Evaluation of resource effectiveness of Circular Economy strategies through Multi-level Statistical Entropy Analysis

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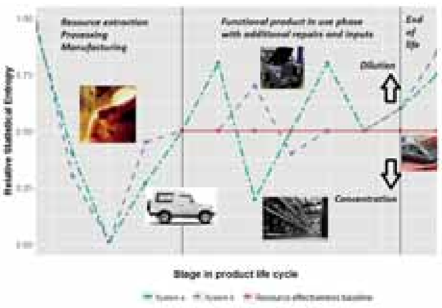
Introduction

The Circular Economy and the resource effectiveness baseline

In a Circular Economy (CE), materials, components and products should be kept at the highest level of functionality, while their loss and "dilution" should be avoided. In an ideal circular world, a product would not require any additional inputs during use phase and it would never reach end-of-life. Hence, in the long term resource extraction and resource losses would be zero. This optimal state is expressed through the resource effectiveness baseline (REB).



The distance to the baseline

By measuring the distance to the ideal circular state (REB), different metabolic production-consumption systems can be evaluated to an absolute level of circularity (conceptually exemplified for two different systems a and b). Any deviation from the REB represents resource losses, which have to be regained. Therefore, system design under consideration of the REB is particularly relevant as low performing systems require more efforts in the form of energy, labour, know-how and additional material inputs, to maintain and restore lost functionality.

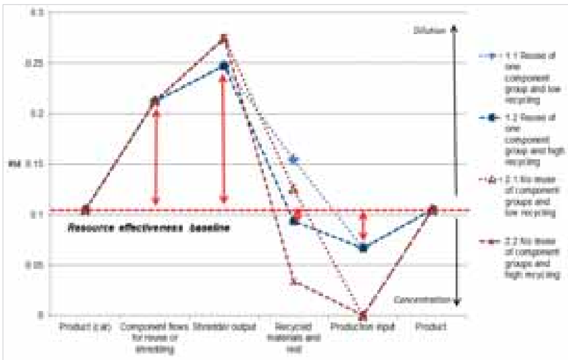
Method, Case Study and Results

Method

The Multi-level Statistical Entropy Analysis (MSEA) consists of two parts. First, the component statistical entropy (SE) is calculated, building on the original approach by Rechberger and Brunner (2002). Second, the component SE is aggregated for the product. The product SE further combines the component entropies, together with the relative frequency of components in a product, resulting in a product entropy value. Normalization to maximum possible SE results in relative SE (RSE). All three hierarchical levels (substance, component and product) are considered, allowing the evaluation of different CE strategy combinations, such as remanufacturing, reuse and recycling.

Case study under different system configurations

Results



- System 1.2 performs closest to the resource effectiveness baseline, which can be explained by its higher levels of reuse and recycling. It leads to a lower RSE value of the shredder output, and requires less overall RSE changes in subsequent stages.
- System 2.2 performs worst, as it lacks any reuse and has a low recycling level, leading to higher dilution, requiring higher recovery (recycling) afterwards.
- The number of reused components and the shredder output stage largely determine system performance and the degree to which RSE has to be decreased in later stages to recover functional (pure) materials which can be reused in the production stage.
- In a system which aims to regain functionality, any increase in RSE requires concentrating processes afterwards. Therefore, the aim is to minimize overall distance to REB from both directions (red arrows).

Conclusion

- The established resource effectiveness baseline provides an absolute point of reference to measure circularity.
- The MSEA method assesses the distance of metabolic system performance to the resource effectiveness baseline.
- Thereby, combinations of CE strategies and their contribution to maintain or restore (but also lose) functionality in a CE can be evaluated and stages with largest contributions to the deviation from the ideal CE state can be identified.

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