Circular strategies for heat pumps

Ecological assessment under technical and economic boundary conditions

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EBC | Institute for Energy Efficient Buildings and Indoor Climate
E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

Overview

- Founded in 2007
- Interdisciplinary team with more than 100 employees
- More than 1500 m² experimental area
  - Laboratory space
  - 2 test halls
- Research funding:

INDUSTRIELLE GEMEINSCHAFTSFORSCHUNG IGF

Bundesministerium für Bildung und Forschung

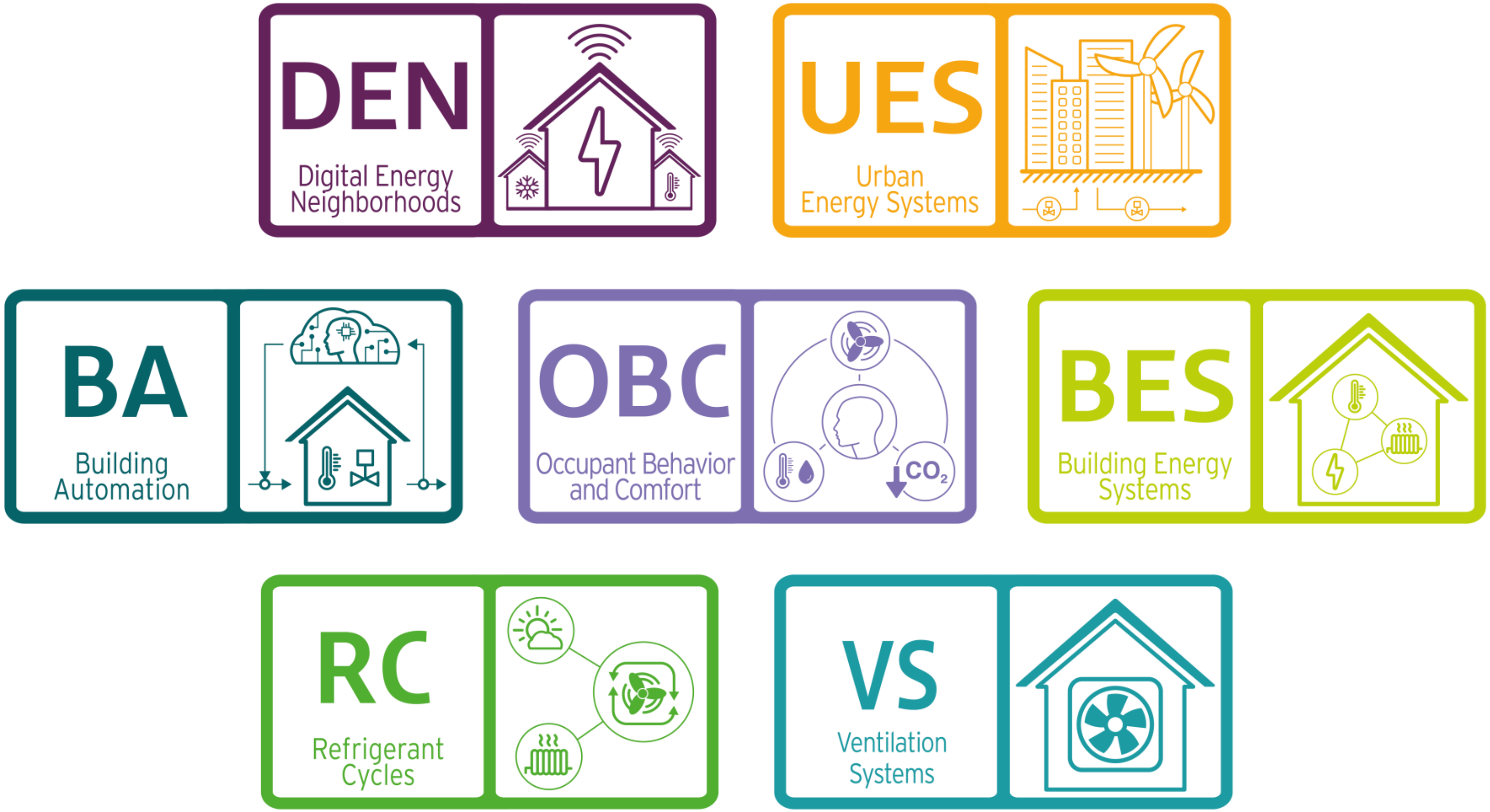
Bundesministerium für Wirtschaft und Klimaschutz

DFG

European Commission

- **Heads of Department**
  - 1 Professor
  - 3 Chief Engineers
  - 7 Team Leaders
- **Academic Employees**
  - ~70 Research associates
  - Approx. 50 student assistants + thesis students
- **Technical and Administrative Employees**

Research Fields/Teams of the EBC



Methods

- Simulation
- Optimization
- Experiment
- HiL
- Field Test
- System Development

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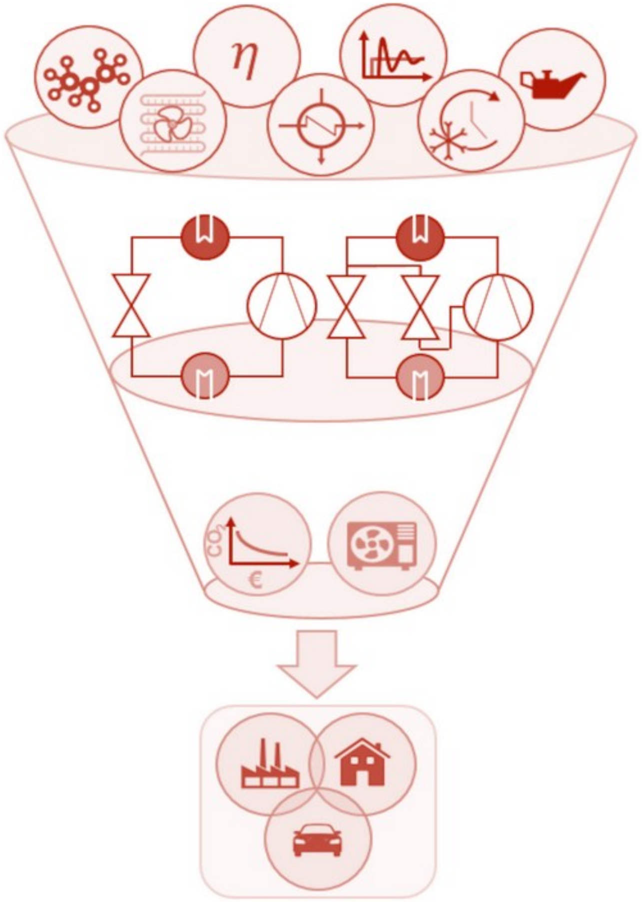
Thematic Overview

Our vision is energy-efficient and sustainable heat supply through systematic development of the refrigerant cycle process - from the molecule to the operating strategy



Fluid Selection

- Optimal mixtures
- Lubricant interaction

Cycle Design

- Component selection
- Charge monitoring

Controller Design

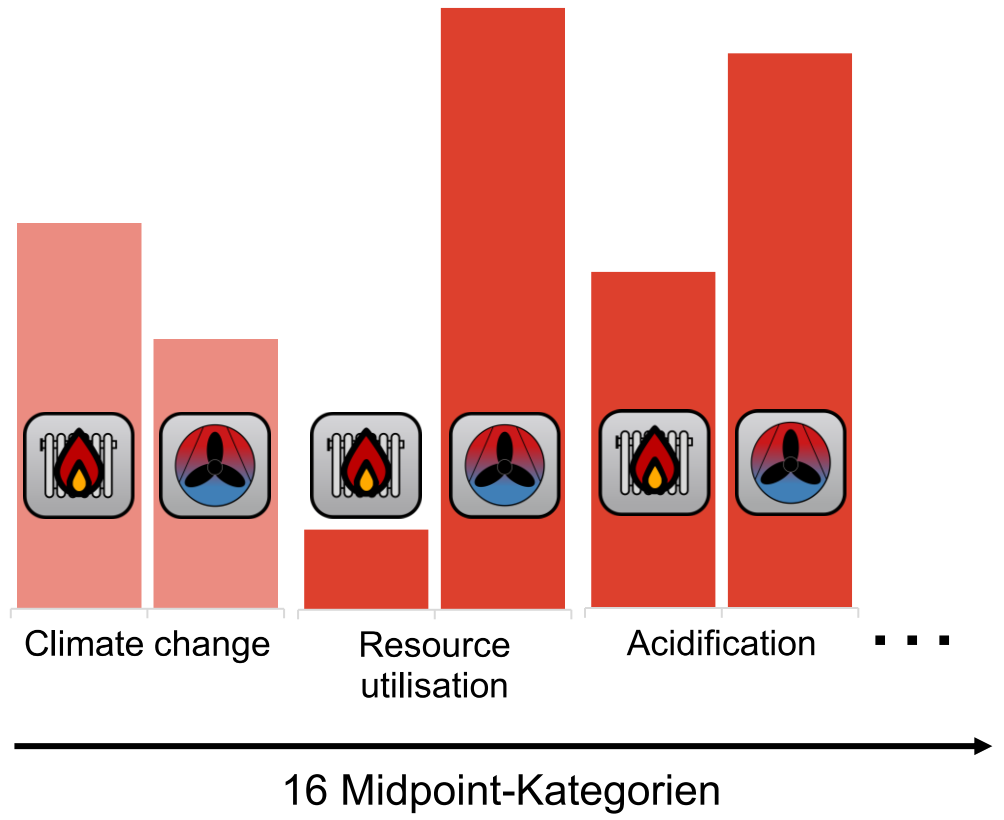
- Model predictive control
- Defrost control

System Integration

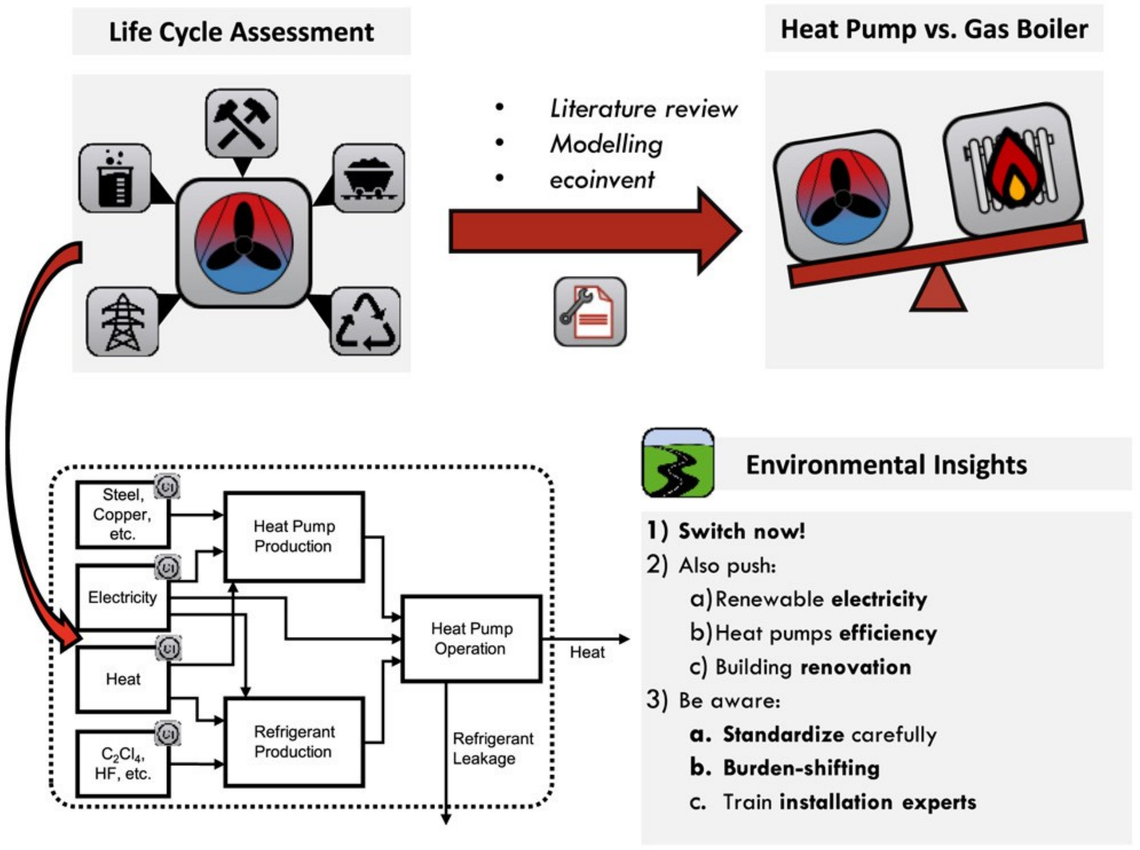
- Large scale heat pumps
- Residential buildings

- **Focus:**
  - Design and integration of heat pump systems
- **Topics:**
  - Optimization of the refrigerant, the cycle configuration and the design
  - Development of efficient controllers
  - Integration of heat pumps into energy systems
- **Methods:**
  - Stationary and dynamic simulation
  - Experimental Infrastructure

How can heat pumps become more environmentally friendly?

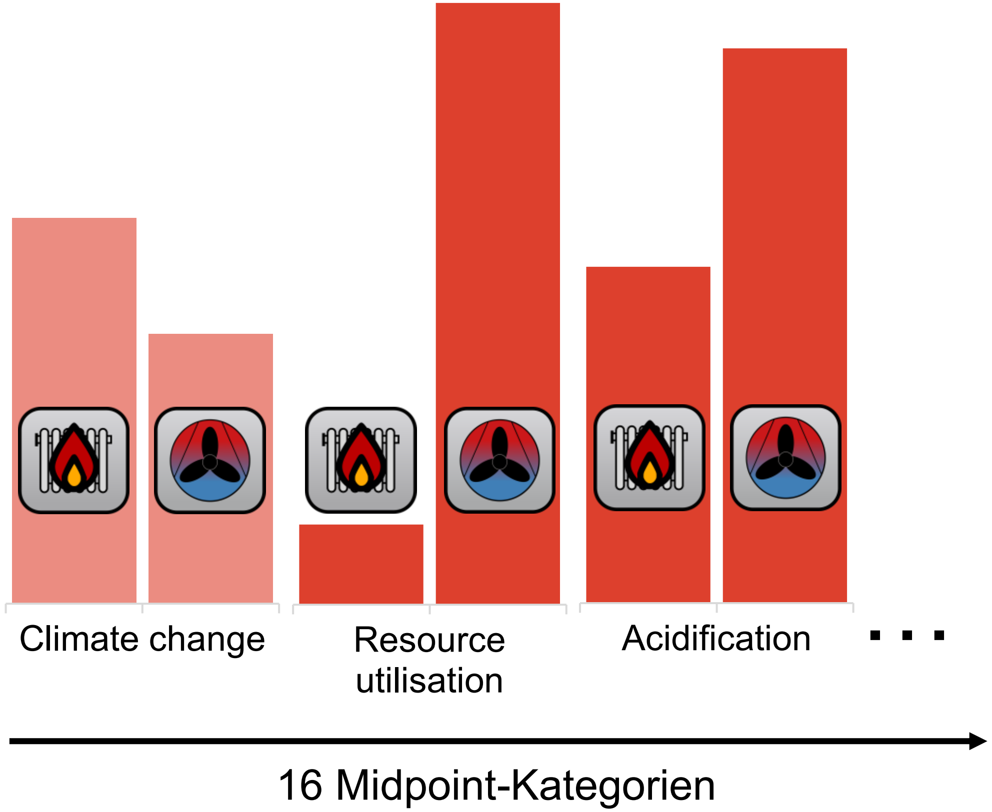


Hey LCA,
Please answer three questions regarding residential heating in Germany:
1) *When to switch from boiler to heat pump and to which refrigerant?*
2) *Which is an adequate hierarchy towards more sustainable heating?*
3) *Which challenges must be overcome?*



C. Vering, C. Zibunas et al., The environmental performance of nationwide heat pump deployment in residential buildings in Germany, *Cell Reports Sustainability*, Volume 2, Issue 9, September 2025

How can heat pumps become more environmentally friendly?



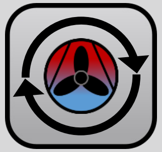
- Life cycle phases of building products
  - Production phase ✓
  - Use phase ✓
  - Disposal phase ✓
  - Reuse, recovery, recycling potential
- Advantages of a circular economy
  - Environmental protection
  - Reduced supply risks
  - Promotion of innovation
  - Creation of jobs

Can circular strategies reduce the environmental impact of heat pumps?

Are there technical or economic barriers?

Procedure for analyzing circular strategies

Deriving circular strategies for heat pumps


→


Modelling the life cycle
under consideration of technical boundary conditions

Manufacture → Operation → End of Life

Create
life cycle assessments
using the model

Cost differences
modelling along the life cycle

Linear Strategy vs. Circular Strategies

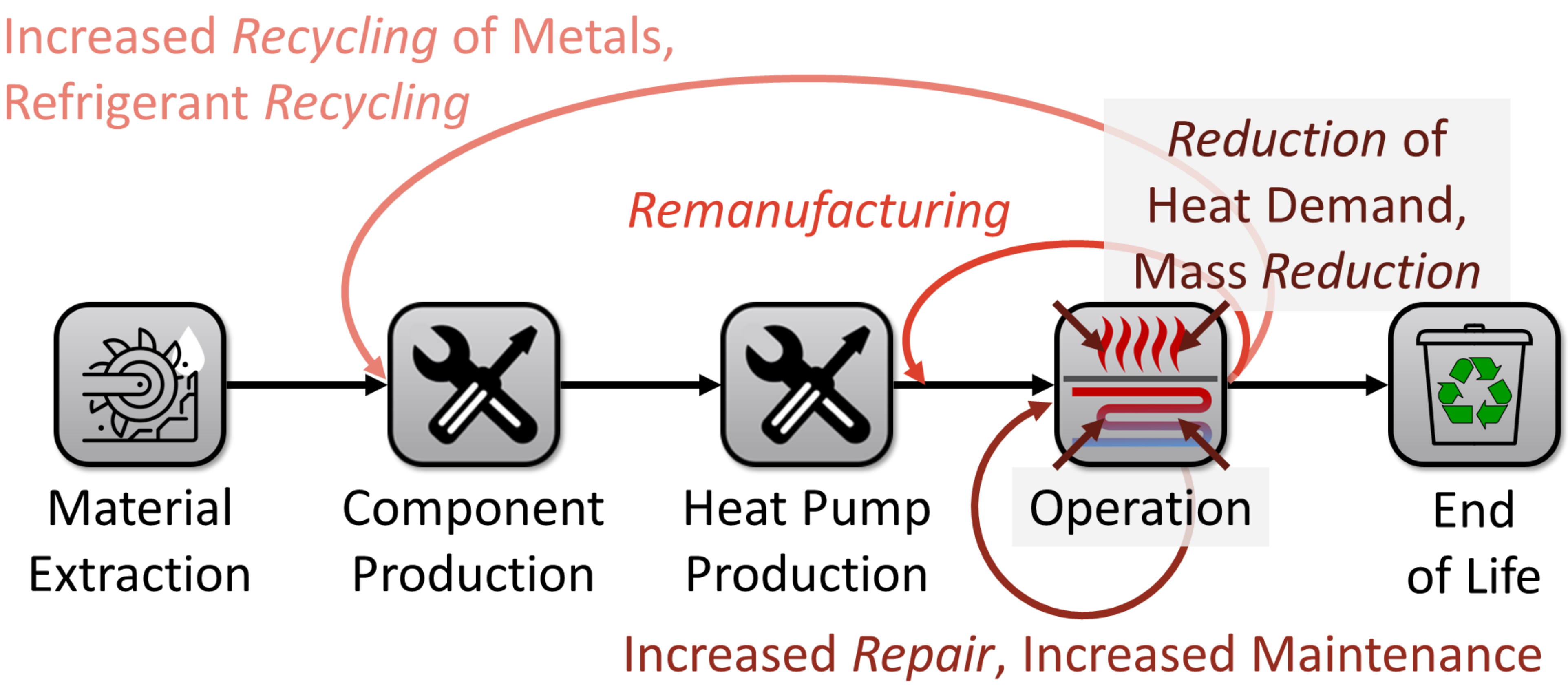
10 R-Strategies

R0 Refuse
R1 Reduce
R2 Reuse
R3 Repair
R4 Refurbish
R5 Remanufacture
R6 Repurpose
R7 Recyle
R8 Recover
R9 Remine

Circular strategies for heat pumps

S1M Reduction of mass
S1W Reduction of building heat demand
S3H Increased repair of hard faults
S3S Increased maintenance to top up the refrigerant
S5 Remanufacturing
S7K Refrigerant recycling
S7M Increased recycling of metals

Linear Strategy vs. Circular Strategies



Modelling the life cycle
Comparison of remanufacturing with the base scenario

Manufacture → Operation → End of Life

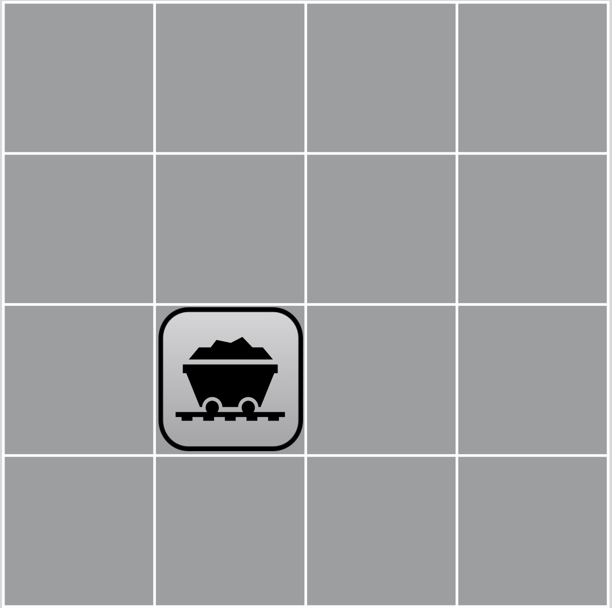
Economic modelling

Technical boundary conditions

- Framework for consideration: Heat pump
- Function: Heating of a single-family house in Aachen
- Strategy: Remanufacturing

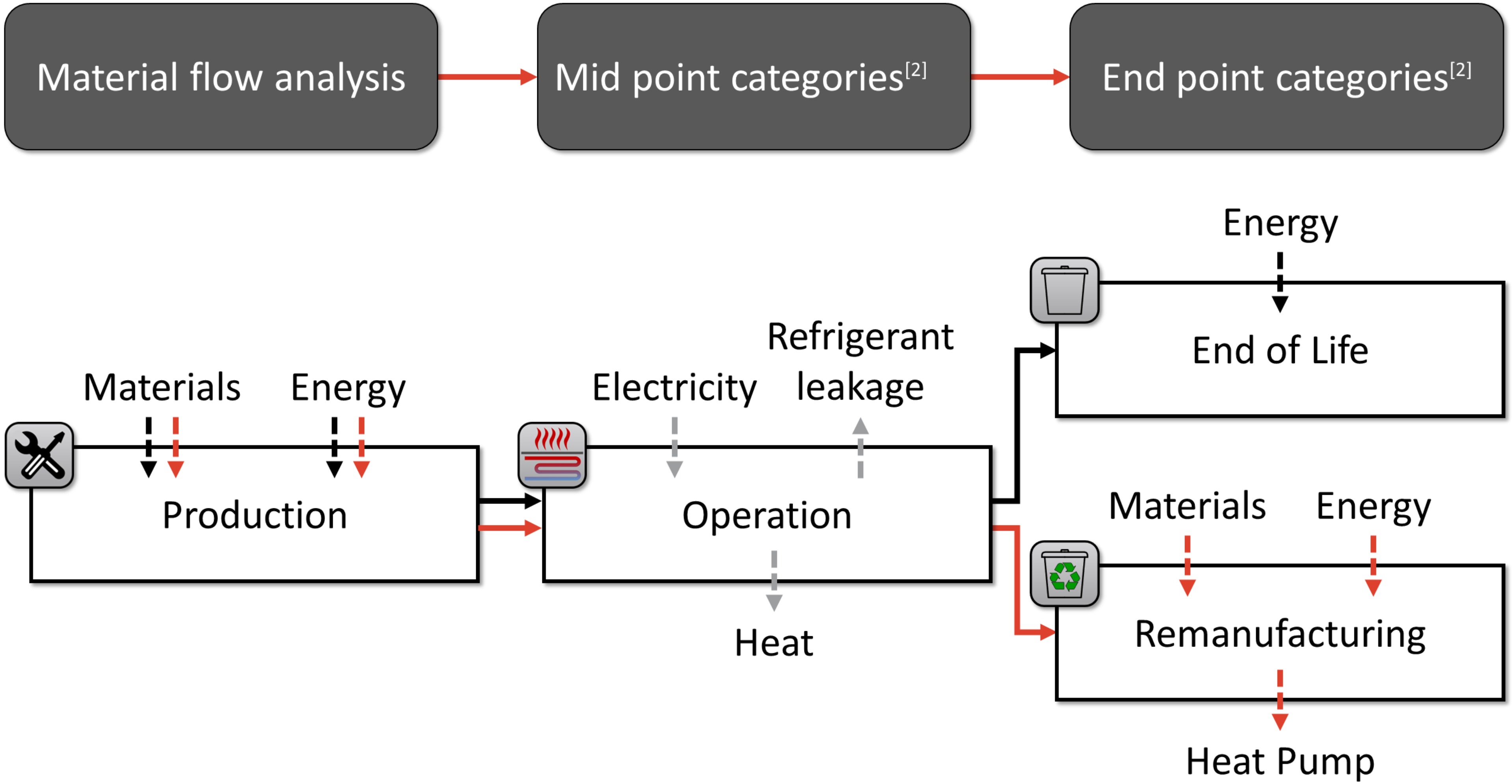
Results of LCA

in the midpoint category of resource utilization, minerals and metals

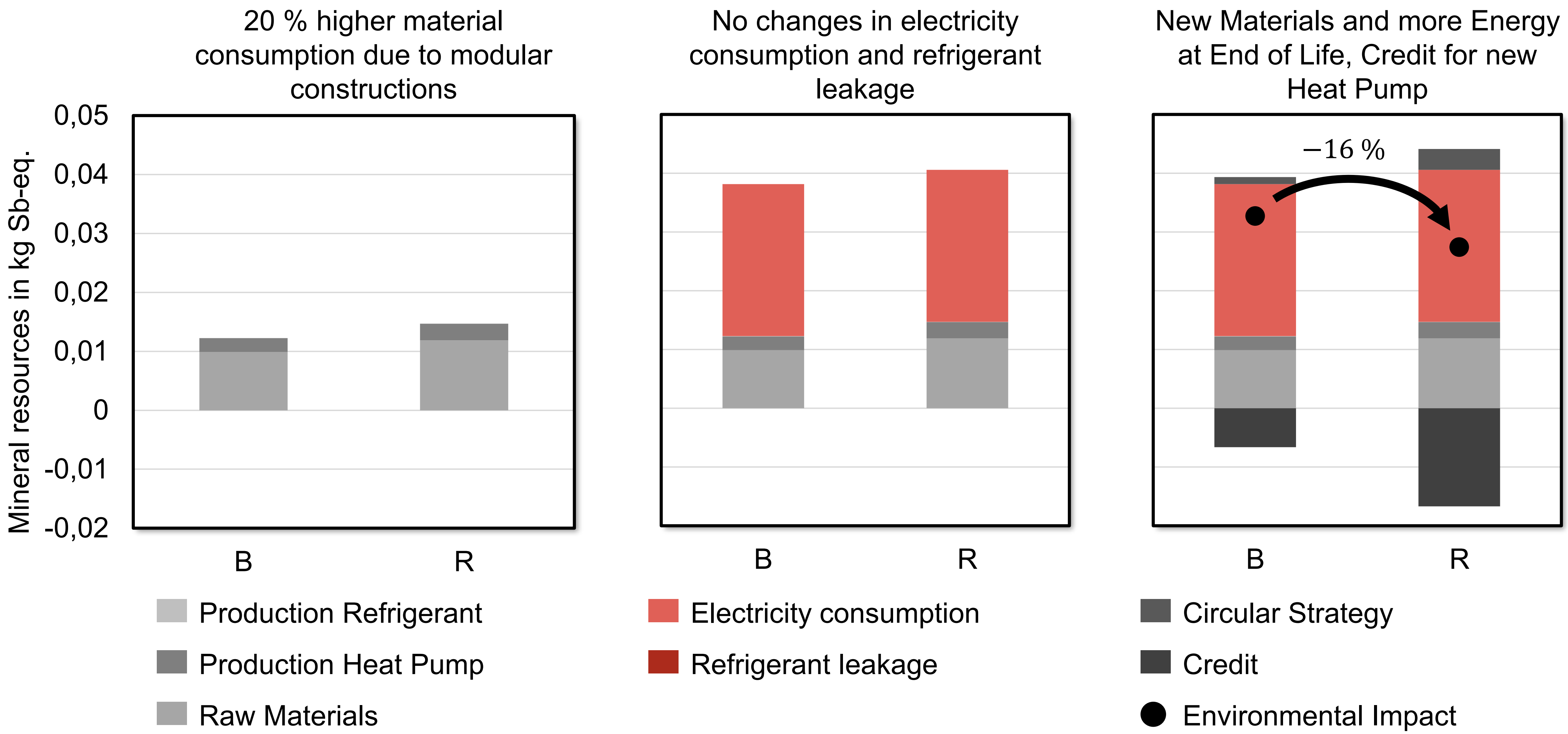


LCA

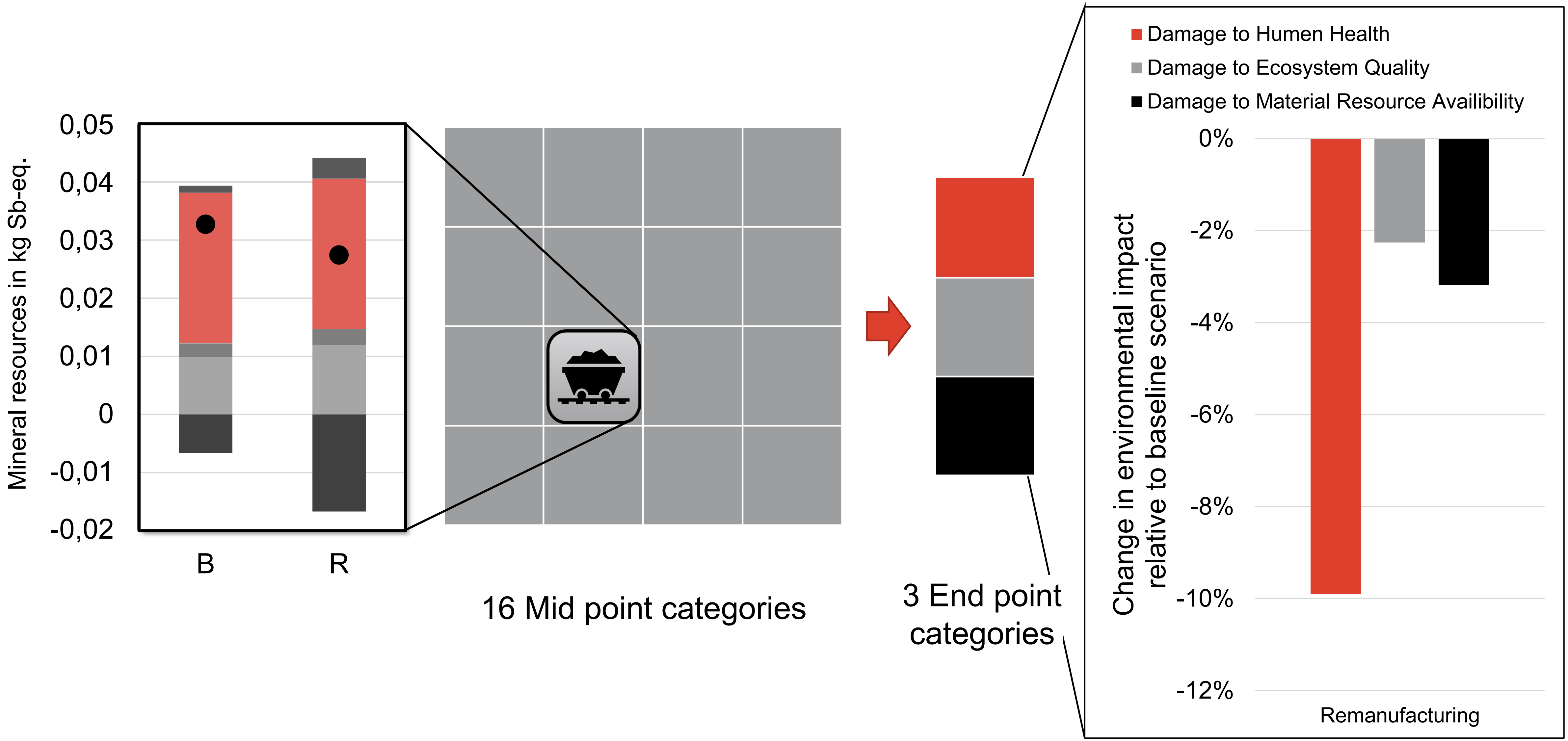
Ecologic modeling of R-Strategies
Example: **Baseline** (B) vs. **Remanufacturing** (R)



Baseline (B) vs. Remanufacturing (R)
LCA of midpoint category Mineral Resources

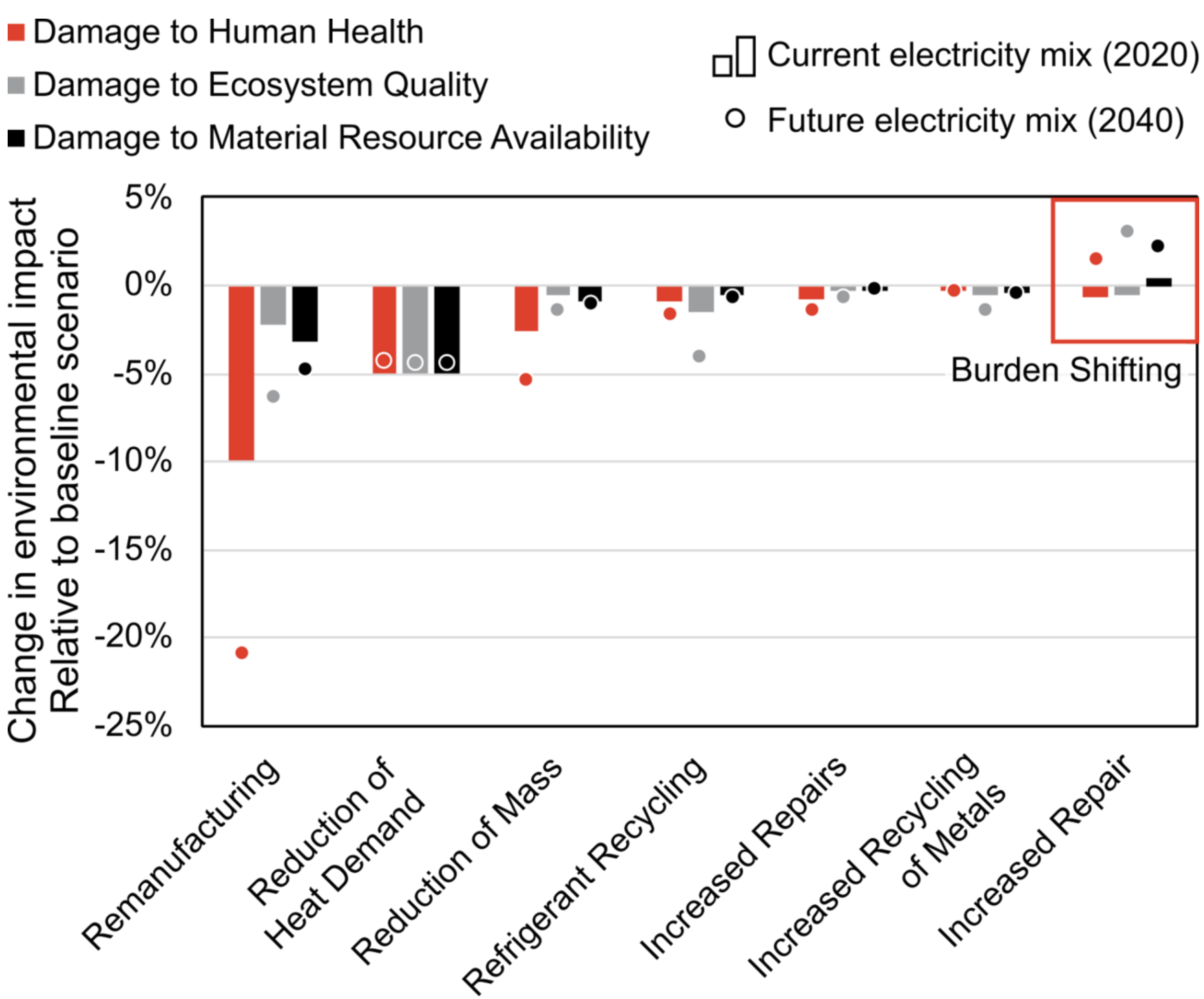


Baseline (B) vs. **Remanufacturing** (R)
From mid point category to end point categories



Overall Results: ecologic modeling
Reduction of environmental impacts through circular strategies

- Reduction of environmental impact in particular through
  - Remanufacturing
  - Reduction of building heating requirements
- Burden shifting
  - Increased maintenance to top up the refrigerant
- Under a future electricity mix, the relative reduction in environmental impact increases

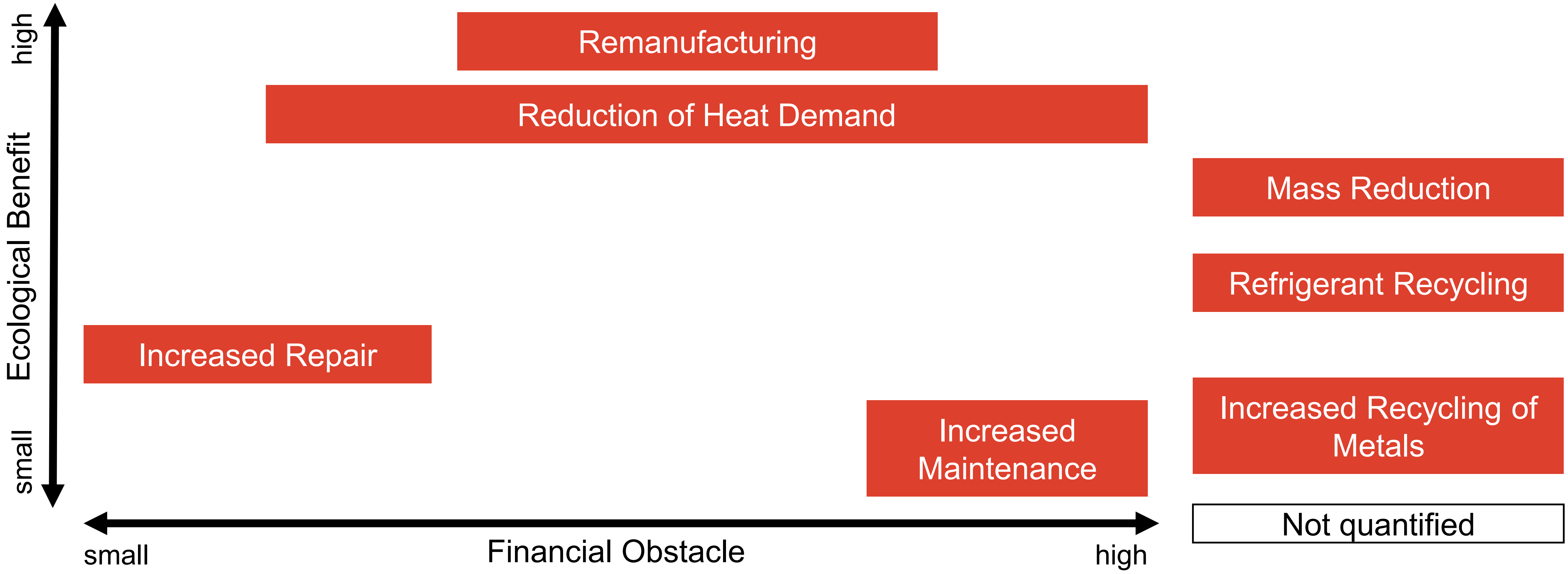


Baseline (B) vs. Remanufacturing (R)
Economic Modeling

Costs	B	R	Comment
First Life Cycle			
Material	3615 €	4338 €	Higher material use leads to higher costs
Second Life Cycle			
Material	3615 €	2429 €	Lower material costs due to reuse of components
Personnel	379 €	592 €	Higher costs for craftmen due to additional steps in manufacturing process
Capital Value:		**−250 €**	

Remanufacturing leads to a financial burden due to higher initial costs for modular construction of the heat pump.
Replacement of components leads to lower overall costs after second life cycle.

Results of economic modeling



A holistic life cycle assessment is essential for integrating circular principles, ensuring sustainable deployment beyond carbon reduction alone.

Limitations and Outlook

The scope only includes the heat pump

Extend the scope to include the heating system or building

Costs of the S1M, S7M and S7K strategies could not be quantified

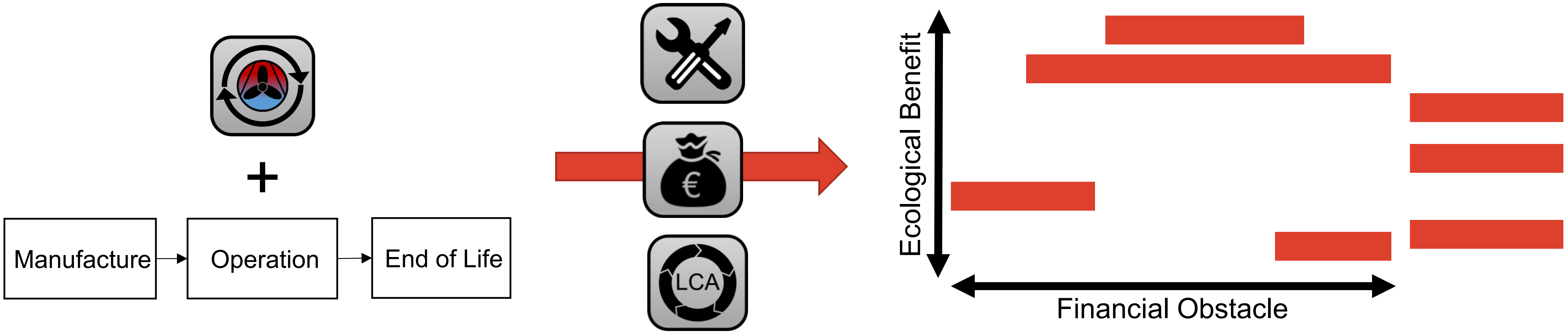
Research into the economics of lightweight construction for heat pumps and the recycling of metals and refrigerants

Many assumptions due to lack of primary data

Collect data in practice

Conclusion

- 7 circular strategies were analyzed ecologically, economically and technically
- Remanufacturing and reducing building heat demand in particular can reduce the environmental impact of the heat pump
- High initial investments represent a financial obstacle
- The ecological potential of circular strategies will increase in the future



Thank you for your attention!

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