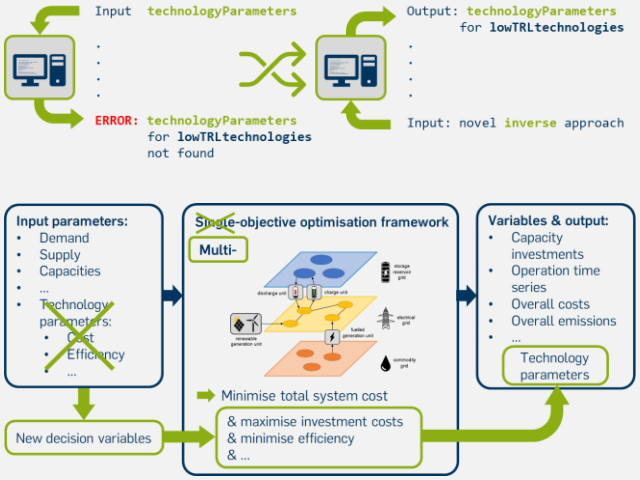

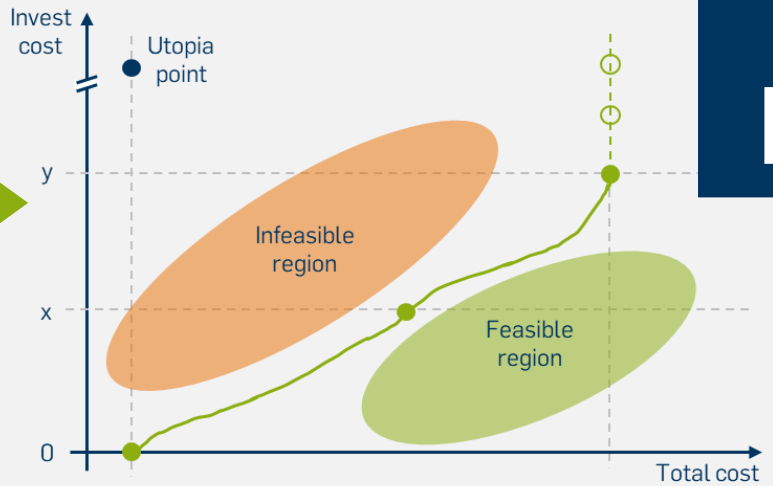

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MULTI-OBJECTIVE OPTIMISATION FOR THE INVERSE ANALYSIS OF DESIGN REQUIREMENTS FOR LOW TECHNOLOGY READINESS LEVEL TECHNOLOGIES

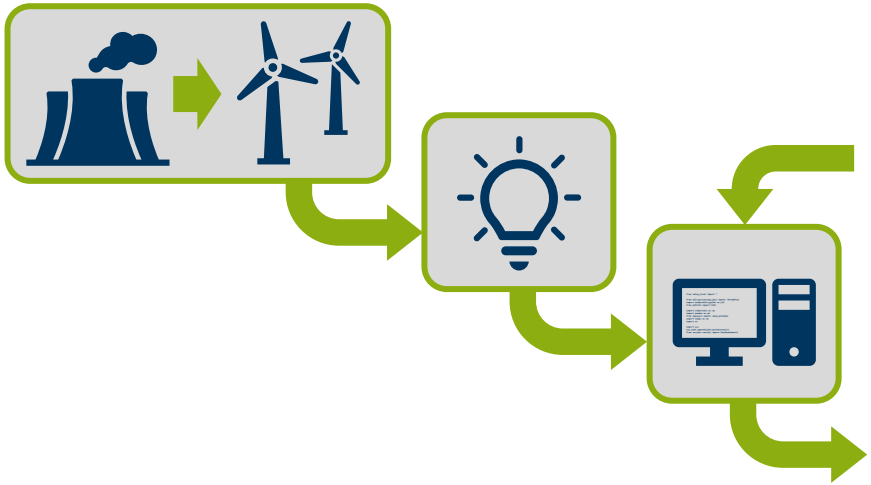
Chair of Energy Systems & Energy Economics

Katharina Esser, Valentin Bertsch, Jonas Finke | 1st of July 2024 | EURO 2024 | katharina.esser@rub.de

Contents

Motivation

Background



Input: technologyParameters

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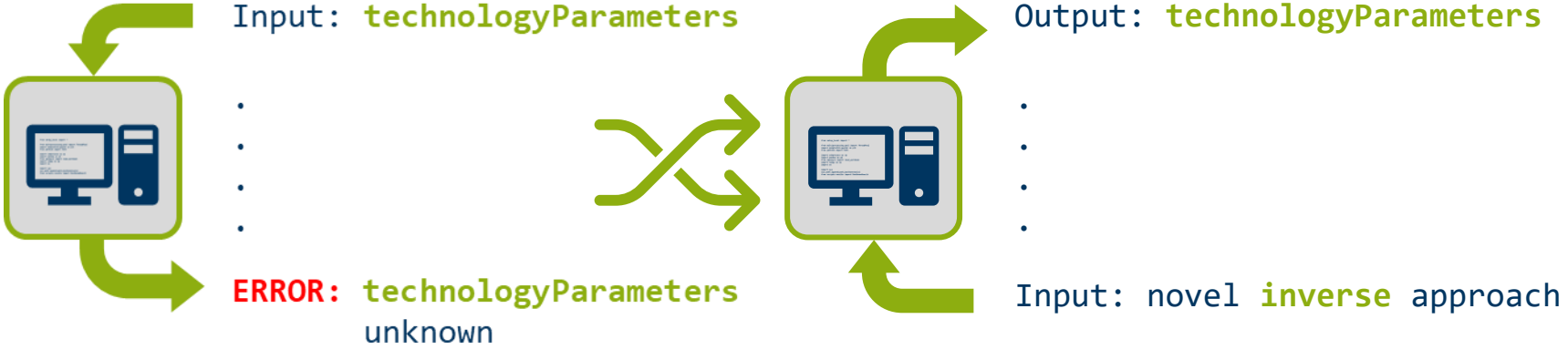
ERROR: technologyParameters
unknown

Motivation

- **Low technology readiness level (TRL) technologies:**
  - Highly uncertain
  - Lacking in models and simulations
  - Lacking in research

- **Relevance:**
  - Potentials for future energy systems
  - Low TRL =
    - High design flexibility
    - Low invested assets

Aim


Input: technologyParameters
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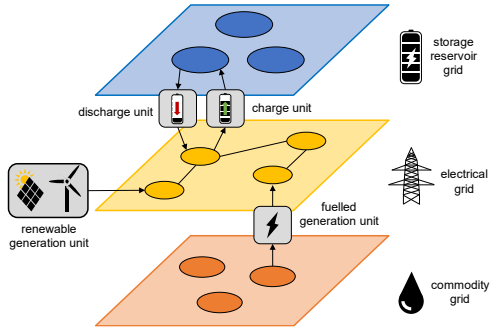
Output: technologyParameters
Input: novel inverse approach

Methods

Inverted methodology – general approach (1)

Input parameters:
- Demand
- Supply
- Capacities
- …
- Technology-parameters:
  - Cost
  - Efficiency
  - …

Single-objective optimisation framework



➡ Minimise total system cost

Variables & output:
- Capacity investments
- Operation time series
- Overall costs
- Overall emissions
- …

Figure from Mutke et al., *Influence of bioenergy and transmission expansion on electrical energy storage requirements in a gradually decarbonized European power system*, Journal of Cleaner Production 2023. https://doi.org/10.1016/j.jclepro.2023.138133

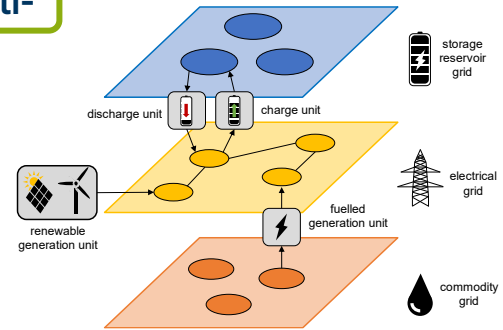
Inverted methodology – general approach (2)

Input parameters:
- Demand
- Supply
- Capacities
- …
- ~~Technology parameters:~~
  - ~~Cost~~
  - ~~Efficiency~~
  - ~~…~~

New decision variables

~~Single~~-objective optimisation framework

Multi-



Minimise total system cost

& maximise investment costs
& minimise efficiency
& …

Variables & output:
- Capacity investments
- Operation time series
- Overall costs
- Overall emissions
- …

Technology parameters

Figure from Mutke et al., *Influence of bioenergy and transmission expansion on electrical energy storage requirements in a gradually decarbonized European power system*, Journal of Cleaner Production 2023. https://doi.org/10.1016/j.jclepro.2023.138133

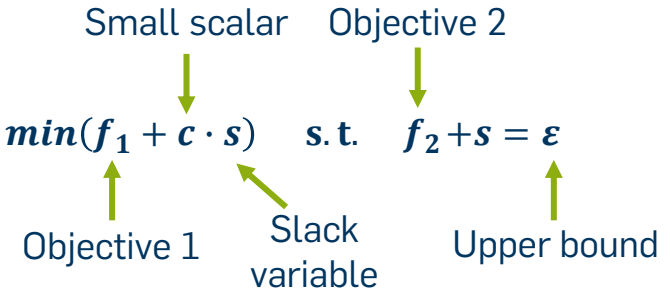
Inverted methodology – general approach (3)

1. Problem **formulation**:
   a) Chose or define method to **solve multi-objective optimisation problems**
   b) Apply method to **inverted** methodology
2. Generate set of **Pareto-optimal solutions**:
   a) Chose or define approach to **build a Pareto-front**
   b) Apply approach to **inverted** methodology
3. Conduct **trade-off analysis** and further research

1a) Problem formulation – general method

- **Augmented epsilon-constraint method (AUGMECON):**

1. Reformulate all but one objective function into constraints
   - Introduce positive constant $c \approx 10^{-6} \ldots 10^{-3}$
   - Introduce positive slack variables s
   - Transform inequalities into equations
2. Give constraints an upper bound ε
3. Optimise only the remaining objective function



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

1b) Problem formulation – inverted approach

1. Introduce new variable to system:
   - $v^{investCost_{opt}}$
2. Insert new quadratical term into cost-describing function:
   - $v^{investCost_{opt}} \cdot v^{investLP}$

a) Use term in new objective function:

- $min\ (totalCost + c \cdot s)$

  s. t. $max\ v^{investCost_{opt}} + s = v^{investCost_{opt}}$
- RQ: lower limits of total system costs where new technology is still invested

b) Use term as new constraint:

- $max\ (v^{investCost_{opt}} + c \cdot s)$

  s. t. $min\ totalCost - s = totalCost$
- RQ: upper limits for a new technologie‘s investment cost

➡ Find Pareto-optimal solutions

2a) Pareto solutions – general approach

- **Generating Pareto-fronts:**

  1. Perform two lexiographic optimisations to determine single-objective optima as boundaries
  2. Decide on number and distribution of caps (= upper bounds ε)
  3. Solve problem for each cap with multi-objective-optimisation

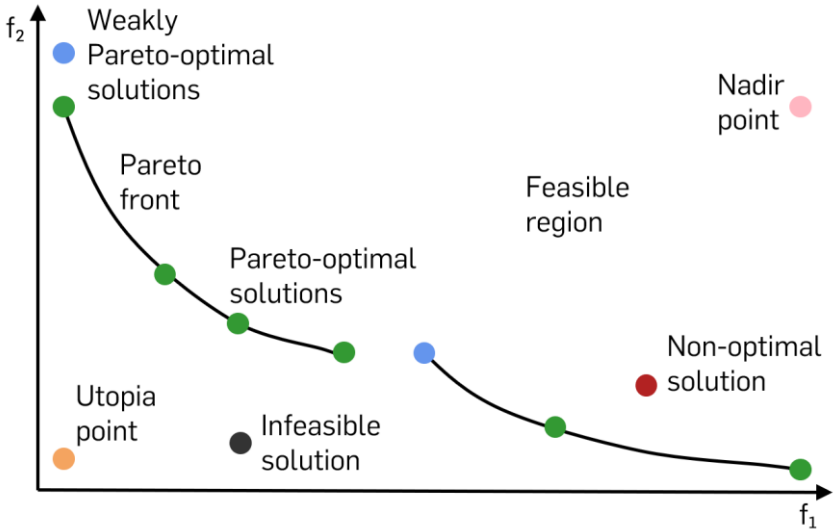


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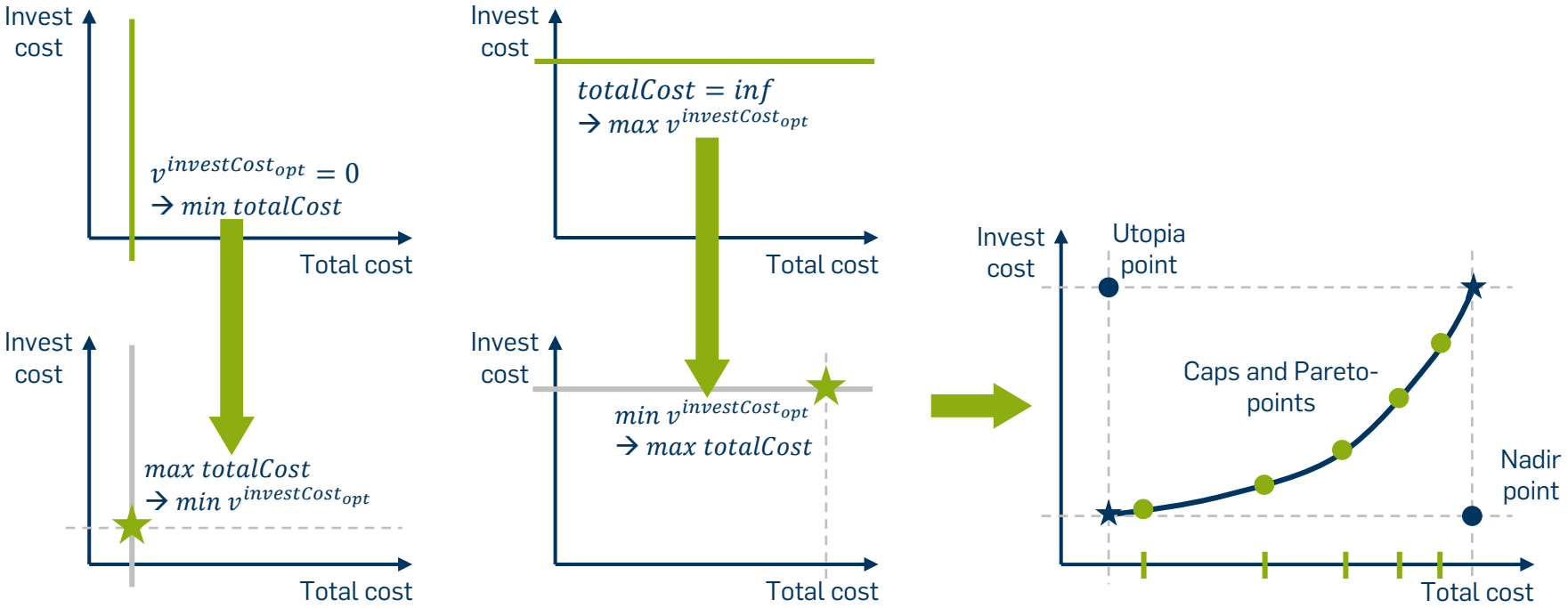
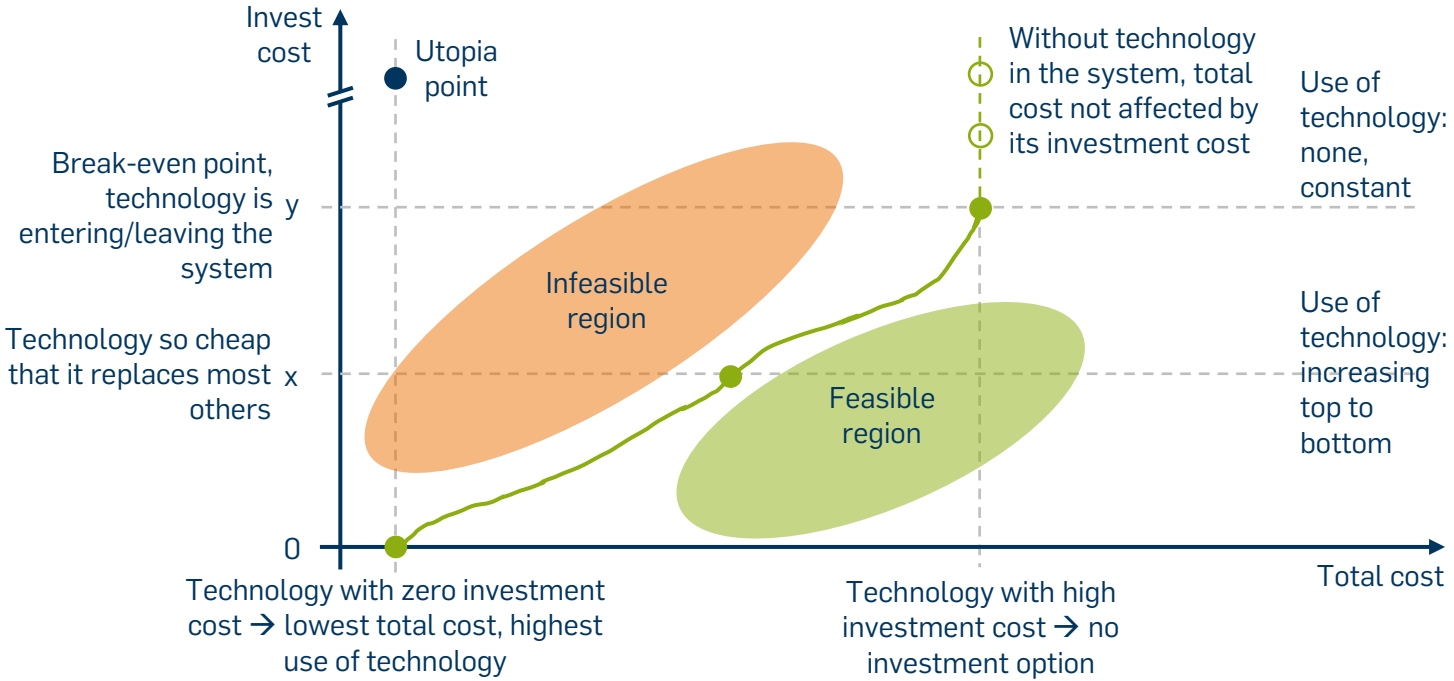
Figure and Backbone-implementation by Finke and Bertsch, *Implementing a highly adaptable method for the multi objective optimisation of energy systems*, Applied Energy 2023. https://doi.org/10.1016/j.apenergy.2022.120521

2a) Pareto solutions – inverted approach



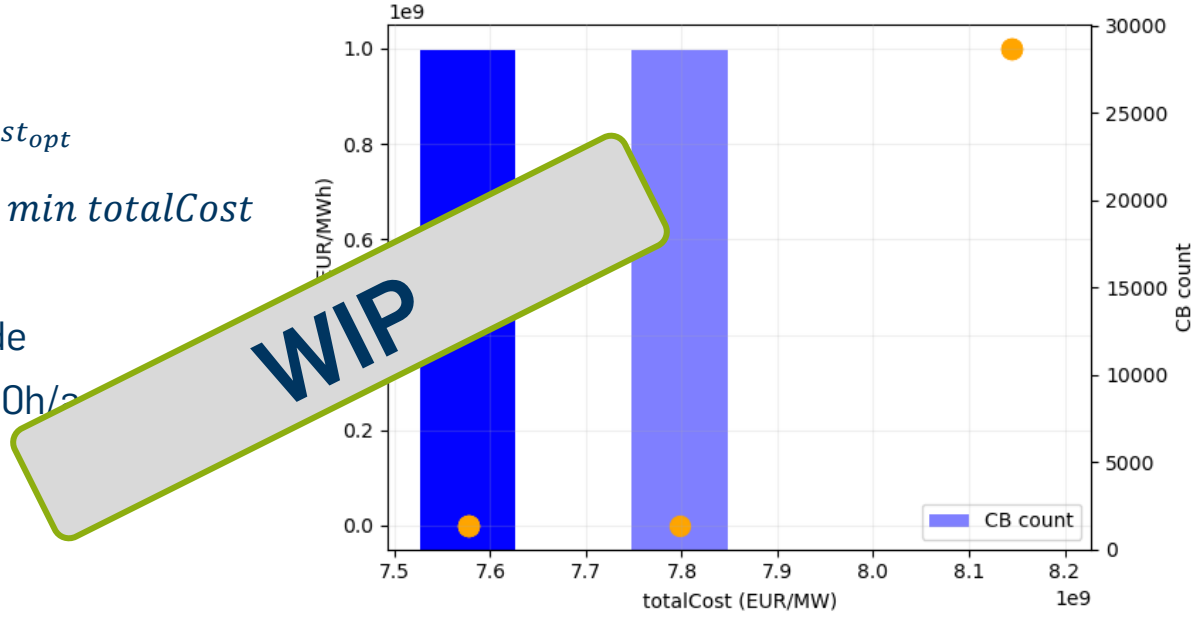
Preliminary results

General interpretation



First simulations

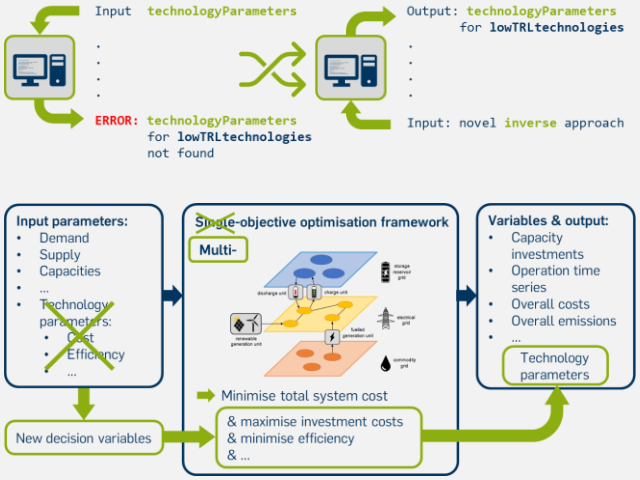
- Small testing system:
  - Backbone
  - Objective: $max\ v^{investCost_{opt}}$
  - Constraint: $totalCost = min\ totalCost$
  - Germany, 2050
  - Spatial resolution: 1 node
  - Temporal resolution: 730h/a

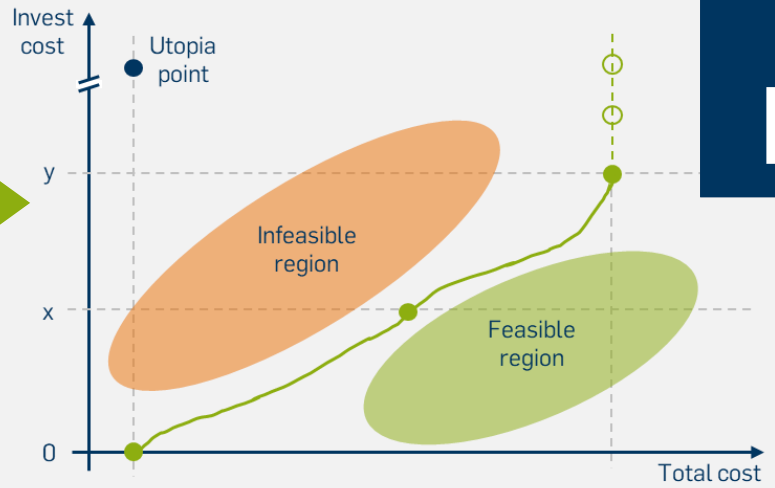


Conclusion and outlook

Conclusion and outlook

- **Conclusion:**
  - **Motivation:** Potentials of low TRL technologies and their absence in current research/energy models
  - **Aim:** Develope novel inverted approach to design low TRL technologies
  - **Method:** Multi-objective inverse (MOIn) optimisation based on AUGMECON
  - **Results:** Work in progress
- **Outlook:**
  - Iteratively advance method:
    - Refine mathematical formulation
    - Incorporate more objectives and enlargen system
    - Explore potentials and limitations





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THANK YOU FOR YOUR ATTENTION

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