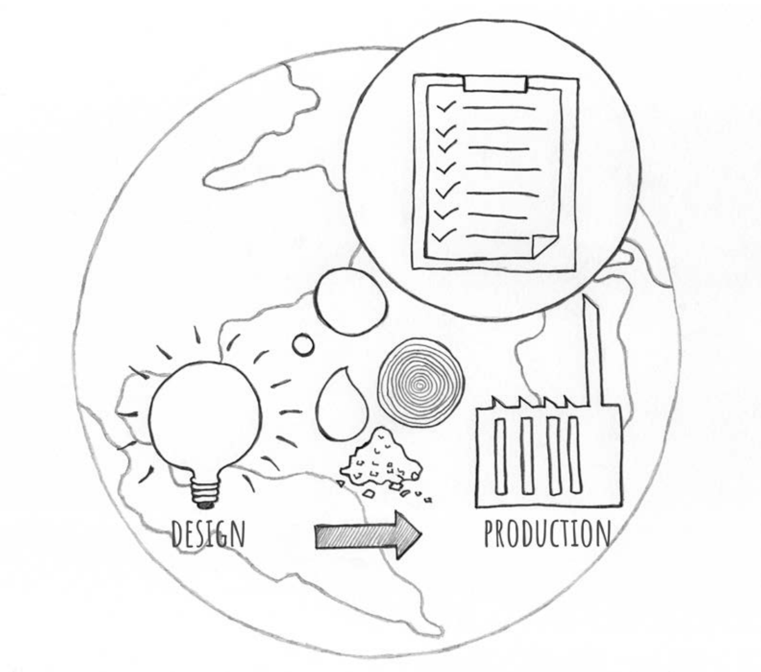
Laboratory for
Applied Circular Economy
(LACE)

Synthesis note of the LACE project n°4

Resource Pressure: a Circular Design Method

Design is a fundamental decision stage affecting the circularity of products and services. For this reason, a simple and easy-to-apply method to quantify the link between multifaceted design parameters and the pressure on resources is pivotal for designers to make informed decisions.



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Design Has a Key Role in a Circular Economy

Design enables decisions to be made at the very beginning of the life cycle of products, defining the quantity and quality of materials and the energy needed for production and operation. At the level of products, design allows decreasing the use of certain resources (e.g. primary resources such as metals or minerals), while increasing the use of others (e.g. recycled materials), thus reducing the overall consumption of resources. How things are designed has in addition an influence on the use phase as well as on options for the end-of-life treatment, determining the quantity and quality of materials and components that are recoverable.

Design is key to enable a sustainable circular economy, by decreasing material and energy consumption, decreasing waste production and environmental impacts, while simplifying the implementation of circular strategies (e.g. by designing products to be easily repaired and maintained).

The Right Tools for Circular Design Are Missing

Various eco-design tools estimating the environmental impacts of products already exist, related to circular economy or more general sustainability frameworks. It remains however difficult to choose the best suited tool, as they are often very **complex and time-consuming to use**. In the meanwhile, broad eco-design guidelines are available and easier to use, but often stay **too general and lack the necessary quantitative perspective**.
In this context, what is needed is an easy-to-use method that can inform designers from the very beginning, providing clear guidance without requiring too much additional knowledge and data.

The above issue is at the core of the research carried out by researchers of Empa, the Swiss Federal Laboratories for Materials Science and Technology, in the context of the Swiss National Research Programme “Sustainable Economy” (NRP 73) – project “Laboratory for Applied Circular Economy” (LACE).

Indeed, the authors proposed a **new decision support indicator called “resource pressure” (quantitative perspective) together with design guidelines (qualitative perspective)**. The method aims at **guiding the selection of materials and circular strategies from early design phases onward, with the goal of reducing the pressure on primary resources and maximizing the utility of materials for our socio-economic system**.

The qualitative guidelines can be used in the early phase of design (when the required data is lacking) to orient the design conception, while the quantitative indicator can measure the effect of design interventions on resource consumption. This combination is a strong feature of the methodology which is often lacking in other design approaches.

The quantitative perspective of the method can be numerically calculated with equations that can be found in the original paper. For the sake of simplicity, this note only discusses the qualitative aspects of the method.

The Resource Pressure Method in a Nutshell

The resource pressure method focuses on the environmental impacts caused by the consumption of resources, measuring the pressure exerted by a product on sustainably available resources. To develop the indicator (see c.), it is thus necessary to define the **sustainable availability of resources** (see a.) and to set the boundaries of a **product system** (see b.).

a. *Ecological resource budget as a benchmark*

The "ecological resource budget" (ERB) can be used as a benchmark to define how much of a material can be theoretically produced while staying within the Earth system boundaries. To calculate this budget different methodologies can be applied. In the paper, the ecological resource potential (ERP) is used.

The ERP represents the production mass flow that, at a chosen probability, does not cause the violation of global boundaries in isolation. This is a relative measure for comparing different materials, which may be limited by different Earth system boundaries. Using ERP allows defining the design that minimizes environmental impacts. The necessary data to calculate the ERP are the uncertainty distributions of Earth system boundaries and the impacts caused by the extraction, production, and final disposal of primary materials. Alternatively, it is also possible to use ecological resource availability (ERA) budgets, which are absolute resource budgets that are possible while considering all societal activities at the same time. The calculation of ERA thus requires the allocation of Earth system boundaries to specific activities (see note n°3 for more information).

b. *Flows of materials in a product system*

A product system represents the continuous flow of material inputs and outputs (emissions and waste) that are necessary to provide the functionality over time of a certain product or service.

Material Flow Analysis

Material Flow Analysis (MFA) is a methodology to quantify flows and stocks of materials or substances in a well-defined system. In the case of a product or a service, the system boundaries are set around the inputs and outputs necessary to provide the functionality of a defined product / service.

As illustrated in Figure 1 below, inputs and outputs to a product system can be categorized into different groups:

• *Consumed materials*: primary virgin material inputs (e.g. fuel) and final losses (e.g. emissions);

• *Recycled materials*: close loop material where the material output does not lose quality and can therefore be an input within the same product system;

• *Cascaded materials*: if a material cannot be used for the same function again, it may be used for lower quality applications and cascaded as an input (i.e. secondary material) to another product system.

Because of mass conservation, every input is turned eventually into an output, at latest at the end-of-life. Averaging the material flows induced by the system over time, the product system can be considered in steady state, i.e. requiring constant inputs and generating constant outputs.

This means that not only primary material consumption produces a pressure on resources, but also that losses at the end of life of a product will lead to an increased demand for primary materials elsewhere in the economic system.

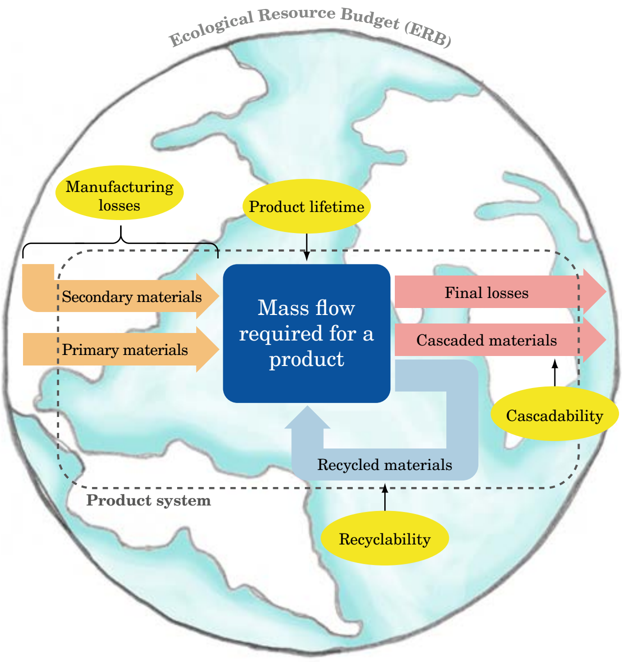


Figure 1 - Flows of materials in a product system and design parameters influencing the flows (and thus the resource pressure)

C. *The design parameters*

Based on the steady state described above, design is fundamental because it can influence resource pressure on both sides, having an impact on the quality and the quantity of the inputs (e.g. through the choice of materials) and the outputs (e.g. by affecting the cascadability).

To evaluate how design can influence the pressure on resources, the material choice together with different design parameters can be considered. Below, the different steps of the design guidelines are presented.

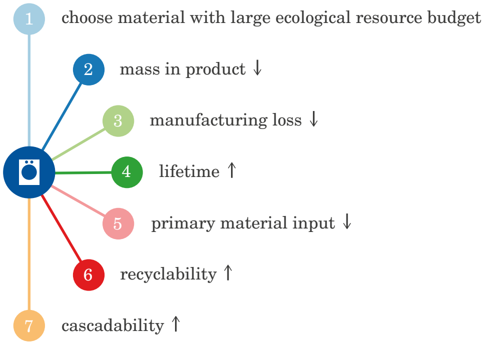
• **Material choice**: the choice of materials can have a profound effect on embodied environmental impacts, it however also influences other design parameters, such as lifetime, recyclability or manufacturing losses;
• **Mass in product**: for the same functionality of a product / service, differences in design can entail differences in the mass of materials (e.g. designing lighter and more compact shipping boxes can decrease weight and volume, which can optimize transport and material use, decreasing resource pressure);
• **Product lifetime**: modifying lifetime of products through design can have an influence on the material needs per service unit (e.g. using more durable materials increases lifetime and decreases the mass flow required for a product over time);
• **Manufacturing losses**: depending on the manufacturing technology, more or less material is lost during manufacturing (e.g. machining swarf). These losses can be collected and recycled or cascaded;
• **Recyclability**: design can influence the possibility to reuse materials at the same quality (e.g. modularity can enhance the separation of materials in recycling, leading to lower levels of contamination);
• **Primary material content**: primary material can be substituted to some extent by secondary material cascaded from a different product system. Depending on the design requirements (color, appearance, mechanical properties,...), more or less primary material is necessary;
• **Cascadability**: different designs can have an impact on the cascadability, which is important to prolong the lifetime of materials by allowing cascading them multiple times until the quality of the material becomes too low.

Design guidelines

Based on the definition of the sustainably available resources, on the identification of the necessary material flows required by a product system and of the design parameters that can influence the resource pressure caused by the material flows, qualitative design guidelines (as shown in Figure 2 next page) can be derived.

Figure 2 - Qualitative guidelines for circular design

(↓ stands for decrease the parameter as much as possible, ↑ stands for increase the parameter as much as possible)



The guidelines aim at being used as a rule of thumb when conceptualizing alternative designs, remaining rather general and not being meant to be exhaustive. **The guidelines are intended to support the conception of design changes, which can be evaluated quantitatively by using the resource pressure indicator.**

Applying the Resource Pressure Method to a Real-life Product Design Decision

To test the resource pressure method, it is applied to a real-life case study, defined in collaboration with V-Zug. The method is employed to compare different possible designs of a heat exchanger (an element of a heat pump, which serves for reducing electricity demand in tumble dryers).

This product is selected because the designers want to evaluate which material alternative (aluminium or copper) is preferable from an environmental point of view and because the changes in the design of the heat exchanger have a negligible effect on the performance of the device in the use phase.

There are two initial design options, which imply different structures, material needs, manufacturing processes and impacts:

- *Design 1 - only aluminium (Al/Al)*: presents a bulky design due to lower thermal conductivity. The manufacturing causes losses of material (that are however recycled) and at end-of-life the product needs to be shredded, causing the contamination of the aluminium, which can't be recycled and thus needs to be cascaded to lower quality cast alloys.

- *Design 2 - aluminium and copper (Cu/Al)*: the different materials allow for a different structure that causes less manufacturing losses and allows for a smaller size of the heat exchanger. For this design copper is sourced from the world market and contains 1/3 secondary copper. At the end-of-life, the copper presents a good recyclability. Instead, the aluminium is contaminated with other elements and can only be cascaded to cast alloy applications.

Comparing the initial design options (see Figure 3 below) for the heat exchanger, it is possible to see that the design made of copper and aluminium (Cu/Al) presents a lower resource pressure. This result derives from the lower manufacturing losses, the possibility to use secondary material and the recyclability of copper at the end-of-life.

By modifying the design of the tumble dryer, the heat exchanger can be easily removed at the end of life. Separating the heat exchanger before shredding allows a more specific recycling, increasing the recyclability of the metals. Indeed, for the Al/Al design, modularity eases dismantling and separate recovery, avoiding contamination and thus increasing the **recyclability** of aluminium while decreasing **cascadability**.

This is not applicable to the Cu/Al design, where separating the two materials would be too labour-intensive to be economically viable and shredding remains necessary for separating the two materials even if the heat exchanger is dismantled.

Thus, implementing modularity will modify the resource pressure of the two products, making the design option Al/Al more favorable than Cu/Al (as represented in Figure 4 below).

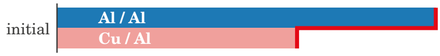


Figure 3 - Resource pressure of the two initial design options for the heat exchangers

Figure 4 - Resource pressure of the two design options by implementing a modular design

Conclusion

Through the application of the methodology to a case study, the authors have proven that because only six parameters are necessary, the calculations are simple and can be performed quickly during the design process. The results can give a clear guidance to design, showing the influence of each parameter on the resource pressure. However, recyclability and cascadability remain hard to estimate and need specific knowledge which is not always available in design teams.

The data needed to calculate the resource pressure indicator are also used as an input for Life Cycle Assessments (LCA). This means that the resource pressure can serve as an indicative preliminary method to be used in the design phase, and thus does not aim at replacing LCA but can instead precede LCA and be validated ex post through a LCA of the final product.

About the NRP 73

This research project is part of the National Research Programme "Sustainable Economy: resource-friendly, future-oriented, innovative" (NRP 73) of the Swiss National Science Foundation (SNSF).

NRP 73 aims to generate scientific knowledge about a sustainable economy that uses natural resources sparingly, creates welfare and increases the competitiveness of the Swiss economy. NRP 73 takes account of the environment, the economy and society as well as all natural resources and stages of the value chain.

73 NRP **Sustainable Economy** National Research Programme

Further information on the National Research programme can be found at:
www.nfp73.ch

About the LACE

The Laboratory for Applied Circular Economy (LACE) is an inter- and trans-disciplinary project that gathers researchers from three Swiss higher-education institutions, and from various disciplines: environmental and material sciences, business administration, as well as law and political sciences. The LACE project is working together with seven well-known partner companies in order to show how the resource-efficient patterns of the circular economy and related business models can be introduced into the value chains of the participating companies. The aim of this project is to demonstrate that the principles of circular economy can be ecologically beneficial and profitable for Swiss companies. The sanu durabilitas foundation is knowledge-transfer partner of the LACE project.

Empa Materials Science and Technology

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Further information on the Laboratory for Applied Circular Economy can be found at:
www.nrp73.ch/en/projects/circular-economy/laboratory-for-circular-economy

About sanu durabilitas

The sanu durabilitas foundation is an independent Think and Do Tank based in Biel/Bienne. Its aim is to develop new practice-oriented and effective solutions for the transition towards a sustainable Switzerland which are being applied in economy, policy and public administration, and also to improve the institutional framework conditions for sustainability. In collaboration with partners from research, business, politics, administration and civil society, sanu durabilitas identifies promising solutions, develops them further, tests their application in the field, draws up recommendations, and brings them to the attention of decision-makers and the general public. The current focus areas of sanu durabilitas are circular economy, sustainable use of soils, and social cohesion in a changing society.

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