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Evaluation of resource effectiveness of Circular Economy strategies through multilevel Statistical **Entropy Analysis**

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The value chains of the global economy are very effective in the extraction of large volumes of resources, the refining of base materials and the creation of functionality through the fabrication of goods and products. This engine of production concentrates materials of value and excretes wastes and emissions (e.g., tailings, slags, heavy metals). After the production of (almost) pure materials in the form of intermediate goods, these are integrated and diluted into components and products. Through this very specific change of distribution of materials, components and products, functionality and value is created, which in the ideal case should be maintained over a maximum period of time (Figure 1). By quantifying both, the circularity, as well as the diluting and concentrating effects of processes like mining, collection and recycling, the resource effectiveness of a system can be assessed.

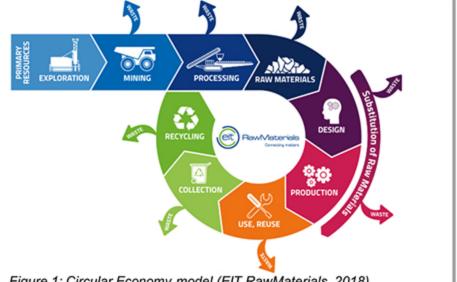


Figure 1: Circular Economy model (EIT RawMaterials, 2018).

Method and case study

The principle of the multilevel Statistical Entropy Analysis (SEA) is the quantification of the distribution of substances, materials, components and products at any state of a system. Thereby, the method can quantify the composition of a car, as well as a batch of components, waste flows or recycled materials by a single value (relative statistical entropy, H_{rel}). For a waste flow with diverse materials that are highly mixed, H_{rel} is close to 1, while for a pure material flow, e.g. pure Cu, H_{rel} is 0. Similar reasoning applies to the component and product level. A product with a high number of diverse components, which have a complex material composition (e.g. smartphone) has a higher H_{rel} -value than a simple product (e.g. coffee machine).

For the demonstration of the method, a simple material flow system is employed, for which different reuse scenarios with different recycling configurations are modelled (Figure 2). The system is run for four system cycles. The final H_{rel} -value is recorded on the (xaxis) (Figure 3), while the required diluting and concentrating effects (efforts), are recorded as cumulated changes of H_{rel} on the (y-axis).

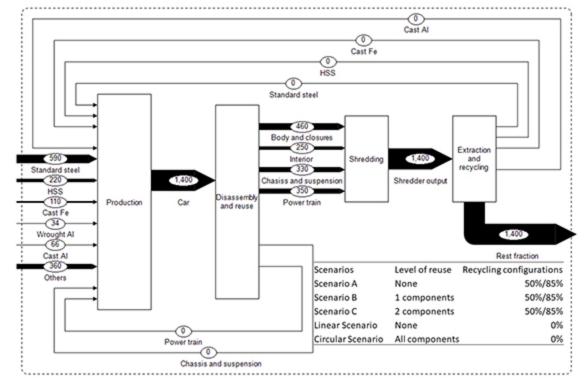


Figure 2: Material flow system structure used to model the scenarios (here showing linear system).

Results

The results of the different scenarios are presented in Figure 3. The H_{rel} -values (x-axis) show that the linear system has the largest distance to circularity, as all input materials are directed to a waste flow and are thereby diluted (Figures 2 and 3). Scenarios with higher reuse of components avoid initial dilution, which is shown by their closer location to circularity, but also by their lower effort requirements (y-axis). For the case study system, lower levels of reuse produce a larger shredder output fraction $(H_{rel}\uparrow)$, so that functionality has to be restored through a recycling process $(H_{rel}\downarrow)$. Thereby, the distance to circularity (x-axis) is reduced, but at a cost of cumulated H_{rel} -changes (y-axis). Both combined, result in the distance to resource effectiveness, a state which maintains functionality with minimal efforts.

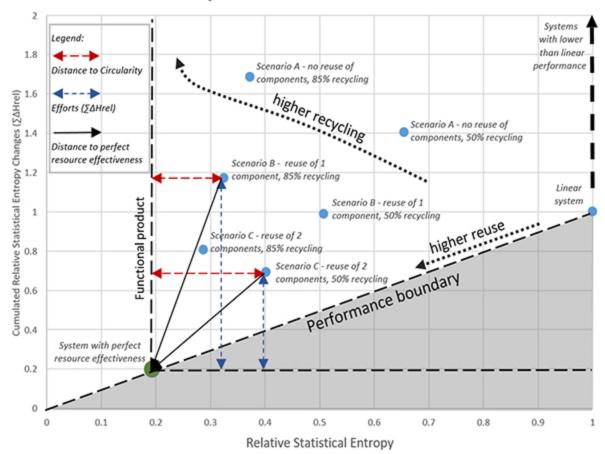


Figure 3: Resource effectiveness framework, which simultaneously shows the distance to circularity (red) when a product function is regained, and the efforts required to regain the function, shown as $\sum \Delta H_{rel}$ (blue) on the material, component and product level. The combined vector of both depicts the distance to a perfect resource effective scenario.

- The multilevel SEA method enables an integrated evaluation of material, component and product CE strategies.
- It allows to identify combinations of CE strategies that minimize the distance to circularity under minimal efforts (resource effectiveness).
- The resource effectiveness framework projects the distance of a system to circularity as well as the efforts that are required to reach that state, which allows to assess and compare the resource effectiveness of a diverse set of systems.



