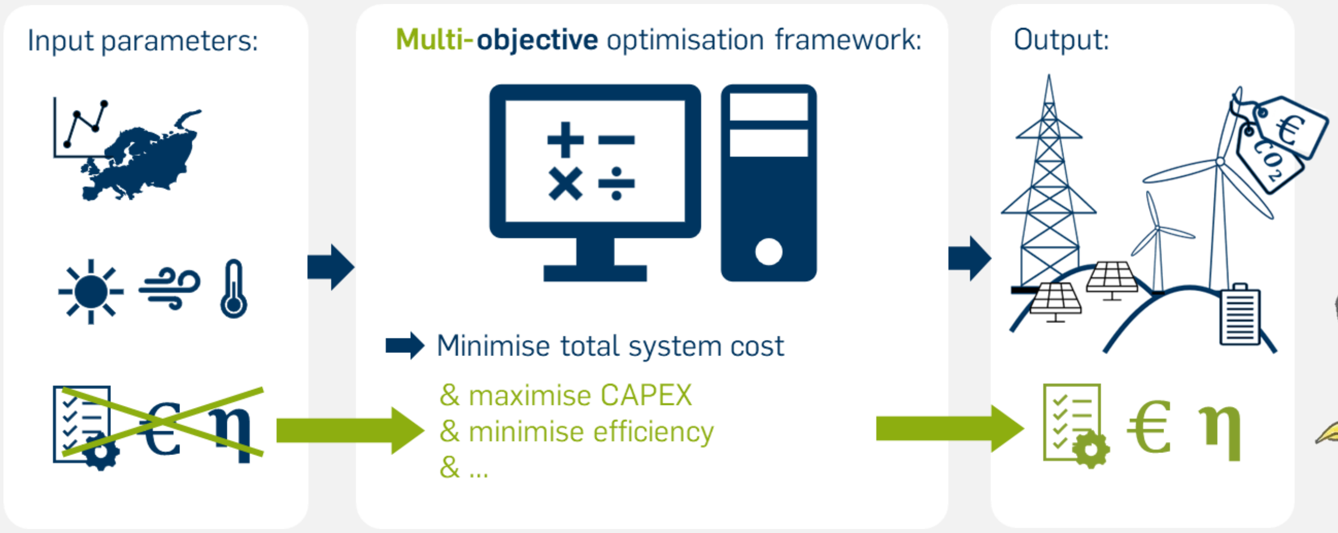


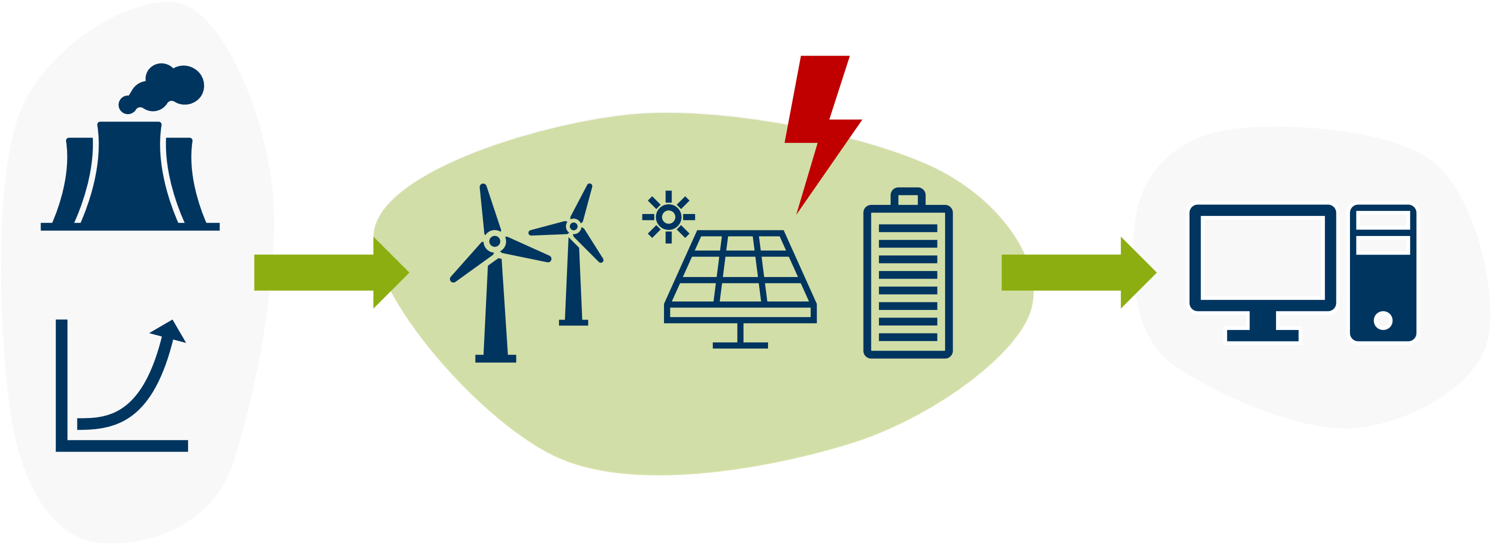
Multi-Objective Inverse Optimisation of Design Requirements for Low Technology Readiness Level Technologies

Chair of
Energy Systems &
Energy Economics

Katharina Esser, Jonas Finke, Valentin Bertsch | 24th of October 2024 | katharina.esser@rub.de

Motivation

Background



Motivation: Energy technologies

Energy system design:

- ✓ Equity, sustainability, security, acceptance
- ✓ Cost minimisation

Energy technology parameters

Uncertainties

Product design: € η

- ✓ Market success
- ✓ Revenue maximisation

Product market

Uncertainties

Aim and novelty

Energy system design:

- Realistic parameters
- Increased market accuracy
- Influence on development process

Product design:

- Revenues and market shares/ target market
- Increased efficiency

Inverted methodology:

- Novel approach
- Limited literature

Methods

Inverted methodology – general approach (1)

Input:

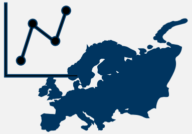
Single-objective optimisation framework:

➡ Minimise total system cost

Output:

Inverted methodology – general approach (2)

Input :

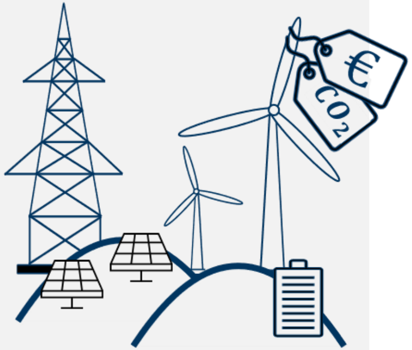


Multi-objective optimisation framework:

Minimise total system cost

& maximise CAPEX
& minimise efficiency
& …

Output:



Inverted methodology – mathematical approach

1) Inverted optimisation

2) Multi-objective (MO) optimisation

3) Multi-objective inverse (MOIn) optimisation

1) Inverted optimisation

Linear — a) New decision variable

$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N$$

Quadratic — b) Integration of decision variable

$$\min_{y \in Y} \pm y$$

Multi-objective inverse — c) Additional objective

$$\left.\begin{matrix} \min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N \\ \min_{y \in Y} \pm y \end{matrix}\right\} \min_{x,y \in S'} F(x,y)$$

$$\text{s.t.} \quad g_i(x) \leq 0, i = 1, \ldots, K$$
$$h_j(y) \leq 0, j = 1, \ldots, L$$

Inverted methodology – mathematical approach

$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N$$

$$\min_{y \in Y} \pm y$$

$$\min_{x,y \in S'} F(x,y)$$

$$\text{s.t.} \quad g_i(x) \le 0, i = 1, \dots, K$$
$$h_j(y) \le 0, j = 1, \dots, L$$

2) Multi-objective (MO) optimisation

3) Multi-objective inverse (MOIn) optimisation

2) Multi-objective optimisation (MO)

2 obj.

a) Transform objectives

$$\boldsymbol{min(f_1 + c \cdot s)}$$

1 obj.

b) Transform constraints

$$\boldsymbol{s.t.\ \ f_2 + s = \varepsilon}$$

AUGMECON based on Mavrotas, *Effective implementation of the epsilon constraint method in Multi Objective Mathematical Programming problems*, Applied Mathematics and Computation 2009. https://doi.org/10.1016/j.amc.2009.03.037
Backbone-implementation by Finke and Bertsch, *Implementing a highly adaptable method for the multi objective optimisation of energy systems*, Applied Energy 2023. https://doi.org/10.1016/j.apenergy.2022.120521

Inverted methodology – mathematical approach

$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N$$

$$\min_{y \in Y} \pm y$$

$$\left.\right\} \min_{x,y \in S'} F(x, y)$$

$$\text{s.t.} \quad g_i(x) \leq 0, i = 1, \dots, K$$
$$h_j(y) \leq 0, j = 1, \dots, L$$

$$\min(f_1 + c \cdot s)$$

$$\text{s.t.} \quad f_2 + s = \varepsilon$$

3) Multi-objective inverse (MOIn) optimisation

3) Multi-objective inverse optimisation (MOIn)

$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N$$

$$\min_{y \in Y} \pm y$$

$$\Bigg\} \quad \min_{x,y \in S'} F(x,y)$$

$$\text{s.t.} \quad g_i(x) \le 0, i = 1, \dots, K$$
$$h_j(y) \le 0, j = 1, \dots, L$$

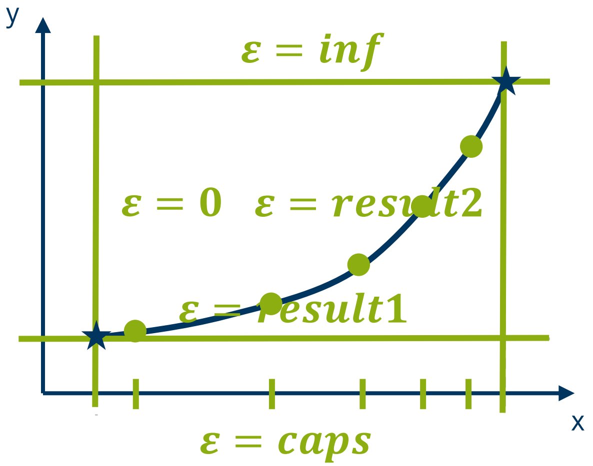
$$\min(f_1 + c \cdot s)$$

$$\text{s.t.} \quad f_2 + s = \varepsilon$$

$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N + c \cdot s$$

$$\text{s.t.} \quad g_i(x) \le 0, i = 1, \dots, K$$
$$h_j(y) \le 0, j = 1, \dots, L$$
$$y + s = \varepsilon$$

3) Multi-objective inverse optimisation (MOIn)



$$\min_{x,y \in S'} \sum_{n=1}^{N-1} c_n x_n + y x_N + c \cdot s$$

$$\text{s.t.} \quad y + s = \varepsilon$$

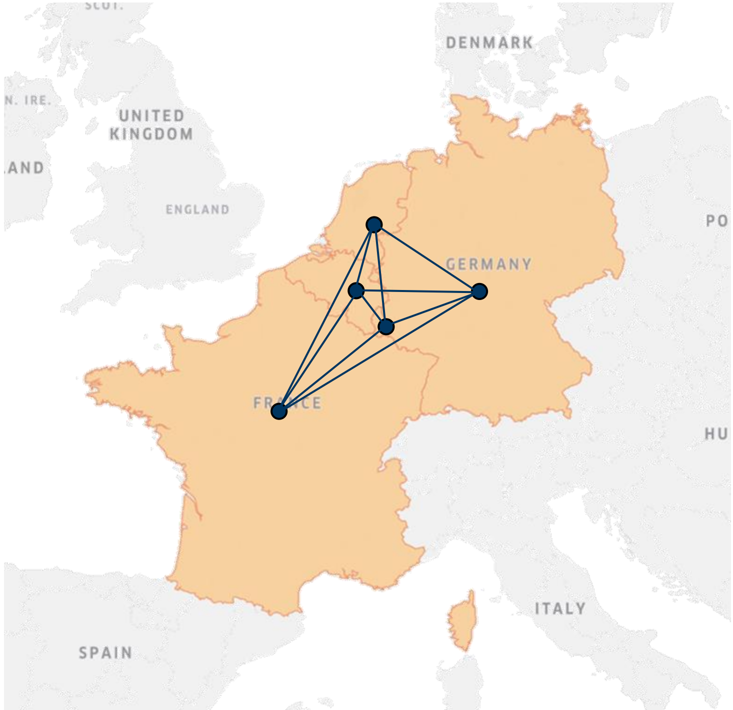
$$\min_{x,y \in S'} y + s$$

$$\text{s.t.} \quad \sum_{n=1}^{N-1} c_n x_n + y x_N + c \cdot s = \varepsilon$$

Case study and (preliminary) results

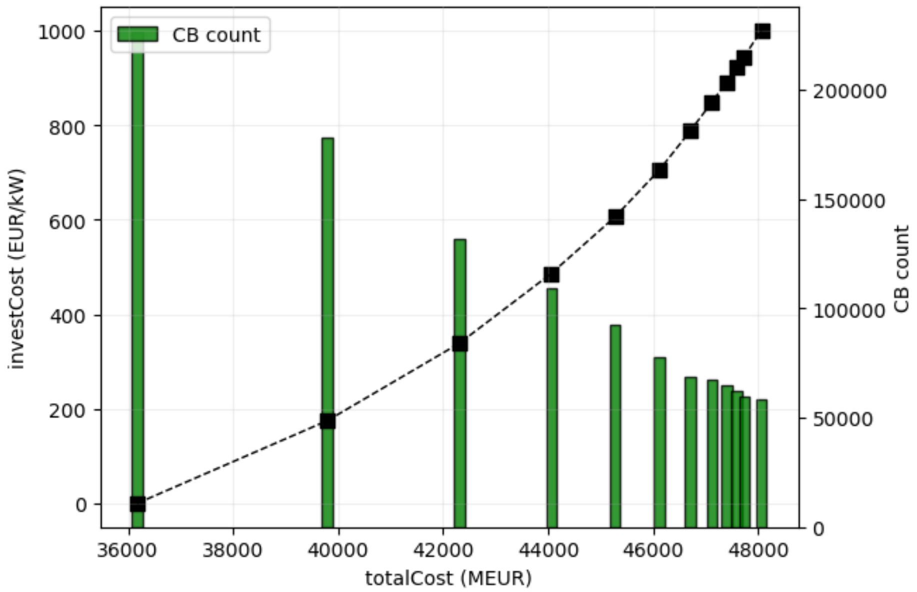
Case study

- Backbone
- 2050
- Central Western Europe
- Spatial resolution: 5 nodes
- Temporal resolution: 8760h/a → 504h/a
- Objective:
  1. Minimise total system cost
  2. Maximise CAPEX of storage technology
     - ➢ Carnot batteries



Backbone: https://gitlab.vtt.fi/backbone/backbone, Helistö, *Backbone—An Adaptable Energy Systems Modelling Framework*, Energies 2019, https://doi.org/10.3390/en12173388

Preliminary results



Conclusion and outlook

Conclusion

Energy system design:

- More effective than “trial and error”-search
- Adaptable for diverse energy system analyses

Product design:

- Market insights:
  - Needs, competing technologies, target market, revenue streams…

Limitations:

- Computational efforts

Outlook

- Iterate results with product designers:
  - Align product development:
    - ➢ Insights for Carnot batteries
  - Align energy system model:
    - ➢ Extend method to further contexts and criteria
    - ➢ Combine with other multi-criterial methods

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Inverse Design of
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