

Circular Product Design and Development

A CIRCit Workbook

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Circular Economy Sustainability Screening A support for decision-making through the sustainability screening of alternative circular solutions in terms of environmental, social and business potential. e-ISBN: 978-87-7475-601-9

2

Circular Economy Business Modelling A guide to the creation of circular business models based on a step-by-step approach, best practice and success cases. e-ISBN: 978-87-7475-603-3

3

Circular Product Design and Development An approach to assess product circularity and a set of circular design guidelines for early product development. e-ISBN: 978-87-7475-605-7

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Smart Circular Economy A look at how digitalisation and smart products can play a role in facilitating the transition to a Circular Economy. e-ISBN: 978-87-7475-607-1

5

Closing the Loop for a Circular Economy An assessment tool and guidelines to support the identification of the best circular strategy for products at end-of-use. e-ISBN: 978-87-7475-609-5

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Collaborating and Networking for a Circular Economy An approach to support circular value chain configurations, seeking innovation through collaboration. e-ISBN: 978-87-7475-611-8

What are we exploring in this workbook?

Circular Economy business models and closing the loop strategies can only be functional if the products and services are designed for circularity. This workbook presents (i) a set of practical design guidelines for circular product design and (ii) a tool to enable the circularity assessment of alternative concepts to support decision-making in the early product development process.

The workbook helps you to integrate Circular Economy into product design and development and answer the question: How to make suitable design decisions for circularity?



Circular Product Design and Development

A workbook in the CIRCit Series

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E-book version and more information at www.circitnord.com



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Introduction to Circular Economy

What is Circular Economy?

Circular Economy is a concept, based on the principle of decoupling value creation from resource consumption. The basic idea of Circular Economy is to move away from the so-called linear mindset, where value creation is based on the 'take-make-use-dispose' dogma.

Circular Economy has the potential to achieve maximum value by increasing resource productivity, enhancing energy efficiency, lowering resource consumption and decreasing waste. To do this, we should continue to extract value from resources for as long as possible, by extending their productive lifetimes. This means, for example, increasingly enjoying product and service offerings that are not necessar-

ily based on one-time ownership, and not necessarily based on single-lifetime products.

On first thought, many might equate Circular Economy to recycling of old and used products and materials. And indeed, *material recirculation* is a possibility, whether it be via recycling, cascading or recovering. Alternatively, and more valuable again, one could consider *product recirculation*, by applying tactics such as upgrade, repair & maintenance, reuse or remanufacturing. Even greater potential could also be achieved, by rethinking whole new ways of generating value, via integrated product/service business approaches, shared-access products, or new service offerings for long life products.



Achieving a Circular Economy requires a fundamental shift in mindset through business model, product design, support of the active product life cycle and closing the product loop, when the user no longer has a need for it. At the core of a Circular Economy lies collaboration, within and across value chains and with different societal stakeholders than we've maybe been used to.

And there's no use being circular, if the outcome is less sustainable than the starting point. Therefore we need to be able to estimate the sustainability benefits and drawbacks of our actions.

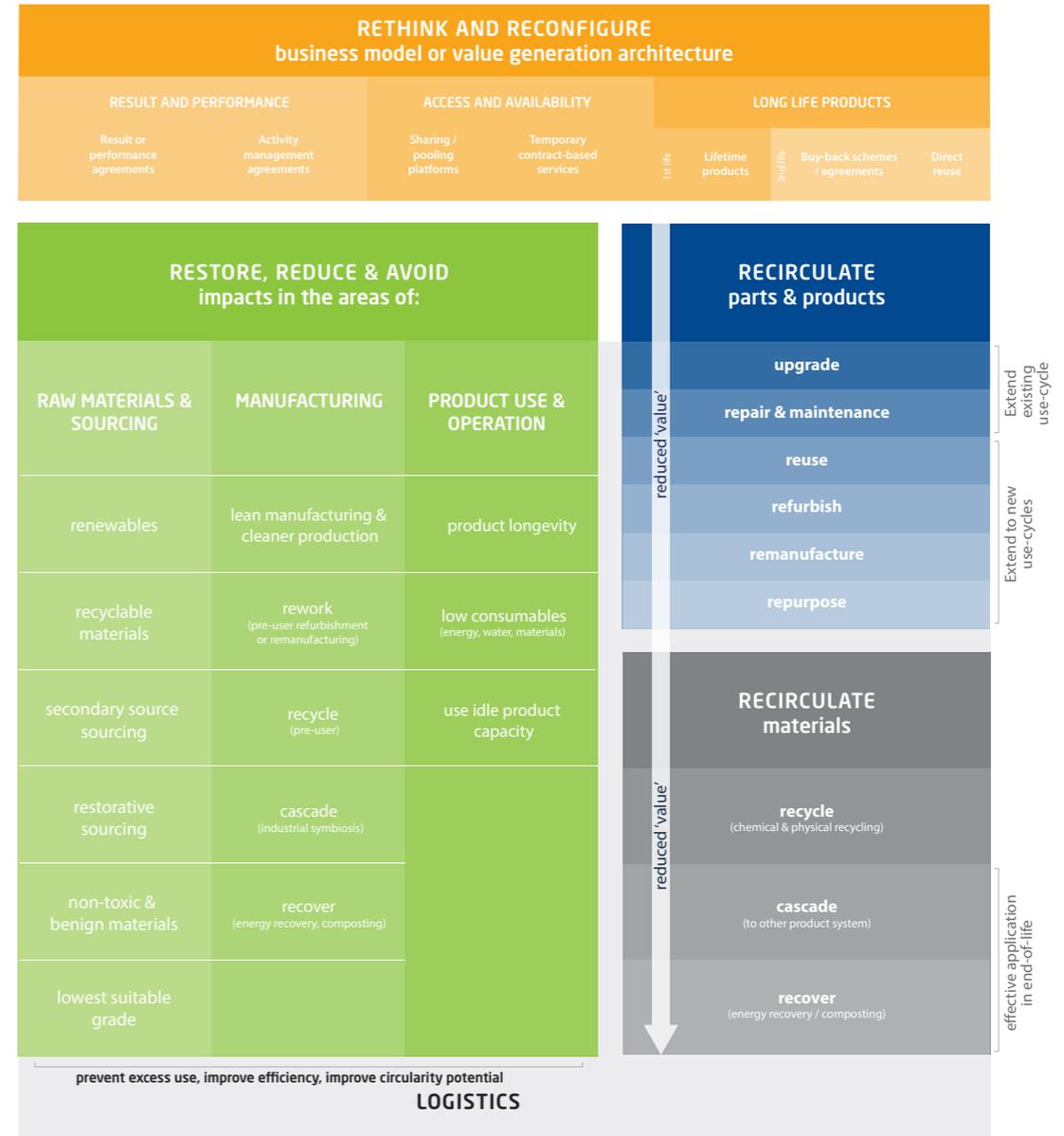
For many companies, there will be obvious low-hanging fruits, such as reduction of single-use packaging

in the production facility, or making small design changes to the product, to ease its disassembly at end-of-life. But for most, there will be a necessity to re-think the way in which business is done, materials and components are sourced, and new types of solutions are developed and marketed, in order to achieve maximum value and circularity from the resources used.

The good news is that there are increasing numbers of examples, in all types of business sectors and within civil society, in general. Circular Economy is a movement that is currently under rapid development, and the many necessary components to shift our mindset from a linear to a circular economy are increasingly manifesting themselves.

change of paradigm

REINVENT
strive for full decoupling



The **Circular Strategies Scanner** can help you to map which strategy or strategies are already being implemented by your company and to identify opportunities of complementary strategies to maximise the value created for as fewer resources as possible. We will refer to this Scanner throughout the six workbooks.



photo Nick Jio, Unsplash

How to make the transition

The basic concept of Circular Economy is easy to grasp for many. It is appealing from a business perspective, as it connects good business sense to good environmental stewardship. After all, which business would not like to reduce the consumption of cardboard boxes in internal production shipping; fully utilise its logistics capacity; or make its product easier to produce, maintain and upgrade?

The tricky part for many companies, however, is in knowing which steps to take first. How ready is your customer and the market in general, to embrace circularity and what role can your company play? Are there drivers or barriers to be found in the way in which regu-

lations are composed in your area of operation – and if so, are there ways of exploiting the drivers or removing the barriers? Should we design the product for upgrade, or should we develop a new business for leasing? Should we make a new partnership for materials sourcing, or should we be better at monitoring our product in-use? As with many new phenomena and business trends, it is often easier to admire and envy the existing good case examples than it is to actually get started on the journey within one's own business.

This workbook is one in a series of six proposed areas to begin the transition to a Circular Economy.



Circular Economy Sustainability Screening



Circular Economy Business Modelling



Circular Product Design and Development



Smart Circular Economy



Closing the Loop for a Circular Economy



Collaborating and Networking for a Circular Economy

Introduction to CIRCit

The CIRCit research project was a 3½-year research project, spanning the five Nordic countries, Denmark, Norway, Finland, Iceland and Sweden. Using a number of action research methods, CIRCit's objective was to support the Nordic industry to discover and implement the opportunities of Circular Economy, through the development, testing and implementation of science-based tools.

The project spanned six main areas, corresponding to the workbooks that you are currently reading, as follows.

Circular Economy Sustainability Screening

This workbook supports decision-making by providing sustainability screen-

ing of alternative circular solutions in terms of environmental, social and business potential.

Circular Economy Business Modelling

This workbook supports the creation of circular business models, based on a step-by-step approach, best practice and success cases.

Circular Product Design and Development

This workbook presents an approach for assessing product circularity in the conceptual design stage, plus practical design guidelines to support early product development decisions.

Smart Circular Economy

This workbook helps to evaluate how digitalisation and smart products can play a role in facilitating the transition to a Circular Economy.

Closing the Loop for a Circular Economy

This workbook provides an assessment tool and guidelines to support the identification of the best circular strategy for products, taken back at end-of-use.

Collaborating and Networking for a Circular Economy

This workbook presents an approach to support various circular value chain configurations, seeking innovation through stakeholder collaboration.

Circular product design and development

This workbook provides insights into how to integrate circular economy into product design and development, supporting decision-making and enhancing the circularity of products, by means of circular design guidelines and a product circularity assessment tool.

Expected outcomes

- Insights into circular product design and development
- Integration of circularity aspects into the early stages of the product design and development process
- Overview of circular design guidelines
- Assessment of the product circularity potential

Who can use this workbook?

This workbook primarily targets key stakeholders working on product design and development, such as designers, engineers, research & development professionals and product owners. It can also support a variety of functions within manufacturing, marketing, environmental management, and general management, as well as sustainable development and Circular Economy.

Although manufacturing companies are the main target of the workbook, private or public organisations can also benefit from understanding and applying the circular mindset. The outline of the guidelines and the tool take their respective starting points from the motivation to think about sustainability

and the importance of linking design and circularity.

This workbook has been designed for use during the early stages of product design and development to guide the design process towards creating more circular solutions. The workbook might also be used for later stages of product design and development, where the product concepts and prototypes are already developed. However, in this respect, the purpose is to evaluate the design in terms of circularity and revision, as changes might be costly. This evaluation can be documented and used to improve future designs.

This workbook is a means of supporting decision-making and enhancing the circularity of products.

The importance of product design and development

Product design and development is a process of conceptualising and development of products that are capable of addressing a specific societal need. Decisions taken during product development (e.g. materials, technologies, functionalities, expected lifetime) will significantly influence the product's quality, cost, aesthetics, and sustainability performance over the life cycle (i.e. from raw material extraction and manufacturing, to use and end-of-use).

Circularity is a means to industrial sustainability by considering the product's use, lifespan and end-of-use scenarios, including strategies such as upgrade, repair, reuse, remanufacturing or

recycling that will extend the lifetime of products and materials. The ultimate goal with circular design is to decouple value creation over the product's life cycle from the consumption of finite resources.



Modular office furniture by Ope

Example 1: Design for reuse

Ope is a Norwegian company that makes office furniture that optimises the working environment in open-plan offices, by providing value in terms of variety and flexibility. Its designs are modular and consist of components that are easily built and taken apart, being adaptable for ever-changing needs. Like LEGO, one can build and rebuild variations from the same basic components, making redecorating cost and waste free. Depending on the room and requirements, the shape and function of the furniture are decided by the owner, allowing for different possibilities, for example, creating simple storage units for the home, room dividers in an office environment, or sculptural structures in public spaces. The main feature and enabler of the design of the

company's furniture lies in the Ope™ connector, which allows the product to be reconfigured and rebuilt as needs change, thereby accommodating a different, scaled down, or expanded purposes. This flexibility provides the freedom to define and redefine spaces through Ope's furniture.

Example 2: Design for repair and maintenance

Vestre is one of the leading producers of urban furniture, and aims to become the world's most sustainable furniture company. Vestre's products are mostly made of high-quality Scandinavian pine and Nordic steel, with the smallest possible carbon footprint. Even so, the company is striving to become even better. Although its products are designed for durability and robust-



Urban furniture by Vestre

ness with minimum maintenance requirements, extensive repair and parts replacement can easily be carried out throughout the life of products. The company also promises to supply spare parts for all its product ranges, even after the production of a particular model ceases. The products are designed to be simply dismantled in a nondestructive way, making it possible to exchange faulty components and parts. In addition, products share similar types and sizes of screws and bolts, which in turn require less time and effort, when dismantling. In 2018, together with the City Mission in Oslo, Vestre launched an initiative to provide jobs to people trying to reenter the workforce, these jobs consisting of maintenance and repair of the many products located around the city.

A generic process of product design and development

Product design and development involves a series of steps to plan, design, manufacture and launch a product on the market. Companies have different product design and development processes, based on the product type and category, production system, market plans, marketing strategy, etc. Several aspects define the core characteristics of successful product development, including the ability to fulfill requirements from users, product quality & cost, and development time. In addition, development capabilities such as coordination, planning and trade-off management abilities are key.

This workbook uses a generic product design and development process consisting of six phases. Each phase will alter in length, from project to project, depending on project, company and product. Industrial design, purchasing, marketing, engineering and manufacturing are core involved stakeholders. Although the process is shown in a linear manner, there are several iterations between phases to refine the design and manage trade-offs.

The six phases are briefly described in the following.

Planning: Development of project mission statement, which identifies the target market, business goals, key assumptions and constraints guided by corporate strategy, market objectives and technology assessment.

Concept development: Identification of target market needs, development and evaluation of alternative product concepts and selection of one or more concepts for further development and testing, identification of competitive products.

System level design: Definition of the product architecture, sub-systems and components and preliminary design of key components, initial design of production and the assembly processes.

Generic product design and development process



Adapted from Ulrich & Eppinger (2017)

Detail design: Complete details of the geometries, functional specifications, aesthetics, materials and tolerances of components as well as the process plans for supply chain, production and fabrication, quality assurance and cost analysis.

Testing and refinement: Testing the overall performance reliability functionality and durability of products by engineering prototypes and implementing necessary design changes. Alpha testing to determine whether the product works as designed and satisfies customer requirements. Beta testing to evaluate and refine production and assembly processes in conformity with the developed product.

Production ramp up: Manufacturing the product with the full operation of the production system to reach the production goals (e.g. cycle time, capacity or quality); training the workforce; and solving remaining problems regarding production.

This generic product design and development process can be divided into *early stages* and *later stages*. Changes in the early product design and development stages are generally less costly.

Overview of circularity inclusion in product design and development



Circular product design and development

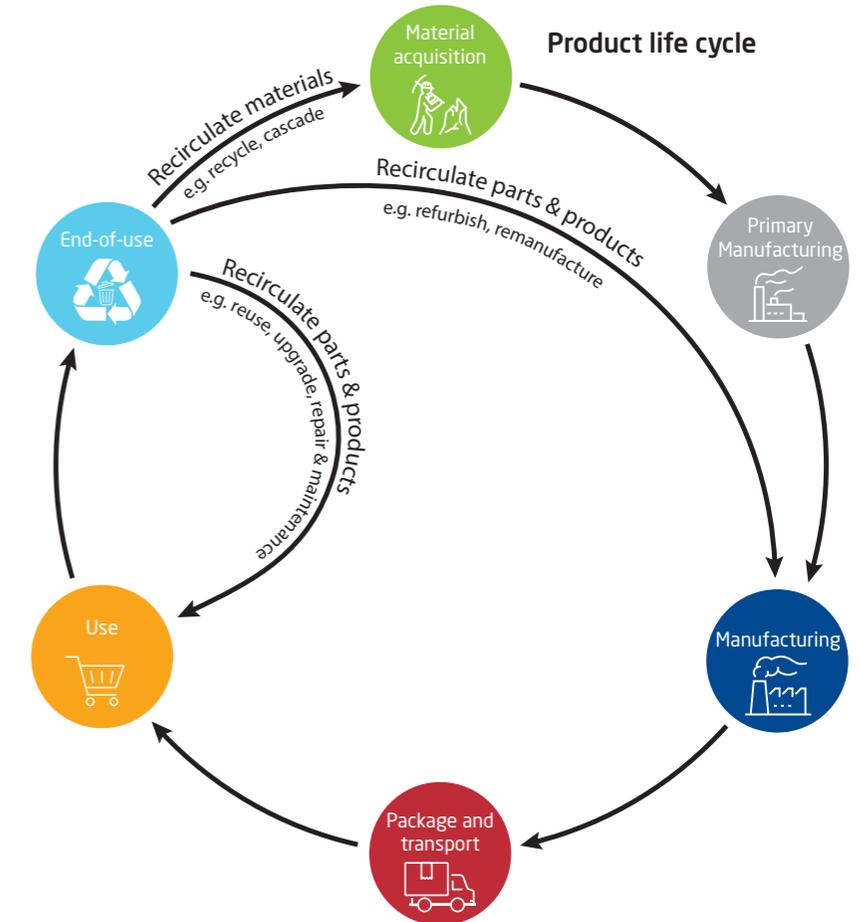
Circular product design and development aims to decouple value creation from the consumption of finite resources by enabling multiple life cycles where products, components and materials have extended lifespans. As a result, not only is the use of natural resources economically optimised, but the value of products, components and materials is also retained, and natural resources are restored.

It is estimated that approximately 80% of the sustainability performance of a product over its life cycle is defined in the early stages of the product design and development process. During these early stages, decisions on environmental and circularity aspects, such as materials, energy, waste handling

minimisation, zero toxic waste and emissions, decreases in other environmental effects, and the exclusion of hazardous materials and nonrenewable natural resources, must be made. Otherwise, once the design concept is established, improving circular performance will mean time-consuming iterations. If one wants a product to be circular – e.g., to be able to be reused, repaired, remanufactured or recycled – then one must consider circularity in the early design stages. It is also important to remember that circular product design and development go hand-in-hand with innovative business models (see the CIRCit business model workbook for more details). For instance, products designed and developed for lease and renting must be more robust

and durable, since they will be used more often and intensively.

In this workbook, a number of steps and sub-steps are proposed for the integration of circularity into the product design and development stages, with particular focus on the early stages.



0. Preparation

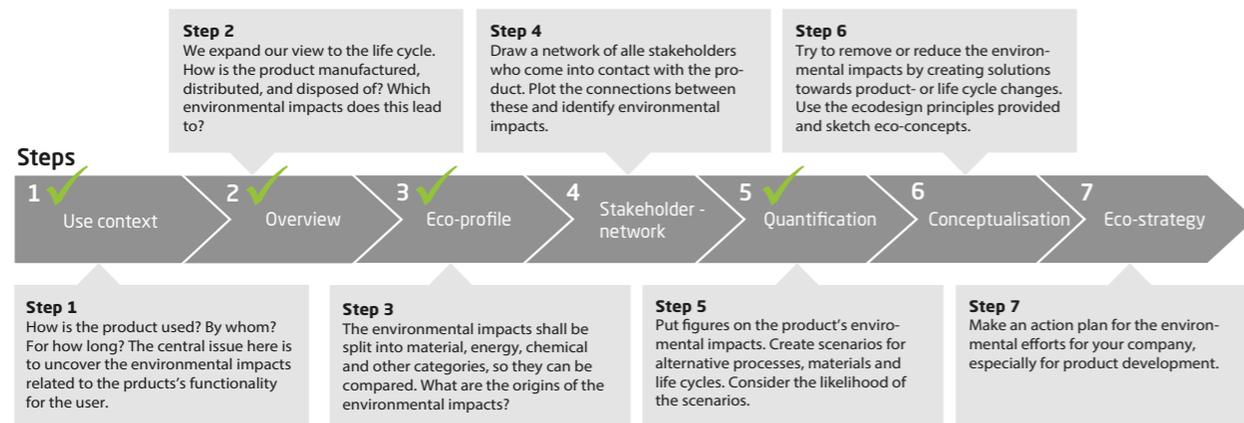
0.1 Map the product life cycle

Different paths in a product's life cycle can be taken towards a circular economy, e.g. sourcing recyclable and renewable materials, repairing and maintaining products, making durable and robust products last longer or sharing products with several users simultaneously.

An important step in the process of integrating circularity into product design and development consists of gaining insights into the product's life cycle as well as its potential environmental effects and circularity aspects in each stage of the life cycle (from material acquisition and manufacturing, to use and end-of-use).

The process of gaining a holistic view of the product's life cycle is called life cycle thinking. Life cycle thinking involves an active and systematic mapping of each stage of the product life cycle with regard to likely scenarios that might influence the product and its components and materials during its lifetime. It is really essential here to gain an overview of the product's environmental effects and concerns, related to its use and its users.

Various stakeholders should be involved in mapping the product life cycle. This approach provides the development team with important insights for each life cycle stage, which can be used to understand the circularity potential and solutions for the whole life cycle. More information about how to map the life cycle of a product can be found in the 7-step guide for environmental improvement, which can be found at www.circitnord.com. Steps 1, 2, 3 and 5 will provide the most help for this pre-exercise.



Adapted from McAloone & Bey (2008)

Map the product life cycle and environmental improvements with 7 steps

0.2 Assemble the right team

To successfully include circularity aspects in the product design and development process, it is important to ensure that the right competences, individuals and teams are present for decision-making.

Common necessary competencies include designers, engineers, research & development professionals, product owners, manufacturing representatives, life cycle assessment practitioners, environmental coordinators and marketing practitioners. Whenever necessary, it is also recommended to involve key stakeholders from finance, legal and services.

1. Definition of circularity goals

The main goal of this step is to **define the goal of circularity for the company or product, and uncover the circularity strategies that relate to the product.**

What will be the outcome?

- Defined circularity goals
- Identified circularity strategies related to the determined circularity goals

Data/Information required

- A good overview of the product life cycle, potential environmental effects and circularity aspects at each life cycle stage
- Printed copy of the *Circular Strategies Scanner* document

- Printed copy of the *Circular Strategy Examples* document

People required

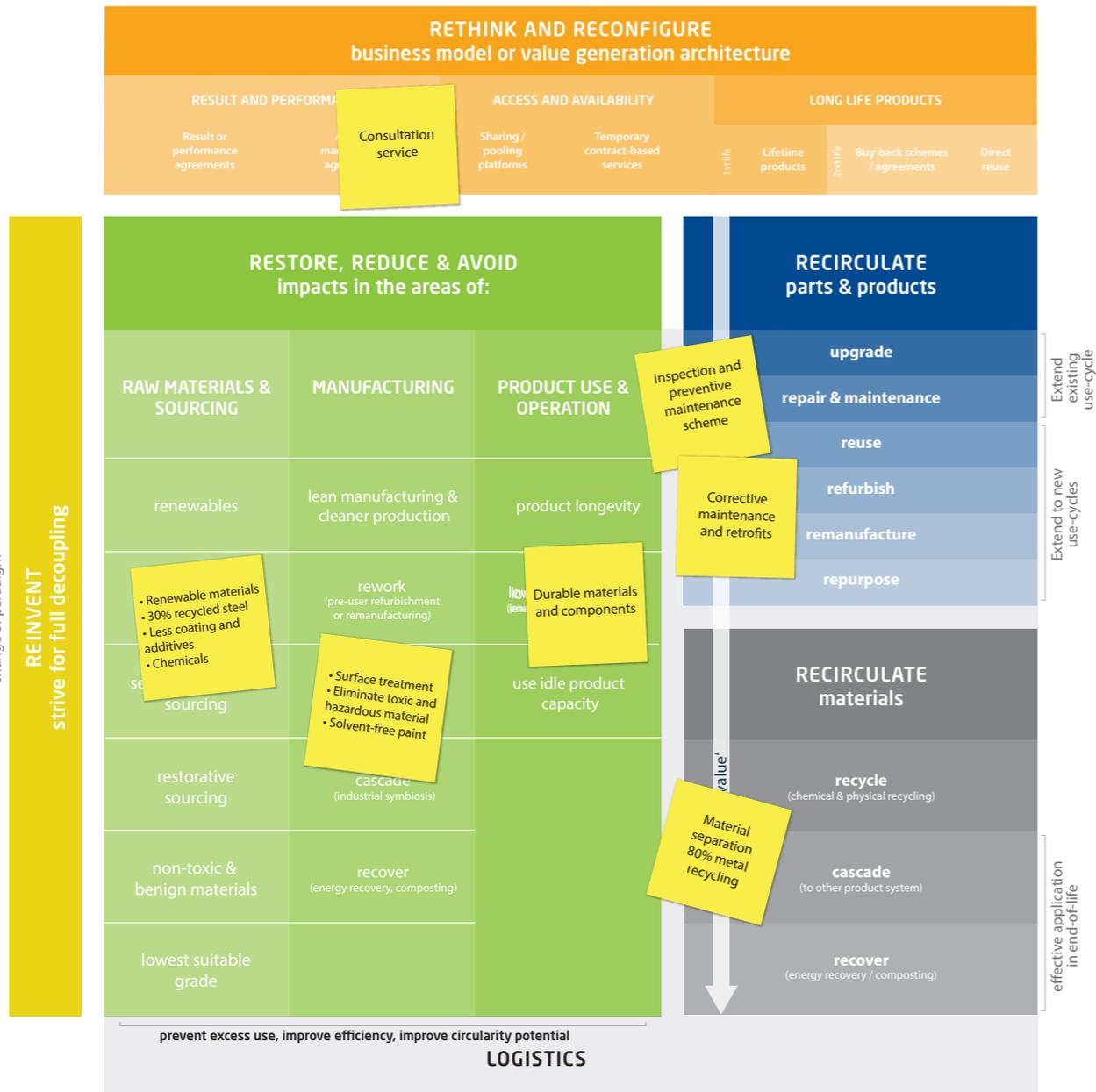
- Designers, manufacturing representatives, purchase and procurement staff, sales and marketing practitioners, product owners, general managers, business development personnel, R&D professionals, LCA experts and environmental coordinators

1.1 Try out Circular Strategies Scanner

When information regarding the product life cycle has been collected and the right team and mix of competencies has been assembled, it is time to carry out an exercise together. Go

through the *Circular Strategies Scanner* and obtain an overview of all possible strategies for the circular economy. Determine which of the strategies are relevant for your product.

Start with *Rethink and Reconfigure* and think about your business model, is your business model circular? Write down your existing business model and your ideal circular business model on sticky notes and put it on the orange part of scanner. Now take a look at the yellow part on the left. Is it possible to deliver the same or more value to your customers via dematerialisation of technologies? Here you should think out of the box. Write down your possible ideas on sticky notes and place them on the scanner. Now let's start



to work on your product value chain (green area); how do you supply raw material? Do you use secondary materials? Do you consider recyclability of the material? How about the manufacturing and its environmental effects? How about the use phase of your product? Is your product durable enough? Discuss these questions and take notes on sticky notes and place them on the scanner. Repeat the same procedure with the end-of-use scenarios of your products (blue and grey areas). What is the fate of your product? What do you want it to be? Remember to use *Circular Strategy Examples* document, if you need inspiration.

This exercise aims to create a shared understanding and shared insights

among all participants, with respect to different circular strategies. The *Circular Strategies Scanner*, the meaning of each strategy, and examples for each strategy can be found at www.circuitnord.com.

1.2 Set the circularity goals
After understanding all circular strategies and determining which of the strategies are associated with your product, it is time to set circularity goals for your product and specify the drivers for enhancing the product circularity. Are more environmentally friendly materials needed? Is there lack of control over end-of-life? Has there been a change in your business model? Which area has the most improvement potential?

It is very important to set the circularity goals from the very beginning, in order to facilitate the process of inclusion and implementation. Subsequently, further discuss which circular strategies may already have been covered at your company. Which of them can still be improved? Which of them are not covered at all? Which ones are absolutely necessary to achieve to your defined goals?

To facilitate the discussion with regards to defining the circularity goals, as well as choosing the right strategies, try to answer the following questions. You can find a spreadsheet to help this at www.circuitnord.com.

- What is the approximate lifetime (first life cycle) of this type of product, both technically and aesthetically speaking?
- What is the primary reason why the users dispose of the product? What are the secondary reasons?
- After the first life cycle, are many of the components or the product still usable in a good condition?
- Are there large impacts in the use stage for this product type, such as fuel, electricity, chemicals etc.?
- Could there be a market for second hand/reused or refurbished products of this type?
- Can the product or its parts be used for something else, replacing other products or components, after its first life cycle?

- Does the product typically contain materials with high environmental impact? Any rare materials? How about toxic materials?
- Does the production of this type of product often include processes which have high environmental impact?
 - Some products become outdated due to technological change. If this is the case, how fast does the product become completely outdated?
 - What does the product packaging look like? Is it easy to recycle, or inherently difficult?
 - Is recycling the product and/or some components possible? For some products, recycling is not a viable option for end-of-life treatment. This can be due to contamina-

tion of product during use or waste handling.

- Is it likely that some products or parts of the product will be cascaded to a lower grade or sent for energy recovery (incinerated or biodegraded)?

When discussing the circularity goals and relevant strategies to achieve these, consider the following points, as well:

- There can be similarities between circular strategies. However, the main focus area will differ. For example, *design for repair and maintenance* and *design for reuse* share similar design guidelines; the former focuses more on the exchangeability of parts,

while the latter focuses more on the durability of parts, even though both share several similar guidelines.

- When choosing one or several circular strategies that are relevant to your circularity goals, think about the consistency, interconnections and dependencies between the circular strategies. It is important to have a broad overview of all the circular strategies and guidelines in mind, when defining the circularity goals. One strategy might negatively affect another, e.g. make it difficult or expensive to carry out. For instance, product durability can be decreased by design for repair, due to the number of joints and connectors. On the other hand, one strategy might be connected to an-

other strategy. For instance, design for remanufacturing requires ease of dismantling to exchange faulty components. The faulty components should also be easy to recycle (design for recycling).

- Design for recycling should be considered under all circumstances, as one product will eventually fail completely after several life cycles; recycling is its final fate.
- Facilitating end-of-use collection and transportation should be considered for the majority of circular strategies.

2. Deployment of the guidelines

The main goal of this step is to become familiar with the guidelines as a whole and as appropriate for your determined circularity goals.

What will be the outcome?

- A list of design guidelines related to the selected circularity strategies to achieve the defined circularity goals

Data/Information required

- Defined circularity goals
- Defined related strategies to your product
- Printed copy of the *Guidelines for circular product design and development* document. You can find this document at www.circuitnord.com

People required

- The same group of people who started the previous step is required here. However, since the focus in this step is more on product design and development, the inclusion of more designers/product developers is desirable.

2.1 Skim and scan the guidelines

The *Guidelines for circular product design and development* document is an extensive, structured document that goes through all strategies one-by-one and presents the relevant design guidelines for each strategy. These guidelines are presented on two levels: general and detailed.

This exercise aims to create a shared understanding and shared insights among all participants, with regards to different circular strategies and related design guidelines. Read through the document, strategy-by-strategy. You can always return to the *Circular Strategies Scanner* to relate the guidelines to strategies. This exercise can be carried out individually or in groups.

At this stage, it is not necessary to go into the detailed level. Just ensure that you have gone through all strategies and general guidelines. A quick skim and scan are enough to become familiar with the guidelines' structure.

Design guidelines for Repair - examples



2.2 List the related guidelines

After understanding the structure and general guidelines, it is time to go through the detailed guidelines. Focus on the selected strategies (based on your determined circularity goals, i.e. step 1.2) and corresponding guidelines at both the general and detailed levels.

Discuss how these guidelines can support the development process of your product. Note that it is not possible for all guidelines to be implemented to all products, but try to be inspired and think outside the box. What can be considered for your product? Which of these guidelines are already being considered in your product design? What is missing? What can be improved? Discuss these questions in groups, and

mark the guidelines that are relevant to your product. Write down your new design ideas that are not listed in the document.

When selecting the design guidelines related to your selected strategies, think about the consequences, such as the cost of changes, ease of implementation, and impact. In addition, identify what supports are required to make the changes. Perhaps the LCA expert should be effectively engaged in the design process?

When discussing the circularity design guidelines related to the selected circularity strategies, consider the following points:

- Although different guidelines are formulated for each circular strategy, the design guidelines overlap with each other to some extent, and similar design guidelines might be applied to several circular strategies. For instance, “make exchanging of faulty components easily accessible” is a common guideline among many circularity strategies.
- Circular strategies might share some common design guidelines, but the same design guideline might slightly differ at the core and fulfillment levels. For example, “use durable and robust components and materials” is a common design guideline among “design for repair and maintenance” and “design for reuse”. However, in

“design for reuse”, it is important that all components have the same durability, while in “design for repair”, it is not vital for all components to have the same lifespan, because faulty parts are designed to be removed and replaced.

- A design guideline may simultaneously (positively and/or negatively) affect several circularity strategies or other design guidelines, although the nature and intensity might differ among them. For instance, “design using recyclable and secondary (recycled) materials” influences “design for recycling” and “design for remanufacturing”, although the effect on the latter is less. Additionally, “design using recyclable and

secondary (recycled) materials” influences both “make it easy to clean the product and components” and “durability and robustness”.

- Some design guidelines are generally applicable for several circular strategies, such as “focus mainly on functionality and quality performance” or “focus to fulfill the customer’s requirements and value creation”, which are both the core part of any circularity strategy. However, the two are more related to a “rethink” strategy than to the other strategies.
- You will probably find more design guidelines, during the design process and analysis of a specific product concept. As a result, it is

recommended to first use the guidelines comprehensively as a whole and then refer to specific design guidelines if needed.

2.3 Identify correlations, contradictions and trade-offs

As mentioned previously, a design guideline may positively and/or negatively affect several circularity strategies and other design guidelines at the same time. For instance, using multiple materials and composites may help with the “durability and robustness” of components and the product. However, it negatively affects the recycling potential and might make the product undesirably expensive. In addition, adding circularity-oriented design changes might worsen the qual-

Matrix 1

Identify correlations, contradictions and trade-offs	N = Neutral C = Contradictory S = Supportive						
	Use durable and robust components and materials	Make exchange of faulty components easily accessible	Make it easy to dismantle the product non-destructively	Make it easy to clean the product and components	Use joints and connectors that can be easily opened and closed multiple times	Design-in modular construction	Design standardised components across different products
Use durable and robust components and materials	N	C	S	C	C	C	N
Make exchange of faulty components easily accessible		S	S	N	S	N	
Make it easy to dismantle the product non-destructively			N	S	S	N	
Make it easy to clean the product and components				N	N	N	
Use joints and connectors that can be easily opened and closed multiple times					S	S	
Design-in modular construction						N	
Design standardised components across different products							
Other guidelines							

Matrix 2

Identify correlations, contradictions and trade-offs	N = Neutral C = Contradictory S = Supportive						
	Product price including production cost, logistics etc.	Product's quality	Technological requirements for both production and product	Safety issues during the use phase	Product launch, commercialisation and time to market	Intended functionality and customer value delivery	Customer acceptance and expectations
Use durable and robust components and materials	C	S	N	S	N	C	N
Make exchange of faulty components easily accessible	N	N	N	N	N	N	N
Make it easy to dismantle the product non-destructively	C	N	C	C	N	N	N
Make it easy to clean the product and components	N	S	N	N	N	N	S
Use joints and connectors that can be easily opened and closed multiple times	N	C	C	C	N	N	C
Design-in modular construction	C	N	N	C	N	N	N
Design standardised components across different products	S	N	N	S	N	N	C
Other guidelines							

ity of the product, change customers' acceptance and expectations or even negatively influence the environmental impact. The correlations and, in particular, the trade-offs, need to be identified and planned to be resolved to the greatest extent possible. In this exercise, try to identify the connections between the guidelines and their effect on cost, quality, delivery, safety, environment, technology requirements, intended functionalities, customer acceptance, etc.

One way of identifying these trade-offs and correlations is to associate guidelines to each other and their possible consequential effects in a matrix and discuss links and effects. It could be done by understanding the correlations within circular design guidelines (matrix 1) or between design guidelines and other product requirements (matrix 2).

3. Incorporation in the development process

The main goal of this step is to integrate the selected guidelines in your product design and development process to refine the concepts and achieve the determined circularity goal.

What will be the outcome?

- An updated product design and development process that includes the circularity guidelines in the early stages

Data/Information required

- A list of design guidelines related to the selected circularity strategies to achieve the defined circularity goals
- Printed copy of your product design and development process

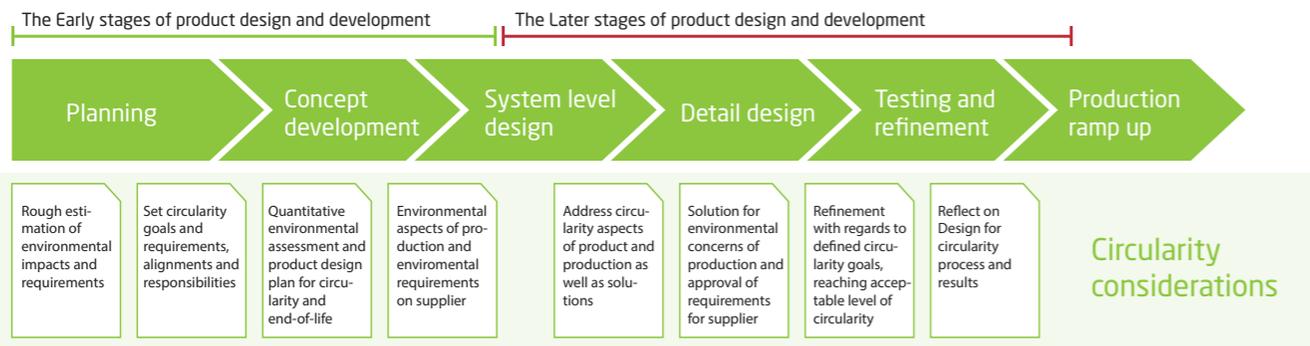
People required

- The same group of people who started the previous step are required here. Since the focus in this step is more on the product design and development process, the inclusion of product owners, environmental managers/coordinators and general managers is necessary.

3.1 Integration in the product design and development process

After creating a list of guidelines that are relevant to your selected strategies and identifying the correlations and trade-offs (steps 2.2 and 2.3), it is time to include the determined circularity goals and guidelines in your product design and development process.

It is recommended to have your product development process ready and printed on paper. Write down the selected circularity goals and guidelines on sticky notes of different colours, to make them distinguishable. Product design and development processes usually follow a stage-gate model, where at each gate, the results in the form of documents are reviewed, validated and accepted, in order to proceed to the next stage. Within a group discussion, place each sticky note on the right stage of your product design and development process. This means that at that stage, those guidelines and circularity goals need to be considered and somehow documented. Remember, some goals or strategies might fit in many different parts of the product



Adapted from Ulrich & Eppinger (2017)

development process; in that case just make copies of the sticky note and put them on every place they fit.

It is recommended to include the goals and guidelines incorporated in the currently existing documents and not in separate forms, as separate forms would make them easy to neglect. You also need to determine the responsibilities; who will make sure that the necessary design guidelines are considered at the right time?

Note that it might not always be possible to apply necessary circularity changes to the product. However, make sure that the guidelines are always considered, and solutions and ideas are brainstormed. If it is not

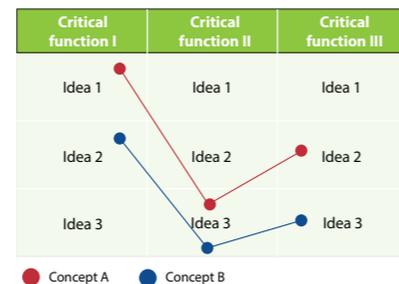
possible to make the change, then document the reason and possible suggestions for improvement, for future reference. A generic example of integration of circularity aspects and considerations into the generic product development process is illustrated above.

3.2 Use the guidelines to create and refine the concepts

Now that the selected circularity goals and guidelines are allocated to the product design and development stages, it is time to create new concepts accordingly or to refine and validate currently developed concepts. This step is technical and requires several rounds of coordination and tests, which might occur outside of the workshop setup.

To facilitate this step, you need to generate several ideas and options and use morphological matrix (or your own way of refining and decision-making tool) to select one solution to integrate into the complete concept.

Morphological matrix to support concept selection



4. Evaluation of circularity concepts

The main goal of this step is to assess the circularity of the concepts of products in the early product design and development process, i.e. “planning and concept development”

What will be the outcome?

- A *total circularity potential score* to support decision making in the early product development process

Data/Information required

- Alternative product concepts
- Sufficient data collected for each concept with regards to guidelines
- The *circularity assessment tool* Excel document. You can find this document at www.circitnord.com

People required

- The same group of people who started the previous step are required here. Since the focus in this step is more on calculating circularity as decision-making support, the inclusion of designers, product owners, environmental managers and general managers is necessary. In addition, the role of LCA experts is essential here, in order to ensure that the outcome really contributes to sustainability improvements.

What is the circularity assessment tool?

The circularity assessment tool has been developed for use in the early product development process, i.e. planning and concept development, to assess product designs and concepts in terms of their circularity potential. The tool has been designed to calculate a *total circularity potential score* for at least two concepts, so that they can be compared in terms of circularity (but it can also be used for a single concept/product to identify hotspots and improvement potentials). This tool is an internal communication support for decision making in the early product development process, and the results should not be used for external communication.

The circularity assessment tool is an Excel-based tool with several sections (tabs in Excel).

The **instruction** section provides how to use the tool appropriately and in what sequence.

The **circular strategies** section refreshes your memory about the circular strategies, with a brief description that was previously presented via the *circular strategies scanner*.

The **circular design guidelines** section refreshes your memory about the general circular design guidelines, with a brief description that was previously presented via the *Guidelines for circular product design and development* document. In this section, you can also see the connection of guidelines to each circular strategy. The black cells indicate a direct effect of the guideline on a specific circular strategy; for example, “make it easy to clean the product and components” is important for the *rethink and reconfigure*, *product use and operation*, and *reuse, refurbishment and remanufacture* strategies. The grey cells indicate an indirect effect of those guidelines on the strategies. For example, “make it easy to clean the product and components” is indirectly linked to the *repair and maintenance* and *repurpose, recycle* and *cascade* strategies.

The **circularity assessment** section is the main tool, where the design guidelines are connected to two main criteria, to calculate the total circularity potential score for each concept. The functionality of the tool will be explained in 4.2.

The **visualisation** section provides a graphical representation of the results in different charts and formats, to facilitate understanding and drawing conclusions.

Instructions

Brief explanation of how to use the tool appropriately and in what sequence

Circularity strategies

Brief descriptive review of the circular strategies presented in *Circular strategies scanner*

Circular design guidelines

Brief review of the circular design guidelines presented in *Guidelines for circular product design and development*

Circularity assessment

Calculate the total circularity potential score for each concept

Visualisation

Graphical representation of the results in different charts and formats

4.1 Try out the circularity assessment tool

The *circularity assessment tool* calculates a “total circularity potential score” for at least two concepts. The lower the total circularity potential score is, the better the concept in terms of circularity. For example, Concept A obtains a circularity potential score of 170, while Concept B obtains a circularity potential score of 195; in this case, Concept A is more circular than Concept B. Alternatively, it can also be concluded that the circularity improvement potentials for Concept B are greater than those for Concept A. Their circularity improvement potentials could be related to the guidelines presented previously.

Step A: Preparation

You need to have (i) a good overview of the product life cycle, possible environmental effects and the circularity aspects at each life cycle stage; (ii) a good understanding of the circular strategy scanner and different circular strategies; and (iii) a good understanding of the design guidelines as a whole. This step has been already covered in previous steps.

Step B: Evaluate the concepts by indicating the “importance” and “level of fulfillment” for each design guideline
The total circularity potential score is calculated by multiplying two main criteria: “importance” and the “level of fulfillment”. Each general design guideline is given a score under each criterion, for each one of the developed concepts. The scoring for each design guideline under each criterion is qualitative, based on discussion among different stakeholders, including environmental managements/coordinators, product owners, product designers and developers, research and development professionals, manufacturing representatives, and marketing practitioners.

Step B.1: *Importance* criterion refers to how important the general design guidelines are when designing and developing a specific product; this should be based on the previously selected circular strategies and the circularity goals determined. In this criterion, each general design guideline is given a score from 0 to 3:

- (3) really important
- (2) moderately important
- (1) slightly important
- (0) not important.

The selection of scores is qualitative, based on the product brief, the product development goals, the environmental and circularity goals, and previous experience from existing products on

the market, or previous generations. Agreement on importance should be achieved among all stakeholders involved, particularly manufacturing representatives, designers and marketing practitioners. Ensure consistency when comparing different product concepts by engaging the same group of people.

The level of importance is often the same for the concepts designed to deliver the same value and fulfill the same requirements, as they often follow the same goal with regard to the product development goal. However, in some cases, the level of importance might differ, when a radical design is introduced and compared with other concepts.

Step B.2: *Level of fulfillment* criterion refers to how much the general design guidelines are applied to/fulfilled for each one of the developed concepts. In this criterion, each general design guideline is given a score:

- (1) *yes*, the guideline has been completely fulfilled by this concept
- (3) *somehow*, but can be improved
- (5) *no*, the guideline has not been fulfilled by this concept and it has to be.

The selection of scores is qualitative, based on agreement among all stakeholders involved, particularly manufacturing representatives, designers and marketing practitioners.

Circularity assessment tool

State your selected circularity goals: General design guidelines	Importance to developing the product Really important (3) Moderately important (2) Slightly important (1) Not important (0)			Level of fulfillment (1) <i>yes</i> , the guideline has been completely fulfilled by this concept (3) <i>somehow</i> , but can be improved (5) <i>no</i> , the guideline has not been fulfilled by this concept and it has to be			Circularity Potential Scores 15: Vital and imperative 10 and 9: Improvement are necessary 6 and 5: Potential circularity improvements 3, 2 and 1: No change required 0: Not a concern		
	Concept A	Concept B	Concept C	Concept A	Concept B	Concept C	Concept A	Concept B	Concept C
Focus mainly on functionality and quality performance	2	3	3	1	3	5	2	9	15
Think about activity supports in the operational stage	2	2	2	1	5	5	2	10	10
Focus to fulfill the customer's requirements and value creation	3	2	3	1	3	3	3	6	9
Try to use digitalisation, ICT and IoT solutions	3	3	3	1	3	3	3	9	9
Make it easy to inspect the product and components	2	2	2	1	3	3	2	6	6
Make it easy to clean the product and components	3	1	3	1	5	3	3	5	9
Make exchanging of faulty components easily accessible	3	1	3	5	5	5	15	5	15
Make it easy to dismantle the product nondestructively	3	1	3	3	3	3	9	3	9
Think about boundary management	2	1	3	5	1	3	10	1	9
Think about incumbent configuration	3	1	3	1	1	3	3	1	9
Think about complementary capabilities	3	1	3	1	5	3	3	5	9
Design using renewable materials	1	1	3	1	5	3	1	5	9
Design using recyclable and secondary (recycled) materials	2	3	2	1	1	3	2	3	6
Consider toxicity and other environmental aspects of materials	2	2	3	5	1	3	10	2	9
Favour cleaner production, processes, machines and equipment	2	1	1	1	1	1	2	1	1
Treat production (pre-consumer) wastes appropriately	3	3	1	5	1	5	15	3	5
Design for reduced energy consumption and usage of renewable energy	2	3	1	3	1	5	6	3	5
Design standardised components across different products and models	2	3	1	3	1	5	6	3	5
Design standardised tools required across different products and models	3	1	1	5	1	5	15	1	5
Use durable and robust components and materials	3	1	1	3	1	5	9	1	5
Design in modular construction	3	2	2	3	1	5	9	2	10
Provide manuals and documentation	2	2	2	5	1	5	10	2	10
Make spare parts and exchanging components easily available	1	1	2	3	3	5	3	3	10
Consider timeless design, emotional attachment and compatibility	1	2	3	3	3	5	3	6	15
Investigate current and upcoming laws and regulations	1	1	3	3	3	5	3	3	15
Use joints and connectors that can be easily opened and closed multiple times	1	3	3	5	1	3	5	3	9
Minimise the number of different incompatible or dissimilar materials	3	2	2	5	3	3	15	6	6
Make it easy to identify the materials and relevant information	1	3	3	5	1	3	5	3	9
Total Circularity potential Score with inclusion of the effect (the smaller the better)							174	110	243

Concept B is more circular ↑

Step C: Calculate Circularity Potential Scores
On the basis of the data provided for each concept, the general design guidelines are given a score by multiplying "importance" and the "level of fulfillment", resulting in a final score for each individual guideline:

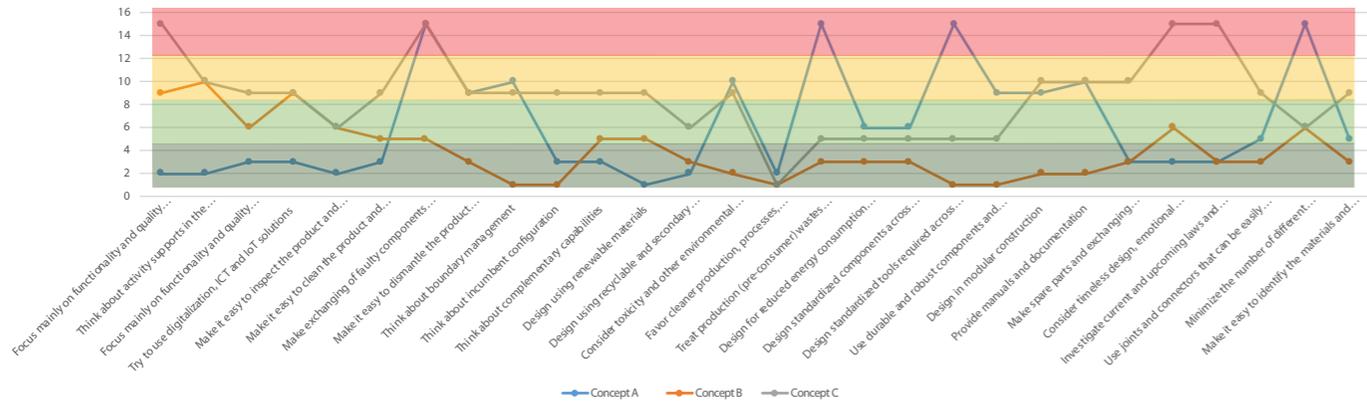
- (0): circularity is not a concern ■
- (1-3): does not require any changes in design and concept ■
- (5-6): there is circularity improvement ■

potential in the current design and concept ■
(9-10): circularity improvements are necessary for the current design and concept ■
(15): vital and imperative design changes are necessary for circularity. ■

		Level of fulfillment		
		1	3	5
Importance	3	3	9	15
	2	2	6	10
	1	1	3	5
	0	0	0	0

Step D: Calculate the Total Circularity Potential Score for each concept
The total circularity potential score for each concept is then calculated by summing all the circularity potential scores of the individual guidelines. The lower the total circularity potential score is, the better the concept in terms of circularity.

Circularity potential scores



Step E: Visualisation of results and interpretation

The results can be visualised in different graphs, which shows the circularity potential scores for the alternative concepts for each one of the guidelines.

The results from tool can be interpreted in several steps.

Step E.1: Identify circular hotspots and improvement potentials for each design concept

Look at the concepts individually and find which guidelines end up in the red and yellow areas. These are the areas that need to be revised and perhaps redesigned to include that specific circularity aspect/guideline. These aspects are vital and necessary for circularity

and also for those strategies and goals you determined, while according to your own assessment, they have not been included in the current design. So you may want to start improving the design concepts based on these hotspots.

Step E.2: Cross comparison of concepts in terms of circularity design guidelines

Now compare different concepts, which one has fewer hotspots? Which one has more? Which one is more consistent with your determined circularity goals and strategies? Which one is more cost effective to revise? Perhaps you would like to select the concept with more hotspots (red and yellow) and make a lot of changes? Or perhaps you directly go with the concept that

ended up in green areas? These decisions need to be discussed in group to reach a consensus while considering other product development aspects. Document the discussion and the decision-making process for future reference.

Remember, even though the tool helps you to move towards circular economy and sustainability, the outcome will never be better than the quality of the input data collections and discussions. Therefore, try to collect as much relevant data as possible. If you have made a lot of rough estimations, the final result is not better than that!

Trade-offs in decision making

Adopting circularity in product design and development by applying guidelines may positively and/or negatively affect other product design criteria, such as the intended functionalities, estimated product price and production cost, customer acceptance, technological requirements, ease of production, and the estimated development time and delivery dates. The ease of implementation of these circular guidelines also needs to be considered. For instance, selecting a specific material in a concept increases the circularity of a product through the ease of recycling or by using environmentally friendly materials; on the other hand, it might increase the final price of the product by 10%, which is not acceptable for manufacturing and marketing.

Hence, these aspects also need to be discussed and included in decision making. In the given example above, Concept B is generally more circular, without considering the cost, quality or other aspects; however, investing in improving Concept A (for example, by improving the design to make it easier to access components that need to be exchanged) might be economically more efficient overall. As a result, the whole picture needs to be considered. The result provided by this tool is only one element in decision support, and it should be considered together with other product design and development criteria.



Photo Anirudh, Unsplash

Example - Beverage bottle

Imagine Company X would like to design and develop 3 new bottle concepts for its popular craft beer. The three concepts look different and are made of different materials: Concept A is made from coconut shell, Concept B is made from paper, and Concept C is made from bioplastic. The company's goal for this product development project is to make the most circular bottle. After collecting the right people in the room, gathering enough primary data on the environmental effects of each concept and becoming familiar with the general design guidelines, we can start using the tool, where everyone will agree upon the scores given.

Going through the general design guidelines in the tool, we can understand that not all general design guidelines are relevant to this product. Irrelevant guidelines obtain "0" for importance (meaning not important) and are highlighted grey in the circularity potential chart (see next page). The rest of the general design guidelines will be given scores for importance, based on consensus among the participants and the defined goals.

In this example, all three concepts receive the same importance score for each general design guideline, as the remaining general design guidelines are equally important for all concepts in this example. However, the level of fulfillment differs for each concept,

and the scores are given based on consensus among the participants and the defined goals. For instance, "design using renewable materials" is really important for this project and the defined goal. Thus, each concept receives a score of "3" for the importance criterion. However, bottles made of coconut shell and paper are more renewable than ones made of bioplastic; thus, they receive fulfillment scores of "1" and "3", respectively (see *circularity potential scores* in the *circularity assessment tool* on the next page).

We continue the same for the rest of the general design guidelines, and while doing so, the "circularity potential scores" are calculated by multiplying the given scores by importance and the

fulfillment level for each general design guideline. Hence, the "total circularity potential score" is also calculated for each concept by summing all the circularity potential scores.

As shown on the circularity potential chart, the bottle concept in which the bottle is made of coconut shell is more circular than the other two concepts, and the bioplastic concept is more circular than the paper concept. If we consider only the durability of the bottle, the coconut shell option has the lowest durability, although it is more circular in general.

Circularity assessment tool used on beverage bottle

State your selected circularity goals: make an environmentally friendly bottle in all product life cycles									
General design guidelines	Importance to developing the product			Level of fulfillment			Circularity Potential Scores		
	Coconut	Paper	Bioplastic	Coconut	Paper	Bioplastic	Coconut	Paper	Bioplastic
Focus mainly on functionality and quality performance	2	2	2	3	3	1	6	6	2
Think about activity supports in the operational stage	0	0	0				0	0	0
Focus to fulfill the customer's requirements and value creation	0	0	0				0	0	0
Try to use digitalisation, ICT and IoT solutions	0	0	0				0	0	0
Make it easy to inspect the product and components	0	0	0				0	0	0
Make it easy to clean the product and components	0	0	0				0	0	0
Make exchanging of faulty components easily accessible	0	0	0				0	0	0
Make it easy to dismantle the product nondestructively	0	0	0				0	0	0
Think about boundary management	0	0	0				0	0	0
Think about incumbent configuration	0	0	0				0	0	0
Think about complementary capabilities	0	0	0				0	0	0
Design using renewable materials	3	3	3	1	1	3	3	3	9
Design using recyclable and secondary (recycled) materials	3	3	3	1	3	3	3	9	9
Consider toxicity and other environmental aspects of materials	3	3	3	1	3	3	3	9	9
Favour cleaner production, processes, machines and equipment	2	2	2	3	3	3	6	6	6
Treat production (pre-consumer) wastes appropriately	2	2	2	1	3	3	2	6	6
Design for reduced energy consumption and usage of renewable energy	2	2	2	5	5	3	10	10	6
Design standardised components across different products and models	0	0	0				0	0	0
Design standardised tools required across different products and models	0	0	0				0	0	0
Use durable and robust components and materials	3	3	3	5	3	1	15	9	3
Design in modular construction	0	0	0				0	0	0
Provide manuals and documentation	0	0	0				0	0	0
Make spare parts and exchanging components easily available	0	0	0				0	0	0
Consider timeless design, emotional attachment and compatibility	1	1	1	5	3	1	5	3	1
Investigate current and upcoming laws and regulations	3	3	3	1	5	3	3	15	9
Use joints and connectors that can be easily opened and closed multiple times	0	0	0				0	0	0
Minimise the number of different incompatible or dissimilar materials	1	1	1	3	3	3	3	3	3
Make it easy to identify the materials and relevant information	3	3	3	1	3	3	3	9	9
Total Circularity potential Score with inclusion of the effect (the smaller the better)							62	88	72

Concept A is more circular ↑

What now?

With a defined goal for your circular product design and development, as well as a detailed understanding of the relevant general design guidelines related to different concepts, it is time to refine your concepts and improve the circularity potentials identified using the tool (red and orange cells).

The refining process is an iterative back-and-forth process between steps 3 and 4 described in this workbook. Be prepared to review and adjust your circular product design and development process (3.1), as well as your circularity goals (1.2), as needed. Sometimes, this means taking one or several steps back in the process. For this reason, it makes sense to effectively document the outputs of each step. This way, it

will be easier to revisit, to adjust the analysis with new insights and to proceed knowing that your approach has improved.

Additionally, maintaining updated versions of the tools provided by this workbook might be a good idea to guarantee continuous organisational learning and circular product design and development improvement. The updated version of this workbook can be found at www.circuitnord.com

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Nordic Green Growth

This workbook presents an approach for assessing product circularity in the conceptual design stage and practical design guidelines to support early product development decisions.



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