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A tool for circular product development with Circularity and potential value capture indicators

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The Circularity Calculator, a Tool For Circular Product Development with Circularity and Potential Value Capture Indicators.

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Abstract: Most products require a redesign to be viable in a circular economy. For instance, by implementing design for disassembly, remanufacturing, recyclability, and using long-lived components. Typically, different solutions can be chosen to improve a products' circularity, and different strategies can be aimed at keeping the product, its components, and materials in the loop.

When developing products for a circular economy, designers and manufacturers want to assess their solutions and choose between alternatives early in the design process. This paper describes the Circularity Calculator, a tool that has been developed to help designers assess the potential resource circularity and value capture of products in the first design stages. The tool provides quantitative indicators that help determine whether and which circular strategies are potentially viable for the company.

This paper discusses the methodology behind the Circularity Calculator, which uses four KPIs that have been developed for assessment; a Circularity indicator, Value Capture indicator, Recycled Content indicator and a Reuse Index. We will explain how the dashboard interface is used to model a linear and circular product system which can be compared on its economic potential. The tool is illustrated with an example concerning the analysis of a household blender.

1.Introduction

Governments and business owners are experiencing global pressure to transform their business from a linear economic model to a circular economy approach by eliminating waste and the use of non-renewable resources (MacArthur, 2013).

Contrary to traditional linear business, circular businesses aim to retain the product value in each stage of their products' life, by designing for longevity, reuse, refurbishment remanufacturing and recycling (Ibid). This requires strategic decisions on the design of the product and business model in the early stage of the development process. However, limited information is available at that stage. Companies generally do not have data about the costs of collection, remanufacturing, recycling, and other processes when they are currently operating in a linear economy.

Different circular design tools have been developed to help companies assess Circularity at various scopes (Saidani et al., 2019). The 'Circularity Calculator' (IDEAL&CO., 2020) is an online tool to inform the design of circular products in the early stages of design. In their taxonomy of Circularity Indicators, Saidani et al. (2019) classify the Circularity Calculator as one of three web-based tools to indicate circularity potential at a micro-level.

The Circularity Calculator was developed and tested within the European ResCoM-project, as part of a design methodology for multiple-lifecycle products (Bakker et al., 2017, Rashid et al., 2013, van Dam et al., 2017). The tool development was initiated upon the need for circular design support of one of the company design teams and specifically geared towards the tool requirements of designers. No tools were available that can assess the circularity and business potential of different circular scenarios (such as reuse, refurbishment, remanufacture and recycling). The development was sparked by the demand for an assessment tool that can be used in the early design stages, that provides an intuitive, visual, and quick way to grasp the potential of design ideas. Following the ResCoM-project, the tool was developed further and is currently used in design education, by OEMs and at design

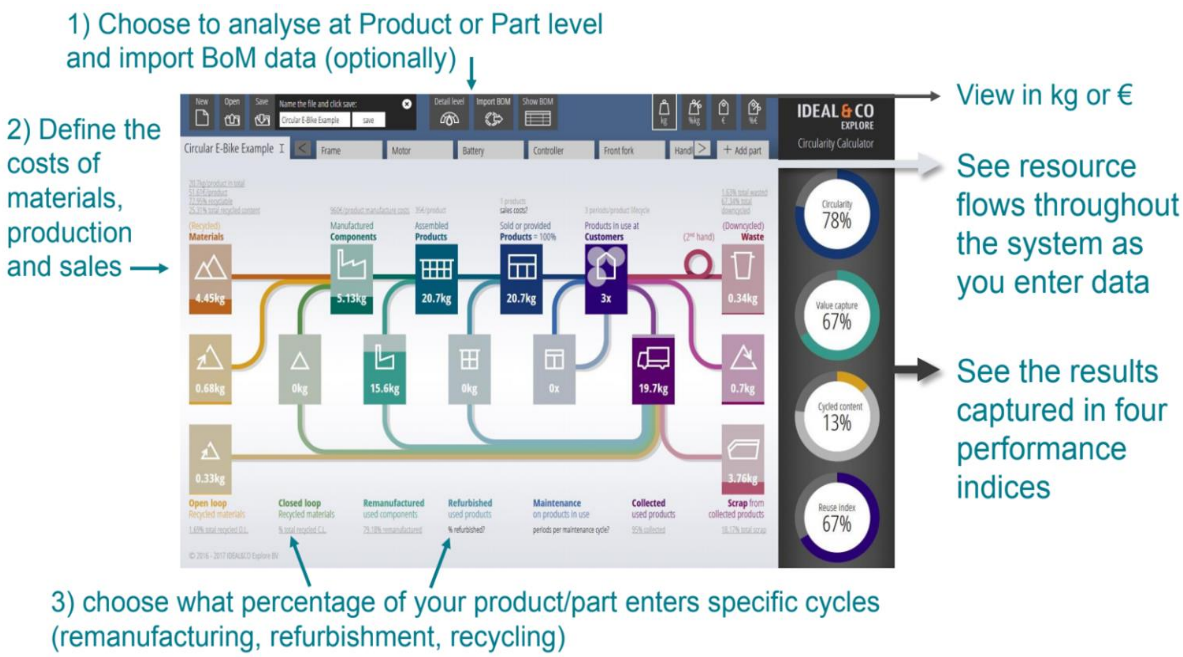

Figure 1. The circularity calculator dashboard.

agencies pioneering in a circular design, to help inform strategic design decisions.

2. Circularity Calculator dashboard

The Circularity Calculator provides a schematic representation of the product lifecycle and the flow of resources in that system (Figure 1). On the left side of the dashboard, *materials* are procured, feeding into the production of *components*, *assembled* into *products*, that are then brought to the market to be *used by the customers*, followed by different linear and circular options for dealing with products after their (first) use period. Products can be modelled to be reused or used longer, and after the use stage, products or specific components can either end up as waste, in a downcycling process, or be collected to re-enter the value chain.

For each of the boxes, the user can enter product or component data (materials, weights, costs) and define what percentage of the product or component enters which cycle. Based on the input, the tool calculates potential mass and value flow in the system (in Figure 1 displayed in the boxes in kg), so the user can see the effects when the product or its components are used longer, refurbished, remanufactured and/or recycled.

The user can model different conceptual design solutions and circular scenarios, to explore and compare design alternatives and see the impact on performance indices.

To be useful for designers, one of the key development criteria for the tool was to provide direct and visual insight into the effects of changes in the design of the product and the overall system. From that criterion, a tool was built that provides a dashboard to the user, a one-view graphical user interface showing the flow of resources combined with circular performance indicators for a specific circular strategy of a product design.

On the right-hand side of the dashboard, the circular performance indicators are shown, which will be explained in the following section.

3. Circular performance indicators

To indicate the 'circularity' and the circular potential of products, the developers defined four

key performance indicators (KPIs). These indicators are (i) Circularity, (ii) Value Capture, (iii) (Re)cycled content and (iv) Reuse Index.
All KPI's are updated dynamically, providing direct feedback to, for instance, assess the impact of changing collection rates, or the potential gains when changing the material of a specific component.

3.1 Circularity

The circularity indicator assesses to which extent the flow of resources in a product system is *closed,* by feeding resources back into the production of new goods. It builds on the work of Ayres (1994), Braungart et al. (2008), Stahel (2010), and Bocken et al. (2016) on closing and slowing the flow of resources in circular systems.
In a fully linear scenario (Circularity 0%), only virgin materials are used that eventually all end up as waste, whereas in a fully circular scenario (Circularity 100%) no virgin material is used (circular inflow) and no waste is generated (circular outflow).
The Circularity indicator represents the percentage of the mass-flow of the resources that is circular, considering the overall number of products that are brought to market. The inflow of materials into the system contributes to half of the Indicator and the outflow to the remaining 50%. The resulting formula to calculate the Circularity indicator is:

$$100\% - \frac{M\%_{virgin} + M\%_{wasted} + M\%_{downcycled} + M\%_{scrap}}{2}$$

Where *M*% is the mass percentage of materials.

3.2 Value capture

The value capture indicator helps assess the economic potential of different circular strategies early in the product development process when different scenarios are still feasible. However, little is known about the costs of collection and resource reuse. This Indicator follows the rationale of Stahels' 'inertia principle': "replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system" (Stahel 2010, p. 195), which is also represented in the Value hill framework by Achterberg et al. (2016), as described in Figure 3. The Value hill explains that the more the product's original integrity is maintained, the higher the potential embodied value you can retain.

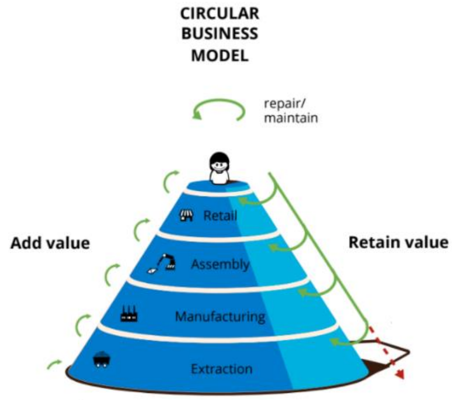

Figure 2. Value hill by Achterberg et al. (2016).

The potential value capture of the product is calculated from the value that is embedded in reused materials, components, and products and described in the **Value Capture Indicator**:

$$100\ \% \cdot \frac{E_{OL}+E_{CL}+E_{RP}+E_{RC}}{E_{provided\ products}}$$

Where E is the embedded value in Euros with OL for materials recycled in an open loop, CL in a closed loop, RC for remanufactured components and RP for refurbished products.

3.3 Cycled content

The **Cycled Content indicator** helps to assess the performance of the inflow of resources, by showing the percentage of the product that is made from recycled and/or rapidly renewable materials. It is calculated from the mass ratio of recycled and renewable materials coming from an open or closed loop in manufactured components:

$$100\% \cdot \frac{M_{cycled} + M_{CL}}{M_{manufactured\ components}}$$

In addition, the **Cycled Content Potential Indicator** shows to what extent the cycled content indicator can be improved without changing materials and is defined as:

$$100\% \cdot \frac{M_{cyclable} + M_{closed\ loop}}{M_{manufactured\ components}}$$

This potential refers to the use of materials that are recyclable but are not (yet) sourced from recycled content.

3.4 Reuse Index

The Reuse Index is based on the classification presented by Bocken et al. (2016) and helps to assess the degree of *slowing* resource flows, which refers to "prolonged use and reuse of goods over time, through the design of long-life goods and product life extension" (Bocken et al., 2016, p 310).
The Indicator measures the extension of the life of a product. Product-as-a-service business models, robust and repairable products and maintenance can extend the life of a product and therefore slow the flow of resources. This slowing of loops does not entail the closing of loops; a product can have a high reuse index and low circularity indicator at the same time if it is long-lasting but ends up as waste.

The designer can model the resulting reduction in production volume to estimate the savings in resources, and the reuse Index provides a performance indicator reflecting the potential decrease in resources by means of slowing resource flows. In a purely linear scenario, the number of use cycles is defined as 1, resulting in a reuse index of 0%. The formula to calculate the **Reuse Index** is as follows:

$$100\% \cdot (1 - \tfrac{1}{N})$$

Where *N* is the number of use periods.

4. Case Study

To illustrate the use of the Circularity Calculator, we describe a case study evaluating a household blender in different scenarios, one 'linear' and two circular scenarios:

- Scenario 1: linear system.
- Scenario 2: life-extension strategy.
- Scenario 3: refurbishment.

Figure 3 shows the household blender, and Figure 4 shows the disassembled product.

Figure 3. The Solis 837 Household blender.

Figure 4. Disassembled motor assembly of the Solis Household blender

4.1 Scenario 1: "Linear" system

We started by modelling the blender in a predominantly linear scenario. We assumed that nearly all components are made from virgin materials. For the metal components, we estimated the materials contain about 40% recycled content, based on Graedel et al. (2011). Furthermore, we assumed that no high-quality recycling is taking place after the blender has been discarded and that its components and materials are either incinerated or downcycled into lower-quality products.

Figure 5. The outcome for scenario 1, the "linear" system.

Figure 5 illustrates the flow of resources in the product system, with the key performance indicators on the right. The Circularity for this scenario is 3%. This percentage stems from the use of recycled content in the metal parts. In total, 580 Tonnes of materials are used for the total production series of 100,000 blenders. The potential value capture is zero because the company does not collect and reutilise the value that is embedded in the product, its components and materials.

This is the base scenario to which the user can compare more circular scenarios.

4.2 Scenario 2: Life-extension strategy

The blender is a high-quality product (with a robust motor). A typical reason for discarding is when the blades become dull. In this scenario, we assumed that the lifetime of the product can be doubled by changing the design of the blade holder, allowing easy replacement of the blades. We modelled that for delivering the same overall functionality (total operating hours) only half the number of blenders (with two sets of blades) would need to be manufactured, assuming a constant market size (no increase of market share due to improved design). No other changes were modelled.

When looking at the results in Figure 6, the reuse index increased from 0% to 50%. The indices for recycled content, circularity and value capture are still as low as in the linear scenario, because -in this scenario- the product still ends up as waste. The total inflow of resources decreased from nearly 570 tonnes to 310 tonnes (of which 294 tonnes virgin materials). This life-extension scenario could be monetised with a performance-based business model such as leasing, since the product can perform twice as long with a relatively small change in the product's design.

4.3 Scenario 3: Refurbishment.

For the third scenario, we modelled a simplified refurbishment scenario (without product life extension). We assume that a highly effective collection system is in place, with an overall return rate of 80% of the products. Furthermore, we assume that the company can refurbish 80% of the products they collect (so 20% do not meet the company's quality criteria for refurbishment, including components that will be replaced during refurbishment). This scenario implies that the company can meet a large portion of market demand with refurbished models. Therefore, the company can deliver the same 100,000 products to market while producing fewer new products.
As a result (Figure 7), the circularity increases from 3% to 67% and potential value capture increases to 64%. The value capture potential of refurbishment is Eur. 6,3 million under the

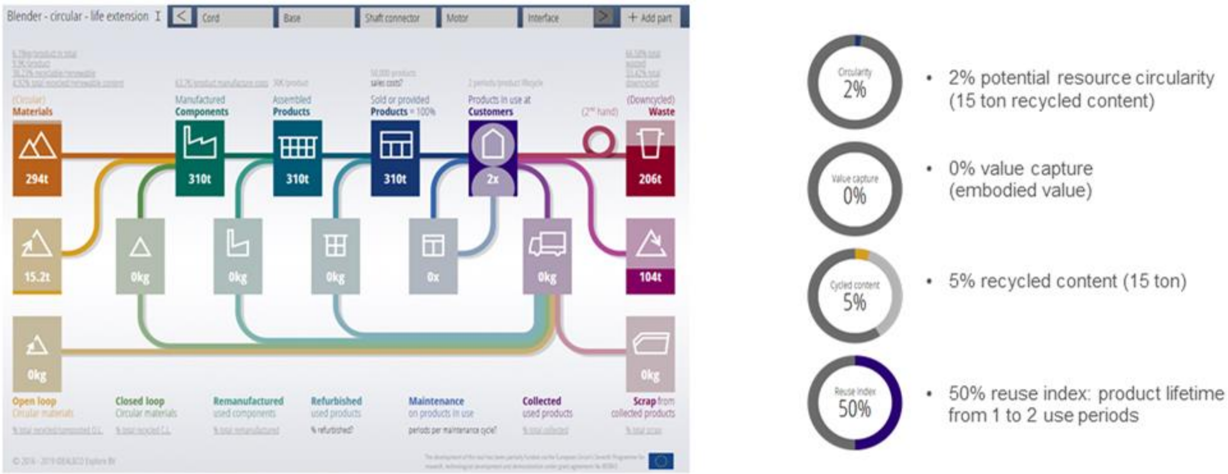

Figure 6. The outcome for scenario 2, Life-extension strategy.

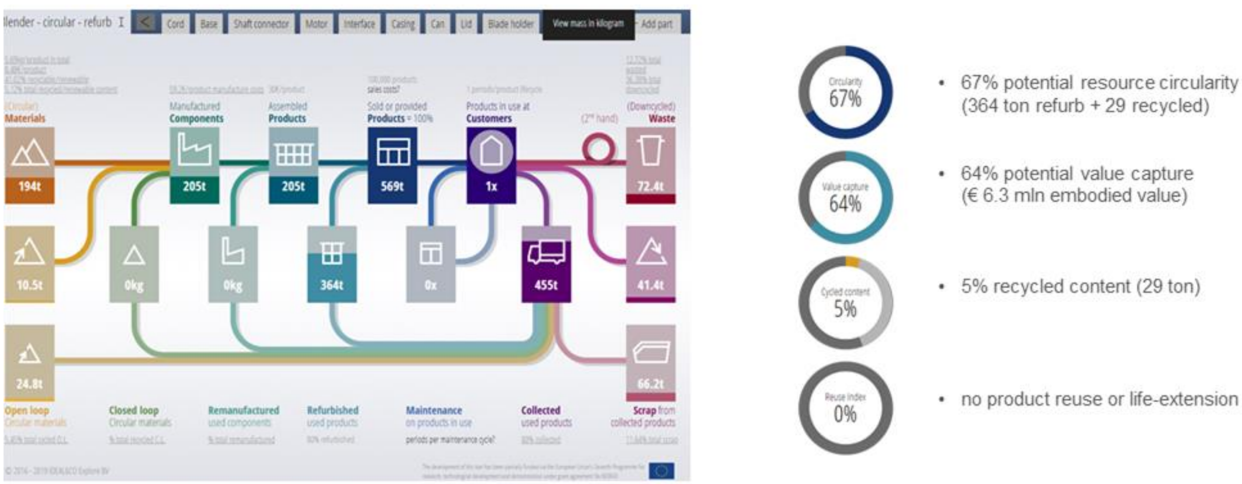

Figure 7. The outcome for scenario 3, refurbishment.

assumptions made. Based on this outcome, the company can decide whether it seems worthwhile or not to make a more detailed analysis of this scenario.

By changing the values of the collection rate and percentage of products entering the refurbishment process, users can see more fine-grained effects on potential resource circularity and value capture.

4.4 Scenario comparison

By comparing the results from the different scenarios, users have several KPIs as well as numbers on resource use and potential value capture in specific cycling scenarios to make informed design decisions in the early stages of a product development process.

For the scenarios analysed in the blender case study, summarised in Table 1, refurbishment seems to hold the most potential for the company, generating a largest reduction in the use of virgin resources, and with a value capture potential that seems sufficient to warrant further analysis by the company.

Indicator	Sc. 1: linear	Sc. 2: life-extension	Sc. 3: refurbishment
1. Circularity	3%	2%	**67%**
2. Value capture	0%	0%	**64%**
3. Cycled content	5%	5%	5%
4. Reuse	0%	**50%**	0%
Use of virgin resources	540 tonnes	294 tonnes	**194 tonnes**

Table 1. Comparison of outcomes for the case study (best outcomes in bold).

In addition to the four indicators, the dashboard provides information on the flow of resources for all system stages. For example, the use of virgin resources listed in Table 1 is taken from the (orange) virgin materials box, which reads 194t in scenario 3 (Figure 7).

In a more extensive case study, the design team would investigate more circular strategies such as recycling and explore the potential of combining cycles, for instance, refurbishment in combination with recycling of products that are no longer suited for refurbishment.

5. Discussion and Conclusion

In this paper, we have described the aim and workings of the Circularity Calculator. The tool provides design teams with early-stage figures to assess whether specific circular strategies may hold economic potential.
By combining scenarios and investigating the influence of their assumptions, design teams can use the outcomes to decide which strategy, or a mix of strategies, to focus on.

In the case study, we saw that the refurbishment scenario yielded the largest reduction in the use of virgin resources with high potential value capture. These outcomes help design teams to decide whether a circular approach holds potential for the company and which circular strategy to design for.

While the value capture indicator provides insight into the economic potential of specific circular strategies, it does not represent the potential profitability of the strategies. The extent to which the potential of a specific strategy can be realised depends on the design of the product and recovery process, as well as the business model. Furthermore, the costs of collecting and subsequent processing of the product, its components or materials determine whether the strategy can be run at a profit. In that sense, the outcomes show whether it seems worthwhile to further investigate a solution's profitability. As soon as companies gain more insight into the costs of circular operations, the tool could be expanded to include potential profitability, rather than value capture.

When using the tool, it is up to the design team to make realistic assumptions on the design changes that are needed. When this expertise is not available within the team, other tools, such as Hotspot Mapping (Flipsen et al., 2020) and the Reman Design Checklist (IDEAL&CO. n.d.) can help design teams identify which design changes to focus on.

In the further development of the tool, it would be beneficial if the model can be extended to include production losses, process costs and additional circularity metrics such as resource scarcity.

References

Achterberg, E., Hinfelaar, J., & Bocken, N. (2016). Master circular business with the value hill. *Circle Economy*, *18*.

Ayres, R. U., "Industrial metabolism; theory and policy," in B. R. Allenby and D. J. Richards (eds), The Greening of Industrial Ecosystems, National Academy Press, Washington, DC, 23–37 (1994).

Bakker, C. A., van Dam, S. S., de Pauw, I. C., van der Grinten, B., Asif, F., Bakker, C., ... & Asif, F. (2017). ResCoM Design Methodology for Multiple Lifecycle Products.

Bocken, N. M., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308-320.

Braungart, M., P. Bondesen, A. Kälin and B. Gabler, "Specific Public Goods for Economic Development: With a Focus on Environment." in British Standards Institution (eds), Public Goods for Economic Development. Compendium of Background papers, United Nations Industrial Development Organisation, Vienna, (2008).

Flipsen, B., Bakker, C., & De Pauw, I. (2020). Hotspot Mapping for product disassembly; a circular product assessment method.

Graedel, T.E., Allwood, J., Birat, J.P., Reck, B.K., Sibley, S.F., Sonnemann, G., Buchert, M. & Hagelüken, C. UNEP (2011) "Recycling Rates of Metals-A Status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel".

MacArthur, E. (2013). Towards the circular economy, economic and business rationale for an accelerated transition. *Ellen MacArthur Foundation: Cowes, UK*.

Rashid, A., Asif, F. M., Krajnik, P., & Nicolescu, C. M. (2013). Resource conservative manufacturing: An essential change in business and technology paradigm for sustainable manufacturing. *Journal of Cleaner Production*, *57*, 166-177.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542-559.

Stahel, W. R., The Performance Economy, Palgrave Macmillan Hampshire, Hampshire UK, (2010).

van Dam, S. S., Bakker, C. A., de Pauw, I. C., & van der Grinten, B. (2017). The circular pathfinder: Development and evaluation of a practice-based tool for selecting circular design strategies. *Plate Product Lifetimes And The Environment 2017*, *9*.

IDEAL&CO. (2020). Circularity Calculator. http://circularitycalculator.com/

IDEAL&CO. (n.d.). Reman Design Checklist. https://www.ideal-co.nl/tool.html#reman