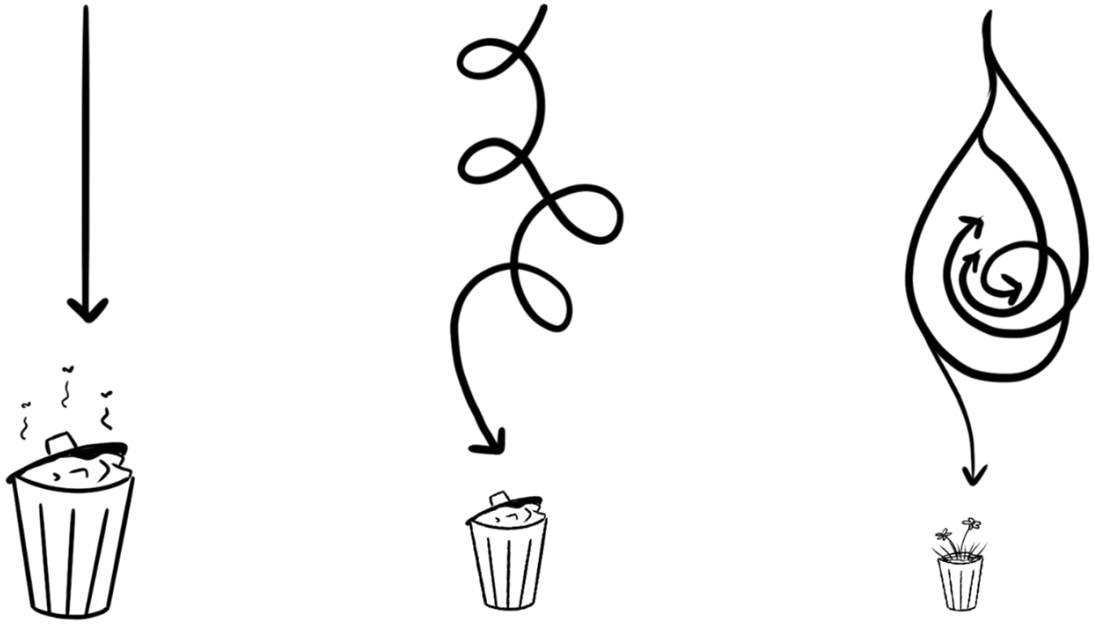
The CIRCULAR pathway

A methodology for exploratory product redesign



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The CIRCULAR pathway: a new educational methodology for exploratory circular value chain redesign

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The circular economy (CE) is gaining global relevance across countries and institutions as a tool to solve some of the most pressing global challenges derived from linear production and consumption systems. However, transitioning to a CE requires significant changes in how businesses and supply chains operate, including redesigning products, processes, and business models. These changes require that future professionals acquire knowledge and skills on the principles of CE, Life Cycle Thinking, and Systems Thinking. However, research on existing higher education programs signals a need for educational resources to develop these skills and knowledge in real-world settings. This paper outlines a new eight-step methodology to introduce students to the principles of CE through the exploratory redesign of a real-world product and value chain in a project-centered learning environment. This methodology was developed in four iterations and was used to teach 251 students from the BSc. Business Engineering at Maastricht University during the academic years 2020–2022. The findings indicate that this method supports students' understanding of complexity, linearity, and the importance of systemic change across the entire value chain, as well as their critical thinking, problem-solving, and decision-making skills. The methodology provided in this paper supports and encourages educational bodies to implement Education for CE in their curricula and further strengthens the complementary fields of Education for Environmental Sustainability and Education for Sustainable Development. Furthermore, educators, professionals and businesses can make use of this tested methodology for exploratory product redesign toward sustainable circularity transitions.

KEYWORDS

education for the circular economy (ECE), project based learning (PBL), circular design, teaching approaches and content, circular economy methodology

Foreword

This methodology is the outcome of four years of research and development of tools to enable a circular economy. The process described here constitutes a key pillar of my PhD dissertation at Maastricht University on how to enable and measure a circular economy in companies and across products.

The initial application of the methodology was among master's students in the program of Biobased Materials. However, the tool has also proven useful at bachelor's level (Business Engineering and Circular Engineering) and for individuals inside organizations interested in life-cycle and systems thinking and the circular economy as frameworks for meaningful transformation towards sustainability.

This document is the fifth and latest iteration of the methodology. It has been adapted specifically for use cases when students must work by themselves in the assignment and for new instructors. The method's roots remain the same, but the delivery methods and templates throughout the process have been improved. The goal remains to support the student's learning journey while providing helpful results to the companies.

As a dynamic and evolving tool, this version of the methodology will also change. Changes will be based on the feedback provided by the course participants. It is essential to developing this methodology to *keep a critical view and an eye for potential improvements* throughout the process.

Finally, this document is a desire and effort to share an approach to circular redesign and circular thinking for every and any person interested in its application to products, processes, and business models. Don't hesitate to contact me directly for more detailed information, case studies, instructions for educators, and potential collaborations.

April 2024,

On behalf of the development team,

Cris García Saravia Ortiz de Montellano

Contents

Background

Part 1: What is the circular economy, and why does it matter?

Currently, the life cycle of everyday products can be generally described as a "**Take – Make – Use – Lose**" straight line. Resources are extracted and transformed into materials and components to create consumer products. Consumers use them (at increasingly higher speed) and dispose of them. *How* and *where* waste is disposed changes from region to region. However, globally waste is mainly sent to landfills and, in some European countries, increasingly to incineration and, to a lesser extent, recycling and composting (*Municipal Waste Statistics - Statistics Explained*, n.d.).

While this linear approach has created wealth for some and increased comfort for many, it has also substantially depleted and polluted most natural resources across the globe. This fast lifestyle and overconsumption also contribute (often unintentionally) to increased wealth gaps, social division, and resource inequalities among people and across countries.

Knowing this, what is, then, the Circular Economy? A circular Economy is one of the ways in which we are rethinking society and the economy to retain value. **Circular Economy is a framework for systems redesign that uses value retention as a strategy for creating environmental quality, economic prosperity, and social fairness.**

This change from producing and consuming goods to creating and retaining value is both a business and a mindset change. At a business level, the Circular Economy fosters the

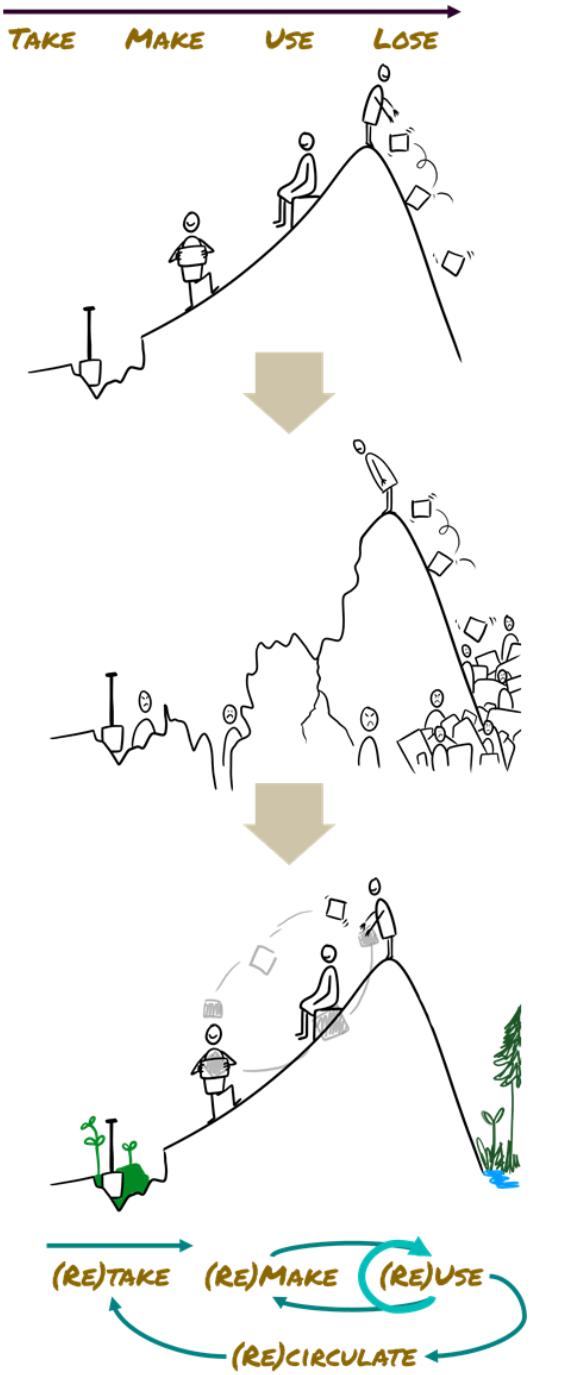

Figure 1: The case for transitioning from a linear to a circular economy

opportunity to reinvent and build systems that retake "waste" streams to produce value and to reuse and recirculate products, components, and materials to extend their lifetime through innovative business models and product design.

More importantly, the mindset for a circular economy allows us, producers, consumers, and decision-makers, to rethink and question what we do and produce, what, why, and how much we consume, and how we interact with and within businesses, institutions, and other members of our communities. (Meadows, 1999)

> *"We should always ask: growth of what, and why, and for whom, and who pays the cost, and how long can it last, and what's the cost to the planet, and how much is enough?"*
>
> - *Donella Meadows, 1999*

Part 2: Re-understanding the notion of value

Value retention, the key principle of a circular economy, is richer and more complex than the increased profit margin, resource efficiency, or 'closing the loop' through mere recycling. To create this paradigm and mindset change, we must understand the meaning of value in-depth. We can recognize that ***value*** has at least five dimensions:

1. **Environmental value:** Climatic resilience, restoration, and overall system health
2. **Societal value:** Fair and distributed access to the systems' wealth
3. **Material value:** Resources already spent in the production and delivery of products and services
4. **Energetic value:** Energy embodied in the product or service through extraction, manufacturing, transport, and sales.
5. **Economic value:** Profitability, economic development, and materials' residual value

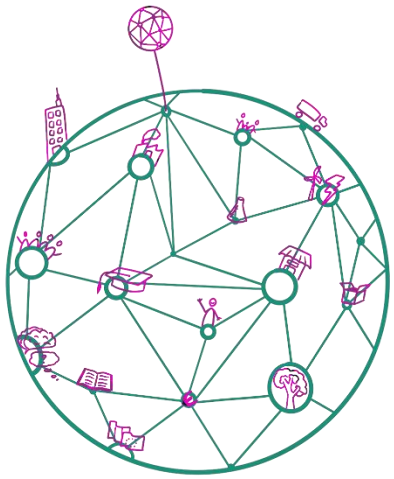

Figure 2: Circular Economy relies on an interconnected set of values

There are other dimensions of value, such as cultural, historical, and personal value. Future research should explore their relevance and contribution to our global development.

Using these definitions of value, and the understanding of the goals of the Circular Economy, businesses can reflect on the ways in which their products and business models are enabling or hampering the preservation of value and ultimately redesigning them for the Circular Economy. (Sterman et al., 2002)

"The most important assumptions of a model are not in the equations, but what's not in them; not in the documentation, but unstated; not in the variables on the computer screen, but in the blank spaces around them"

- John Sterman, 2002

Part 3: Retaining value through circular strategies

Note: This section is a brief summary of the paper:

> Garcia-Saravia Ortiz-de-Montellano, C., & van der Meer, Y. (2022). *A Theoretical Framework for Circular Processes and Circular Impacts Through a Comprehensive Review of Indicators*. Global Journal of Flexible Systems Management 2022 23:2, 23(2), 291–314. https://doi.org/10.1007/S40171-022-00300-5.

For more information, please refer to the source: (Garcia-Saravia Ortiz-de-Montellano & van der Meer, 2022).

The framework upon which this methodology has been developed identifies two areas of concern for the Circular Economy: Circular Processes and Circular Impacts.

3.1 Circular Processes:

They refer to the different ways in which the maximum value of any product, component, and material can be kept within a system. These are called Value Retention Strategies (VRS). VRS constitutes the building blocks of a circular system. There are eight main strategies: redesign, (re)use, re-sell, refurbish/remanufacture, recycle, recover and recirculate. They cover transformations on six levels:

1. The **product** itself, including its design and the business model around it
2. The **components** of the product (the pieces that constitute the product)
3. The **materials** from which these components are made, and
4. The **business models** in and around the recirculation of the above three elements
5. The **logistics** required to circulate such elements.
6. The **systems** in which the business is embedded.

3.2 Circular Impacts:

If the *Circular* Processes are the strategies to retain value, then the *Circular Impacts* concern the ultimate goal of the Circular Economy: the sustainable and fair

improvement of life's quality for nature and society. These circular impacts can be summarized into three major blocks:

1. Contribute to **social development**,
2. Improve **environmental performance**, and
3. Ensure a **socially fair and market-relevant economic contribution**.

A more detailed description of the indicators within each process and impact can be found in the following figure:

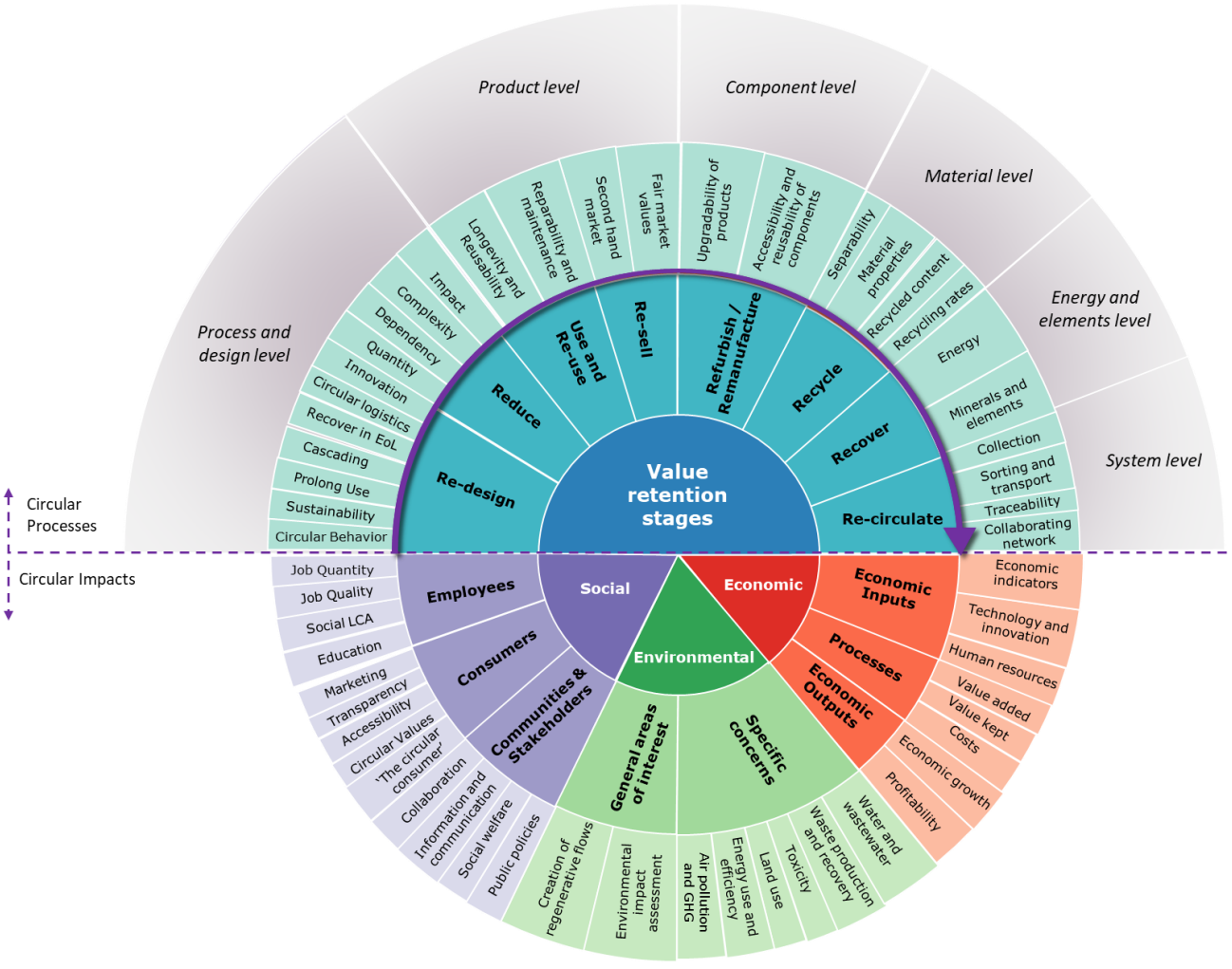

Figure 3: A framework for a circular economy. Circular processes and impacts

Introduction

"Firms need a purpose far more inspiring than merely maximizing shareholder value"
- Kate Raworth, 2017

This methodology puts theory into practice by translating the Value Retention Strategies (VRS) mentioned before into an actionable tool for circular product redesign. Redesigning *business-as-usual* and *products-as-usual* for a circular economy is not a straight line. However, we can use this map as a guide for the process while being open to exploring surprising solutions. (Raworth, 2017)

Four thinking lenses

To best use this framework, we require four tools essential for sustainable redesign. We call these *the four thinking lenses.* Each lens has distinctive core values. In combination, they represent a change in mindset, from the impossible to the possible, from restrictions to opportunities, and from business as usual to transformative business models. If these mindsets for thinking could speak, this is what they would say:

Thinking lens	Core mindset
Design Thinking	*I look for **user-centered solutions**, and I build ideas that have emotional meaning and functionality through empathy, collaboration, expansive thinking, and experimentation.*
Life Cycle Thinking	*I consider an **integrated view of processes**, from the extraction of raw materials until the end of life of products and their impact on the environment and society.*
Systems thinking	*I know that the whole is more than the sum of its parts. I look for solutions that are integrated and **consider the influence of the system** in which they are embedded.*
Circular Thinking	*I look for solutions that **keep value alive** several times after the first use. I **close the loop** through alternative product design, business models, end-of-life options, and innovative supply chain strategies.*

Redesigning a value chain, business model, or product from linear to circular requires creativity, exploration, iteration, and out-of-the-box thinking. There is no right or wrong answer, and several viable solutions might exist. Therefore, it is recommended to approach each project with an open mind and curiosity, and to *use your research, synthesis, analysis, and critical thinking skills.*

The different origins of circular products

Through the iteration of this methodology across groups and companies, we have identified four main pathways from which to determine the starting point, described in the following figure:

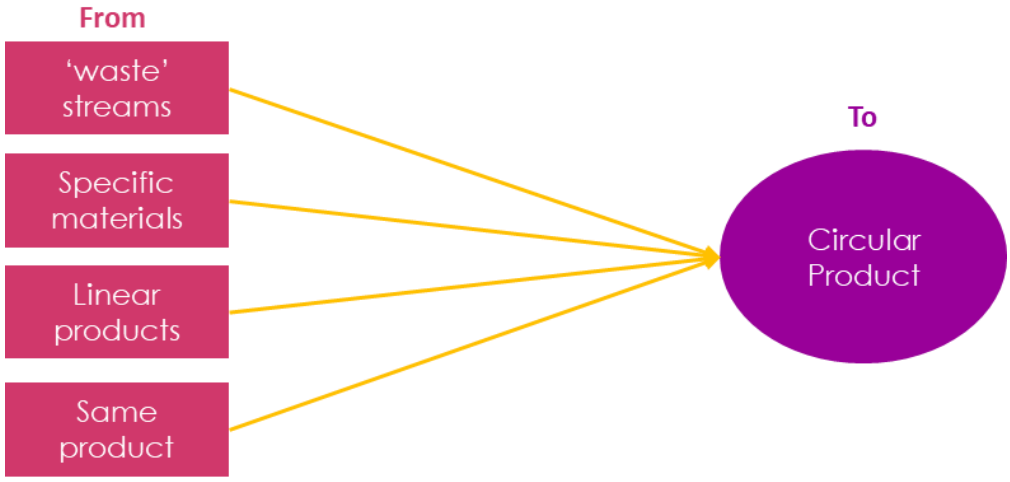

Figure 4: The different origins of circular products

The journey toward circular products might start from the need to valorize undesired waste streams, such as citrus peels or byproducts from industrial activities. Other times the starting point is specific materials, such as rubber or methanol, that need more circular manufacturing and applications. At a product level, transformation occurs from linear products such as disposable coffee cups, footwear, or furniture that require a complete redesign; or products that require new circular business models and value chains, such as existing recyclable tote bags or industrial footwear already redesigned for circularity. In short, any product or business model can benefit from more circular practices.

Can you think of other examples for each of the different pathways? Can you identify to which pathway your challenge belongs? Is it more than one, or is it one that is not considered in this diagram?

A note on supply chain and product design

> *"The supply chain begins on the drawing board. Design decisions can have a significant effect on supply chain and business outcomes"*
>
> *- Omera Khan, 2019*

It might be tempting to believe that there is little connection between the specific design of a product and its supply chain. In many businesses, *product design and the supply chain are two very different organizational silos* (Khan, 2019). However, it is also true that eighty percent of a product's costs are determined during its design phase. Not only that but also 80% of the product's environmental and social impacts (!). These impacts are a consequence of the material, manufacturing, and packaging choices (Brass & Bowden, 2009). For this reason, there is an increasing demand for interconnected design processes that include product designers and engineers, supply chain specialists, sustainability experts, and social scientists. (Khan, 2019)

This methodology is a guided tour to exploratory circular product design for any person involved in such fields and a call for a deeper understanding of the relationship between a product, its consumers, supply chain, and end of life.

Methodology: A circular pathway

The CIRCULAR pathway is an eight-step approach that guides you through the process of exploratory product and supply chain design. In short, together with the company, you will **co-define** the topic, understand its pressing challenges and develop an initial brief of requirements. With this brief, you will **identify** the need that the product satisfies and its current value chain, from extraction to use and end of life. You will then use the theory in this booklet to **recognize** where are the critical problems of linearity in terms of value retention and sustainability. These first three steps comprise the problem definition phase.

Using the information you obtained, you will **create** multiple alternatives to these problems at different levels and categorize them to **uncover** which of them solve the problems of linearity and the pressing challenges in better ways. Very often, the best solutions happen when we chain more than one alternative together to **level up** the game from mere ideas to *visions of change*. With these three steps, we conclude the idea exploration phase.

Finally, we will take these selected visions and **analyze** their risks, limitations, and opportunities. In closing this process, we will **reflect** on these visions' impact on the

business, environment, and society, which is the consolidation phase of the process. As you can see, we started from the general requirements and dived into specific ideas which converged into visions. In this final stage, we take these ideas and expand them again to see their potential impact on the planet as a whole.

Have you already noticed that this methodology conveniently follows the C.I.R.C.U.L.A.R. acronym? Here is a chart to guide you!

Co-define: The theme or topic, product, functional unit, and properties

Identify: Value proposition, value chain, system, and boundaries

Recognize: Challenges and problems of linearity

Create: Maps of alternatives for bottlenecks at different scales

Uncover: Pathways of solutions by chaining ideas into *visions*

Level-up: Improving your new value chains for full circularity

Analyze: The assumptions, barriers, and risks of the selected scenarios

Reflect: On the impact of your solutions on the environment, society, the economy, and the industry/sector in general

Let's take a look at each of these steps in detail.

1. Co-define: The challenge, pressing issues, and expectations

Goal: Understand the challenge	*Outcome:* ***Brief of requirements***

Five guiding questions:

1. What is this challenge about, and the functional unit to be analyzed?
2. What needs and market niche is this product currently satisfying, and how (product characteristics)?
3. Why is the company interested in becoming more circular (goals, motivations, pressing challenges)?
4. What is their expectation of this process?
5. Which key information must you keep into account, according to the company?

In this initial stage, we will set the scene. The goal is to understand the challenge as in-depth as possible. For this, it is useful to know why is the company interested in redesigning its product or value chain. Is it an intrinsic motivation to become more sustainable? Or do they have specific challenges that they need to solve? Identify what the company's expectations and vision are.

Understanding this will help to identify a **key product,** also called a *star product,* to be used as an example throughout the process. This is a common practice in business transformations. Instead of changing *all* products and lines, choose one, experiment, and evaluate the outcome.

Figure 5: Step 1 - Choose your star product (and functional unit)

Once the key product is selected, we must identify the **function** and **group target** that this product fulfills and the **performance requirements** that this product needs. To provide an example: A product might be a *pair of shoes.* The function of this pair of shoes is to *provide sufficient support and comfort for non-elite running purposes.* Its group target can be a *medium-fitness* average man with a *shoe size 48*. Finally, the performance requirements for the specific product, function, and group target could be *to provide support for 12 months by means of preserving its shape, sole pattern, and water resistance.*

Then, the **functional unit** of this example could be: *A pair of running shoes, size 48, with a lifetime of twelve months under an average use of three times per week*. Considering

lifetime as the length of time in which the shoe keeps its grip, inner sole shape, and water resistance. Even if this sounds like too much, one can clearly see that this pair of shoes is radically different than one for a six-year-old school boy or walking shoes for an elder.

With the information you gathered, make a *brief of requirements* or *project brief*. This is the "birth document" of your project. It must be as short as possible while still containing the most relevant information. In the following table, you can find an example. However, each project is unique, so feel free to add as much as you consider necessary. Essential elements of a Project Brief for this methodology are the **Drivers for change**, **Product** and **Functional Unit**

Note that this template is supplied as a digital Annex.

Project Brief			
Project name:	*Give this project a unique name*		
Date start:		**Date end (expected):**	
Team members		**Company's contact person:**	
		Name:	
		Email:	
Context definition			
Background information	*One paragraph to summarize: What does the company do? When did they start and why? What is their mision as a company?*		
Drivers for change	*What are the five most pressing challenges for the company at this moment?*		
Expectations	*What would be the desired outcome of this project for the company? What has been agreed with them that fits the time and resources available for this project?*		
Project definition*			
Product:	*What is the chosen product to work on*		
Function	*How is this product used? What function does it fulfills?*		
Performance requirements	*What key indicators define the product's quality or performance? (strength, shelf-life, resistance to abrasion/erosion, etc?)*		
Target group	*Who are the users of this product? What are their specific characteristics?*		
Functional unit:	*Using the information above, what is the functional unit selected?*		
Market:			
Users / market niche	*Who is the main user of this product?*		
Other	*Other relevant market information*		
Communication process			
Communication stream	*How and when to contact the company?What are the preferred means / times of communication?*		
Notes:			

Figure 6: Project brief, or brief of requirements

Note that this template is also available as a digital Annex.

2. Identify: Value chain, system, and boundaries

Goal: Define value chain and product composition	*Outcome:* ***Value chain map***

Five guiding questions:

1. *What is the product made of?*
2. *How is the product created/manufactured?*
3. *How is the product used/reused?*
4. *How is the product cascaded into different applications?*
5. *How is the product disposed of?*

During this second step, we zoom inside the product to see its component and material compositions, the source of these materials, the retail, delivery, and use of the product, and the final destination(s) it has at the end of life. Using your analytical and research skills and the company's information, map the product's value chain from extraction to end-of-life.

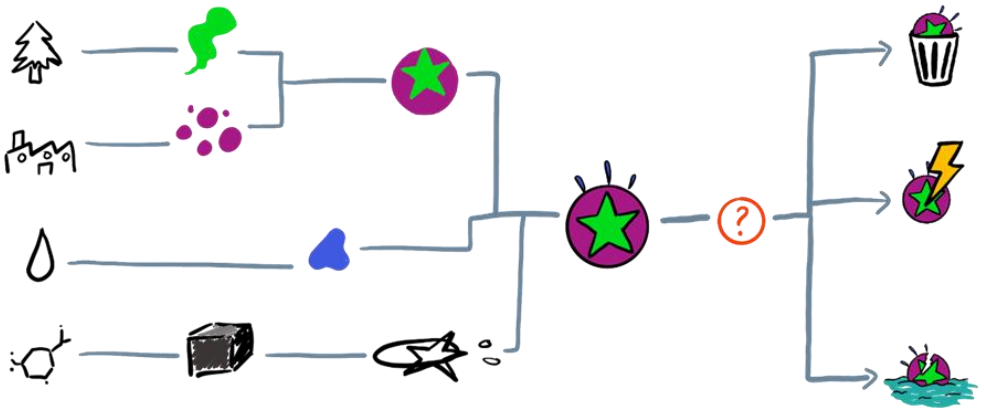

Figure 7: Step 2- Identify the product's value chain

To circumvent the confusion between a value chain and a supply chain, in Circular Economy, we assume that a *circular value chain* has three main elements: **Supply chain** (value creation), **use chain** (value retention), and **retrieval chain** (value recovery). In this stage, we identify the three of them. There are important elements to consider when making a value chain analysis. These can be summarized as follows:

1. **Product composition:** You can think of it as the exploded view of a product with details on its components, materials, assembly elements (such as glues and screws), coloring, or performance-enhancing elements (dyes, flame retardants, coatings, etc.), and packaging (boxes, bags, and tags),

2. **Supply chain:** Looking *backward* from the final product, what is the general process, from the extraction of raw materials to the production and assembly of components and products? Once the product is ready, how is it transported and delivered to its retail place? Which consumer types purchase this product? How do they access it (online, front desk, etc.?)

3. **Use chain:** We now look at a product's use phase. Here, we want to identify how long the consumer uses this product (is it a single-use product? Or is it reusable? Is it used on average for two days or five years?). What happens *after* the initial consumer uses the product? Is it repaired, is it re-sold, or refurbished? Does it have more than one use/user?

4. **Retrieval chain:** As the product ends its use phase *as a product*, what happens to it? Do different components get recovered? How and by who? Do different materials get recycled/composted? How, where and by who? Is the product just thrown away in the general waste collection system? Is it separated from other waste streams? Does it go to a landfill? How is the value of the product recovered? Or if not, then where is the value disposed of? Is there more than one route at the product's end of life?

5. **Logistics:** Even though logistics is already a key element of supply chains, it deserves special mention because of its importance within and among the different chains. How is the product moved across its various stages? Is special transport needed? Is special packaging needed to transport the product? How is the product recovered from the user's hands? Through deposit systems, refund systems, or general disposal? How are the reverse logistics arranged for the retrieval chain?

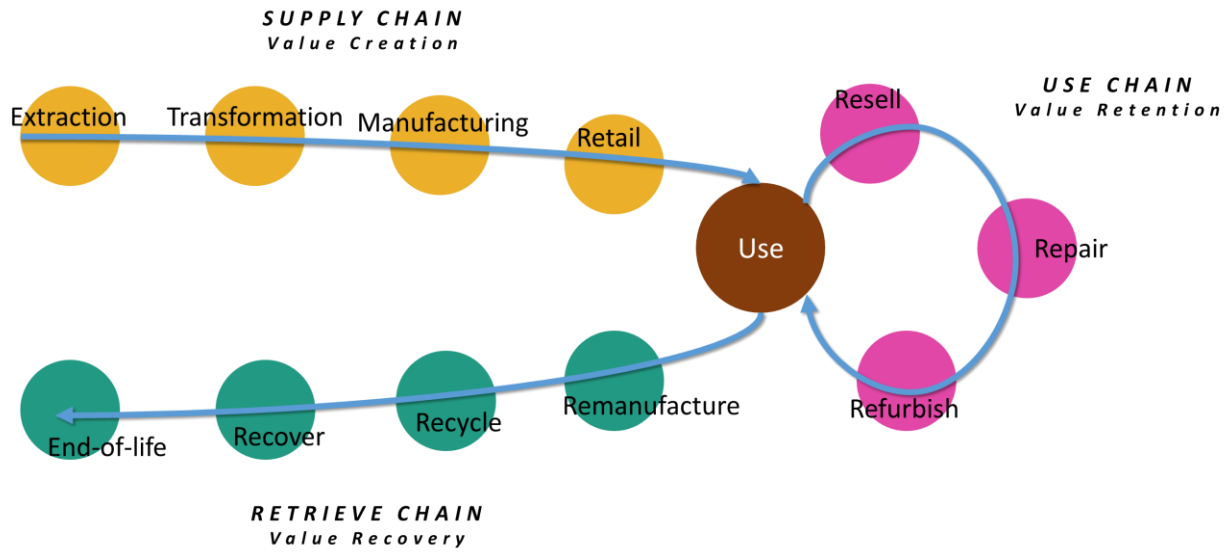

Figure 8: Key elements in a value chain

Remember that the deeper our understanding of the current system, the more in-depth solutions we will be able to provide. Aim at gathering a bird's eye view of the whole value

chain and a detailed understanding of the key elements in the supply, use, and retrieval chains. The chart provided in the digital annex and shown in Figure 9 can support this process, but remember that templates are just guidelines. Feel free to enrich it with your own experiences and observations! Furthermore, our experience has shown that *drawing the map* instead of just making a list of elements greatly increases the understanding of the value chain, recognition of gaps, and use of systems thinking.

	Value chain					Use chain		Recovery chain				Logistics	
Description	**Raw materials**	**Materials**	**Components**	**Product:**	**Retail**	**Use 1**	**Uses 2-n**	**Cascading**	**Recycling**	**Recovery**	**End of life**	**Recirculate**	*Other*
				Start here									
Material explosion													
To these questions: If yes, then enlist "which and how much?"	Are these materials made out of one or more raw materials?	Which materials are used to create each component?	Is this product made out of different pieces? Don't forget to include assembly elements and additives	What is the product (that fulfills the functional unit)?	Are there additional materials (e.g. packaging) required to transport to retail?	Which materials/components get thrown away or consumed immediately after purchase? Which materials/components remain in use for longer? What happens to the packaging?	Is the product reused? Shared? Resold? Which parts do so? Are there additional materials or comonents required for its reuse (e.g. spare parts, cleaning agents, etc)?	After use, are different components used for other applications either through refurbishment or remanufacturing?	Which materials are recyclable and/or get recycled?	Which materials or components get incinerated or composted for the recovery of energy or minerals, what is recovered (energy? Minerals? Nutrients?)	Which materials and components have no further value and get disposed? After how many cycles?	Do the transport of materials, components and product require additional materials?	Are there any other important considerations for these materials?
Process description													
To these questions: If yes, then describe "how?"	Briefly, how are each of the raw materials extracted, where do they come from?	What is the manufacturing process from raw materials (e.g. sugarbeet) to materials (e.g. ethanol)	How are the materials assembled and trnasformed into components?	How are the components assembled, packed and finsihed into the product?	How is the product delivered at the purchasing point?	How is the product used? For how long? What is the function of the different elements of the product at the user stage (packaging, consumables, single use, multiple use, etc)	How is the product reused? By whom? How is the product transferred from one user to the next one?	How are the products collected for recovery of components or materials? Where are they transported? How are the components recovered and used?	What are the sorting, cleaning, processing and recyclin processes involved in this stage?	How are the components or materials recovered? Which processes are involved?	How and where do the materials and components get disposed? How long do they remain there? What happens afterwards?	How are materials, components and products transported to their next destinations and back?	Are there any other important considerations for these processes?

Figure 9: Supply chain analysis as provided in the digital annex

3. Recognize: Challenges and problems of linearity

Goal: Identify potential intervention areas	*Outcome:* ***STEEP Analysis and linearity analysis***

Five guiding questions:

1. How does the material composition of my product affect its circularity?
2. Do the business model and consumer relationship promote a circular economy?
3. How is the company using or fostering value retention after the product use phase?
4. Which local and global trends can critically affect my sector, business model, or products?
5. What are the biggest challenges of the system, inward and outward?

This is the final step of the problem definition phase. During this step, we explore 1) **inward** by taking a critical look at the value chain map (Step 2: Identify) and recognizing the areas where value is lost and the reasons behind it, also called *linearity analysis*; and 2) **outward** by looking at the Social, Technological, Economic, Environmental and Political trends (STEEP Analysis) affecting the value chain.

The linearity analysis will focus your attention on the hotspots where a circular economy has the potential to increase value retention. In contrast, the STEEP analysis will give you insights, perspective, and alignment between proposed solutions and their global context. It is essential to recognize that businesses do not operate in isolation. They are part of a socioeconomic system embedded in a specific geography and responsive to particular policies, societal pressures, and environmental challenges.

Part 1: Linearity analysis

As you know, a circular economy aims to keep value in circulation for as long as possible, using different strategies at different levels. Primarily we can recognize these levels from small to large scales, i.e., From elements, to materials, components, products, business models, retail systems, cascading systems, retrieval systems, and collaborative networks. We will evaluate the linearity by using a 1-to-10 scale based on what you find in the literature, what you know by now of the product, and through peer discussions with your team. Use the digital annex to guide this process. The template is shown in Figure 10. The categories used for this analysis are based on the paper *A framework for the circular economy through a comprehensive review of indicators* (Garcia-Saravia Ortiz-de-Montellano & van der Meer, 2022). Refer to this paper for more detailed information.

	Value chain					Use chain		Recovery chain				Logistics	
Description	**Raw materials**	**Materials**	**Components**	**Product:**	**Retail**	**Use 1**	**Uses 2-n**	**Cascading**	**Recycling**	**Recovery**	**End of life**	**Recirculate**	*Other*
Linearity analysis													
10 = Circular	Raw materials are sourced from recovered, renewable, local and widely resources in un-endangered ecosystems, through socially and environmentally responsible practices.	Materials are reusable, recyclable and/or biodegradable. They do not require additives that make them unsuitable for recycling or degrading. They are incuous to the environment during manufacturing, use and end of life.	Components are monomaterial, durability matches use time, assembly is modular, they are standarized for repair, reusable and accessible for retrieval.	Product lifetime matches use time. It is designed for repair, maintenance, refurbishing and/or remanufacturing. Product is assembled in a way that allows access to components, including removable glues, coatings and dyes. No packagin is needed.	Business models support consumer engagement and circular beahaviour* over consumerism and fast consumption. Rental, repair or maintenance are preferred over disposal. Consumer support is part of the business models through leasing, spare parts, buy-back systems or dispose-back systems.	Match between the actual and desired length and intensity of a product's use. Product is designed to be used for longer with low need for repair or upgrade. Single-use products and packaging are designed for biodegradability, high recyclability and clear disposal.	Product can be shared with other perople from the community, re-used, sold as used product or sold back to the company for refurbishment or remanufacturing. There is a market for second hand products where people can buy and sell at lower prices	Components can be extracted to be reused in Remanufactured products and new pieces can be placed in old product to refurbish them. Clear product and component streams go from consumers to businesses	Used products and components can be disposed in clear waste streams for high-quality material recycling. Infrastructure exists and is available for recycling of materials. Logistics are in place for the recovery sorting, and transport of materials. Market exists for recycled materials	When materials cannot be further reused or recycled, infrastructure is available for the recovery of energy, nutrients and minerals, through pyrolisis, composing or other technologies.	There is no leackage of residues into the environment at the end of life. Nutrients and minerals that reach the ecosphere enhance ecosystem recovery and are regenerative to the environment	Systems for the transport of products components and materials at all stages are available, low in energy and optimized for minimum environmental impact. System level recirculation is powered by strong connections and communication among companies, consumers and stakeholders.	
1 = linear	Raw materials are non-renewable, scarce, rare and foregin. Extracte with non-strandarized, energy demanding, and unfair social and environemental practices.	Materials are non reusable, recyclable or degradable. They leach components that are toxic to humans or the environment, they break into microparticles that might damage the ecosystems.	Components are made out of multiple, uncompatible materials that prevent recycling. They are interconnected in ways that prevent repairability or access to parts for repair. Properties of components are not preserved after disassembly	Product lifetime largely exceedes usetime and has no further possibility for being reused, or repaired. Product's value to consumer is short lived. Product is asemmbled and coated with glues and additives that hamper cascading and recovery. Packaging is excessive and unnecessary	Business model supports consumerism and single or short lived use of products. Does not provide support to repair or maintain products. Does not provide with alternatives for return at end of life.	Product's use time is single-use or very short. Materials cannot be clearly disposed or separated in clear wastestreams by the consumers given their context. There are no warranty, maintenance or repair schemes available.	There is no possibility for reuse, share or resell of products. There is no market place for second hand products.	There is no possibility to refurbish or remanufacture the product. Product is encased in a way that does not permit access to parts.	Materials are not recyclable, nor the infrastructure and logistics are avaiulable. Products have mixed materials that do not allow for clean waste streams.	Energy, nutrients or minerals cannot be recovered and waste streams are disposed or exported.	Waste streams are un-managed and reach the environment causing pollution, toxicity, human health problems and environmental degradation	Logistics are energy intensive, damaging to the environment, long in distances and sub-optimal. No reverse logistics are available for the recovery chain	
Score (1-10)													
Argument													
Possitive focus points													
Negative focus points													
NOTES	* Promotion of circular consumer behaviour is the design of products and business models that support, encourage and guide consumer to take the right circular choices at the purchase and end of life of products												

Figure 10: Linearity analysis as provided in the digital template

Part 2: STEEP Analysis

STEEP is the acronym for Social, Technological, Environmental, Economic, and Political trends. Companies use it to understand the external changes that might impact their business.

With this analysis, you will ensure that important global trends and opportunities are considered when looking for solutions to increase circularity. To perform this analysis, you must be able to answer one or more of the following questions at the business, product, and value chain levels.

Social: Identify social developments that are reshaping the business landscape, such as changes in consumer behavior, demographics, lifestyles, and relevant social movements.

1. Are consumer opinions and preferences changing regarding your product or service?
2. Are consumers' values and views changing? How?
3. Is the population demographic changing, increasing, or decreasing? How does it affect your business?
4. Are the lifestyles of the consumers changing and following other significant trends?
5. How are consumers' interactions changing towards the business and other consumers or community members?

Technological: Identify relevant technological advancements at local, regional, and global scales.

1. What new and important developments are taking place regarding communication, manufacturing, energy and transport, and the life-cycle of products?
2. What technology is critical for business operations?
3. Are there new technologies available that could expand, improve or threaten your business?
4. Are you using technology to stay ahead of the competition, and if so, how?
5. What are the new technological platforms relevant to the business niche?

Economic: Recognize any relevant economic shifts and movements, including international trade agreements, changes in purchasing power among consumers and countries, and relevant events regarding taxes, inflation, subsidies, employment, and entrepreneurship.

1. How much does globalization affect your business?
2. Are there essential trade agreements happening at the moment that might affect the business?
3. What are the state of employment, purchasing power, and economic strength in the consumers' location for your business?
4. Are there important changes happening to taxes, subsidies, and interest rates?

5. Is your business niche dynamic and entrepreneurial or consolidated and corporative? Is this changing?

Environmental: Recognize key environmental developments and issues such as energy sources, water, soil and air pollution, ecosystem degradation, and food production, as well as important regulations taking place to prevent environmental damage.

1. Are there important developments on waste disposal or environmental protection laws that affect your business?
2. Does your business contribute substantially to environmental factors such as energy consumption, land use, global warming, soil, water, and air pollution, ecosystem damage, or other factors?
3. What is the general attitude of your consumers towards the environment? Is it shifting? How?
4. What is the general attitude of your business niche towards the environment?
5. Are there any important environmental claims or criticisms of the business sector that must be addressed?

Political: Political and policy developments can substantially affect the categories mentioned above and the business. Identifying any relevant policy and political movements that can affect the business positively or negatively is important.

1. Are there new regulations you must follow regarding social or consumer interactions, technology use, environmental protection, economic distribution, or others?

2. Are policies generally in favor or against your market niche? How?

3. Are there specific regulations to consider, such as recyclable products/materials, local sourcing, social compliance, etc.?

With the linearity analysis and the STEEP analysis, you should be able to identify the ***linearity bottlenecks,* which are the areas, materials, trends, or parts of the value chain that require attention**.

This marks the end of the problem definition and provides us with the right ingredients to start searching for solutions. In the next three steps, you will use the knowledge you have gained on the business and its operations, global and local trends, and challenges of linearity to identify a wide array of solutions to innovate and transform the selected functional unit for a circular economy.

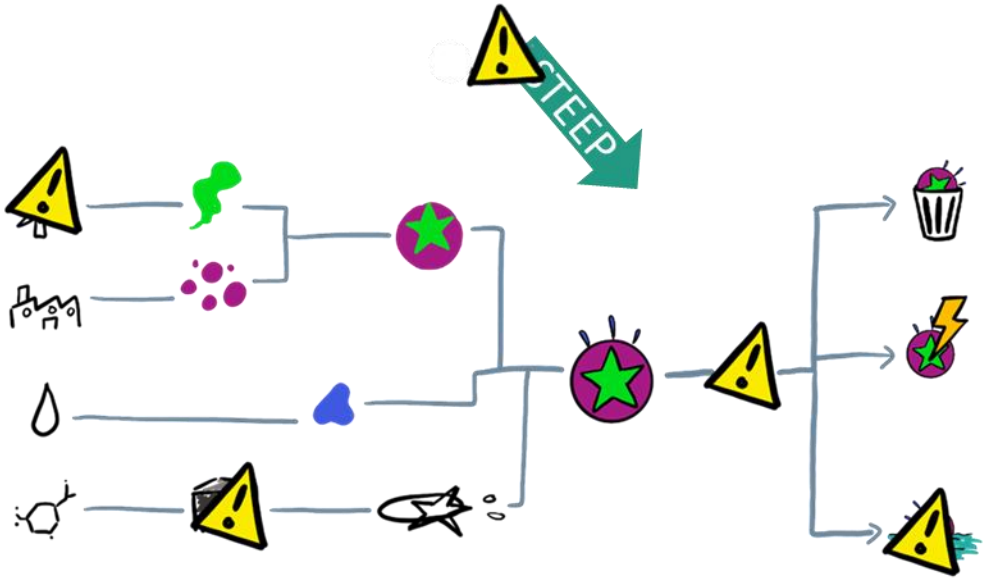

Figure 11: Alert! Recognize trends and problems of linearity

4. Create: Maps of alternatives for bottlenecks at different scales using the circular compass

Goal: Gather as many ideas as possible	*Outcome:* ***Inventory of ideas***

Five guiding questions:

1. Are there other industries facing similar linearity bottlenecks?
2. What are other industries doing to replace linear materials / processes?
3. What would need to happen across the value chain to double / triple / ten-fold this product's longevity?
4. What would need to happen to make this product entirely biodegradable? And to make it entirely recyclable?
5. Is there new research being developed for replacing materials or processes that are relevant here?

Solutions to the challenges you have identified can be found anywhere. Sometimes, other unrelated industries use technologies that could be helpful. Other times there is research on innovative materials or new business and communication models. Information is everywhere. For this reason, in this step, you are asked to create an

inventory of innovations for each identified bottleneck. Innovations can happen *at least* at five levels:

1. At a **system level** (e.g., the waste collection system, the industrial park, the whole city)
2. At a **business level** (e.g., switch from product-based to service-based, change suppliers to local ones, change the business model)
3. At a **product level** (e.g., Redesign the product to extend use time, change the building technologies to improve disassembly)
4. At a **component level** (e.g., Replace a specific component that is difficult to separate, design products for modularity and reassembly)
5. At a **material level** (e.g., change materials for other, less polluting ones, increase recycled materials, reduce additives, etc.)

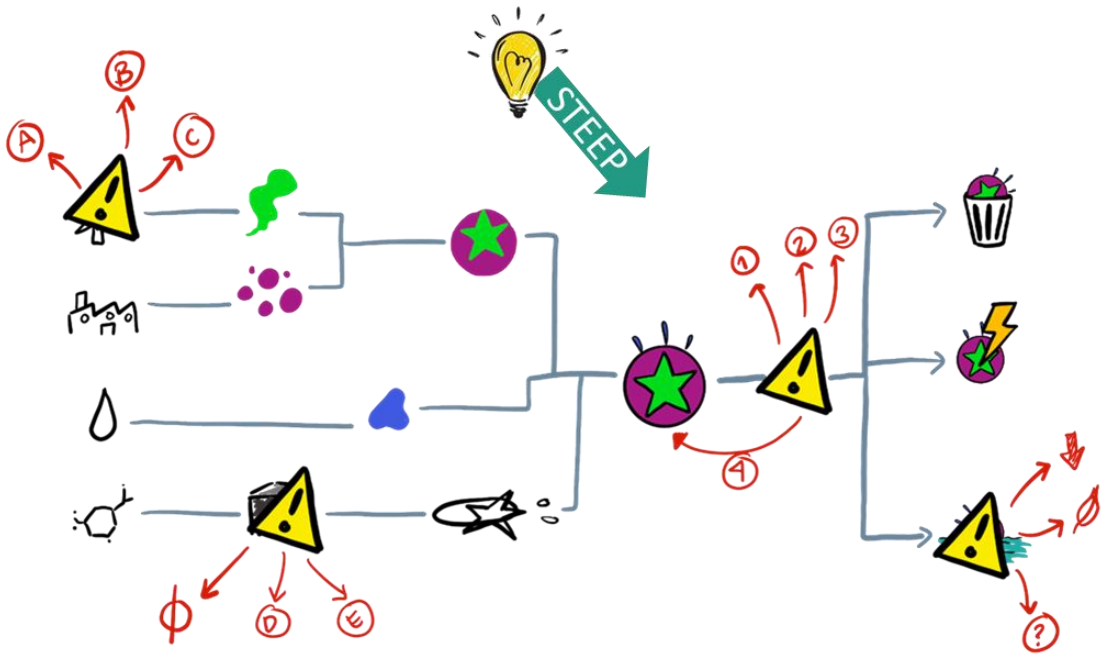

Figure 12: Create an inventory of solutions across the different problems of linearity

You must bring your most creative, explorative, and out-of-the-box self for this part of the process. The goal is to build an inventory of ideas and solutions at all levels. For this, we will make use of the blank circular compass provided in the digital annex and the following approach:

1. Look back at the *Key pressing challenges* (Brief of requirements), *linearity assessment,* and *STEEP Analysis*

2. Identify the most pressing bottlenecks
3. Using the *circular compass,* ask yourself the questions from figure 13 (also available in the digital annex).
4. Use the question of each Value Retention Strategy to trigger ideas at each of the five key levels.
5. Find ideas and solutions to as many system levels and value chain levels as possible.
6. Make sure to invite big ideas from books, social tribes, movements, and unrelated industries. Push outside your comfort zone!

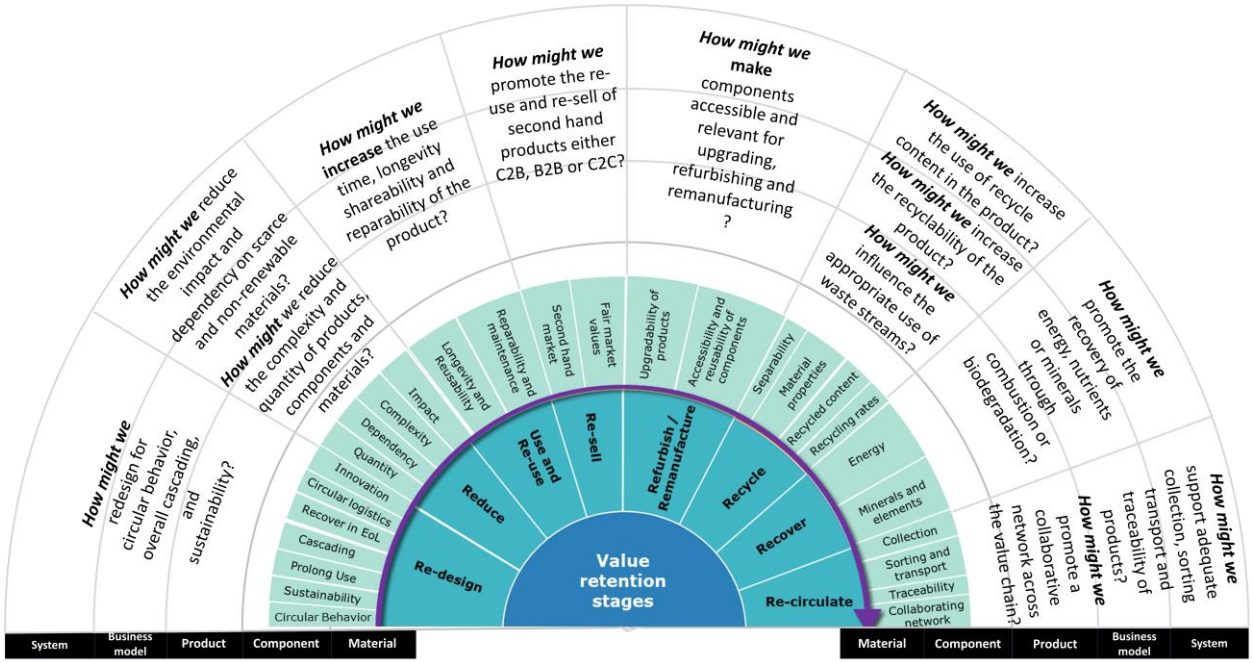

Figure 13: Key questions for solution hunting

Where to start searching?

a) *In the field:* What are companies of the same industry doing? Can you "borrow" ideas from companies in an unrelated industry? Are there start-ups tackling similar problems? Are there other disruptors of the industry? Which industrial data can you obtain to gain a better picture of the field?

b) *In research:* Look at research papers that describe or propose solutions to your bottlenecks. New materials being tested, comparative assessments among processes or materials, data on the quantity of waste, production, and consumption of your value chain can also point towards potential solutions.

TIP: *Start by using keywords like "circular economy + value chain + polyurethane" in different search engines, such as your university's Online Library, Scifinder, or Google Scholar*

c) *In applied research:* Patents are another relevant source of information because they are inventions with industrial applications.

   TIP: *Good databases for patents are Google Patents, European Patent Database, and WIPO: World Intellectual Property Organization and Justice Patents.*

d) *In the voice of others:* What are thinkers and industry leaders saying? Who are important influencers for your sector, and key challenges? How different are their visions from your current product?

e) *Inside your own analysis!* Very often, the solutions hide already at the intersection of your key challenges, linearity problems, and global trends analysis.

For this step, we highly suggest working **off the screen.** If possible, print or draw the diagram provided on a large piece of paper, and write on post-its as you encounter solutions. We have seen a *significant* increase in creativity and useful output by taking the task to the drawing board and off the computer.

5. Uncover: pathways of solutions by chaining them

Goal: Transform ideas into visions for reality	*Outcome:* ***Description of three scenarios (visions)***

Five guiding questions:

1. Which of the ideas hold the most potential for this sector's joining a Circular Economy?
2. Which of the ideas support the most pressing challenges of the company?
3. Which of the ideas contribute toward positive global trends?
4. How can these ideas be grouped together into visions of reality?
5. Which names would you give to these visions of reality?

Now that you have gathered all the possible ideas and innovations relevant to solve the challenge, it is time to mix and match. Build three scenarios as new value chains by using the solutions you have found. There is no unique solution, so we are creating different alternative *visions for reality*. Each vision solves the challenge in a different way.

For example, one scenario might be better at compostable materials (recovery strategy), while the other might be better at recycling plastics (recycling strategy), and both might need to dematerialize the components (redesign and reduce strategies).

Together with your team, sketch different visions and discuss how they might work for the business. What else would need to be in place for the different scenarios to work? Are there problems still to be solved that require you to go again and look for solutions?

In the figure below, see a representation of three different scenarios created using the other alternatives. Once your three scenarios are selected, make sure to give them a reference name.

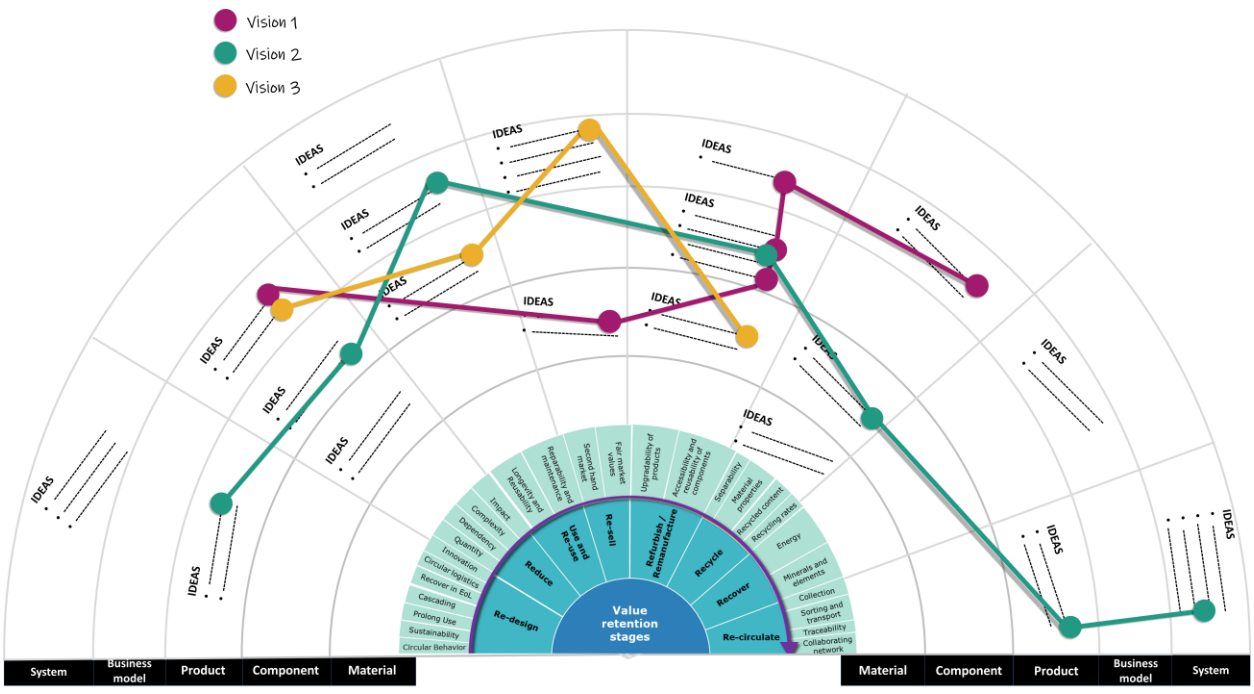

Figure 14: Uncovering scenarios by assembling several solutions in three different visions of reality

6. Level-up: By comparing your scenarios to the status-quo and looking for further improvements!

Goal: Evaluate and improve the visions for a Circular Economy	*Outcome:* ***Creation of visions***

Five guiding questions:

1. Where does each element of the different visions fall within the value chain?
2. Are there elements of the value chain that haven't been considered but that remain important?
3. How do the different elements of the visions score in terms of circularity and as a whole?
4. How can we improve these solutions by looking at them from a value chain and systems perspectives?
5. How do they score compared to each other and the original product?

We are getting there! Don't give up! This is the final stage of the creation part of this methodology. To perform this step, we will turn back to our *Value chain and linearity analyses,* but now we will apply them to the three chosen scenarios. It is expected that you won't have as much or as detailed information on them as you have on the current product, but you should still be able to map the key elements of each solution. Use the Template provided in the digital annex and referenced in the figure below. Don't forget to write down the scores using the categories from the linearity analysis.

	Value chain					Use chain		Recovery chain				Logistics	
Description	Raw materials	Materials	Components	Product:	Retail/business model	Use 1	Uses 2-n	Cascading	Recycling	Recovery	End of life	Recirculate	*Other*
Vision 1													
Describe here the key aspects of the first selected scenario. Add any additional elementsin the "other"cell.													
Circularity score (1-10)													#DIV/0!
Vision 2													
Describe here the key aspects of the second selected scenario. Add any additional elementsin the "other"cell.													
Circularity score (1-10)													#DIV/0!
Vision 3													
Describe here the key aspects of the second selected scenario. Add any additional elementsin the "other"cell.													
Circularity score (1-10)													#DIV/0!

Figure 15: Comparison of solutions using the linearity analysis

There is not a sharp cut between linear and circular, as every product is highly dependent on its context. However, by comparing them against each other, we can draw conclusions about how circular or linear they are.

7. Analyze: The assumptions, barriers, and risks of the selected scenarios

Goal: Understand limitations, risks, and opportunities of scenarios	*Outcome:* ***Statement of limitations for each scenario***

Five guiding questions:

1. What are the key assumptions made for each scenario?
2. Which barriers must be considered when moving toward a circular economy for this company and product?
3. Which are there visible risks detected for the solutions found?
4. How do the solutions help solve risks that the current product faces?
5. How do the scenarios support or hamper the key pressing challenges of the business?

Each of the *visions of reality* you have discovered will work under specific circumstances. These are called **assumptions**. Reflect under which circumstances the redesigned product might work and what would happen if the assumptions made (e.g., available recycling facilities) were not in place. Furthermore, discuss and elaborate on which **barriers** could be expected for these scenarios. As stated by (Khan, 2019), barriers for change take place across multiple dimensions. They can be barriers in terms of:

- Distance and geography
- Organizational structure and culture
- Availability of resources
- Systems surrounding the enterprise

Can you identify other **risks** that the company must keep into account for the solutions proposed? For example:

- Supplier-related risks
- Technology availability and cost
- Component or material-related risks
- Consumer related risks

Are these risks *likely, possible,* or *remote*? Would their impacts be *manageable*, *major,* or *critical*?

8. Reflect: On the impact of your solutions on the environment, society, the industry/sector in general, and the specific business challenges of the company.

Goal: Zoom out to place visions into a global and business context	*Outcome:* ***Statement of impact***

Five guiding questions:

1. What is the main contribution that each solution can provide to the Circular Economy?
2. How do these solutions join in relevant positive trends and respond to changes (and challenges) in the sector and region?
3. How do these solutions support the sustainable development of society, the environment, and the economy?
4. Can these solutions also create adverse consequences? Which ones and why?

The last step! But before we dive in, let's recap: So far, you have developed a brief of requirements to understand what are the pressing challenges of the company and its vision for the future. You have chosen a functional unit and understood its supply, retention, and retrieval chains. Furthermore, you have researched the essential trends happening around this sector at the moment. Using the VRS, you have analyzed the problems of linearity of this system and developed alternative solutions across the board, considering changes in product design, materials, components, business models, and system. After the exploration of alternatives, you have *converged* them into three plausible scenarios, and you have analyzed their circularity, risks, assumptions, and potential barriers for implementation. It is now time to take a step back and close this loop in a full circle.

For this, we must be able to state how doe each solution contributes (or not) to the *key pressing challenges of the company* and to the different Social, Technological, Environmental, Economic, *and Political* trends we identified before.

As systems thinkers, we must reflect as well on the contribution (or not) that the proposed solutions have to global goals and challenges, such as the Sustainable Development Goals *(figure 16)* and the key pressing social and environmental challenges (Figure 17). As we cannot develop a full quantitative analysis, this step requires your critical thinking to connect the elements present in each of the *visions of reality* to the different global concerns by means of critical reasoning on the implications, challenges, and limitations of your choices.

Figure 16: The sustainable development goals

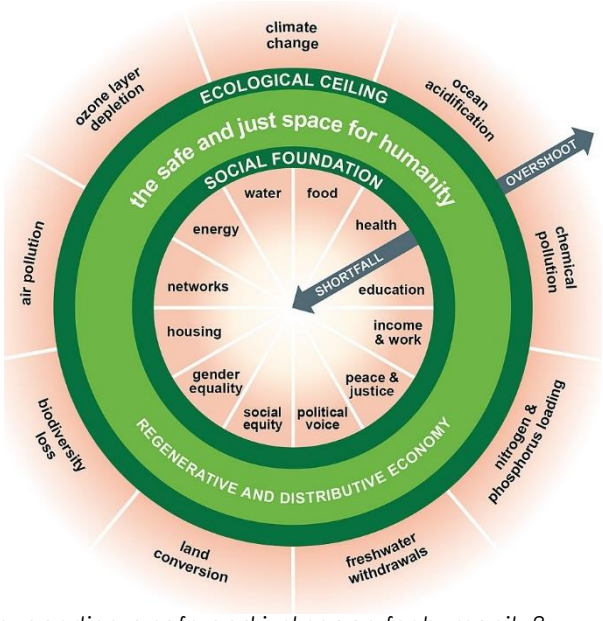

Figure 17: What is the role of circular products in supporting a safe and just space for humanity?

This marks the end of your journey to redesign products and systems for a circular economy. In the following pages, we summarize where we have applied this methodology in other industries and case studies. We finalize the document with a brief discussion on the limitations of the method here presented and a short questionnaire for you to support the development of this methodology through your experience.

Some examples

Over the past three years, we have worked with various products, materials, and waste streams across industries and countries. Here you can see a guiding overview of the type of challenges suitable for this methodology.

Type	From	To	Company
material	seaweed	innovative products	Green Chemestry Campus, Bergen op Zoom
	wood pulp	circular release liners	Mondi Group
	Rubber	circular rubber use	Arlanxeo
process	linear methanol production	circular methanol production	Brightsite
	polyolefine production	circular polyolefine production	Sabic Geleen
product	linear industrial footwear	circular indutrial footwear	EMMA Safety shoes
	linear carpet	circular carpet	Arapaha
	tote bag	circular tote bag	Arapaha
	Furniture	Circular furniture	Rijaya Mexico
	kitchen sponge	Circular kitchen sponge	Biobased Master Maastricht
waste	citrus peels	circular products	Citrofrut Mexico

Figure 18: Previous case studies

LIMITATIONS AND FEEDBACK

This methodology was developed with the aim of teaching students and practitioners, tools for turning the concepts of the Circular Economy into practice. As an exploratory tool, it does not dive into implementation strategies, change management practices, or process engineering. Thus, it must be considered a first exploratory step towards the redesign of products, processes, and waste streams for the circular economy and paired up with the right disciplines for its use in implementation strategies.

This methodology is constantly evolving and has been improved with feedback from participants across different disciplines and knowledge fields. It is, therefore, **incredibly valuable** for us to receive your feedback.

We would appreciate it if, throughout the use of this methodology, you could keep these questions in mind and provide us with feedback

Learning experience

1. How would you rate your overall learning experience?
2. Do you feel that your knowledge or skills have improved by taking the course?
3. Would you consider further training on the topic on your own?

Methodological approach

1. Which parts of the methodology did you feel were lacking or could be improved? In which way?
2. What did you like the most about the methodology and process?
3. What would you change in the methodology's design?

Delivery

1. Was the course easy to follow?
2. Did you feel equally engaged in each course section?
3. Were the information and graphics sufficient, clear, and supportive of your learning journey?

DIGITAL ANNEX:

Templates can be accessed through the supplementary material of the published paper: Garcia-Saravia Ortiz-de-Montellano C, Ghannadzadeh A and van der Meer Y (2023) The CIRCULAR pathway: a new educational methodology for exploratory circular value chain redesign. Front. Sustain. 4:1197659. doi: 10.3389/frsus.2023.1197659

References

Brass, C., & Bowden, F. (2009). *Design for Social and Environmental Enterprise*.

Garcia-Saravia Ortiz-de-Montellano, C., & van der Meer, Y. (2022). A Theoretical Framework for Circular Processes and Circular Impacts Through a Comprehensive Review of Indicators. *Global Journal of Flexible Systems Management 2022 23:2*, *23*(2), 291–314. https://doi.org/10.1007/S40171-022-00300-5

Khan, O. (2019). *Product design and the supply chain : competing through design* (1st ed., Vol. 1). Kogan Page Limited.

Meadows, D. (1999). Sustainable Systems. In *Lecture at the University of Michigan*.

Municipal waste statistics - Statistics Explained. (n.d.). Retrieved September 24, 2022, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics#Municipal_waste_treatment

Raworth, K. (2017). *Doughnut economics: seven ways to think like a 21st-century economist.* (1st ed.). Penguin Random House.

Sterman, J. D., Forrester, J. W., & Standish, J. S. (2002). All models are wrong: reflections on becoming a systems scientist †. *Dyn. Rev*, *18*, 501–531. https://doi.org/10.1002/sdr.261

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