RUB

Chair of Energy Systems & Energy Economics

Modelling to generate alternatives for the energy transition – advancements in participatory and market-based approaches

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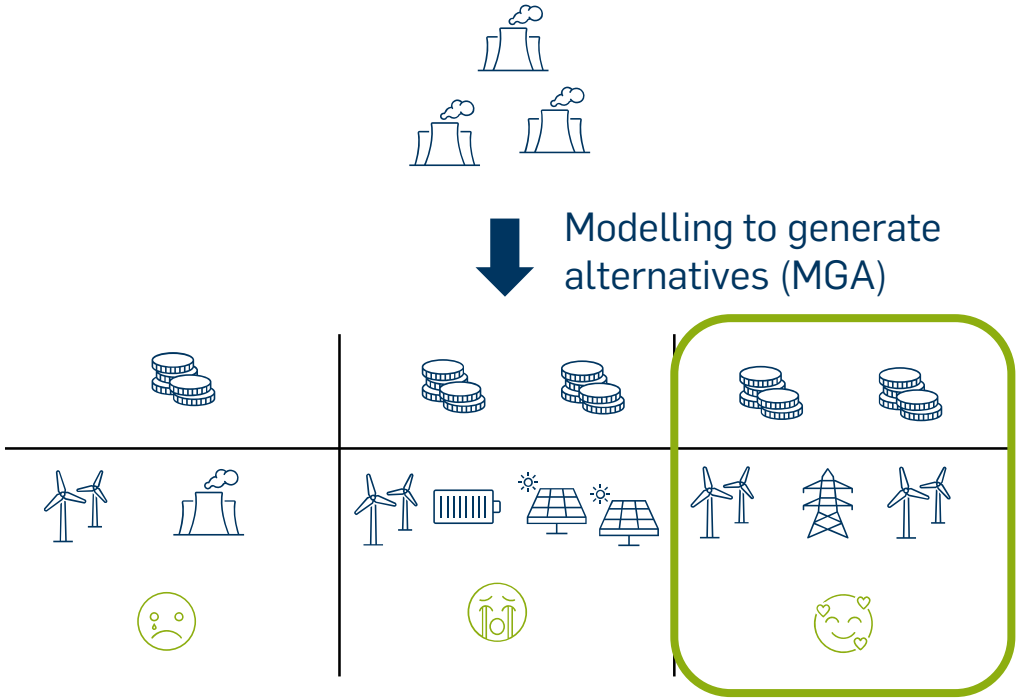
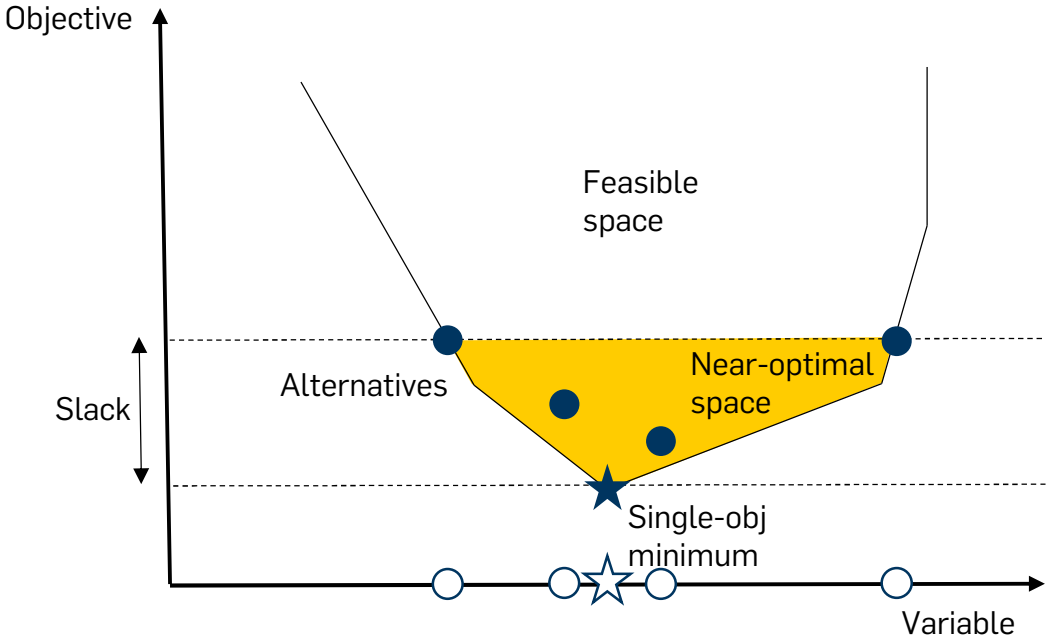
Why is modelling to generate alternatives (MGA) useful for planning the energy transition?



How does MGA work?



Weights

Cap = Minimum + Slack

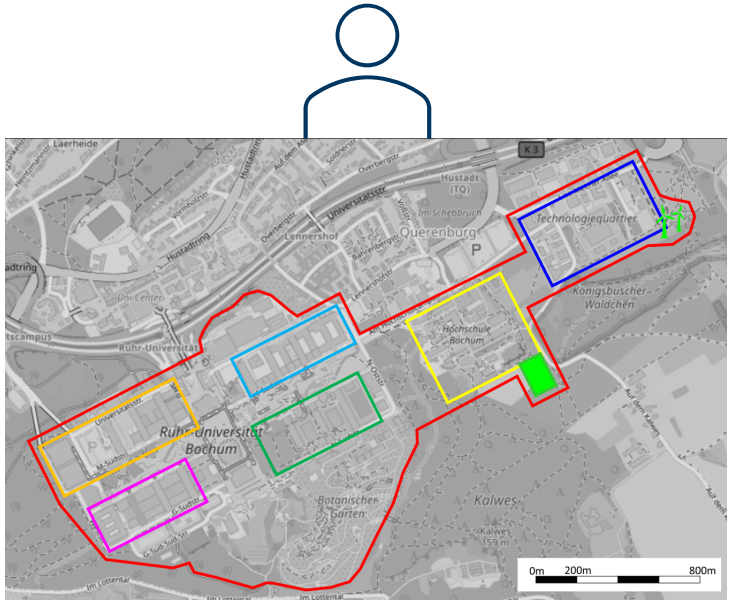
$$\min_{x \in X} \sum_i w_i x_i \quad \text{s.t.} \quad F(x) \leq \epsilon$$

Variables

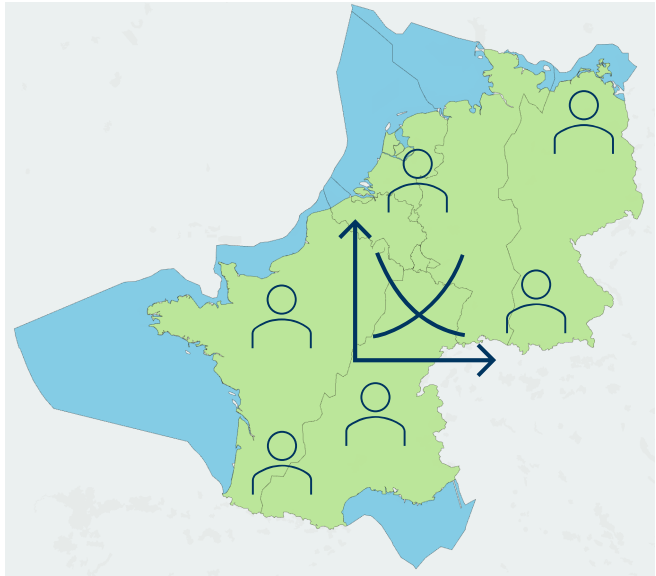
Objective

Introduction of MGA to energy system models is due to DeCarolis, *Using modeling to generate alternatives (MGA) to expand our thinking on energy futures*, Energy Economics 2011. https://doi.org/10.1016/j.eneco.2010.05.002

How to ease realisation of alternatives?



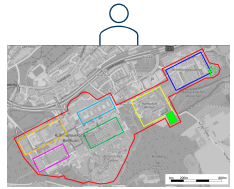
Participatory MGA

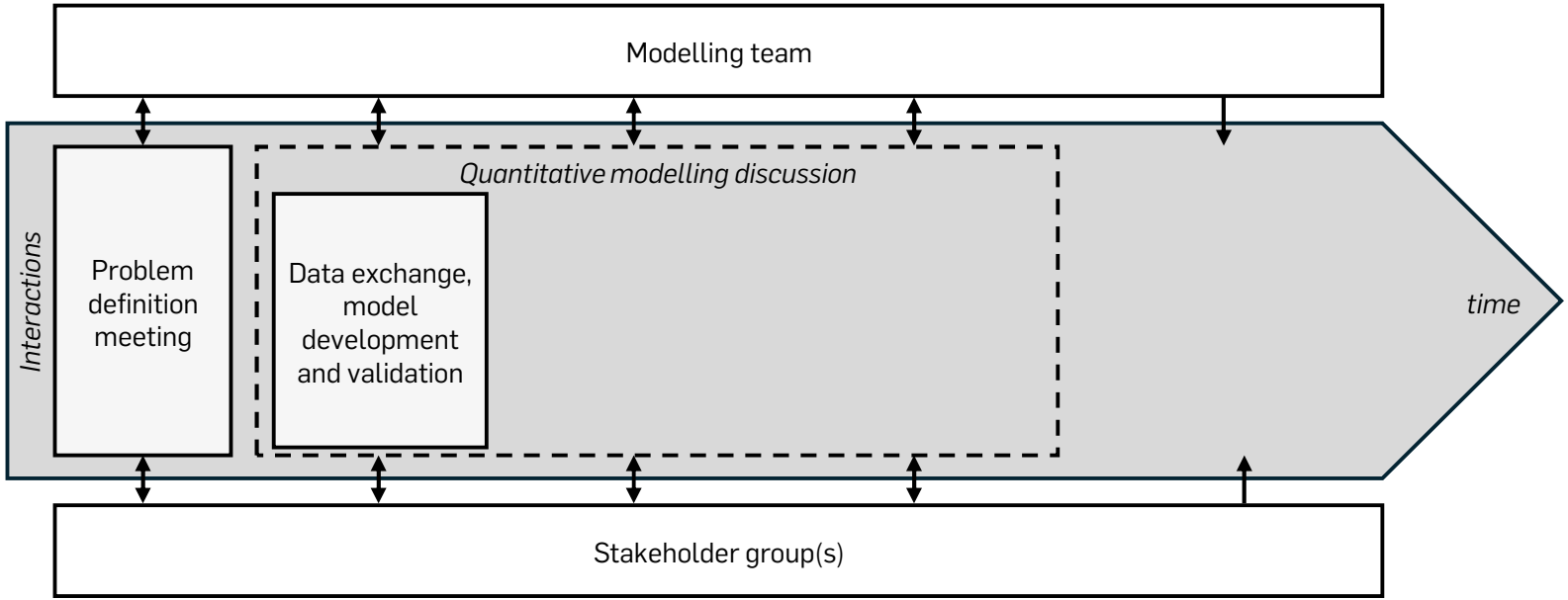


Market-based interpretation of MGA

Participatory MGA

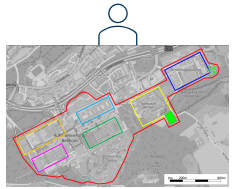
Participatory MGA approach

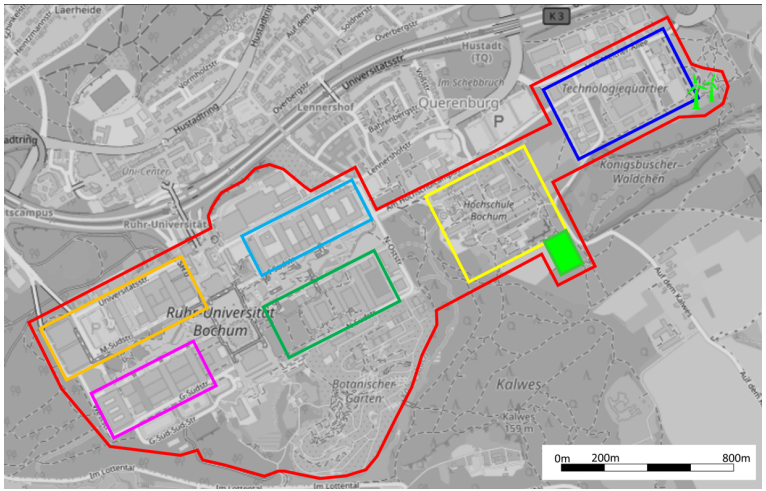




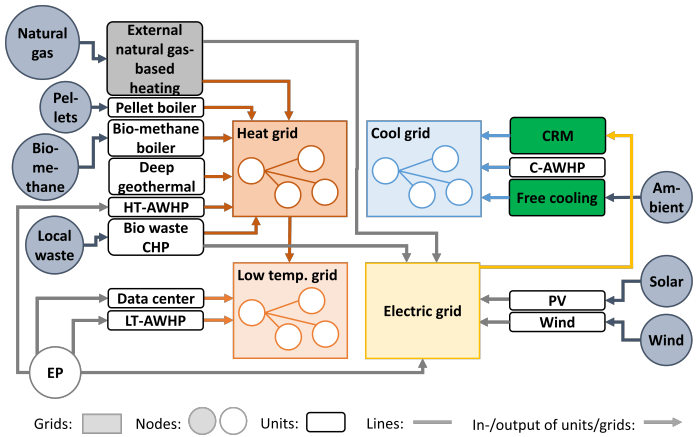
Esser et al., *Participatory modelling to generate alternatives to support decision-makers with near-optimal decarbonisation options, Applied Energy 2025.* https://doi.org/10.1016/j.apenergy.2025.126184

Ruhr University Bochum's power, heating and cooling supply





Aim: Explore ways to achieve climate-neutrality by 2045



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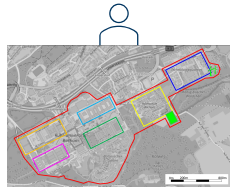
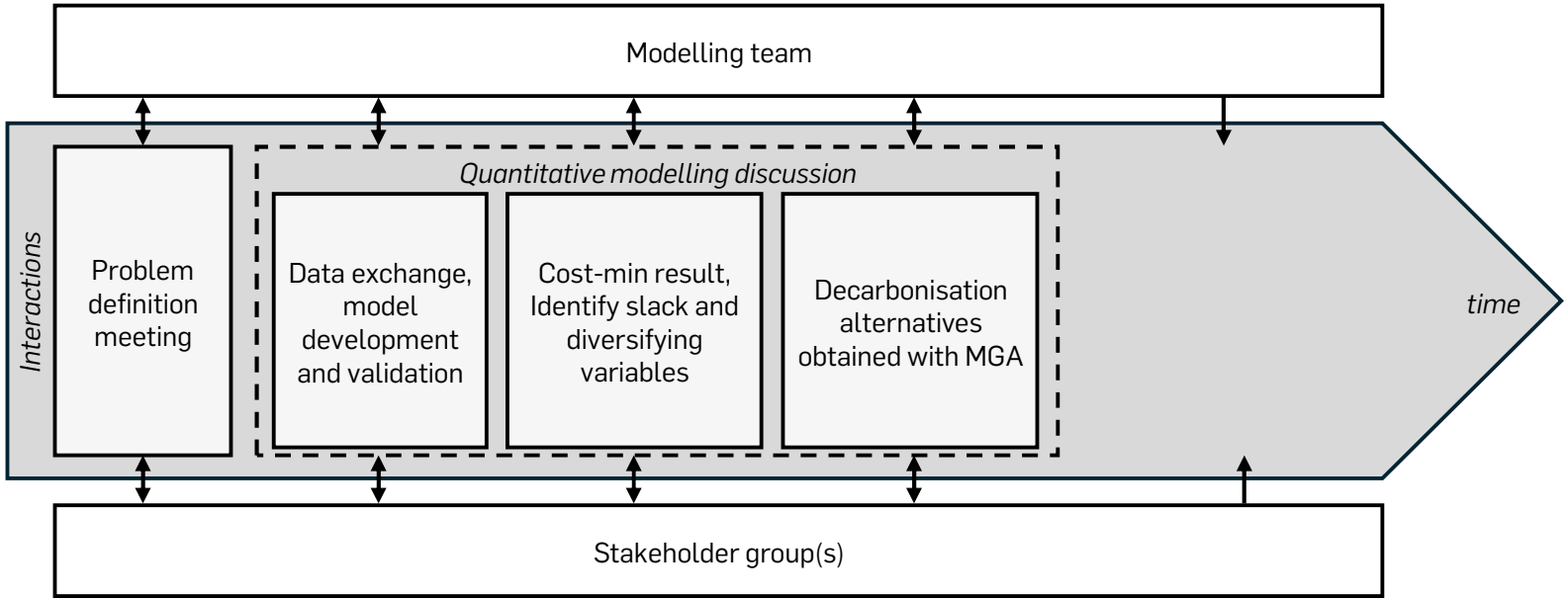
Participatory MGA approach





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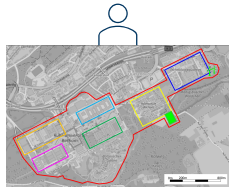
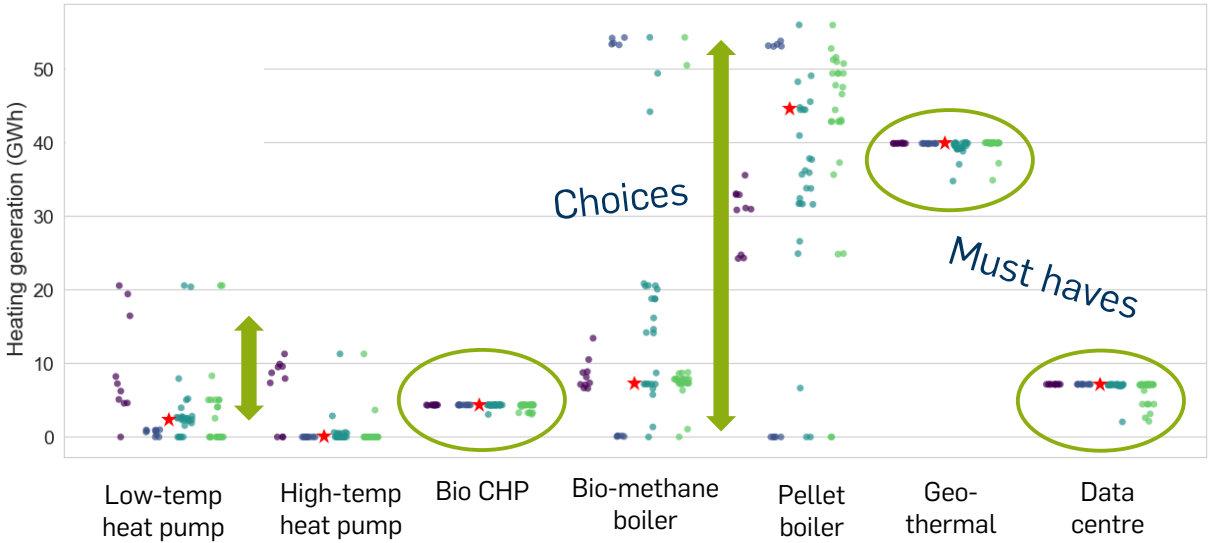
Must haves and choices at 1% extra cost





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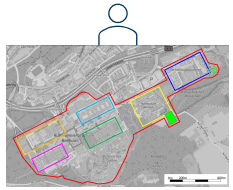
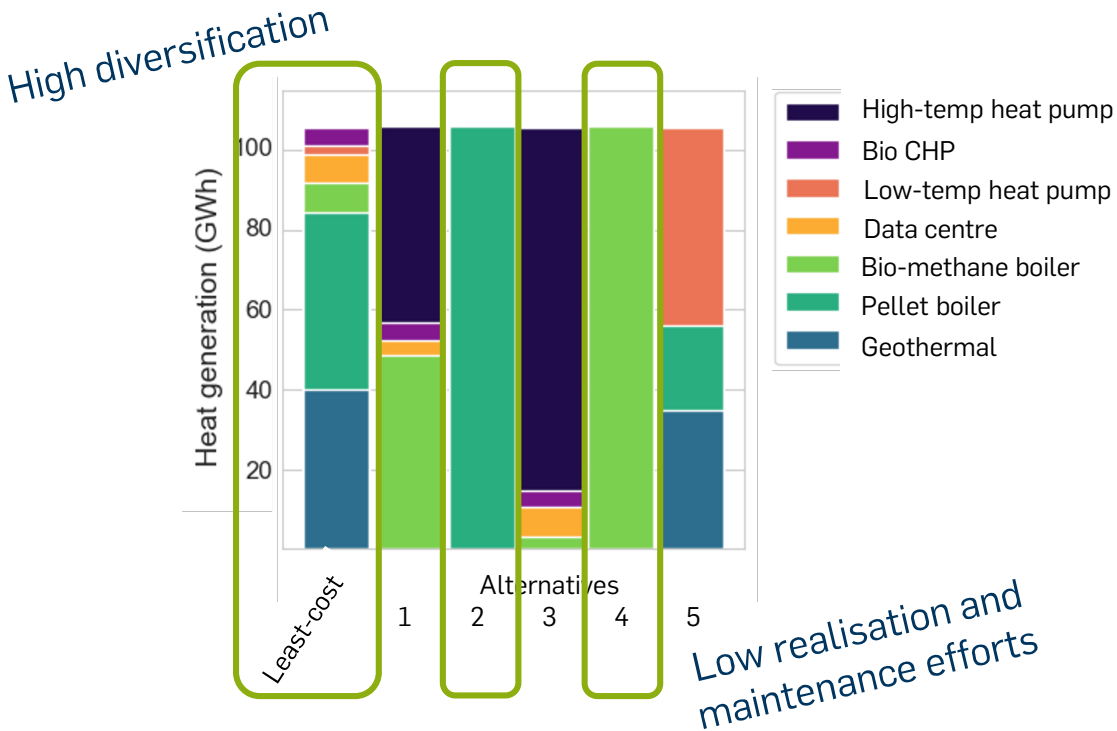
Discrete alternatives and stakeholder interests





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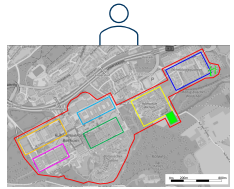
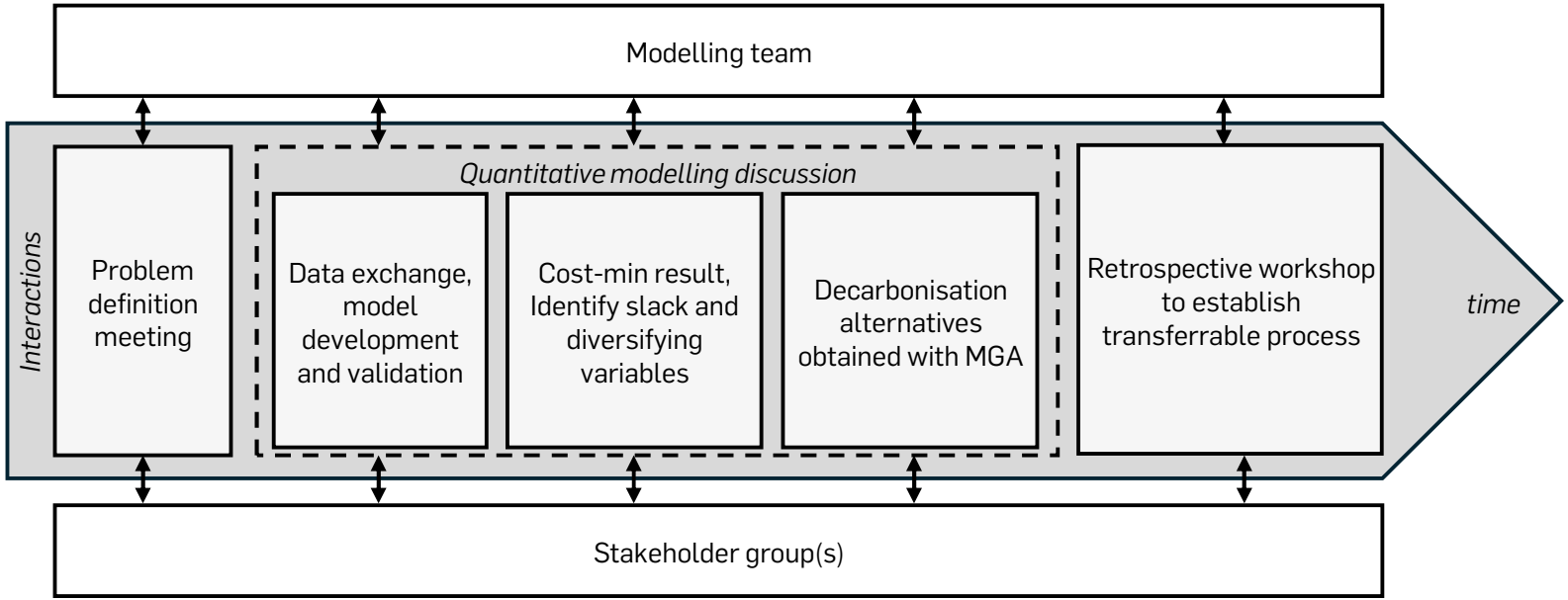
Participatory MGA approach





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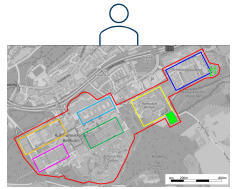
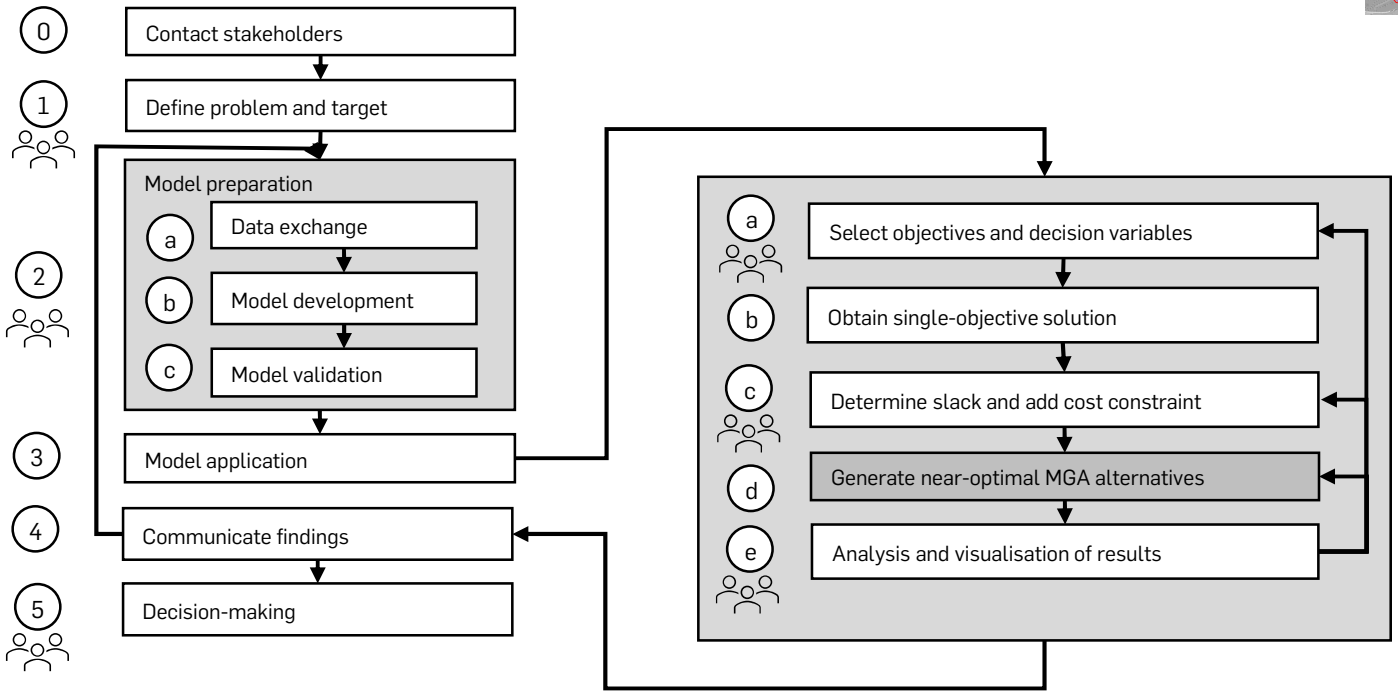
Participatory MGA – Transferrable process





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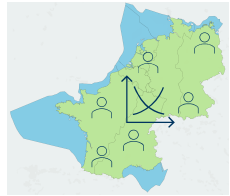
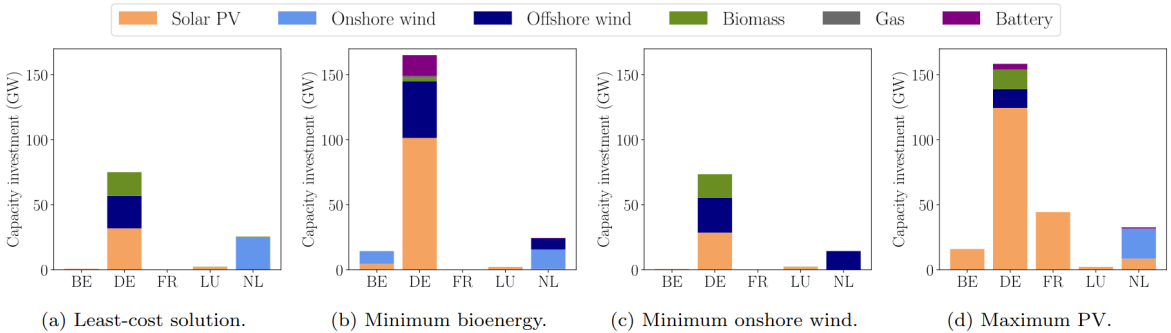
Market-based interpretation of MGA

Capacity expansion planning in multi-national power system model





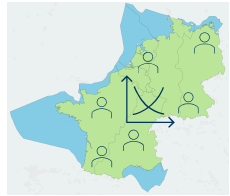
(a) Least-cost solution. (b) Minimum bioenergy. (c) Minimum onshore wind. (d) Maximum PV.

1) Investments optimal for agents
2) Investments profitable for agents
3) Duals interpreted as market prices

Finke, J., Weber, C. & Bertsch, V. *Linking Modelling to Generate Alternatives, Multi-Objective Optimisation and Market Equilibria – On the Economic Interpretation of Near-Cost-Optimal Solutions in Energy System Models*. Available at SSRN: https://dx.doi.org/10.2139/ssrn.4812751

The power system model used here is very similar to the one studied by Finke et al., *Exploring the feasibility of Europe's renewable expansion plans based on their profitability in the market*, Energy Policy 2023. https://doi.org/10.1016/j.enpol.2023.113566

MGA is equivalent to a cost-minimising energy system model with modified cost terms



Modelling to generate alternatives

$$\min_{x \in X} \sum_{i \in I} w_i x_i \quad \text{s.t.} \quad F(x) \leq F_0 \perp \mu$$

Lagrangian

Modified energy system model

$$\min_{x \in X} \left(F(x) + \sum_{i \in I} \frac{w_i}{\mu} x_i \right)$$

Cost minimisation with extra cost term

$$c_i^{\text{inv}} \rightarrow c_i^{\text{inv}} + w_i / \mu$$

1) Same optimal primal solution (e.g. investments)

2) Duals (i.e. marginals) differ by a factor of μ

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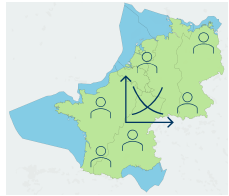
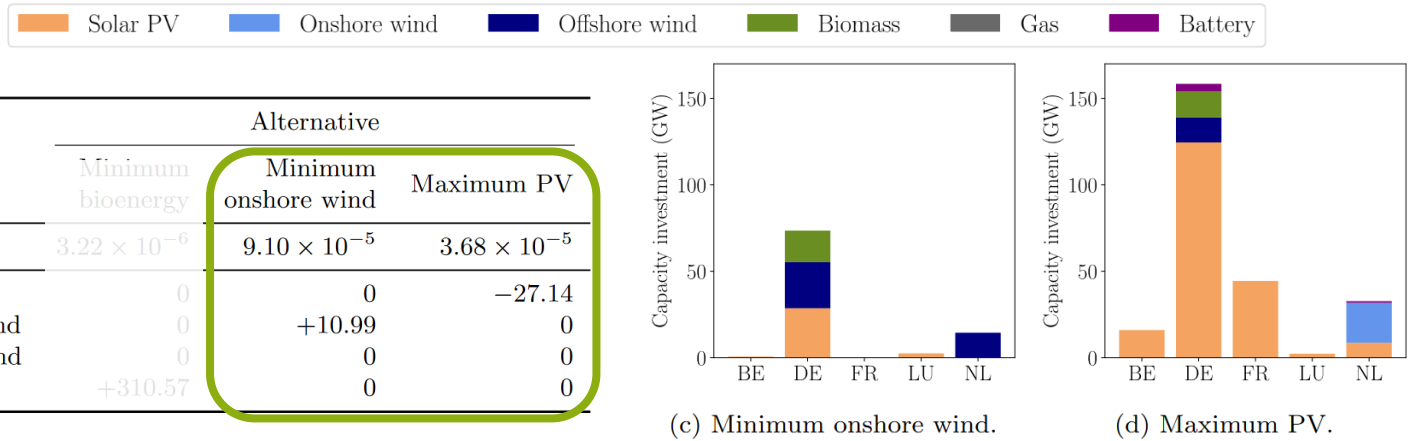
Penalty / subsidy needed to establish MGA alternative as competitive equilibrium



		Alternative		
		Minimum bioenergy	Minimum onshore wind	Maximum PV
Dual μ (MW/€)		3.22×10^{-6}	9.10×10^{-5}	3.68×10^{-5}
Extra cost /revenue (€/kW)	Solar PV	0	0	−27.14
	Onshore wind	0	+10.99	0
	Offshore wind	0	0	0
	Bioenergy	+310.57	0	0

$$c_i^{\text{inv}} \rightarrow c_i^{\text{inv}} + w_i/\mu$$



(c) Minimum onshore wind. (d) Maximum PV.

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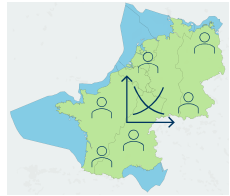
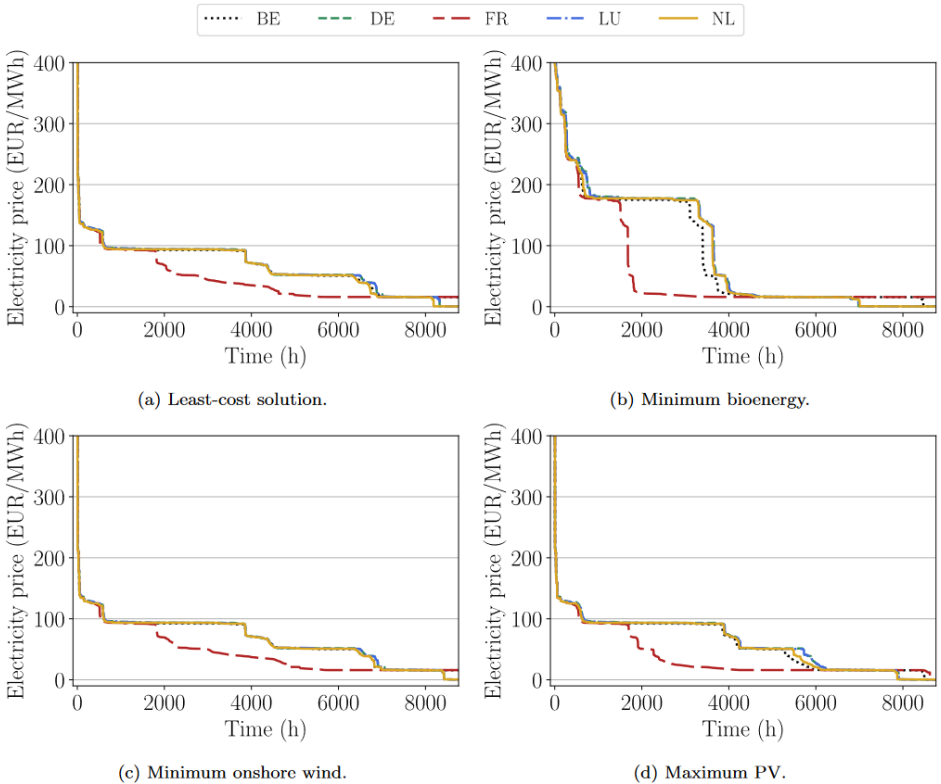
Market prices





(a) Least-cost solution.

(b) Minimum bioenergy.

(c) Minimum onshore wind.

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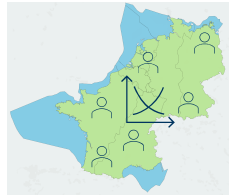
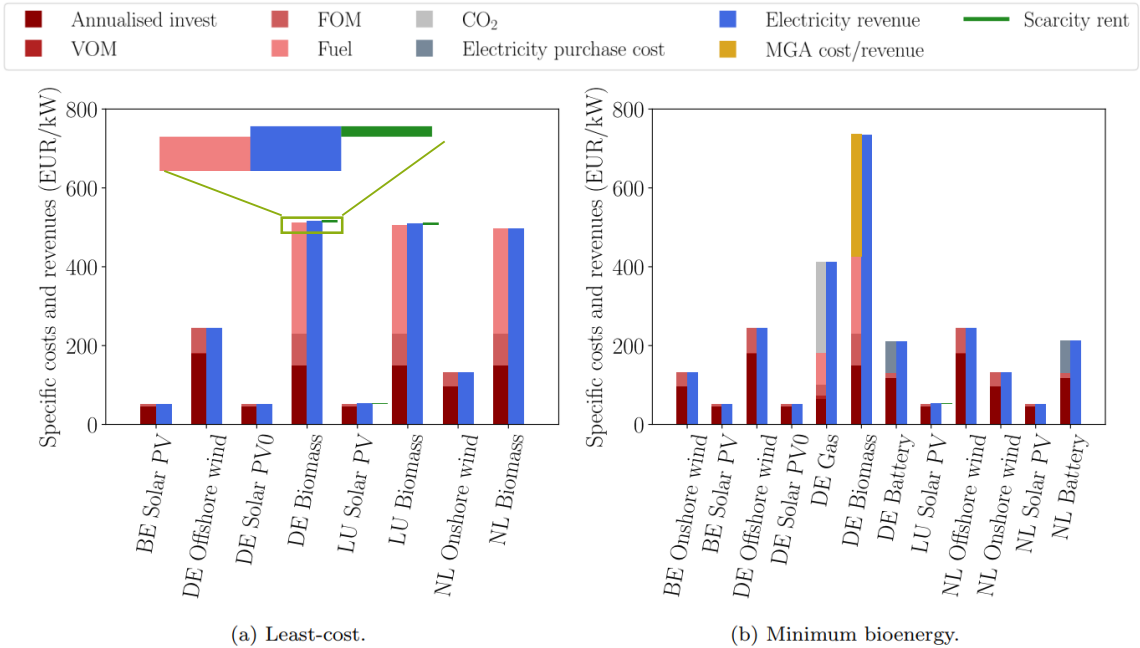
Costs are recovered, thus investments profitable





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Conclusions

Conclusions

- MGA is a great modelling tool that should be used and interpreted depending on the situation
  - Central decision-maker → Participatory MGA
  - Profit-maximising decision-makers in competitive markets → Market-based interpretation

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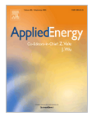

Participatory modelling to generate alternatives to support decision-makers with near-optimal decarbonisation options

SCAN ME

Katharina Esser [a], Jonas Finke [a], Valentin Bertsch [a], Andreas Löschel [b]

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Linking Modelling to Generate Alternatives, Multi-Objective Optimisation and Market Equilibria – On the Economic Interpretation of Near-Cost-Optimal Solutions in Energy System Models

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https://dx.doi.org/10.2139/ssrn.4812751

Thank you!

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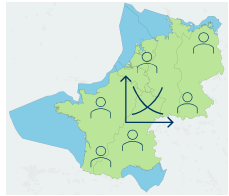
Backup

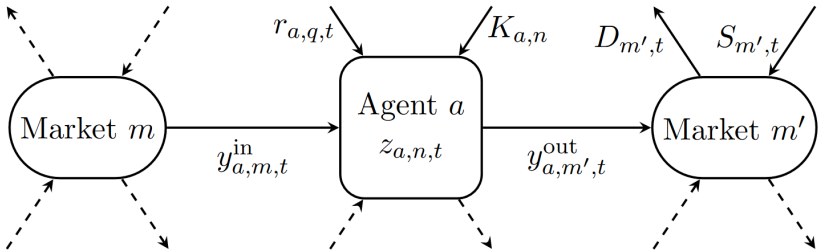
Cost-minimising energy system model is equivalent to competitive market equilibrium of profit-maximising agents



1) The **same decisions are optimal** for profit-maximising agents and energy system model

2) Marginals (duals) are interpreted as **market prices** in competitive equilibrium

3) Revenues exactly recover all costs and spendings, thus **investments are profitable**



What is a market-based interpretation of alternatives generated with MGA?

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Similar results are derived by other authors, e.g. Özdemir, Ö., Hobbs, B. F., van Hout, M., & Koutstaal, P. R. (2020). Capacity vs energy subsidies for promoting renewable investment: Benefits and costs for the EU power market. Energy Policy, 137, 111166. doi:10.1016/j.enpol.2019.111166 or Junge, C., Mallapragada, D., & Schmalensee, R. (2022). Energy Storage Investment and Operation in Efficient Electric Power Systems. The Energy Journal, 43, 1–24. doi:10.5547/01956574.43.6.cjun.