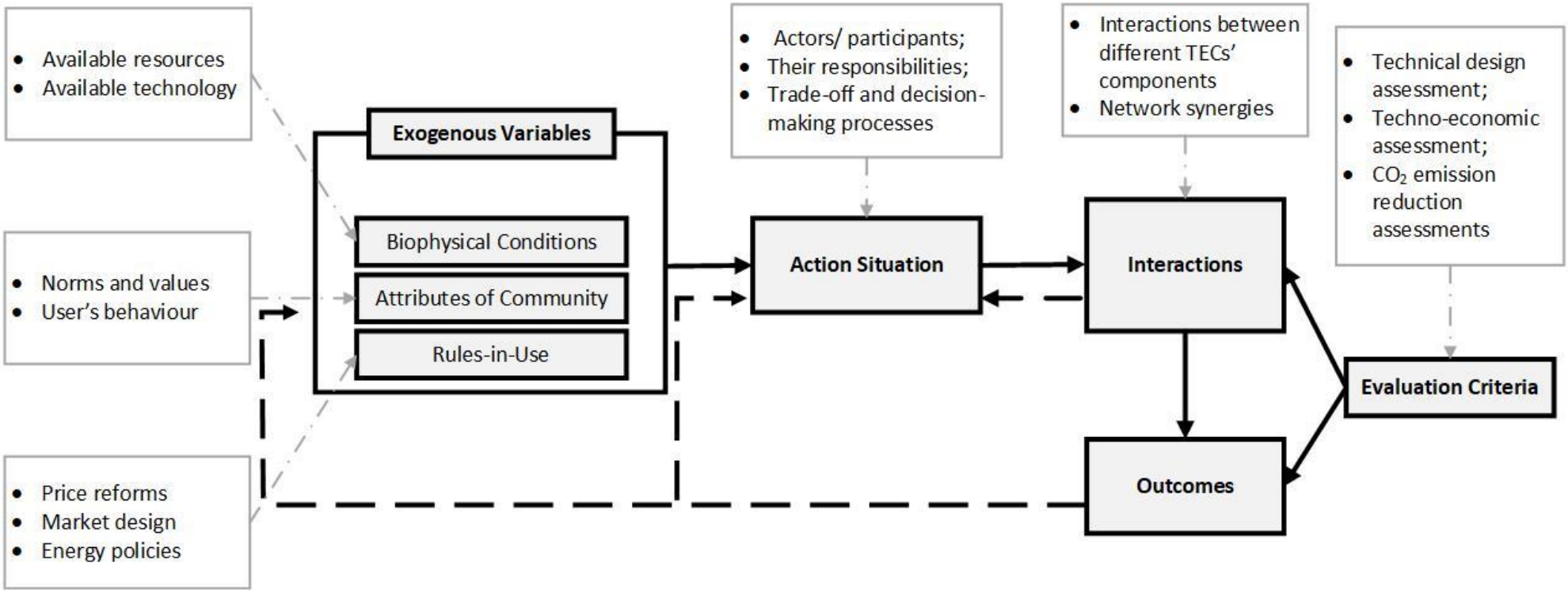
- Not many available real-world cases;
- The available real-world cases are so young;
- Availability of data;
- Data is heavily contextual;
- Sensitivity and biases;
- ….

Backbone of our model on TEC formation (1)



Four-layer model of Williamson

Backbone of our model on TEC formation (2)



Institutional Analysis and Development (IAD) framework

WE used the Netherlands, as the case study to populate our model.

Agent-Based Modelling (ABM): Exploring technical and institutional conditions (1)

Energy technology

- Generation (Collective):
  - Biogas
  - Aqua thermal energy storage (ATES)
  - Residual heat from surface water (TEA)
- Generation (Individual) :
  - Solar thermal
  - Heat pumps
- Distribution: District heating
- Demand: Household insulation

Agents/ Actors

- Municipalities/ Government
- Households
- TEC board (e.g. cooperative committee)

Municipality

- Subsidy strategy
- Subsidy amount
- CO_2 tax
- Providing trainings

TEC boards

- Participation policy
- Expansion policy
- Trained
- Technology choice

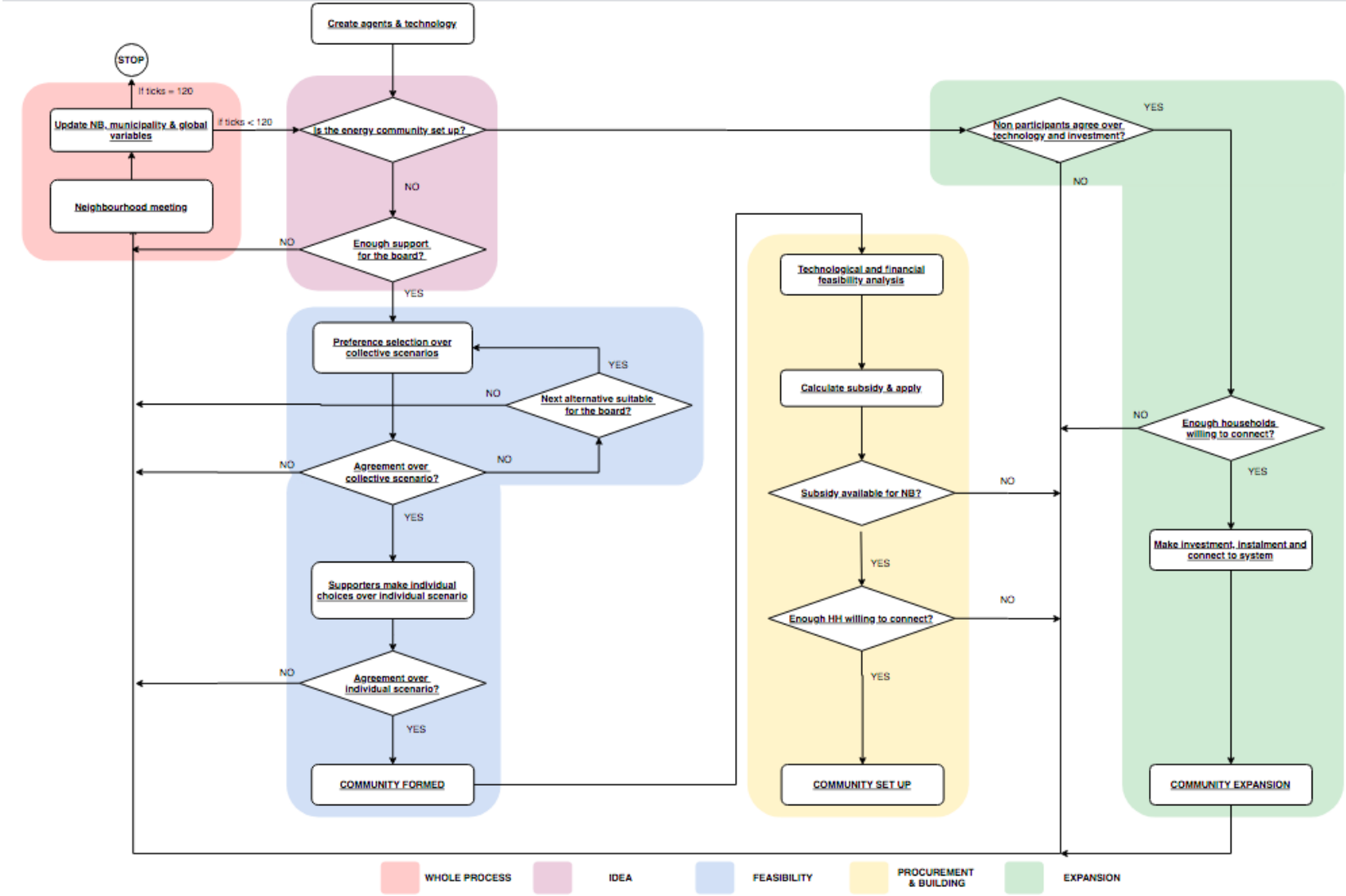
Households

- TEC board support
- Investment decision

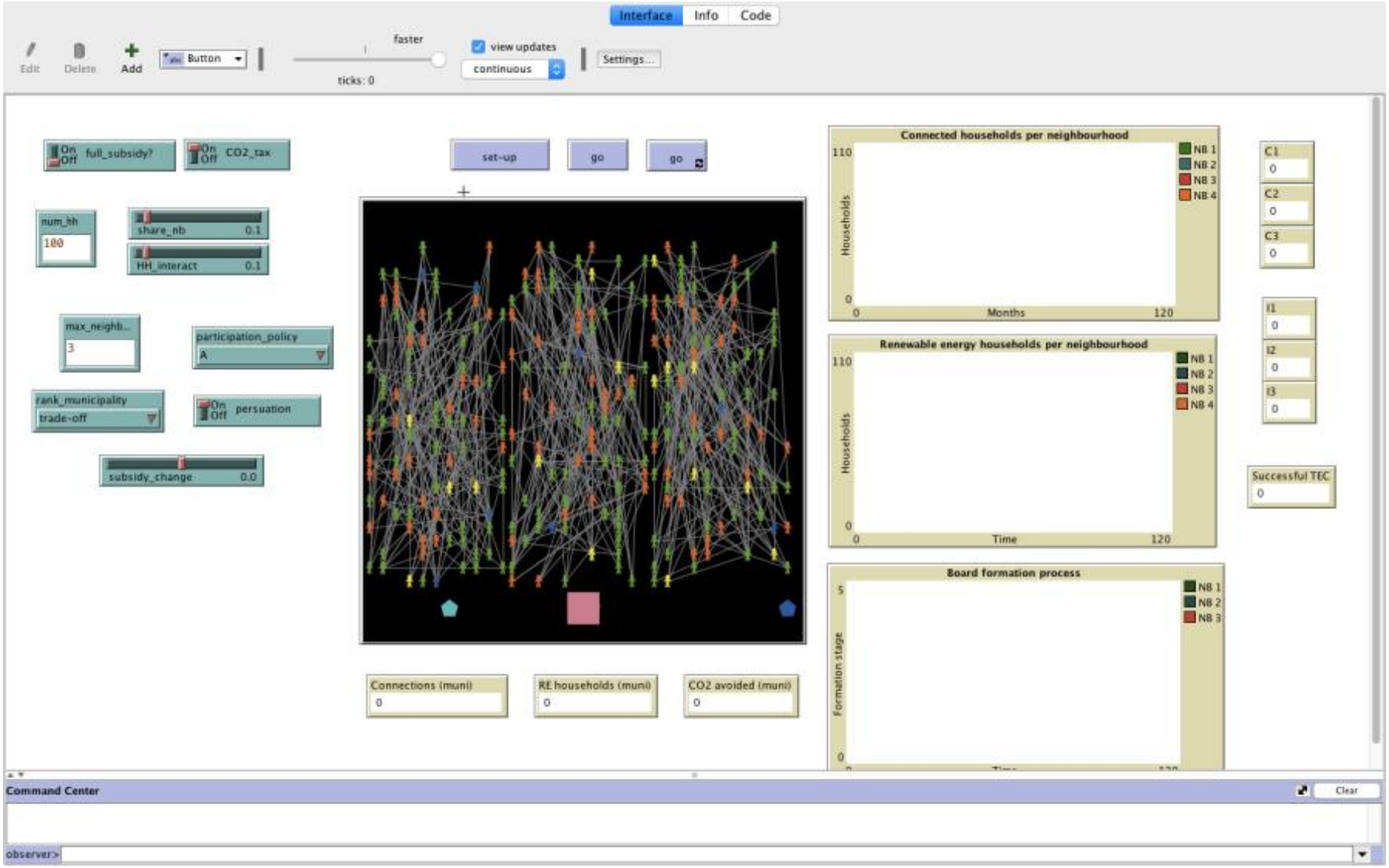
Motivations

- Environmental concerns
- Economic/ financial drive
- Energy independence
- Trust/ community belonging

Agent-Based Modelling (ABM): Exploring technical and institutional conditions (2)



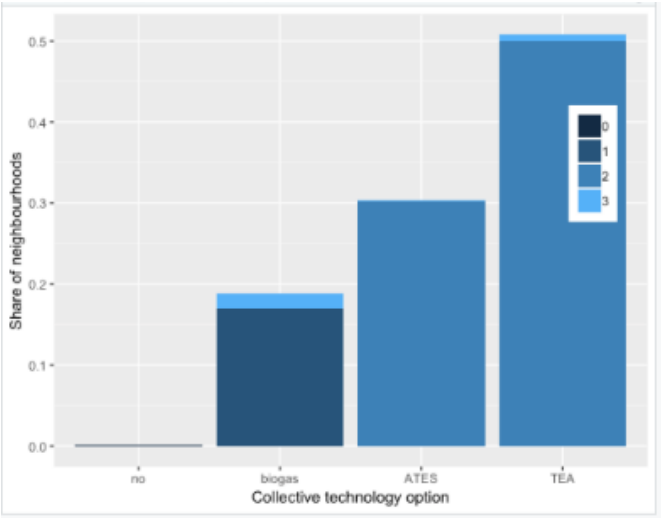
Agent-Based Modelling (ABM): Exploring technical and institutional conditions (4)

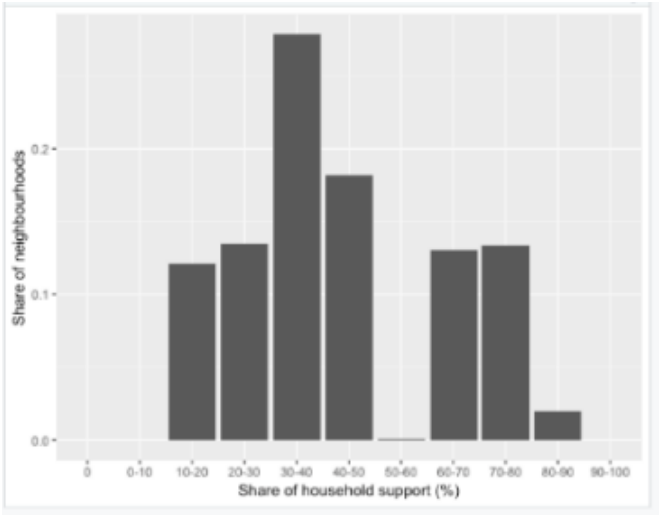


Results (1)
Overall results

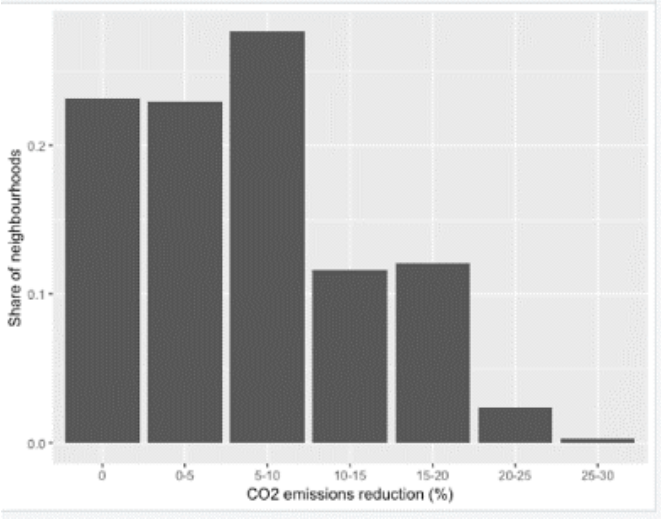
Neighbourhood distribution for technologies

On average it took 3 years for TEC to be established





Neighbourhood distribution for share of households support



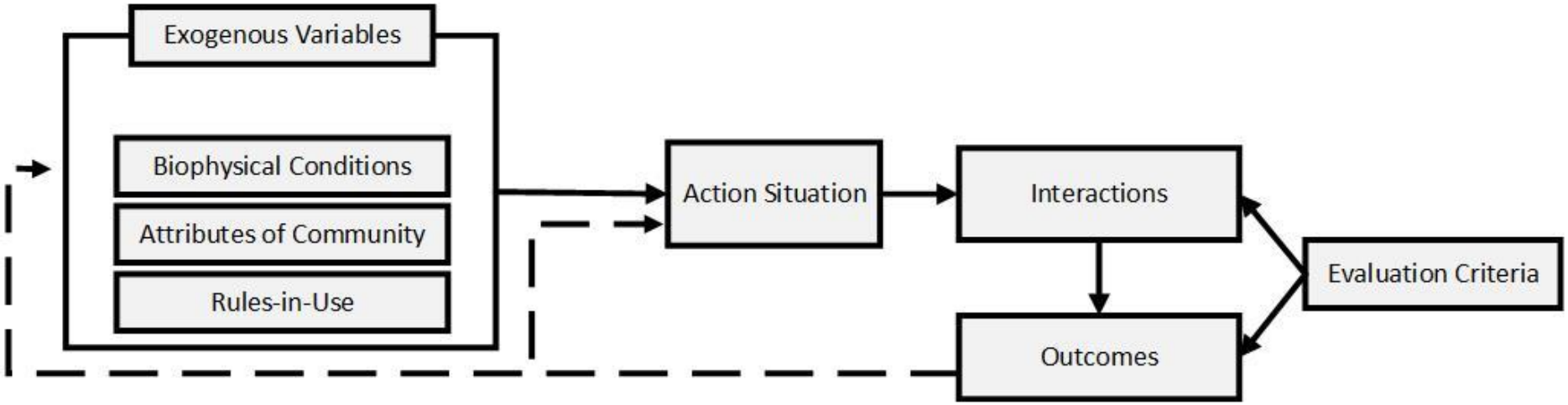
Accumulated of CO_2 emission reduction

Technological scenario	Bio	ATES	TEA
Fully collective	14.000	23.000	20.000
Collective + individual	18.000	26.000	22.500

Results (2)
Successful and unsuccessful neighbourhoods

		Successful neighbourhood (best performers in 3 main KPIs)		Unsuccessful neighbourhood
Municipalities	Subsidy policy strategy	Trade-off	Environment	Economy
	Training	Providing workshops for TEC board members		No workshop for TEC board members
TEC Boards	Technology scenario	TEA +ST		ATES +ST
	Values	Balanced values with environmental concerns as highest		Focus only on value (mostly economy and social)
	Subsidy	Yes		No
Households	Support	75%		<50%
	Investment	25000		15000

Conclusion and recommendations of this specific ABM



Recommendations for stakeholders:

- Technology selection itself is not the most crucial condition for the TECs' formation.
- Institutional conditions have considerable influence on TECs' formation.
- Providing training for community boards, could make a substantial difference.
- Only financial considerations are not sufficient for TECs' formation.
- The balance between all of the motivations for decision-making, is key to success.

Scientific contributions:

- Using four-layers of Williamson and IAD framework together in an ABM
- Understanding collective action towards local thermal energy transition

Epilogue (1)

Final thoughts on using ABM for studying the energy transition

- It is still relatively new approach;
- Studying socio-technical systems;
- Exploring, explaining and predicting;
- Assumptions, sensitivities and uncertainties;
- Communication about the model itself and findings;
- Like any-other modelling practices, ABM represents a simplified version of reality.

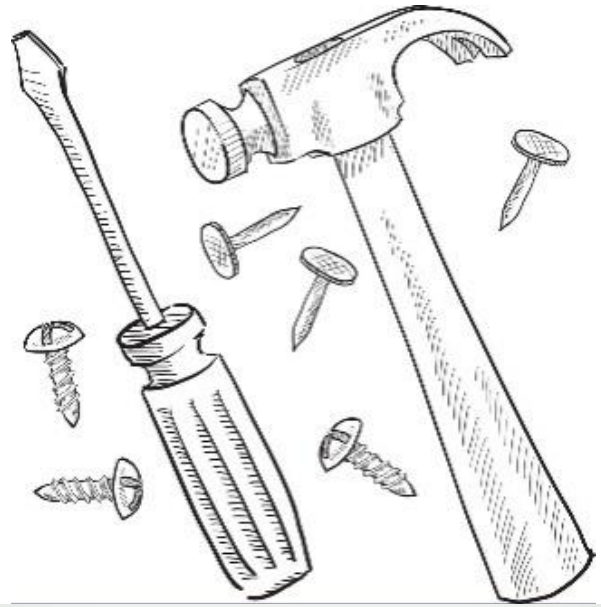
Some ideas for research agenda on using ABM

- Inventory of data for ABM;
- Coupling models (ABMs and other models);
- Energy-Water-Food nexus;
- More creative conceptual thinking (e.g. resilience of TEC, climate security and energy transition, energy security, …)

Epilogue (2)

Should we use ABM for studying the energy transition?!?

- It depends…;
- The research approaches/ tools should complement each other;
- ABM can potentially be interesting for all stakeholders (e.g. policy-makers, households and communities);
- Trade-offs between details, realistic and usable model;



"All models are wrong, but some are useful"

- J. Fouladvand, M. Arangouren Rojas, T. Hoppe, A. Ghorbani, "Simulating thermal energy community formation: Institutional enablers outplaying technological choice," applied energy
- J. Fouladvand, N. Mouter, A. Ghorbani, and P. Herder, "Formation and Continuation of Thermal Energy Community Systems: An Explorative Agent-Based Model for the Netherlands," Energies, vol. 13, no. 11, p. 2829, Jun. 2020.

Thank you for your attention "Agent-based modelling and simulation in the energy transition"

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Overview

- Overview on ABM in the energy transition
- Why ABM? Benefits, Challenges and examples
- Thermal Energy Communities and a detailed ABM
- Results and reflections

Capitalism and **individualistic approaches** are not the answer for a sustainable world!

We need to act **collectively**

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Agent-Based Modelling (ABM): Exploring technical and institutional conditions (3)

Experimentation setting

Parameter	Alternatives			
Municipality size	Small	Medium	Large	
Connection policy	A		B	
Boards' training availability	No		Yes	
Municipality subsidy policy	Environ.	social	financial	trade-off
Municipality subsidy amount per neighbourhood	3M		4M	

Model's KPIs

CO_2 emission reduction	Process duration
Neighbourhood support	Neighbourhood participation
Collective technology selection	Individual technology selection
Share of community investment	Average household investment