Optimal Facility Location and Sizing for Waste Upcycling Systems

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1 Introduction

To achieve carbon neutrality, turning into renewable energy is not enough by itself, innovations must be made throughout the industry, improving or replacing current processes.

Chemical recycling (upcycling) offers the advantage of reducing the carbon footprint by:

i. utilizing end-of-life materials that would otherwise be incinerated or landfilled,

ii. producing a diverse range of virgin-equivalent valuable molecules that can replace or reduce the use of fossil-based feedstock in the production processes.

However, integrating chemical upcycling technologies with the waste management infrastructures is a challenging task that requires careful analysis to ensure efficient operation and economic viability.

A flexible computational tool which supports strategic planning and decision making

2 Methods

The problem is formulated in the form of a mixed integer linear program (MILP) in which **the number, location and size of the processing facilities**, as well as **the amount of materials to be transported between the nodes of the network** is optimized under an economic objective.

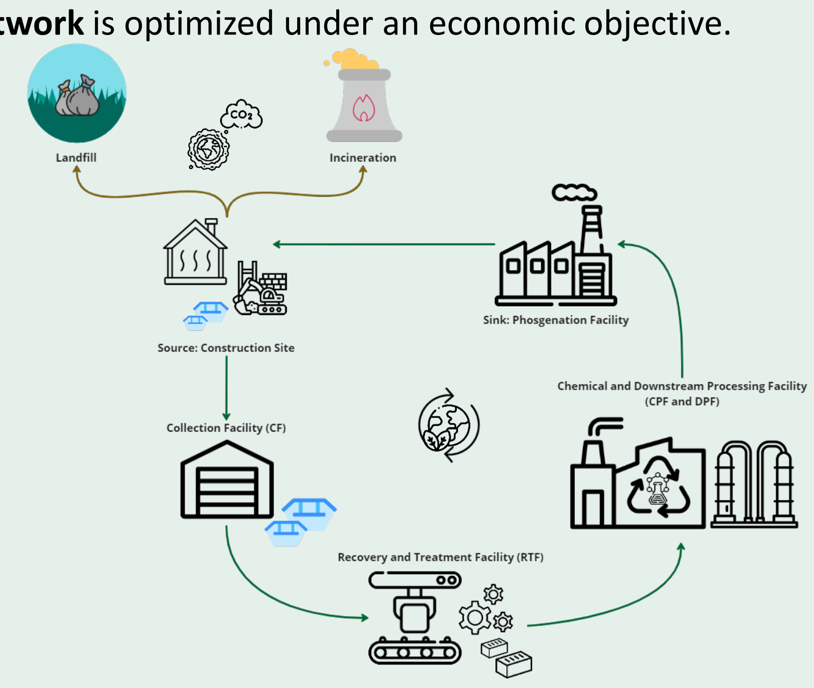

Figure 1: A schematic representation of a polyurethane upcycling network

The functionality of the holistic optimization framework is tested in a case study of end-of-life rigid polyurethane foams in Germany.

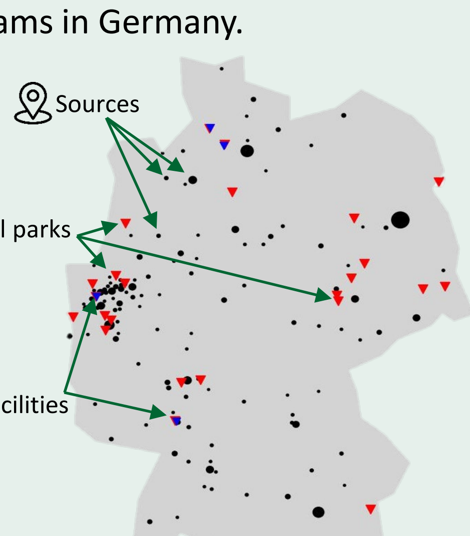

Figure 2: Polyurethane waste distribution in Germany. The relative amount of waste material is indicated by the sizes of the dots.

1 123 cities with population > 70,000

2 50 kt PU waste/year from construction sites

3 Smart pyrolysis as chemical upcycling route

4 Transportation by road

For the details of the model, please refer to the paper.

3 Results

Base Case Scenario

The base case scenario has 203,586 variables (294 binary, 203,292 continuous) and 2,826 constraints.

PU waste is **collected separately in big bags on-site** and not mixed with other construction waste.

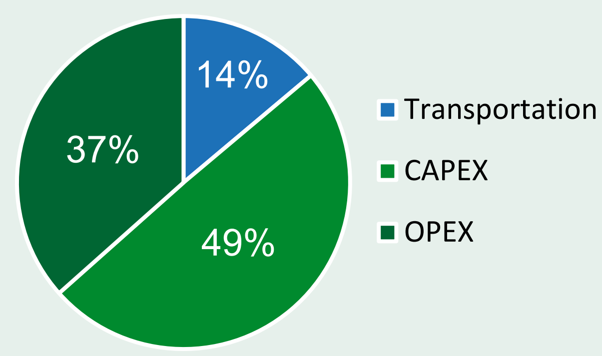

Figure 3: Total cost breakdown of base case scenario

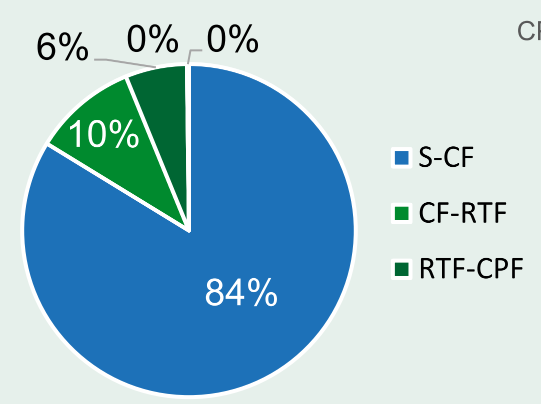

Figure 4: Transportation cost breakdown of base case scenario

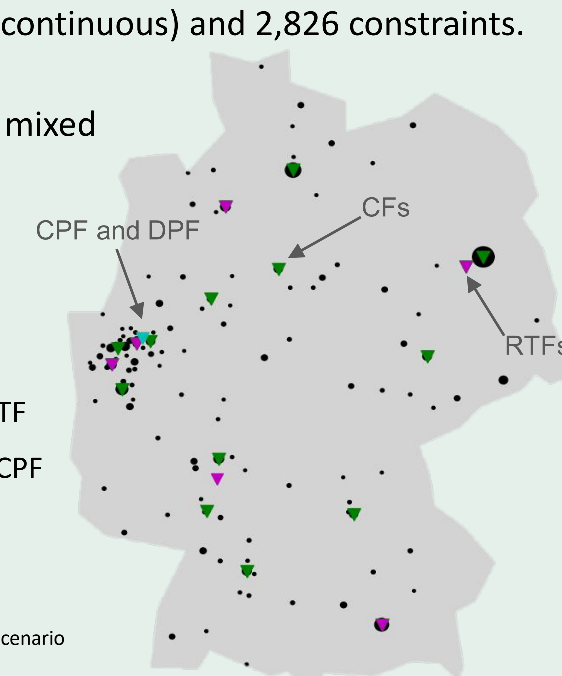

Figure 5: Optimal layout for the base case scenario (CF: Green, RTF: Purple, CPF and DPF: Blue)

Mixed Case Scenario

All the construction waste is **collected in mixed-waste containers** and brought to CFs via skip trucks where pre-sorting has to take place.

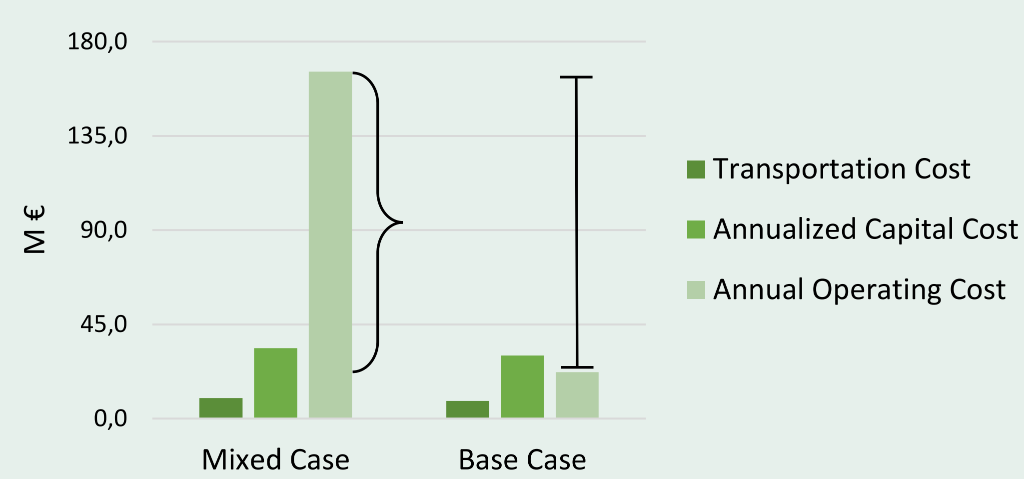

Figure 6: Total cost breakdown of mixed case scenario and base case scenario

→ The expenditures of the collection facilities increased hugely due to the required additional workforce and machinery to process the mixed waste.

Decentralized Pyrolysis Scenario

→ The maximum capacity of CPFs are reduced to 25% of base case scenario.

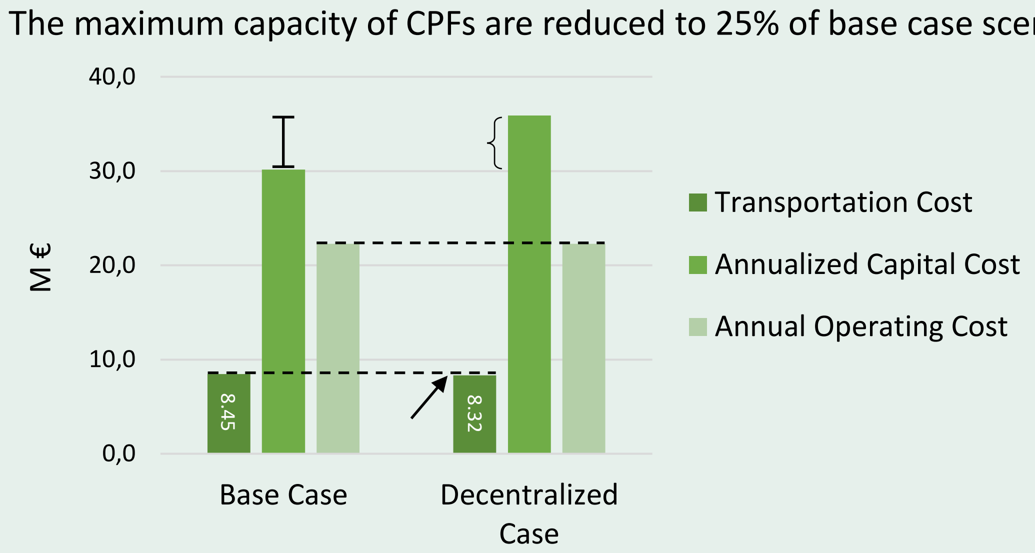

Figure 7: Total cost breakdown of mixed case scenario and base case scenario

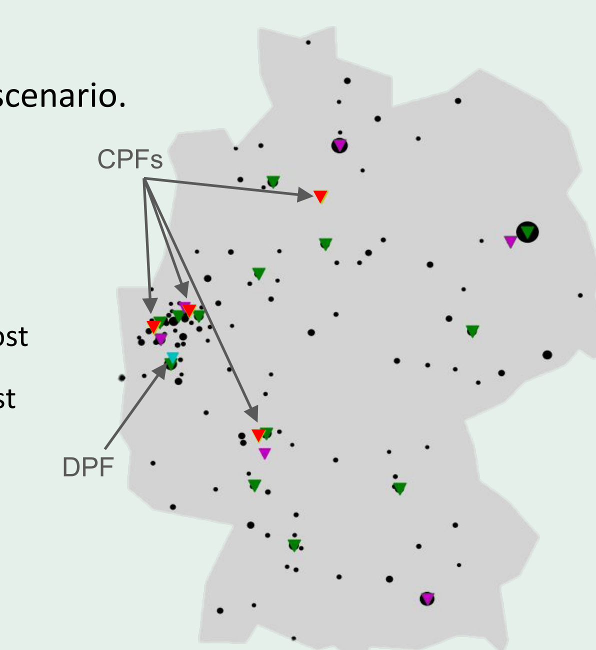

Figure 8: Optimal layout for the decentralized case scenario (CF: Green, RTF: Purple, CPF: Red, DPF: Blue)

→ More decentralized pattern reduces the transportation costs

→ Increase in CAPEX > Decrease in transportation cost

4 Conclusions

- Structure is always decentralized at the collection stage. As we proceed along the value chain, layout tends to be centralized. This is due to three factors: i. high transportation costs associated with carrying low density PU over long distances, ii. increased transportation efficiency as a result of changes in material density, iii. increased investment costs due to increased complexity of the facilities (CPFs and DPFs).
- The economic impact of implementing basic regulations that can substantially improve the overall operation is illustrated. Total cost is reduced more than threefold by the initial collection of PU waste in big bags rather than mixed containers.
- The proposed framework can be used broadly to solve large-scale facility placement and sizing problems and can provide the basis for analyzing the effect of uncertain parameters in complex large-scale problems.
- The location of the waste sources as well as the amount of the waste material collected are variable over time, especially in the construction industry, making the process of locating different elements of the supply chain difficult. Moreover, the composition and the quality of waste is unpredictable, requiring the development of technologies that can handle different grades of waste material. Therefore, in order to guarantee a sustainable operation and to ensure compliance with the (future) regulatory framework, more sophisticated models should be developed that can also capture the dynamic nature of circular supply chains.

References

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