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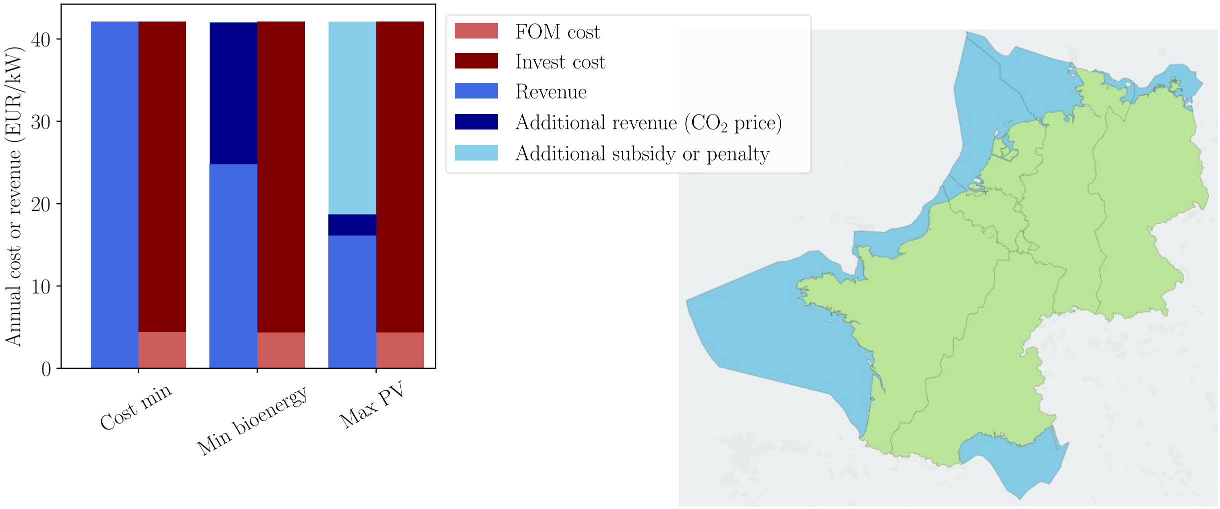


RUHR-UNIVERSITÄT BOCHUM

HOW POWER PRICES AND RENEWABLES' MARKET VALUES DIFFER BETWEEN NEAR-OPTIMAL FUTURE ENERGY SYSTEMS

Chair of
Energy Systems &
Energy Economics

Jonas Finke, Valentin Bertsch, Christoph Weber # 25.07.2023 # jonas.finke@rub.de

Introduction

Near-optimal solutions

- **Energy transition** needs **complex decisions**, which can be supported by **energy system models**
- Many models **minimise costs**, but neglect **people's other interests**
- Modelling to Generate Alternatives (MGA) to obtain **near-cost-optimal system** alternatives
- These can be more **"interest-optimal"** and socially **feasible**

Existing studies

- Generate alternative future power systems
- Alternatives for energy generation, transmission or renewable expansion
- Identify special alternatives, e.g. low wind/bioenergy or homogeneous spatial distribution

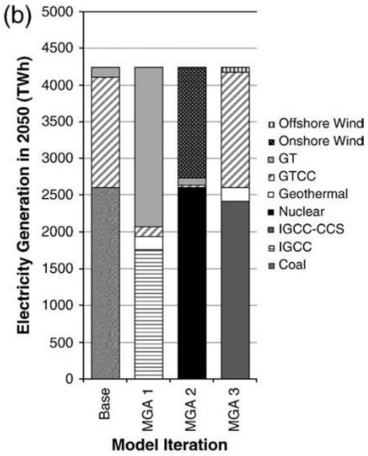


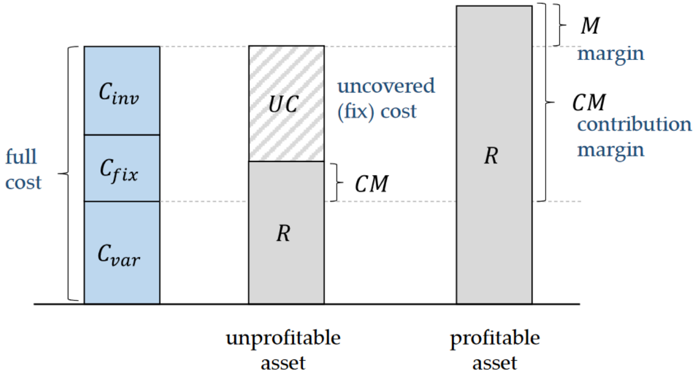
Figure taken from DeCarolis, *Using modeling to generate alternatives (MGA) to expand our thinking on energy futures*, Energy Economics 2011. https://doi.org/10.1016/j.eneco.2010.05.002
For a short overview of existing MGA studies, see e.g. Neumann and Brown, *The near-optimal feasible space of a renewable power system model*, Electric Power Systems Research 2021. https://doi.org/10.1016/j.epsr.2020.106690
For a recent application of MGA, see Lombardi et al., *Policy decision support for renewables deployment through spatially explicit practically optimal alternatives*, Joule 2020. https://doi.org/10.1016/j.joule.2020.08.002

Market prices and revenues

- Market with investment decisions based on revenue expectations
- Profitability of investments important for feasibility

Existing studies

- Analyse market prices, market values, missing money or profitability



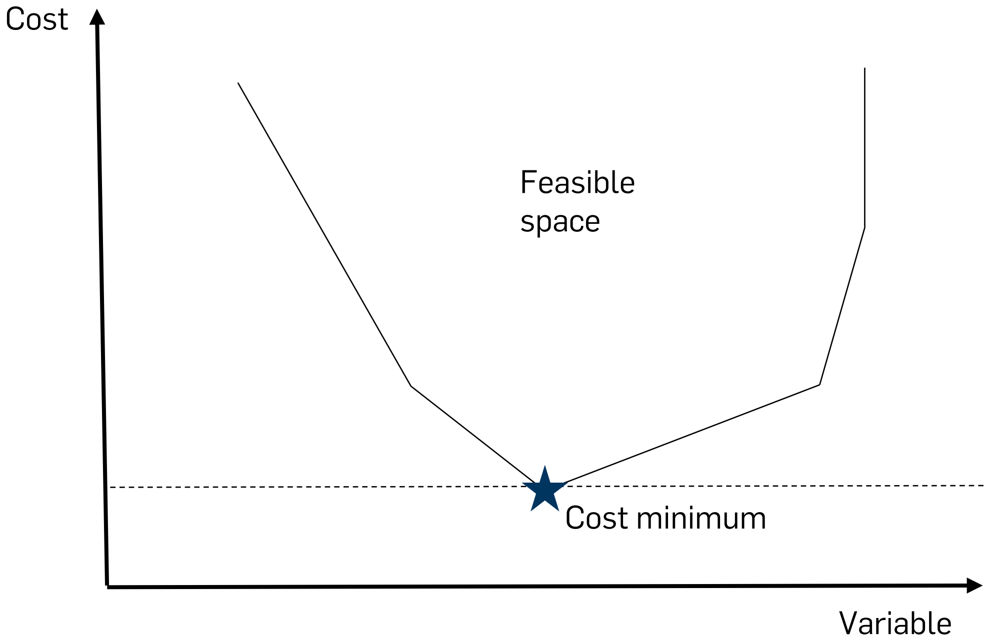
Aim of this talk:

- Bring both areas of research together
- Analyse **market prices** and their implications in **near-cost optimal alternatives**

Figure taken from Gillich and Hufendiek, *Asset profitability in the electricity sector: An iterative approach in a linear optimization model*, Energies 2022. https://doi.org/10.3390/en15124387
For a study on renewalbes' profitability see also 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
For a study on market values, see e.g. Ruhnau, *How flexible electricity demand stabilizes wind and solar market values: The case of hydrogen electrolyzers*, Applied Energy 2022. http://dx.doi.org/10.1016/j.apenergy.2021.118194

Modelling to Generate Alternatives (MGA)

MGA – General approach



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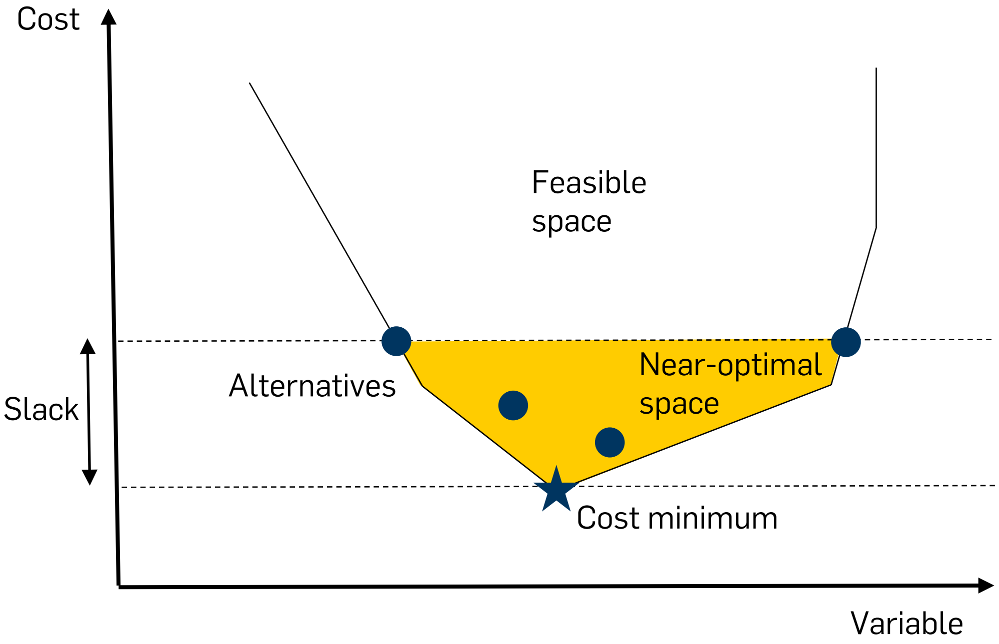

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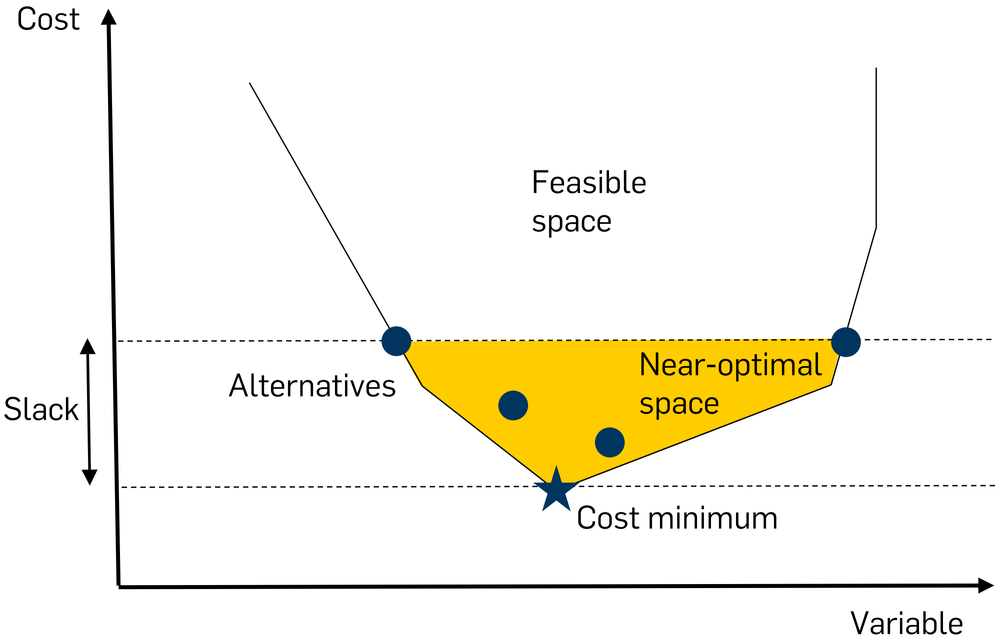


Weights

Cap = Minimum cost + slack

$$\min_{x\in V}\sum_{i\in P} w_i x_i \quad \text{s.t.} \quad F(x) \leq \epsilon.$$

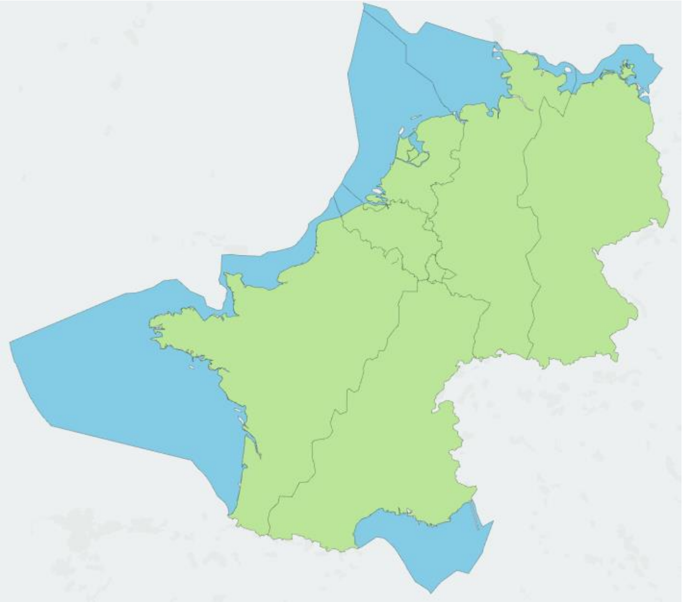
Variables

Cost function

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

Power system model

- 5 countries: BE, DE, FR, LU, NL
- One year at hourly resolution
- Brownfield investment & operational planning for 2030
- Investments in PV, onshore wind, offshore wind, bioenergy, batteries



MGA

- 5 % cost slack
- Alternatives for renewables' investments as variables

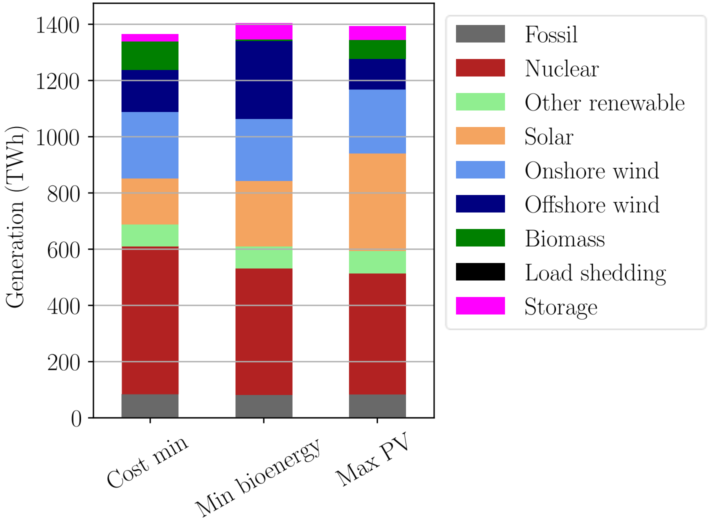
Except from the included countries, the power system model used here is very similar to the one studied by Finke et al., *Exploring the feasibility of Europe's renewable expansion plans based on their profitability in the market*, Energy Policy 2023. https://doi.org/10.1016/j.enpol.2023.113566

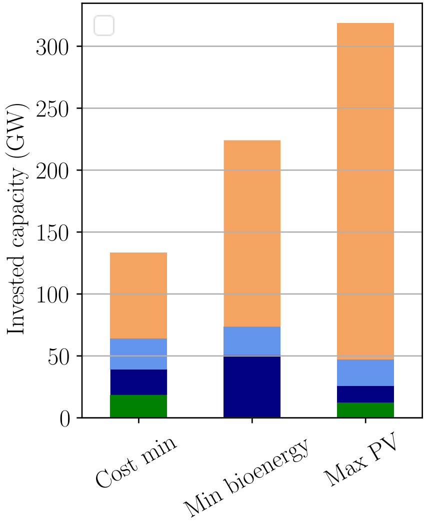
Demand, transmission capacities, existing conventional capacities and renewable potentials are generated with Hörsch et al., *PyPSA-Eur: An Open Optimisation Model of the European Transmission System*, Energy Strategy Reviews 2018.

Costs and efficiencies as well as the CO_2 price are taken from Pietzcker et al., *Tightening EU ETS targets in line with the European Green Deal: Impacts on the decarbonisation of the EU power sector*, Applied Energy 2021.

Helistö et al., *Backbone – An Adaptable Energy Systems Modelling Framework*, Energies 2019. See also https://gitlab.vtt.fi/backbone/backbone.

Three illustrative alternative system designs





How do **market prices** change between alternatives?

Market prices and cost recovery

Market prices and values vary across alternatives

- Market prices proxied by **marginal cost** to meet demand
- Example from now on: Germany, Solar PV

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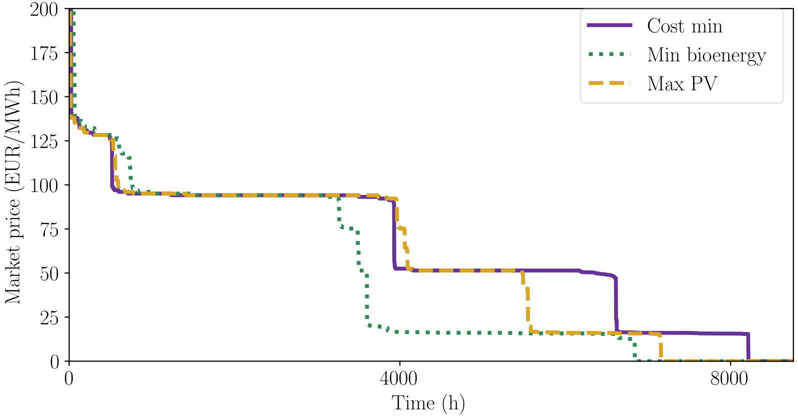

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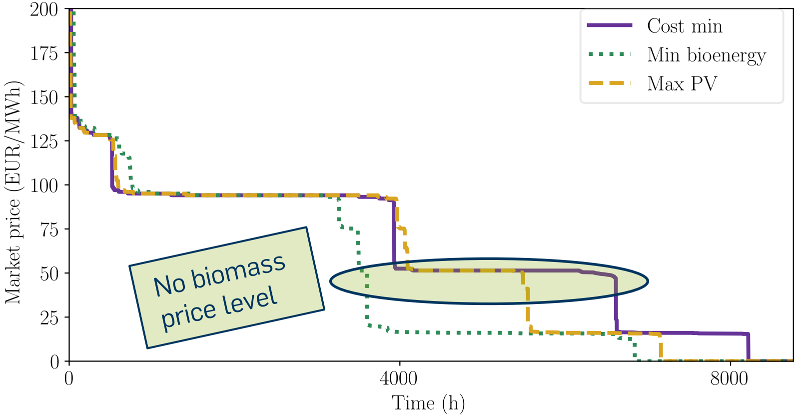

No biomass price level

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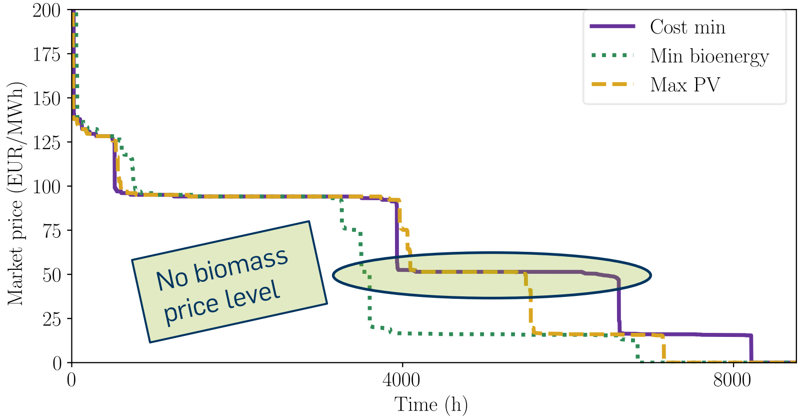

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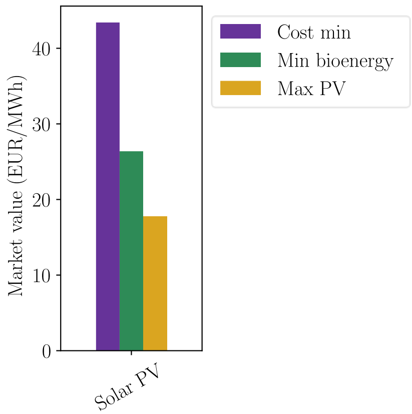

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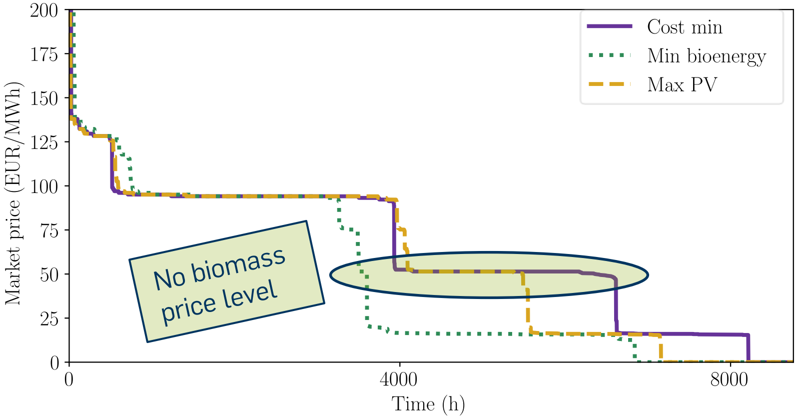

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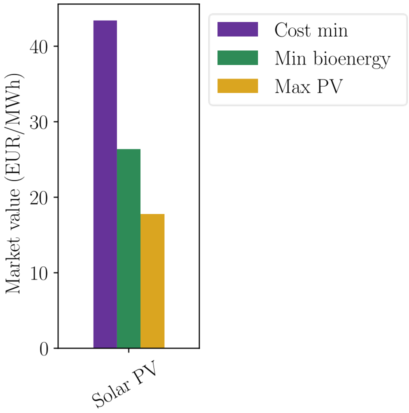

? Are **investments profitable** for the alternative systems? ?

Investments do not recover costs in alternatives

- In linear cost-minimising model without “market-distorting” constraints, **cost recovery** of endogenous investments is guaranteed
- MGA alternatives don’t result from cost minimisation and we observe **revenues < costs**

For theory on cost recovery, see e.g. Brown and Reichenberg, *Decreasing market value of variable renewables can be avoided by policy action,* Energy Economics 2021. https://doi.org/10.1016/j.eneco.2021.105354

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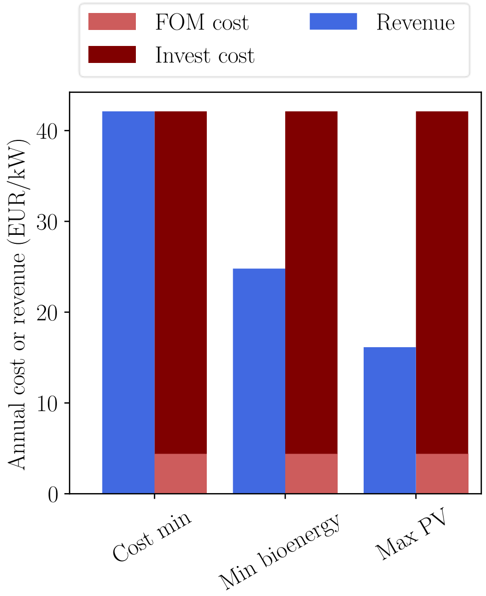

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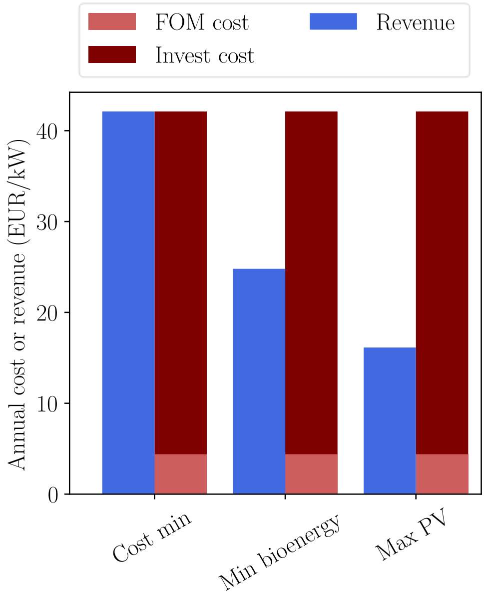
- If investments are expected to be unprofitable, they are **unlikely to be made** in the first place
- Hence it is unlikely that these alternatives will result from **market-based investment decisions**



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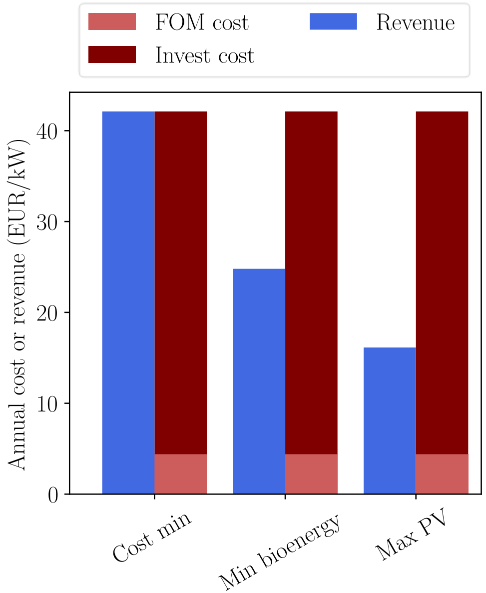

How can profitability be achieved and the alternatives be **realised** in the market?

For theory on cost recovery, see e.g. Brown and Reichenberg, *Decreasing market value of variable renewables can be avoided by policy action,* Energy Economics 2021. https://doi.org/10.1016/j.eneco.2021.105354

MGA is equivalent to cost minimisation (with additional terms)

Partial Lagrangian yields two extra cost terms

$$\underbrace{\min_{x\in V}\sum_{i\in P} w_i x_i}_{\text{Weighted sum objective}} \quad \text{s.t.} \quad \underbrace{F(x)\leq \epsilon}_{\text{Cost constraint}} \text{ and } \underbrace{G(x)\leq G_0}_{\text{CO}_2\text{ constraint}}$$

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

Lagrangian multipliers

Partial Lagrangian yields two extra cost terms

$$\underbrace{\min_{x\in V}\sum_{i\in P} w_i x_i}_{\text{Weighted sum objective}} \quad \text{s.t.} \quad \underbrace{F(x)\le \epsilon}_{\text{Cost constraint}} \text{ and } \underbrace{G(x)\le G_0}_{\text{CO}_2\text{ constraint}}$$

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

Lagrangian multipliers

Capacity subsidy / penalty

Additional CO_2 price

$$\min_{x\in X}\left(F(x) + \boxed{\frac{w}{\mu}}\cdot x + \boxed{\frac{\nu}{\mu}}\cdot G(x)\right)$$

Cost function

Investment variables

CO_2 function

Partial Lagrangian yields two extra cost terms

$$\underbrace{\min_{x \in V} \sum_{i \in P} w_i x_i}_{\text{Weighted sum objective}} \quad \text{s.t.} \quad \underbrace{F(x) \leq \epsilon}_{\text{Cost constraint}} \text{ and } \underbrace{G(x) \leq G_0}_{\text{CO}_2\text{ constraint}}$$

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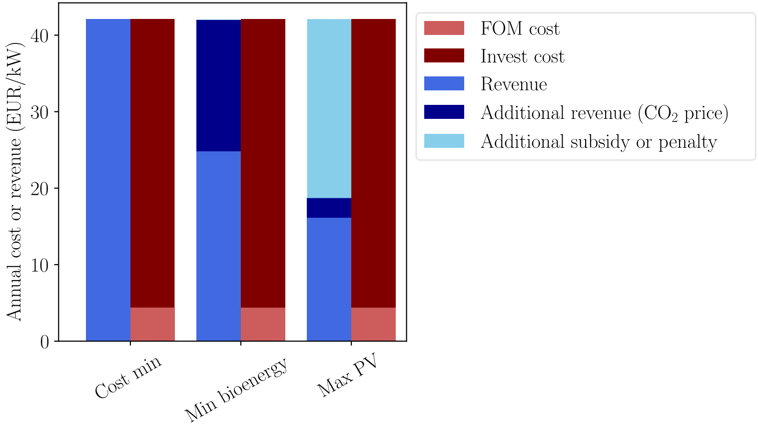
Lagrangian multipliers

$$\min_{x \in X} \left(\underbrace{F(x)}_{\text{Cost function}} + \overbrace{\boxed{\frac{w}{\mu}}}^{\text{Capacity subsidy / penalty}} \cdot \underbrace{x}_{\text{Investment variables}} + \overbrace{\boxed{\frac{\nu}{\mu}}}^{\text{Additional CO}_2\text{ price}} \cdot \underbrace{G(x)}_{\text{CO}_2\text{ function}} \right)$$

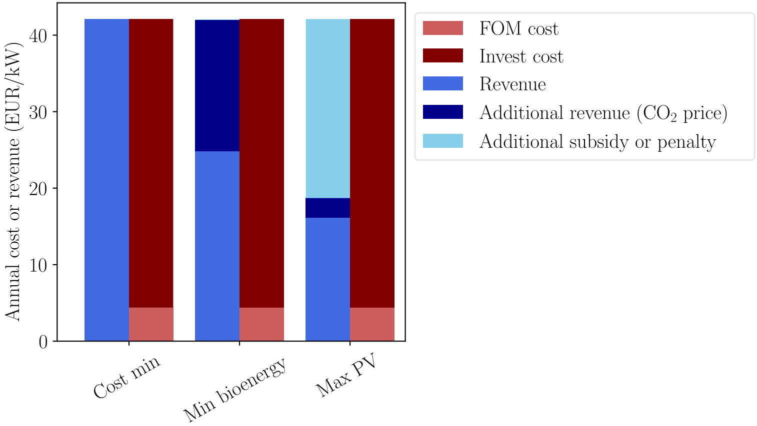
	Additional CO_2 price (€/t)	Subsidy for PV (€/kW/a)	Penalty for bioenergy (€/kW/a)
Min bioenergy	246		304
Max PV	9	23	

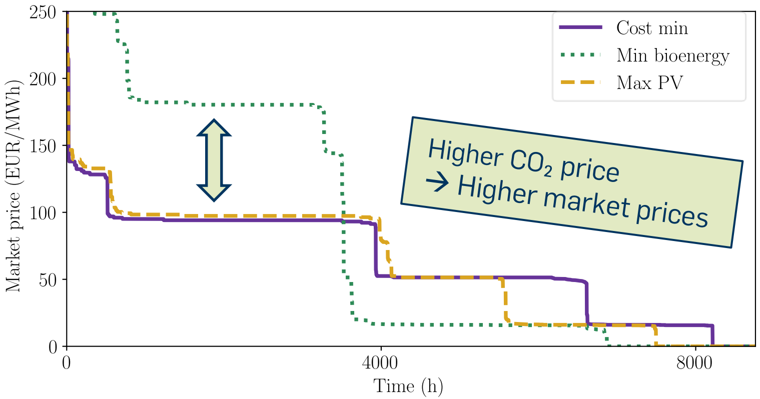
Cost minimisation is equivalent and recovers cost



- With the extra terms, cost minimisation **reproduces MGA alternative**
- Guarantees full **cost recovery** of investments

Cost minimisation is equivalent and recovers cost





Higher CO_2 price
→ Higher market prices

- With the extra terms, cost minimisation **reproduces MGA alternative**
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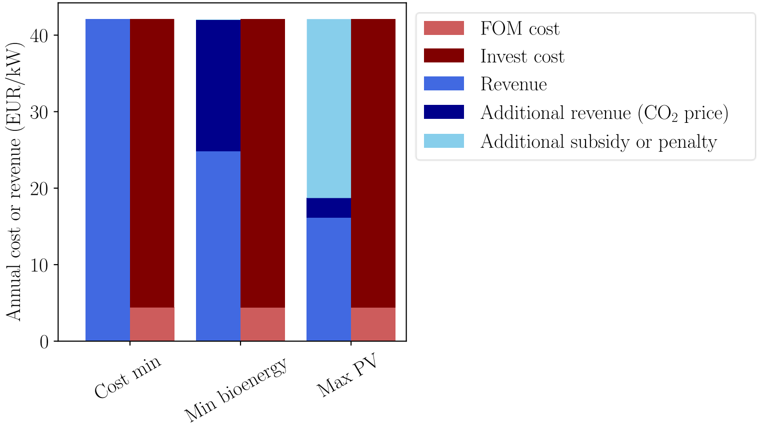
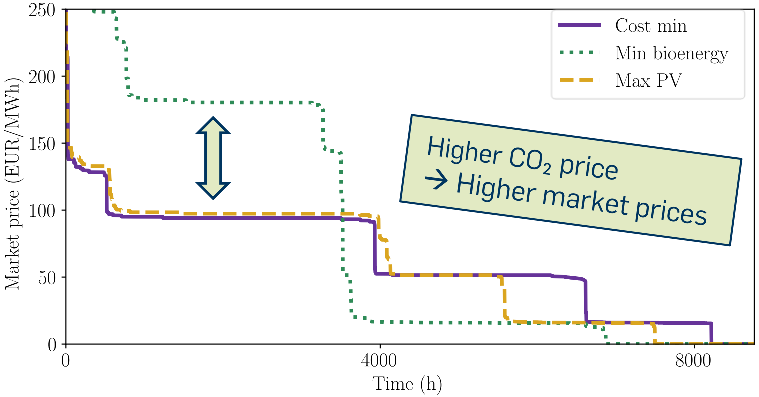
Cost minimisation is equivalent and recovers cost





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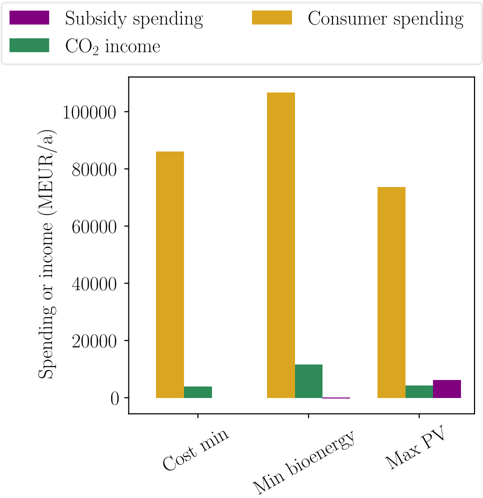
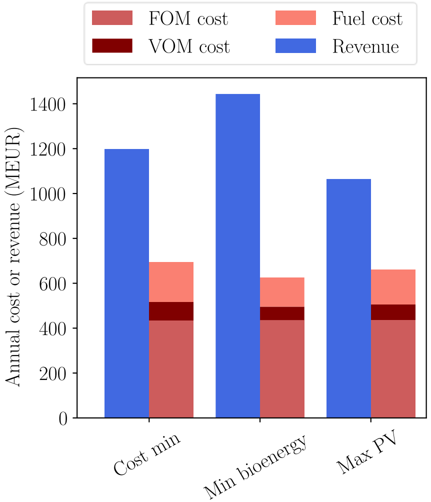
How does this affect **consumer spendings**?

Shift between consumer and producer surplus





Consumer spendings and state income / spendings vary

Existing generators’ surplus (e.g. nuclear in BE) varies accordingly

Conclusion

Conclusion

- Modelling to Generate Alternatives (MGA) generate potentially more interest optimal and feasible **near-cost-optimal energy futures**
- At the same time, **profitability of investments** is key for feasibility

Key findings

- Showed a way (subsidy/penalty & CO_2 price) to **realise more appealing / socially feasible alternatives as cost minimum**
- This guarantees **cost recovery for investments** and ensures **feasibility in market**
- This affects **consumer and producer surplus**, which has to be considered in decision making

Thank you for your attention!

Questions?

Suggestions?