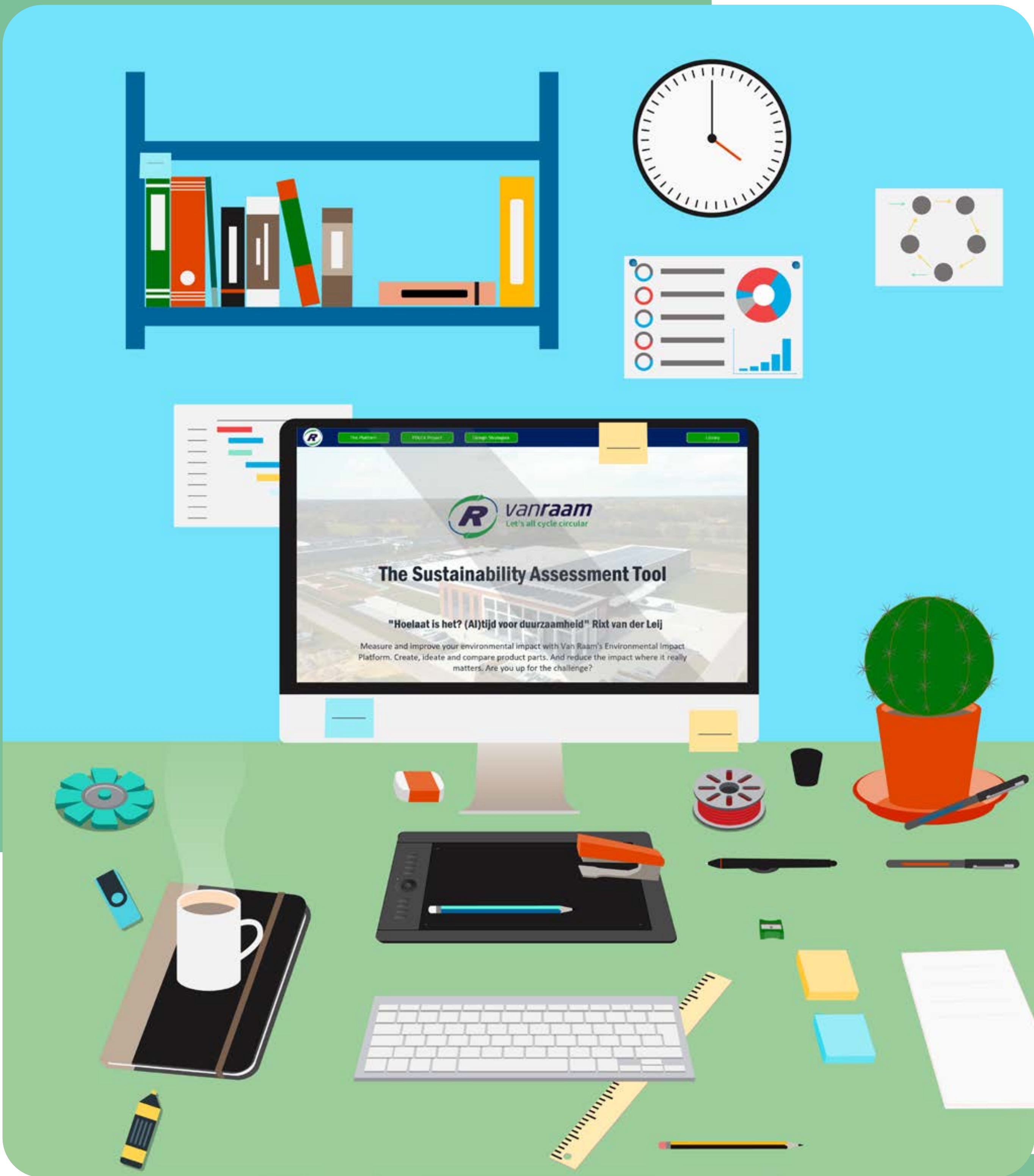
THE DEVELOPMENT OF A METHOD AND TOOL TO QUANTIFY SUSTAINABILITY FOR DECISION-MAKING IN PRODUCT DEVELOPMENT

A CASE STUDY APPLIED AT VAN RAAM



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PREFACE

This research has been performed for the graduation of the master track Management of Product Development at the University of Twente, in cooperation with Van Raam Reha. The master thesis 'The Integration and quantification of sustainability for decision-making in product development ' was created from September 2021 to November 2022. I want to thank Maaike Slot, my university supervisor, for the support she has offered me throughout this process. I have learnt many things from her and throughout this process in writing a thesis.

For my master's thesis, I wanted to find a research topic within packaging or sustainability. I was not that familiar with sustainability within product development, but after coming in contact with Jolien Heeman of Van Raam, the match was quickly made. The work in Varsseveld took place in The Ideeënfabriek, a concept founded by Jolien.

The Ideenfabriek is a workplace to develop ideas in a short time by having all the tools needed to build a prototype. As Van Raam is rapidly growing, the space to create new ideas was harder to create, which is why the Ideeënfabriek was established. The assignment I performed was initiated by the findings of Jolien at Van Raam. She has worked at Van Raam for over 15 years and noticed that Van Raam could improve its sustainability vision and incorporate this within the company's development processes.

Within the assignment, the hardest but most informative part was working with a target group. were reluctant to participating in the created sessions. Sometimes this was a motivational setback, but I learned not to take this too personally. The change of location to the Ideeënfabriek was also not conducive to the research, as it created a distance between the target group, Van Raam's product developers, and me as the researcher. Nevertheless, it was a nice atmosphere to work in and I learnt many things about myself and learnt a lot from others around me.

I would like to thank Van Raam and especially Jolien for giving me this opportunity. As stated above, als my supervisor, who guided me through the whole process from an academic point of view. My parents and boyfriend for supporting me. Vera van den Groenendal for allowing me to carpool to Van Raam and finally the University of Twente for making the six years of studying great.

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SUMMARY

Sustainability must be integrated into manufacturing companies' processes for them to keep existing. Many resources will be lost within one generation due to overconsumption and climate change. To limit environmental changes companies, need to follow the SDGs. These goals are developed to make sure the environmental impacts are limited. For companies to survive, they must transfer to a circular development model, where they reuse resources and pollute fewer emissions to fight global warming. A resilient company can overcome threats by achieving social, economic, and environmental cohesion. However, for manufacturers the SDGs are unclear, and they do not know how to apply the long-term goals within their short-term focus. Therefore, this research aims to answer the following question: How can sustainability be integrated and made measurable for decision-making in product development?

The research supports product developers in defining and quantifying sustainability in order to create short-term goals that will help them achieve the long-term SDGs. The research focuses on sustainable product development because 80% of a product's emissions are defined during the product development stage [17]. To develop more sustainable products, the ideas and the decision-making moments need to consider the environmental impact of the product. The research uses a case study at Van Raam to understand the decision-making moments in the product development process. The product developers at the company also supported the development of a solution to make the quantification of sustainability possible.

Sustainability can be quantified by calculating the environmental impact of a product using Life-cycle assessments (LCAs). Because the LCA framework can be confusing and difficult to use for product developers, this research develops an LCA approach and tool that meets the needs of product developers. This LCA tool should make the assessment simple and useful for product developers in the context of product development and improvement. To support manufacturers, the Product Development Life Cycle Assessment (PD-LCA) approach and the Sustainability Assessment Tool (STAT) were created.

Based on the LCA framework, the PD-LCA method enables the quantification of sustainability in the early stages of product development. The method focuses on improving the concept as well as concept comparison. To make the method tangible and accessible for manufacturers, the STAT is developed. This is a platform that applies the PD-LCA to define the environmental impact of a concept or product and supports the user within the assessment. The results must be compared to a context that is suitable for the stakeholders. This can be accomplished by developing eco-labels for each product category. The label supports determining short-term goals and can motivate developers as stakeholders to improve products and its label. To make change happen, the STAT and the eco-label must be properly applied. People involved in the transition must understand the importance of this implementation. As a result, change must be managed in order for people to be willing to adapt.

Sustainability can be made measurable by applying the PD-LCA method in STATs within the concept phase. An internal eco-label is required for product development decision-making to specify requirements and short-term sustainable goals. All of this must be put into action under the direction of change management, where the urgency of the transition must be established. These elements are required as the world is changing, and in order for a company to be resilient to the threats, it must have social, economic, and environmental cohesiveness. All these adjustments are required to take the first step toward implementing sustainability and transitioning to a circular consumption model.

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ABBREVIATIONS

B2B: Business to business

LCA: Life-cycle assessment

PD-LCA: Product development Life-cycle assessment

SDGs: Sustainable Development Goals

FU: Functional Unit

UCD: User-Centred Design

UFD: User Focused Development

DfE: Design for Environment

mPt: milli Point

Pt: Point

CO^2 : Carbon Dioxide

CO^2-eq : Carbon Dioxide equivalent

DEFINITION OF TERMS

Decision factor: A factor that is included in the requirements list to define if a certain aim is achieved or not.

Requirements list: A list of aims and needs for a product to fit the target group, the regulations, the costs, the quality, and the wishes to make the product successfully.

Sustainability:
- European Union 'providing a long-term vision for sustainability in which economic growth, social cohesion and environmental protection go hand in hand and are mutually supporting' [17]
- (Research focus) environmental sustainability to achieve the SDGs by being resilient and have social, economic, and environmental cohesion.

Environment: The ecosystem in which humans, animals, and plants live.

Environmental impact: The environmental impact of a product due to harmful substances emitted during its production, transportation, use, and disposal.

Sustainable Development Goals: Worldwide goals to protect the earth, end poverty and ensure that by 2030 people enjoy peace and prosperity.

Manufacturer: A company that produces and sales products.

Planned obsolescence: Intentionally reducing the life of a product to ensure that people buy new products more often.

Linear model: A company that makes money using a linear model makes money by manufacturing and selling a product without considering its disposal.

Circular model: A company that makes money by a circular model is by providing a service or selling a product in which the disposal is part of the company's responsibilities.

Function Unit: The purpose of an LCA must be defined to clarify which parts or products are being compared according to the unit of the function. According to the function parts can be compared which makes the assessment equal to the performed function.

Measurement method: Classifies and characterises the environmental impact. There are numerous measurement methods for defining environmental impact in addition to various characterization factors.

Characterisation factor: The determined value of explaining the impact for the environmental, based on harmful emissions. Such as, CO^2-eq, NO^3-eq and, mPt.

Life-cycle assessment: quantifies the impact of the product over its life-cycle. Which makes the product assessable for measuring the environmental impact. This is done by identifying the product's material, processes, transport, use, and disposal [18].

Product developer: A person that follows multiple steps to develop or improve a product or system.

Product development: A series of steps to create an idea, concept a detail product to be marketed and sold.

1 INTRODUCTION

Since the industrial revolution, the number of goods that are being manufactured is increasing rapidly. This increase has made it possible for companies to make more money by producing and thus selling, more products. Since the 19th century, a product's lifetime, i.e., the use stage of a product, has been reduced because of regulations around health and hygiene. Products such as razors, napkins and tampons can only be used once before disposal [19, 20]. If the product lifetime is shortened, a higher quantity of product is used and disposed within the same timeframe; this causes a need for more production and an increase in waste. The manufacturers needed to increase buying resources and improve production to keep up with the demand. Whereas manufacturers make profits by producing and selling products. Due to the consumers' demands and the manufacturers' focus on producing, the linear model or 'take-make-use-dispose' model is followed. The linear model focuses on the product life-cycle from creation up to disposal, but not on what happens after the disposal of a product.

The increase in production also created opportunities in other markets; more money could be earned by making more products, but this had positive and negative effects on customers. For example, General Motors (GM) saw that producing more cars did not make it earn more money, because the market was saturated. Everyone who could pay for a car already had one, so GM devised a strategy to persuade customers that one car per lifetime was not enough. Customers had to buy newer models to stay fashionable as the car became a part of the person's persona and status. The strategy is called 'planned obsolescence.' The shortening of products' lifetime became notorious [21]. The second example is the Phoebus Cartel, a group of lightbulb manufacturers. They saw the same thing happening to them as to GM. They did not make customers want new models, but they decreased the lightbulbs' lifetime from 2500 hours to 1000 hours [21]. The decrease in the quality of the product was profitable; even now, companies use this trick. Such as the last example, Apple products. It used software updates to slow down or throttle a phone's performance [22]. For customers, it is great that new products enter the market to be able to show their identity, but the deliberate decrease in the quality of the product is bad for customers. Yet people have become used to a short technological lifetime by buying new products before the expected lifetime is over [23]. In recent years, more people have started to recognise the negative effects of planned obsolescence, but it is hard for them to withstand companies that deliberately do so.

Planned obsolescence is becoming an enormous problem not only because it is unfair to customers but also because the earth will run out of resources. Currently, more resources are consumed than the planet can renew. Therefore, within one generation, we will lose the availability of many materials due to (over) consumption [24]. Besides consuming goods, the world is also affected by the manufacturing of products. This is due to emitted substances, which pollute the earth. These emitted substances are causing global warming and endangering all living creatures [25]. The society already has created irreversible damage to the planet due to our linear way of living, which has come so far that we are currently consuming microplastic particles that can be found in our blood [26]. Furthermore, waste production increases with a growing and more urban population. Of the disposed waste, only 40% is recycled, composted or reused [6, 27]. That means that 1,5 million tons of waste are currently 'lost' in landfills, incinerated or even worse, scattered all over the earth, and this waste will only grow. We, therefore, need to change our way of consumption and companies' strategies for earning money through planned obsolescence and the linear model.

Papanek and Fuller mentioned already in 1960 that the linear model was a problem [21, 28, 29]. They promoted economic and environmental design & engineering to develop with efficiency and achieve more with fewer materials, processes, and waste. Walter Stahel proposed, in 1970, that resources should be managed in a 'closed loop' [30]. Waste becomes a resource in a system called 'cradle to cradle' or the circular model. He also recognised the need to extend a product's lifetime by repairing and remanufacturing. Their combined visions ignited a movement that focuses on making waste a resource. The circular use of materials could ensure an infinite flow of resources and could well be the solution to the problem of manufacturing with increasingly limited resources.

For creating an infinite flow of resources, the circular model needs global recognition and collaboration to make a change for the environment. The model is visualized in Figure 1 and focuses on reducing, reusing, repairing, and remanufacturing to use resources again and again [1, 6]. In the Figure, the linear model is also visualized. This model disposes and incinerates most of its resources, while the circular model reuses the resources repeatedly. Planned obsolescence is part of the linear model as it shortens the product lifetime and creates more waste in contrast to sustainable products, which elongate the planned lifetime. Waste is used again as a resource. The global problem of the linear model is recognised, and to manage a sustainable planet, the United Nations (UN) has acted by composing Sustainable Development Goals (SDGs).

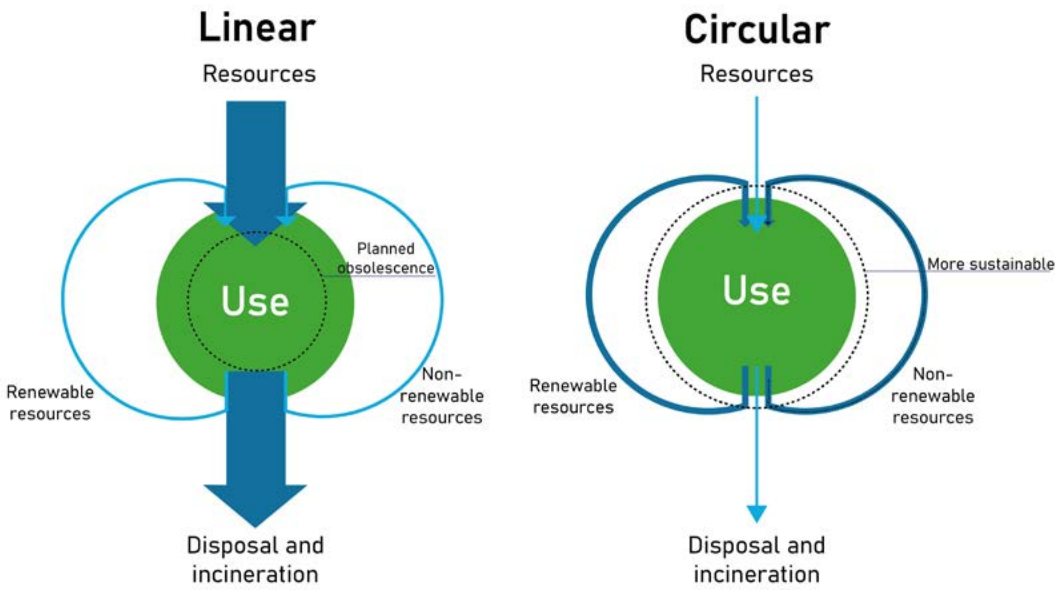


Figure 1 The linear and circular model of consumption adapted from [1, 2]

The SDGs have been set up through collaboration with more than 160 countries. This ensures the goals are recognized worldwide, but the targeted problems are therefore also global and broad. The 17 Goals are visualized in Figure 2, but the main goal is to protect the earth, end poverty, and ensure that by 2030 people will enjoy peace and prosperity [31]. At the same time, sustainability must be developed by balancing social, economic, and environmental actions. To prevent irreversible damage to the climate, the SDGs are essential, together with decreasing the carbon footprint by 49% in 2030 compared to 1990. The goal in 2050 is to have net zero emissions [31]. With these goals set, problems arise with the way the goals must be achieved. There is no clear structure for a company to follow and transfer the SDG into clear steps to change.

The sustainable development goals are set, but there is no guidance on how to decrease the environmental impact and how to achieve these goals. Because of that, it becomes hard for a company to understand the changes it must make. Furthermore, people have become used to short product use through always changing social trends and marketing, therefore keeping up with the market demand. The transition for a manufacturing company from a linear model to a circular one is challenging. They are accustomed to the linear model in their business model, and changing the business model is often seen as a risk [32]. Research that focuses on eco-methods shows that companies have a hard time making changes to their development strategy and applying methods that have not yet been determined as successful. Especially, with legal push and not yet decisive customers the gap of sustainability application increases [33]. The required change and the unclear approach to achieve these goals, which makes it difficult for companies to decrease their environmental impact and implement the SDGs. The world needs to transition to a circular economy to sustain itself, but the problem for companies is starting their transition towards a more sustainable company. Therefore, this research focuses on the first step in the transition to a circular model by decreasing the carbon footprint of manufacturing companies for attaining the SDGs.

Figure 2 The Sustainable Development Goals [10]

1.1 The Case Study

This research makes use of a case study to examine the research from a manufacturer's perspective. This company is Van Raam, a manufacturer of special needs tri- and bicycles in Varsseveld, The Netherlands. The company designs, develops, produces, and sells products to retailers. The company welds and assembles the products in-house. The origin of Van Raam goes back to the 1900s. The company started as a blacksmith's forge in Amsterdam and moved to the east of the Netherlands in the 70s, where it began to make bicycle frames. In 1986, the company shifted to developing special needs bikes.

As the market leader in its niche, the family-owned company is growing rapidly by 30-40% per year. Van Raam has founded a factory in Poland to keep up with the pace. The growth creates revenue, but on the downside, pressure arises for the employees to perform more work with the same number of people, in a tight labour market [34]. The production pressure creates a short-term vision as the growth problems must be solved first, because the company wishes to help all its clients that require a bi- or tricycle for their daily life.

The increase in sales causes pressure on all company departments. The pressure is causing the focus to be only on the short-term manufacturing goals, leaving the long-term plans not to be included in the short-term actions. Sustainability is one of these long-term goals. Despite the short-term focus, Van Raam values the company's sustainability and that of its products. The company has had a vision map for many years that shows a green sustainable environment, shown in Figure 3.

Van Raam needs to transition to a circular model to achieve its vision. Besides internal motivation, external factors such as the government have influence. The customers of Van Raam in the Netherlands are governmental institutions. These social and health institutions need to follow government guidelines to get the budget for buying products such as bi- and tricycles. As the government follows the SDGs, Van Raam needs to comply with these, to keep its primary clients. The long-term vision shows that Van Raam must change to a sustainable model to ensure the company's future.

Because of the internal and external factors, Van Raam needs to prioritise the integration of sustainability. Van Raam is occupied with producing and delivering products, so they do not have the time or people to focus on decreasing its environmental impact. However, the product development department could be the critical factor in implementing sustainability goals in the short-term strategy. The product development department is crucial because they decide on 80% of the material and processes the product will be manufactured with and therefore its environmental impact [16]. Product development makes decisions based on multiple factors to decide which concept suits better to the requirements. The decision factors are, for example, the quality, price, availability of goods and total size of production. The SMART specification must be followed when defining a requirement with higher changes to be met. This means that the requirement must be Specific, Measurable, Attainable, Realisable, and Traceable to all understood specifications [35]. By making requirements quantifiable the changes of meeting sustainable requirements are also higher. As a result, this study focuses on manufacturers who require support in incorporating sustainability into their product development processes for decision-making moments.

Figure 3 Van Raam's Vision map [7]

2 RESEARCH EXPLORATION

There is a gap for manufacturing companies to achieve the SDGs as there are no concrete steps to achieve these goals. More guidance is needed for companies to make valuable changes, and to set and achieve short-term goals to attain the long-term SDGs. Therefore, the main question for this research is:

How can sustainability be integrated and made measurable for decision-making in product development?

To answer the main question, multiple sub-questions are established, dividing the research into smaller essential subjects for structure and accessibility of the subjects. Sustainability needs to become assessable by making it more measurable and understandable, not only for product development but also for product assessment in decision-making. The first subject is the definition of sustainability, not only its meaning in literature but also its practical meaning for product manufacturers. Secondly, the measurability of sustainability needs exploration, together with defining the decision factor(s) that help to assess sustainability. In addition to exploring the measurability of sustainability, the goal is to provide a solution that supports companies in sustainability assessment in the product development process, which follows the third sub-question. To implement the solution in the company, the current development process must be adapted. This adaptation must be managed to ensure a smooth transition. All essential subjects are thus outlined in the questions below:

1. What does sustainability mean for product manufacturers?
2 What do product developers need to quantify sustainability?
3. How can a product's environmental impact support sustainable choices in decision-making?
4. What is required to implement sustainability as a decision factor in a company?

2.1 The Structure

This research follows the structure of the research questions to where the sub-questions support the answer to the main question. The first and second sub-questions are addressed in Chapters 3 and 4. Chapter 5 defines the requirements for developing a solution. As a result, Chapters 6 and 7 explain how to use the developed solution. The third and fourth sub-questions are then clarified answerd in Chapters 8 and 9. The research concludes with a discussion in Chapter 10 and a conclusion in Chapter 11 that answers the main questions.

2.2 Research Approach

This research makes use of the User-Focused Development (UFD) process, shown in Figure 4, as the foundation for the development of a solution for the gap between the SDGs provided by the government and the actual implementation within companies. This is used to design and develop a solution for sustainability assessment to the make sustainability of a product assessable for product development.

The User-focused Development (UFD) is a method that focuses on product developers. This is done by understanding the market, scoping the research, and developing a solution that can be implemented in the environment. The UFD is based on the combination of two design methods; the User-centred Design (UCD), and the Design Thinking method [2, 3]. These design methods fit within the purpose and focus, but the structure of developing a solution is missing steps. Both methods focus on the user through empathy, problem-solving, using iterations and collaborations. The UCD then focuses on the users' needs with feedback and develops something that the users need. Design Thinking is more focused on the desirability and feasibility of solving problems by thinking 'outside' of the box. The focus of both methods suits this research, but the UCD and Design Thinking both miss the analysis of the market, besides the user [2, 3, 36]. Also, the implementation misses, as this is important for the solution to be applied within the environment. The developed UFD adds the missing steps and brings together the required development process for this research.

The UFD focuses on the user to develop a solution through iterations and reviews. It is leading in developing a suited but feasible solution. The UFD method will support the research's structure and execution. The research aims to find a solution that brings additional value to the company's sustainability goals, is accessible for setting short-term goals, to make a valuable and lasting change for the future.

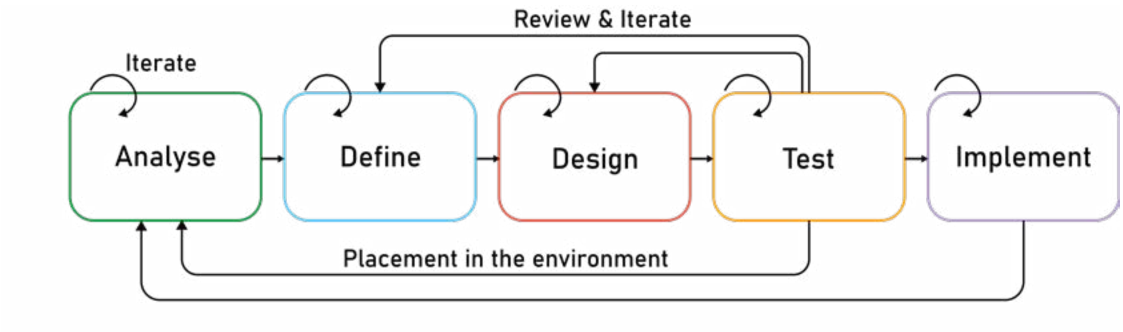


Figure 4 User-Focused Development (UFD) process, developed based on [2,3]

3 ANALYSING MARKET

The gap between the linear model and the circular model is too broad for companies to make straight-forward, valuable changes. However, some companies did manage to close the gap to become more sustainable. Their approach and meaning towards sustainability could be interesting to understand why, how, and when they made changes. Therefore, this chapter answers the first sub-question: **'What does sustainability mean within product manufacturing?** The question focuses not on the common definition, but the meaning in which sustainability can be executed for product manufacturers. Multiple companies' approaches toward their sustainability vision and goal are explored. By analysing the market, companies that did succeed in their sustainability transition can be an example to help other manufacturers to start with their approach to the transition. Besides identifying the current level of sustainability and its application in the market, a case study is used to elaborate on the meaning of sustainability in the market.

3.1 Product Manufacturers

The definition of sustainability is rather abstract for a manufacturer to work with. According to the European Union, sustainability means 'providing a long term vision for sustainability in which economic growth, social cohesion and environmental protection go hand in hand and are mutually supporting' [17]. The definition mentioned that sustainability focuses on the long-term, but this is hard to do if the short-term has a higher priority. Though to identify sustainability within a company, the three values can help. The balance between the economic, social, and environmental values can be used in a framework to measure a company's sustainability, which is the Triple Bottom Line (TBL). The TBL uses three circles that cross one another, and, in the middle, there is sustainable cohesion [37]. The identification of a company's balance can define a company's strengths and areas for improvement. For a company to sustain economic, social, and environmental cohesion is needed to be resilient to the hazards that come.

The meaning of resilience is for a company that it has economic, social, and environmental cohesion and can overcome (sudden) challenges. For example, treating the employees right can increase well-being and work efficiency which can improve the economic area. If the prices of materials increase, or are not available, then having other resources available or reusing materials will save expenses. A company becomes more independent by achieving cohesion. This is essential for the future as resources run out, waste increases and more people will live on earth. A company that is prepared and resilient can continue to exist. Active adaptations are needed for sustainability and circularity whereas reactive changes increase pressure and costs, which create unbalance.

Figure 5 The modularity of the Fairphone 4 [7]

Some product manufacturers are actively applying sustainability and are on their way to a circular consumption model. Such as by selling shoes created from ocean waste [38]. By creating headphones or mobile phones designed for disassembly and can be easily repaired [39]. In Figure 5, The Fairphone is visualized, this company aims to create products that last, reduce e-waste, use fairer materials, and have fairer factories. Thereby, it focuses on all three elements of sustainability. A product can also be rented from a company with this strategy a service is sold. With a service, the product ownership is at the company. Hereby, the quality of the product is maintained as high as possible. A high-quality product can save money for the company as people pay per use or per month, such as with Swapfiets or Go sharing [40]. On the other hand, the service creates that consumers take less care of the product, and this decreases the lifetime. The companies also see that sustainability has a brand purpose and support to promote their product or service to customers. People are willing to pay more for sustainable development as this increases revenue and brand value and creates distinction from other companies [32, 41]. Therefore, sustainability is creating revenue within a circular consumption model.

3.2 Sustainability application at Manufacturers

For companies to create revenue from a more sustainable approach is appealing, as people and other businesses are more willing to pay more for sustainable products. This willingness is pushing the market for faster change, and some manufacturers manage this, despite the gap between the goals and the strategy. In this section, four manufacturers are analysed by desk research to see how they attained sustainable cohesion. The focus of the desk research is on bicycle manufacturers as this gives a good example of how even a sustainable product such as a bike, which is better than using a car, can be optimized, and improved to become more circular. Besides that, this makes the comparison to Van Raam clearer as it is within the same industry. Friesland Campina does not make bicycles but is a large company that is added to identify the bigger picture for comparison and broadening the analysis. Therefore, a big leader in a large industry needs to adapt, but the changes in a major company can differ from the bicycle market.

3.2.1 TREK

This company is the biggest bicycle producer in the United States. It was the first bicycle company that looked 2018 at its emissions and thereby in the production of the bicycles, shown in Figure 6. The company's CEO is concerned about environmental changes and wants to decrease the impact of TREK bicycles. This life-cycle assessment was not performed before in this market, as bicycles were already seen as 'green products. Together with the consultancy WAP Sustainability, the company investigated its impact on the environment, which is put in a sustainability report [10]. The social and economic environmental focus is hard to identify TREK, as their view on sustainability focuses fully on environmental sustainability.

Figure 6 TREK's Rail Bike from the Sustainability Report [11]

3.2.2 Gazelle

Gazelle is another major bicycle manufacturer that is following TREK by applying life-cycle analyses. The company just started, in April 2022, to work with PRé Sustainability [42]. PRé Sustainability is a company that developed life-cycle assessment methods for calculating the environmental impact of a product [42]. Gazelle performed this research to identify the effect of one of their electric bicycles to determine where the problem areas are and to set a plan for decreasing the impact. Gazelle shows a sustainability page on their website, in which they explain that they focus on a couple of SDGs. Although they focus on these SDGs, how to achieve them in the short term is not explained by any structure or results. The TBL is hard to define, but Gazelle mentions that it does focus on all the sustainability elements except those elements are not SMART-defined [44].

3.2.3 Roetz

Roetz is also a bicycle manufacturer that does the development and manufacturing in-house. It is a social enterprise employing people at a distance from the labour market. The bicycles are made by restoring and treating existing bicycle frames [45]. Roetz is also working for the 'OV fiets' to repair the shared bikes and make them usable again. The company is relatively new, as it was established in 2011 in Amsterdam. However, its impact is significant as the company is trying to make a 100% circular bike so that it can be repaired or remanufactured to become a new bicycle. Roetz invests in social, economic, and environmental sustainability by being a social enterprise, restoring, repairing bicycles, and using as less new materials together by collaborating with other organisations to increase the availability of work.

3.2.4 FrieslandCampina

The last company that suits sustainable change well as a market leader is Friesland Campina. The company created the tool; RESPACKT. The company produces over a billion kilograms of consumption products per year. For this, it uses many types of packaging all over the world. Which varies by country and product, if the materials can be recycled and how to be efficient [46]. For that reason, Friesland Campina created the RESPACKT tool. RESPACKT evaluates packing not only to decrease product materials but, also, to reduce product leftovers. The goal is to ensure lower environmental pressure, less food waste, and better recycling [46]. This developed tool shows that a company can develop a program to suit their production, as there was not something on the market that suited Friesland Campina in its sustainable goals.

The company also focuses on the SDGs but, translated the goals to their vision within the shorter term or even longer term than the SDGs provide. The social sustainability it provides within supporting farmers in their emission by also having developed a tool for them. The economic sustainability is by collaboration with many suppliers and manufacturers and as a market leader, its economic focus is important to maintain. As a large company in the dairy industry, although it pollutes the environment through its emissions, it has reduced its emissions and met its 2020 sustainable targets, as shown in Figure 7 [13].

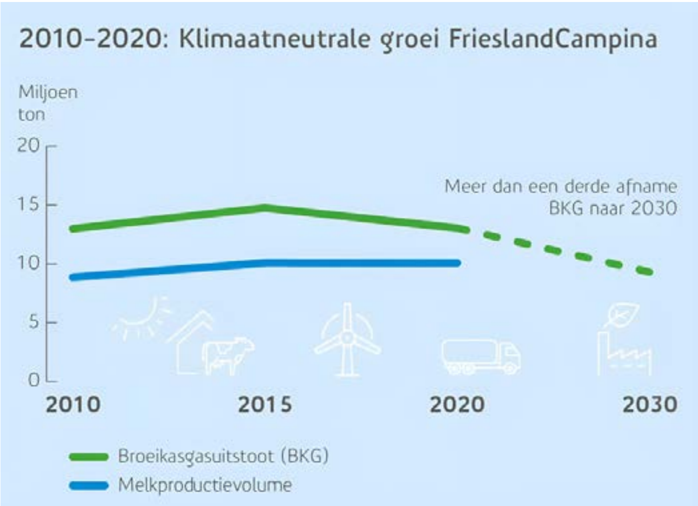


Figure 7 The Climate-neutral growth of Friesland Campina [13]

3.2.5 Conclusion

The manufacturers all have in common that they are trying to apply sustainability to stand out from their competitors. What emerges is that sustainability is mainly perceived as making environmentally conscious choices, the social and economic aspects are hardly mentioned in this subsection. Gazelle and TREK show their environmental sustainability changes and are not explaining the SDGs into how they will achieve the goals. While FrieslandCampina established and explained its own short-term goals to achieve the SDGs. The motivation to pursue the environmental sustainability changes differ per company, but they show that there are multiple ways to make adaptations for environmental impact, with applying LCA's, looking at the reuse, remanufacture, reduce and, developing a tool that decreases its environmental impact.

3.3 Company Visits

Besides the desk research, field research is examined by visiting two manufacturers. The visits provide more insight into the challenges companies face and their examination of their vision and goals. Thereby, the TBL is also looked at to determine if the company is resilient to hazards by having a sustainable balance. The visited manufacturers were Royal Auping and Huka. Royal Auping is a mattress manufacturer which is open to visitations to spread its knowledge and process. The visitation was guided by a product developer of the company. HUKA, was visited as this is a Van Raam competitor and thereby is within the bi and tricycle market. Therefore, it is interesting to see if, and otherwise how, they achieved the balance.

3.3.1 Royal Auping

Royal Auping is a Dutch manufacturer of beds which makes a sustainable change in its market by developing circular mattresses. Thereby, it is prone to show its strategy and the challenges it has and still is facing. In 2012 the company started to make a sustainable change to create the first 100% circular mattress. Its vision was achieved in 2019, and its current products are all 100% recyclable as it is made from recyclable and recycled materials. Figure 8 shows the circulation of the mattress, this is possible as no glue is used, and every part of the product can be separated for recycling [12]. The approach for managing the change was to hire a circularity manager. The manager sets deadlines and meetings to create a sustainable push. This did work, but only managing sustainability did not develop the solutions on how to achieve the goal. To make a valuable change, the product development team searched for opportunities to manufacture circular mattresses. The outcome is great, but there are still improvements to make.

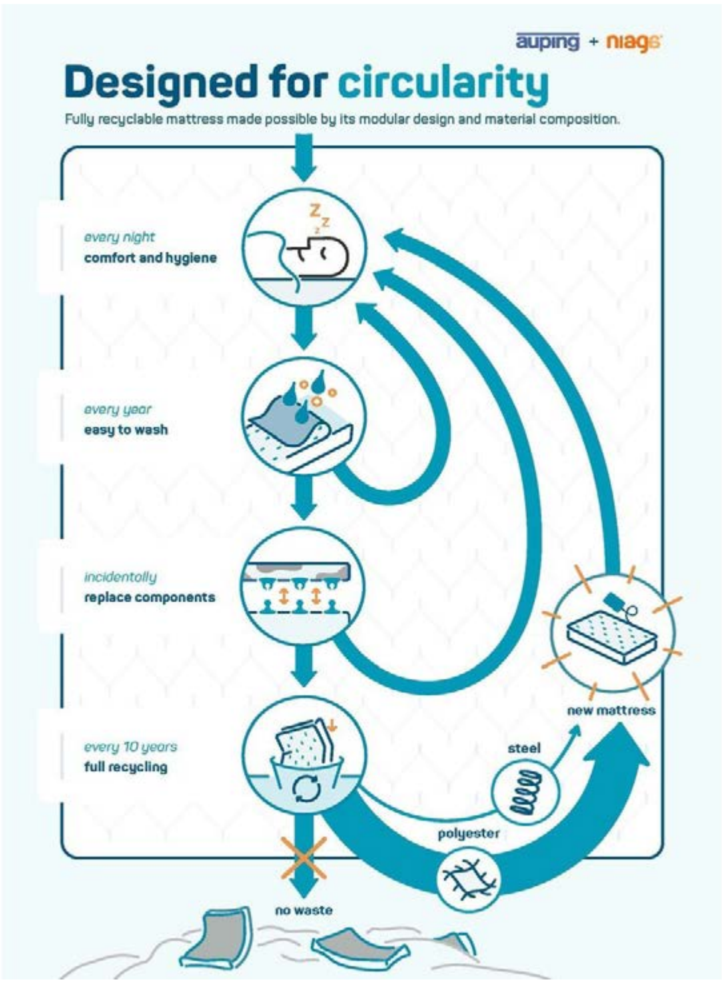


Figure 8 The circular model of Auping and Niags [12]

The spark to change in 2012 was the amount of waste indicated in the mattress industry. Within the Netherlands, more than one million mattresses are disposed of every year [12]. The process of disposing was not going well as many mattresses were left outside and could cause a fire because of moulds, which is dangerous. For the transition, Auping collaborates with other companies and universities to achieve a better recycling process and keep improving the products, such as with Niags, Figure 8. Auping supported the law that mattresses needed to be collected by mattress manufacturers. It was already collecting its mattresses, so it did not have to change, but for the competitors, it was sudden to transform their business model to collect mattresses. All in all, looking at the social, economic, and environmental cohesion, the company achieves a good balance and is therefore resilient for its future.

3.3.2 HUKA

HUKA is a bi- and tricycle company in the Netherlands, Oldenzaal, which is working for over 40 years in the bi- and tricycle industry, see Figure 9 and has much knowledge about the products and their market. The company develops and assembles its product locally, and it works together with a design agency to improve and make new products. The product development consists of two persons who focus on translating the designs into the product to be manufactured. Many things have changed at HUKA growing rapidly as a company but also in the international market, then the change of company's ownership and having issues with its supply. The company is working on their sustainable strategy, but this is not defined. HUKA is proud of its employees and products to help people that need specialized bikes. The vision of the company is 'Products that make your world easier' [5]. The company shows on its website that it will invest in sustainability and corporate social responsibility. Though, there is no strategy shown to achieve this vision. To conclude, HUKA seems to have a high social value, and a well economic balance, but the environmental value is lacking in concrete action.

Figure 9 Huka Cortes [5]

3.3.3 Conclusion

The visits to the manufacturers show how environmental sustainability can be a key selling value and how it is still hard and unknown how to apply it within the company. Huka is an example of many manufacturers that want to change but do not know how. Thus, it puts the SDGs in the long run. Royal Auping succeeds to have the TBL balance by collaborating with other companies and having a structure with a board of directors and a sustainability manager who pushes the developers to find solutions. It becomes clear that the push from the board motivates product developers as well as someone taking the lead in planning the transition. To tackle the problem of not knowing how to apply sustainability, the strengths and, opportunities of the company need to be analysed through a sustainability analysis, to make easier and more suitable changes.

3.4 Sustainability Interpretation

In the market, it becomes clear that manufacturers perceive sustainability in different ways. One has found a method to make environmental sustainability applicable, while the other is hesitant and fearful of the risks of adaptation. It also appears that manufacturers perceive sustainability only as environmental sustainability and leave out its social and environmental elements. The misunderstanding of the balance only creates more distance for applying sustainability within the company for achieving SDGs and overcoming climate change-related risks.

However, the market analysis through desk and field research only partially shows the meaning of sustainability, as the companies can present themselves how they wish to be perceived. The applied sustainable methods do give an idea of how sustainability can be applied in product manufacturing, but to make valuable changes, a manufacturer must understand what sustainability means in its context. The changes need to be close to the manufacturer's strengths and opportunities, as is the case at Auping. This is especially relevant for companies like Huka and Van Raam that do not know how to implement sustainability. Therefore, a sustainability analysis can be performed. The sustainability analysis is meant to identify the strengths and improvements of a manufacturer according to the TBL. This analysis identifies the possible changes that are needed, which can define short-term achievable goals to change for creating a sustainable balance. This sustainability analysis will be performed at Van Raam, but in general, this is applicable and useful for other cases of manufacturers.

3.5 Case Study: Sustainability Analysis

The case study is used to apply the sustainability analysis to identify the manufacturer's strengths and improvement according to the TBL to make short-term sustainable changes close to the company's core. Multiple product developers are interviewed to understand the meaning of sustainability for product manufacturing. The sustainability analysis includes interviewing the target group, and the product developers, but also meeting the board of directors is valuable. They are essential to support product development to develop more sustainably and establish short- or long-term goals that support the SDGs.

At Van Raam the target group, the product development department, is interviewed which exists of eleven people divided into the function of Product Management (PM), R&D Engineering and R&D Manufacturing. In Attachment A the complete interviews are described. In the interview, only the sustainability vision of Van Raam is important for the sustainability analysis. Though the interviews are more extensive but that is not applied within this section. The sustainable values mentioned in the interviews resulted in Figure 10. The image shows that Van Raam has high social strength, but the environmental value is undermined. The company's social value is vastly maintained throughout the years, but the environmental focus is put aside, whereas the economic focus is almost balanced.

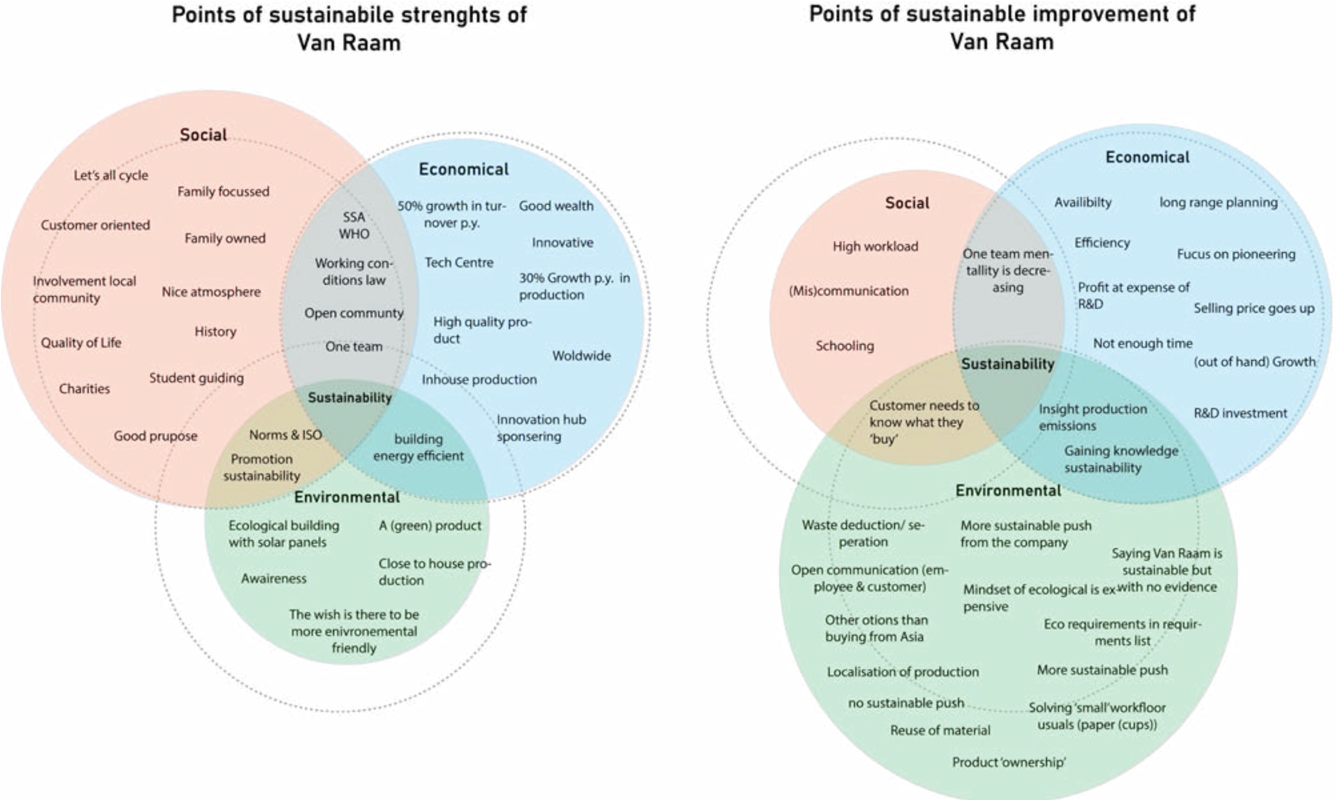


Figure 10 The Sustainable Strengths and Improvements of Van Raam by applying the TBL

3.5.1 Target Group's meaning of Sustainability within Van Raam

In the interviews, it became clear that the target group feels that the board of directors must push the developers to more sustainable improvements. They feel there is not enough time, money and sometimes product resources, available to make adaptations. The projects of new developments are in rush, especially because of not enough people and thereby a high workload. This is mainly caused by the focus of the company and employees on the quality, costs and new technology as the company wants to keep the prices low to be affordable but also provide the best for their customers. In these situations, even limited environmental requirements are overlooked. At only one part of the tricycle, the bamboo tray, the design for sustainability was the key focus. Though this was a hard process as not everyone in development agreed. In general, the target group is open to change, but the change must be effective and support for defining sustainability needs to have enough added value. So, for the target group, the environmental sustainability needs more attention by spending more time researching appropriate additions to include sustainability in product development.

3.5.2 Employer evaluation

The results of the interviews were surprising for the board of directors, as this steered the meeting. They expected that the social and economic values were good and, maybe the environment was lower, but they did not expect it to be so low and problematic. They agree that they, as Van Raam, must do something. However, they want clearance and some assurance in the change. They mentioned in the conversation other companies and countries that do not have sustainability within their cooperation, so why would they do it? Additionally, the vision of Van Raam is not to be the most sustainable company as the focus is on: Let's all cycle. Though, if to apply sustainability they would like it clear and simple, such as product labelling, which is done with refrigerators. Also, to push such a change they would like product development to take the lead, as they have the product knowledge. The board was therefore surprised that 75% of the electric bike emission comes from the manufacturing and transport of the product. While, 10% is used and 15% is disposed [47]. The product itself has much impact. Thereby, the manufacturer can influence decreasing the environmental impact. The board is prone to do something, but it must be clear, needs added value and with low risks. The board is interested in sustainable change but because of the lack of knowledge they are hesitant and in denial, but there is a willingness to make changes.

3.5.3 Conclusion

The sustainability analysis shows that Van Raam has high social but a low environmental value, thereby the sustainable balance is off. To improve the balance, the company needs to focus on their environmental sustainability, exploring the improvements that are mentioned. The environmental improvements do overlap with some of the methods that are used by manufacturers in the market. Then, the sustainability push from the board of directors is a difficult case, as the board of directors thinks that the target group can lead any environmentally sustainable changes. Both parties are pointing to one another, which will make changes harder as no one feels obliged to adapt. The perception of Van Raam of sustainability is. Yet both are reluctant because they want a solution that is valuable but with few changes and risks.

3.6 The Chapter Conclusion

This chapter answers the research question: **"What does sustainability mean for product manufacturers?".** Sustainability for manufacturers means being resilient for the future by establishing social, economic, and ecological cohesion to overcome hazards. Though this meaning is not understood by all manufacturers as they perceive the definition as only its environmental facet. The misunderstanding of the balance creates more distance to making sustainability applicable within the company for achieving SDGs and overcoming climate change-related risks. Though some manufacturers did succeed as they perceive sustainability as an opportunity to separate themselves from competitors and to maintain within the future. For manufacturers, sustainability can be seen as an opportunity to differentiate itself from competitors while for others it is an unknown area which will cost investment and research to understand how to become more sustainable. The meaning of sustainability for manufacturers is not the same. That shows that more research is needed to understand sustainability for product manufacturing. Therefore, more exploration is needed into the methods the manufacturers applied to make essential sustainable changes for making sustainability part of the company's decision-making.

4 SUSTAINABILITY ASSESSMENTS FOR PRODUCT DEVELOPMENT

The problem in including sustainability in product development is understanding how, when, and where to apply it in the process of development. As the meaning of sustainability is perceived as environmental sustainability, the research will focus on this area. Sustainability is therefore used as its meaning is the environmental impact. In the market analysis, companies made use of tools and methods to apply sustainability. Those companies show that there are various ways to use sustainability tools and methods within product development to make valuable changes. In the introduction, it was mentioned that the quantification of sustainability is important because with SMART requirements the targets will be easier to conform to, especially in a diverse development team [35]. The quantification makes the goal assessable and understandable for decision-making. Though the manner of how, when, and where to quantify sustainability is not yet determined.

To develop a solution to apply quantification of sustainability within product development, the question that arises is: **What do product developers need to quantify sustainability?** The product developers are the target group and the users to quantify sustainability, and therefore their needs are essential to find a solution that fits. The chapter investigates by literature research the methods that are mentioned in the market analysis to understand those approaches. Next to that, the product development process is identified with the case study to understand the developers' needs for sustainability during that process. Eventually, the findings come together to identify if there is a method that supports product developers to quantify sustainability.

4.1 Literature Research

As mentioned above, this literature research will further explore the sustainability methods and tools used in market analysis. Roetz focused on the reuse of materials, TREK and Gazelle on life-cycle assessment (LCA) and Friesland Campina developed a tool. Besides that, in the interviews, the product developers mentioned a product that was designed for the environment and the board of directors of Van Raam talked about product labelling. All these practical examinations and ideas are appealing, but more research is needed for answering how, when, and where to apply the methods, to understand their use and potential. In this subsection, the literature research is performed with the following methods: the R-method, Design for Environment, the LCA's, and product labelling.

4.1.1 Awareness by The R's method

The R's method is a method extracted from the vision of Papanek and Fuller, who were already looking at an economic and environmental perspective by reducing materials processes, as mentioned in the introduction [21, 28, 29]. The R's method is meant to decrease the amount of waste by looking at aspects to prevent the waste from existing. The method implies extending the life-cycle by, for example, recycling. The amount of Rs per method goes from general to more specific aspects, which are explained below. The methods are shown in the Figures 25-28 in attachment B.

The most general R method is the waste management of 3R's to Reduce, Reuse and Recycle. Another waste management R method is the waste hierarchy of the Ladder of Lansink [48]. A Dutch politician introduced the 6R's method to prioritise the avoidance of material, and if needed, the recovery is made for high-quality reuse as recycling and energy recovery. Wheatear disposal as landfill and incineration is the least preferred. Besides the waste management R methods, there are also circular focused methods to create a strategy for easier circular development. The most known circular model is the Butterfly model of the Ellen MacArthur Foundation with 7R's [6]. The model focuses on three principles: 1. Concentrate on preserving and enhancing natural capital 2. Optimise resource yield by circulating product 3. designing negative externalities (reducing damage and pollution). Then in 2018, the 'Planbureau voor de Leefomgeving' (PBL) came up with a report that showed 9Rs to focus on developing a circular economy [1].

The R methods support awareness of decreasing the use of (new) resources and design for the needed function, and additional functions or attachments that are not required can be refused. The methods help designers think about the design's necessities and rethink the design to reduce waste. The recycling element is one of the last options for the product. The R methods are short and straightforward and do support awareness of sustainability. However, the method is not as numerical and tangible to define the impact of the product.

4.1.2 Design for Environment

Another development method that focuses on the general principles of sustainability is the Design for Environment (DfE). The definition of DfE is "the systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life-cycle."[49] DfE focuses on the early implementation of the product's life-cycle within the design phase. It has similarities with other methods such as design for manufacturing (DFM), design for assembly (DFA), and design for production (DFP). Two researchers investigated the development and application of DFM and DFE requirements in product design. The DFM requirements are similar to the DfE ones, as the goal of DFM is to reduce costs and time for manufacturing. It is not only about saving costs, but also about the reduction of energy use. The goals of DFM are similar to the improvements of the DfE by materials and energy efficiency, and reducing materials use waste and costs [50, 51]. However, DFM is more excessively used in companies than the DfE.

29

By designing from a specific view, the focus is on one area for improvement, which makes problems visible, and a design can therefore be improved within the earlier design stages. The DfE design method is the umbrella of the other processes that can be implemented. The advantages of DfE are cost reductions, reduced business, and environmental hazards, expanded business and market potential, and compliance with environmental standards. The complete DfE can be large and too much for a developer to integrate [52]. That is why focusing on sub-parts can make the assessment easier. Some aspects are Design for Modularity, Maintenance, Reuse, Disassembly, and Recyclability. These types of design focuses can all help to improve the product on its sustainability aspects.

The DfE is not a commonly known method but has similarities to the DFM. The method focuses on one element to identify problems which are otherwise overlooked. The DfE makes the user aware of the problems and therefore valuable changes can be made already in an early stage of the design process. The DfE stirs the developer to think about the product from different viewpoints, but it is still bound to the developers' insight to design for environmental purposes as well as the tangible or quantifiable tools they will use.

4.1.3 Quantification by Life-cycle assessment

An LCA quantifies the impact of the product over its life-cycle. Which makes the product assessable for measuring the environmental impact. This is done by identifying the product's material, processes, transport, use, and disposal [7]. In Figure 11 the LCA Framework is shown which is developed according to the ISO 14040 standards. The LCA is used worldwide as a manner to quantify sustainability. The LCA makes it becomes possible to compare products or parts in its Function Unit (FU). The FU makes an LCA assessable to the function the products are set to [53]. The analysis can support sustainable choices for decision-making, as it gives the product's environmental impact compared to its performance. The framework shows the user's steps to identify a product's impact on improvement, planning, policy-making, marketing, etc. The framework indicates comprehensive steps with many interactions between phases. Besides that, there is no beginning or ending in the framework, and an ever-interacting back and forward flow. The construction can confuse people who want to apply an LCA. Thereby, a LCA is sensitive to data diversity due to the several programs, methods and the person entering the data.

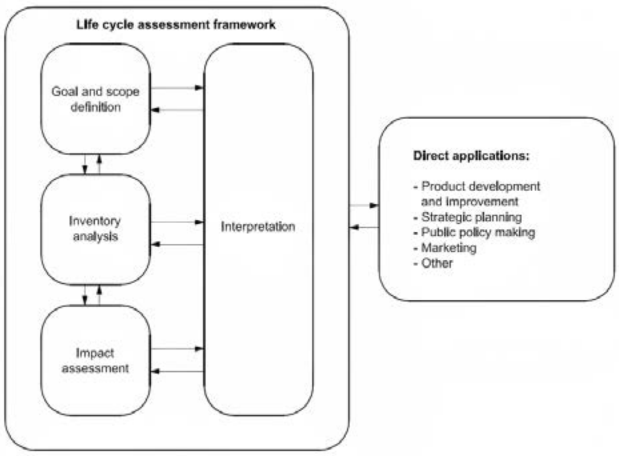


Figure 11 LCA Framework stages [7]

To apply an LCA measurement methods and calculation programs can be used, matching the type of assessment. The measurement methods classify and characterise the environmental impact, such as ReCiPe, Eco-Indicator 99, CML 2001 [54]. These define environmental impact in categorization factors, such as CO^2 equivalent (CO^2-eq) or milli points (mPt). The categorization factors, quality and accessibility of the data vary among the methods. These methods are applied in various programs. The programs differ in advancement, quality, and time it takes to assess. SimaPro and GaBi are advanced but very time-consuming programs. The user needs the experience to understand and evaluate the LCA. Other programs such as EduPack, Solidworks or Eco-It are easier to use. Less expertise is required to determine a product's environmental impact [55]. However, the programs do need a lot of input to assess an LCA. In many cases, some factors, such as the type of disposal, are not always known. Unfamiliar situations within an LCA assessment can be a barrier to implementing LCAs. However, the analysis can be interesting for marketing, as showing the customer a decrease in environmental impact can be prof-

4.1.4 Marketing by Product Labelling

Product labelling helps to show companies' customers its quality and vision to create an outstanding product. The labels can be achieved by different conditions and by assessing an LCA for a product. According to the ISO, third parties can check if the products suit the label's requirements and release the label for the company to use. There are over 400 ecolabels in all kinds of markets and countries, many labels from FSC to energy labels [56]. The energy labels were applied already by law, in 1990. The EU energy labelling is meant for major appliances such as fridges. The energy label was introduced to create competitiveness in the market, decrease emissions and increase efficiency. The label was first established for several home appliances, then expanded In 2004 and rescaled in 2019, Figure 12 [15]. The label has a comparison scale ranging from A (most efficient) to G (least efficient). Before 2019 it went from A+++ to D. This means that before 2019, a product labelled as A+++ is now a C label. The change was necessary because too many products were scaled in the highest label (A+++). This new situation creates better distinction for the customer and companies develop more energy-efficient models to stand out against the competition.

Energy ratings are found all around the globe but besides energy labelling, eco-labelling is founded [57]. A collective of companies started a trial in supermarkets like Lidl and Carrefour to label products on their environmental impact [58, 59]. This 'eco-labelling' helps customers to become aware of the ecological impact of the product. However, there are non-authorial institutions that made not trustworthy product labels. An example is the 'ik kies bewust' (I choose consciously) logo, which over 60% of consumers believe was created by the Dutch government. In contrast, it was commercially created and not verifiably assessed [60, 61]. This logo fooled customers and lowered people's trust in such labels. So, before implementing a label for marketing purposes, the label must be accurate and checked but labelling can help internally to improve a product with clearer achievements, such as the colour-coded energy label.

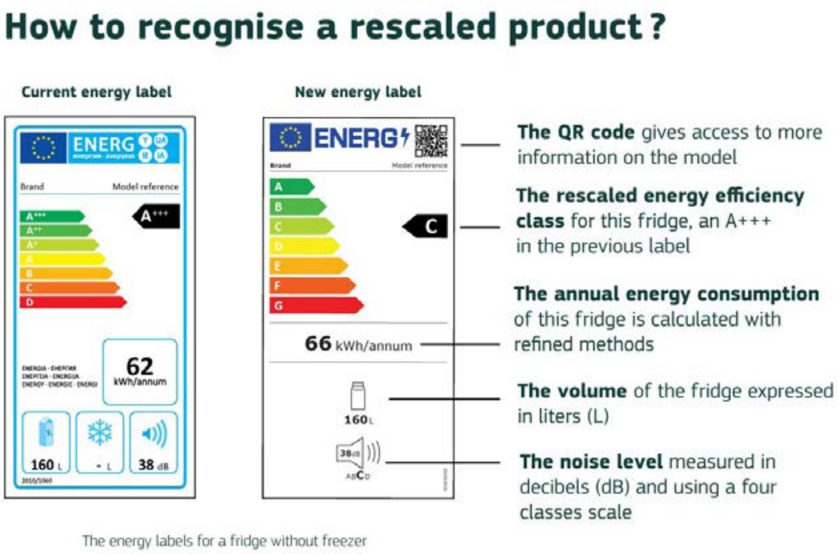


Figure 12 The renewed energy label [15]

4.1.5 The Conclusion

The examination of the methods shows that only the LCA method can assess and quantify sustainability. The other methods also have qualities that could be applied. The traffic light labelling gives a clear indication of how good or bad a product is and that would apply well to the results of an LCA to make the data understandable. The Rs and DfE focus on sustainability awareness and remind the user to think about certain aspects. This fits every step of the development process, but these methods are not as concrete. The solution to apply LCA is not yet specified, as the current LCA framework is unclear and complicated to understand let alone apply. The LCA programs are labour intensive even though there are emerging programs, and more research is needed as to whether they are accessible enough, but for that, the needs of the product developers need to be investigated first.

4.2 Case Study: Product Development Process

The product development process and its structure provide insight into the development of its stages, importance, and challenges. The different decision-making stages also have various examinations and focus points to determine the product's release to the market. Per company the product development process can differ, for this examination the product development process of Van Raam is applied and utilized as the case study. Thereby, Van Raam is experienced in product development as they are in the manufacturing market for over 100 years. In this section, the process is examined to define the target group's needs and the decision-making moments.

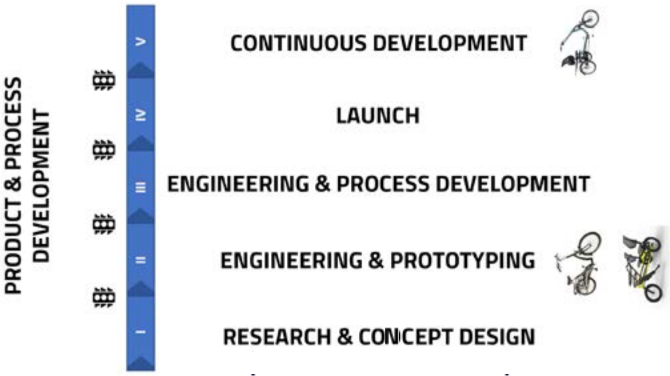


Figure 13 The Product Development process at Van Raam

A complete development process of a product at Van Raam takes at least one and a half years from idea to launch. When a product has been developed, the product is manufactured for over ten to 15 years. The product's expected lifetime is also 10 to 15 years. In Figure 13, the product development process of Van Raam is visualized. This research focuses on the first three phases, as these are key for product development and environmental impact [17]. In Figures 30 & 31 in Attachment C, The Product development funnel is shown and of the first three phases a flow diagram is extracted for a more specific flow of examination and decision-making, which is extracted from the funnel and meetings with the target group. In the meetings, the process was in more detail explained than the funnel shows. Those meetings were arranged by the target groups' function which was with PM, R&D Engineering and R&D Manufacturing. In the following section, the first three phases are examined. The results of the interviews, mentioned in the case study, show the developers interests and needs in applying within their

4.2.1 Phase 1: Ideation

In the first phase, PM is in charge and focuses on the Project Initiation Document (PID) to Project moment, seen in Figures 28 & 29. The decision when PID becomes a Project is done by a meeting with the board of directors and other R&D colleges. Multiple PIDs are presented and assessed based on the PID's presentation factors. In Figure 30 the PID presentation view is shown. The assessment is based on ergonomics, look & feel, price & quality, safety etc. The factors are not all as measurable, but these factors are determined by knowledge and research. However, the PID is merely the idea without a further determined design. Therefore, the story around the product is as important as the above factors. Out of this poster presentation, a choice is made, and a PID becomes a Project. When this transformation is happening, a list of requirements is established for the project to determine the target group, the use, and the focus points. The example list of requirements is visible in attachment D.

4.2.2 Phase 2: Conceptualization

After the ideation phase, A Project is transferred to an R&D project leader in the conceptualization phase. The product developer sets the requirements for the project and still plays a part as an executive member of the project. A project team is created, and as the development takes up to a year, the project leader focuses on the expenses, planning, and assessment over that time. In between the process, interim appointments with the executive board are held to determine if the project is on the right track. Ideas and concepts are defined in smaller detail than in the first phase. The comparison is done based on the materials, processes, availability and especially costs while sticking to the requirements. To view the concept in real size, the prototyping and testing become more significant. If the product fits all the requirements and is approved by the developers and the board of directors, the product goes to the third phase.

4.2.3 Phase 3: Detail

In the third phase, the focus is to make the concept ready for manufacturing. The R&D production is becoming involved as they create the production dies. The concept must be changed to operate the product in production and assembly. Many purchase products are already purchased and therefore defined as extended delivery time. So, the developers must design around the fixed features. If the product is manufacturing-ready, the product is launched and put on the market. In the last phase, not further explored in this research, the maintenance and development will be ongoing.

4.2.4 Product Developement needs to define Sustainability

In the individual interviews of Attachment A, the expectation and needs of the target group are found. The product developers all agreed that a change needs an added value, as mentioned in section 3.2. The added value must be easy to apply, understand, and interpret, but must bring new information which is reliable to use in decision-making. As an example, in the last years a 'bamboo tray', a tray of a tricycle, was developed to be a sustainable product. Much effort and discussion were put into the product, but it was hard to define if such a tray is certainly more sustainable than a 'normal tray'. This comparison aspect would be beneficial. Many people explained that sustainability is a subject of which it is hard to define the meaning, inclusion, and focus areas. Therefore, the support needs to be clear, not take a lot of time, provides added value, and focus on a specific part.

In the interviews, people did not all agree with each other, as they work in different phases of the process, or they do not see why they should put effort into applying sustainability. Some R&D Engineers want a high-quality program, while others would like a structure that gives direction for making sustainable choices. Though, a program that makes use of calculations sounded useful and reliable to most people. The target group has not worked with any sustainability tools apart from the 'bamboo tray' development. All in all, the target group is eager to help and is interested in the results.

4.2.5 The Conclusion

Each stage has different focuses and need to implement sustainability. In the ideation stage, one of the concepts will become a project which requirements are created for. So, in the concept presentation and in the requirements, sustainability can be assessed and implemented. In the concept stage the options for product parts are compared in its quality, price, and availability and according to the requirements. Whereas in the detail stage the preparation for manufacturing is of essence and changes are made to make production easier, which is a harder stage to make sustainable changes. The needs of the product developers are generally matching. They need a support that is easy to use, apply, and must provide additional value. It does not have to be complicated, but the support needs to be valid and understandable.

4.3 Sustainability assessment in Product Development

There are multiple methods, tools and, programs that can be used to assess sustainability in product development. The methods differ in the depth, ease of use and application. The research focuses on quantifying sustainability, which can be done by an LCA. To understand all the methods' purposes within the development process, Figure 14 is established. The examined methods are according to the UFD process identified for product developers to use. Besides the UFD, the development process of Van Raam is visualized to show the case study's connection to the methods. In Figure 13 it becomes clear that within the ideation and conceptualization phases there is no quantification method as the LCA is only applicable in the detail and the continuous development stage.

The gap of having no quantification method to define sustainability in the earlier stages means that for the development of a solution that applies sustainability in product development, more focus is needed on those stages. The other methods, such as the Rs method and DfE can be applied during the whole product development process. These methods support awareness and are easy to implement, though they do not support the needs of this research's aims. The current LCA framework is not applicable for product developers, as the LCA programs are labour-intensive and can only be used at the end of the development process. The same applies to product labelling, as this can be based on the results of the LCA, and the labelling is used for and promotion. Though it makes the results easy to interpret, there is no sustainable label on the market for the manufacturing of products. Overall, the gap needs more exploration to implement sustainable quantification in the earlier development stages.

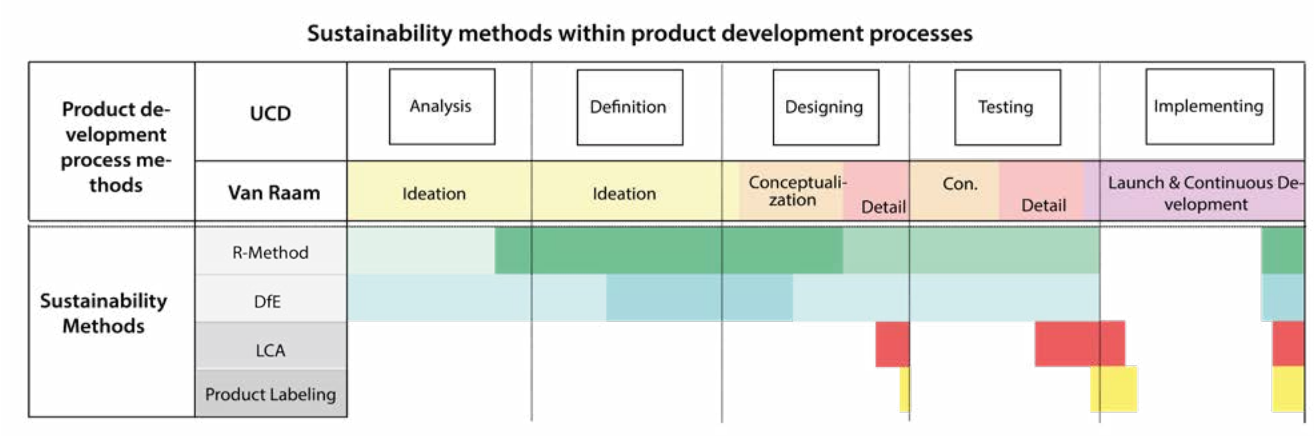


Figure 14 Sustainability assessment methods within the product development process

4.4 The Chapter Conclusion

The second sub-question: **'What do product developers need to quantify sustainability?'** can be answered. The product developers need an LCA method and program that is easy, accessible, provides valuable support and gives results that are trustworthy for decision-making. Depending on the development stage, the developers have different focuses, variables and needs. The quantification can only be done by an LCA program which makes use of a vague LCA framework. The LCA must be easily accessible, compressible, and understandable with the results, as clear as product labelling. Such a program must engage the designer to improve the product by decreasing its environmental impact. The design iteration can the developer do by itself, but support for fitted iterations is needed. The use of quantification of sustainability in the process needs to have added value to be applied. Besides the functions, the assessment demands a low threshold for application in the current product development structure. So, the requirements for a solution can be established to make environmental product assessment suitable within the conceptualization stage.

5 DESIGN BRIEF

The main problem of the research is that manufacturers need to transit towards a circular economy to sustain themselves, but there is no clear approach to accomplishing sustainable and valuable change to follow the SDGs. Looking at the main question quantifying sustainability for product development can be achieved by applying an LCA but more research is needed to identify if existing LCA programs can be used to compare products and to support sustainable choices in decision-making. The environmental impact is an outcome of an LCA, but this result will only be a number if not put into context. Therefore, the results must be valid, understandable, and valuable for the decision-making moments.

For the design brief, requirements for a new LCA method are defined as the LCA framework is unclear and needs to be redesigned to have a suited approach for product developers. To assess the environmental impact an LCA program is needed but this program needs to suit the developed LCA method and the target group. The users are product developers which have a low to middle knowledge about life-cycle assessment. Thus, more research is needed to identify is an existing LCA program can be used and to develop any adaptations around that program, or if a new program is needed. The design brief states the requirements extracted from the interviews and meetings with the target group from the case study.

5.1 LCA Method

The LCA method must be developed to create a more suited LCA process to decrease a products environmental impact by the product developer's knowledge. The current LCA framework is not understandable, has too much back and forth and is therefore unclear. The framework only aims to define the environmental impact and not to improve the results. The LCA method aims to improve results by including iterations of the concept to redesign the product to create less impact and follow short-term goals. Not only the method is crucial, the program and the measurement method also influence the accuracy and reliability of the results. The program defines research capabilities and provides support. The measurement method includes all life-cycle phase data in materials, processes, transport, use and disposal. The measurement method also determines the scope of the study based on the available data. However, without an LCA method, the essential assessment steps that make the analysis accurate by defining why, how, and what the assessment is meant to make a fair comparison of products.

Table 1 shows the requirements for the LCA method which are divided into four categories these are based on Van Raam's requirements list, in Attachment D. The general requirements are the overall vision, focus and purpose of the method. The requirements are ranked by importance from 1 to 5 to define the most and least important goals. The SMART method is used to define the methods for defining the requirements [35]. The most important requirements are the added value and implementation of redesign for product improvement, as target groups need to learn and develop more sustainable products through trial and error. A product developer needs to understand the process through graphical and textual explanations. However, in addition to the LCA methodology, LCA programs should also be examined to see if they match the methodology and needs of the target group.

Table 1 Requirements lists of an LCA Method for Product developers

	Requirement	Specification	(1-5)*
General	*Focus on product development*	The target group for this method are product developers that almost finished their studies or work as a product developer (Product Management, Engineering, R&D)	2
	Focus on manufacturing of physical manufacturable products	Products that are made and designed by the company to define the material, processes, transport, use and disposal of physical use products.	4
	Is applied within the conceptualization stage of the product development process	The assessment of concepts that are determined in its materials, processes, transport, use, and disposal	1
	The process needs to create added value	The product developer can identify the environmental impact and redesign to lower this impact.	5
	Explanation of the method	Shortly notify the product developers of the purpose of every stage	4
	Method description	Make the product developer understand the use, goal, and purpose of the method	3
Use	*Meant for concept comparison*	The results have meaning when it is compared to other elements that are understandable	4
	Makes use of circular iterative process	The method is circular as product improvements are supported	2
Function	*Easy and accessible LCA*	Include clear steps and is appealing for the user	4
	Precise start and end points of the LCA	The start of the method and the end must be clear by using visuals as icons	2
	The redesign is needed for a more sustainable product	Follows iterations to improve the product by including a redesign stage and assessing a product again after redesigning	5
Design	Attractable and remarkable method design	Use of colours, Figures, and text to show the steps of the methods used	3

*** Importance of the requirment defined in numbers of value.**

5.2 LCA Programs

A life-cycle assessment makes it possible to quantify a product's environmental impact, but do the available LCA programs suit the needs of the product developers and the new LCA method? Or is there a new program needed? To know whether a current program could be suited, six LCA programs identified and examined according to the stated requirements in Table 2. The assessed LCA programs can score points between -2 to 2 according to the extent to which the requirement applies. To be able to define the best-suited program and if that program is good enough, to compare the environmental impact of concepts.

The requirements are compared with six LCA programs which are: Open LCA, Granta Edupack, SolidWorks eco tool, GaBi and Eco-it. These programs were chosen as they are accessible and are also assessed in literature [62]. The results are shown in Attachment E. This shows that most of the programs do not meet the requirements. Granta Edupack is the most suitable because the program is generally acceptable for assessing a product. It has a comprehensive database, but the program focuses on material and process selection, and the eco-assessment is therefore limited. The cost cannot be found, while it could be a problem for a company to rent the program for all its capabilities, but only use such a small part of the program. Thus, cost may be a barrier. Therefore, available LCA programs are not accessible enough for product developers to apply life-cycle assessment. So, a new life-cycle assessment tool is needed to make product assessment easy and attractive.

Table 2 LCA program requirement list for product development

	Requirement	specificaiton	-- -/+ ++
Interface	*Clear and easy UX*	Being able to walk through the program with little prior knowledge to assess a product within 20 min (excluding collecting the data inventory for the product)	
	Feedback for improvement of result	Provides information to reduce the environmental impact	
Use	*Easy overview of database*	Shows list of impact by life-cycle stage (materials, processes, etc.)	
	Easy to use	The steps are understandable and within the product developers' knowledge to perform the assessment.	
	Provides background information on calculations	Provides information on how calculations are performed	
	Applicable for a Low level of expertise	The user is not experienced, but can assess a product's life-cycle after reading the LCA method and following the program's steps.	
	Can compare concepts within one flow of assessment	Multiple conceptual products can be assessed and then compared by its results all within the program	
	It is possible to assess a conceptual product in the program	The data inventory is possible within the conceptual knowledge of the product, which means that a couple of materials, processes, and transport is known and the general idea of its use and disposal	
Quality	*Good quality of data*	The validity of the results is medium or high	
	Low in costs (for the company)	The price of the program is 200 euros per month	
	Data can be stored.	The assessment and the results can be saved in the program to make easier adaptations	
	Follows the LCA method & framework steps	Support the user by defining the goal & scope, collecting data inventory, presenting, and interpreting results and decrease the product's environmental impact.	
	Adaptation of data	The data of the measurement method can be updated and adapted	
Design	*Clear results*	The results are understandable for people that are not product developers but do have influence in the decision-making process	
	The results must be understandable within one view	The results are visualized and put into context which is viewed in one page	

5.3 LCA Tool

An LCA tool will be developed because there is no LCA tool available on the current market that meets the needs of product developers at the concept stage. The main purpose of the LCA tool is to compare concepts with their environmental impacts and make the results understandable and suitable for decision-making. Accuracy and validity are important, but the most essential feature is that the environmental impact results are applicable to improve a design, support sustainable choices in decision-making and set short-term goals.

To improve the design, the product developer should be guided to understand the key impact and then rethink the concept to reduce the impact. It is important to create products suitable for the circular model, rather than the linear model, Figure 1. To support sustainable choices in decision making, the results should be easy to understand, briefly. Not only product developers need to understand the results, but also all parties involved in that decision-making. Subsequently, short-term objectives are essential to develop products that meet sustainable SMART requirements.

The LCA tool is intended for product developers with little to medium knowledge about life-cycle assessment. Therefore, the tool should be more than just assessing the environmental impact of a concept. It should inform the user about why, how, and when to use an LCA, provide additional information on sustainability methods, and include a reference and a database of sources. The LCA tool should base the assessment on components over which the product developer has influence. This makes the steps easier for the user. Besides that, the user is supported in at each step of the LCA to get the most accurate results.

The requirements are listed in Table 3. At the end of the Table are the requirements for the measurement method, as the LCA tool needs a measurement method to obtain accurate data for assessing the environmental impact calculations. The requirements for the LCA tool include those in Table 2, as they are still important for the development of a tool. The assessment of the requirements can be done by ranking, as each requirement has an importance from 1 to 5, with a total of 100 points. The tool is tested with the target group with the case study, but more research is needed to test the tool with other manufacturers. The tool's assessment area covers products physically manufactured in the manufacturer's factory, which does not include any electrically produced product. The product may use batteries, but the battery cannot be included in the product assessment.

Table 3 The Requirements list for a Product Development LCA Tool

Type	Requirement	Specification	(1-5)*
General	The tool can be used in a digital environment	On a computer	2
	The tool provides information on sustainability	For product developers in companies that design and develop manufacturing of use goods	4
	Data can be adapted.	When there is an update or change in the measurement method, data can be adapted	2
	The process flows in the program are informatively supported	The user can click on an icon to get more information about the step	3
	The data can be stored	Saved in the program or by PDF print	1
	The tool makes use of a sustainable measurement method	More specifications are established below**	
	There is a database for easy access to suitable sources	The database is connected to the other parts of the tool as the LCA	3
	Provides background information on calculations	Provides information on how the calculations are done	2
	The tool makes life-cycle assessment easier for product developers than the current LCA programs	The tool scopes the input needed for information, so the user has only the choices they influence, and those matters	5
Safety	The tool can only be found in the data folders of the manufacturer	Online the program cannot be seen without a code or password (encrypted)	1
	Security is ensured by not storing data in the program	Results must be stored separately from the program at the company's internal cloud	2
	The tool cannot be modified 'just like that.'	Code encrypted to adjust 'background' data	2

Use	Easy to use	A n LCA can be filled in, in five to twenty minutes (data collection excluded)	4
	A low threshold to use	Accessible for all situations in the product development process	5
	Easy implementation	The tool is added to processes as a requirement	3
	Used alongside the current process and program of design	Little adaptability needed to use the tool	4
	Few computer skills are needed to use the program	The program requires basic computer skills	5
	The user is guided through the program.	The steps are self-explanatory and are explained where necessary.	4
	The tool makes use of the product development LCA method	The tool assesses an LCA according to the method	4
	Can compare concepts within one flow of assessment	Multiple conceptual products can be assessed and then compared by its results, all within the program	2
	It is possible to assess a conceptual product in the program	The data inventory is possible within the conceptual knowledge of the product, which means that a couple of materials, processes, and transport is known and the general idea of its use and disposal.	4
Function	The tool provides support on how to reduce the impact of a product	Advice by design structures, recycling or the reuse of materials is made applicable	4
	The tool provides information about the environment for sustainability materials & processes	Basic knowledge of the program	3
	Making LCA results understandable and usable	A clear vision of the results through graphs and comparison which can be understood by the stakeholders	3
	The tool can be adapted toward the company's goals & vision	Data is customisable by Van Raam employees	2
	Focus on eco-sustainability in the tool	Warming, water, acidification, acidification, health	3
	The tool is an interactive system.	The program responds to choices that are made / information that is chosen or filled in	3
	The tool is simple but creates reliable added value	Concrete steps and process flow is created by making the assessment accurate within detail	3
	Data from the program connects to current manufacturing processes	The materials, processes, transport, disposal, and end-of-life potential.	3
	The tool supports sustainability for iteration and conceptualization stages	Design strategies are incorporated within the program.	2
Design	Visually appealing	Using colours, clear contrasts, and graphs, visualize as much as needed	2
	The tool is designed as a website page	The tool looks like a webpage with a taskbar and interaction features	3
	The results must be understood within one view	The results are visualized and put into context which is viewed in one page	3
Legal	The results are meant for internal use.	The results of the tool are not meant for marketing and promotional purposes	3
			Total	**100**

Sustainable measurement method **	Accessible	Available for use	5
	Easy to understand	Simple calculations with understandable characterisation factors such as CO^2-eq or mPt	4
	Reliable	Data is qualitative and verifiable by literature.	3

5.4 The Conclusion

The needs that product developers must quantify sustainability are translated into requirements for the development of a LCA method and tool. Because to quantify environmental sustainability in the conceptualization stage a solution is needed as there are no current programs available that suit the product developers' requirements and the LCA method's focus. In Chapter 6 the results of the LCA method are explained, and Chapter 7 describes and assesses the LCA tool.

6 PRODUCT DEVELOPMENT LCA METHOD

Based on the previous described requirements, the Product Development LCA method (PD-LCA method), was developed. The PD-LCA method is based on the LCA framework. The PD-LCA is a visual method, shown in Figure 15, to visualize the LCA phases. The PD-LCA method makes the assessment process understandable to product developers who have limited experience with LCAs. The PD-LCA stands out because it shows a clear beginning and end of the assessment and makes improvements to the design results through redesign. The user must do the redesign to improve the concept, if changes are made, the concept must be assessed once again before being able to present the results. From this method, programs and tools can be developed by using a measurement method and a program for performing calculations. This chapter explains PD-LCA into further detail and elaborates on its use and integration with other sustainability methods.

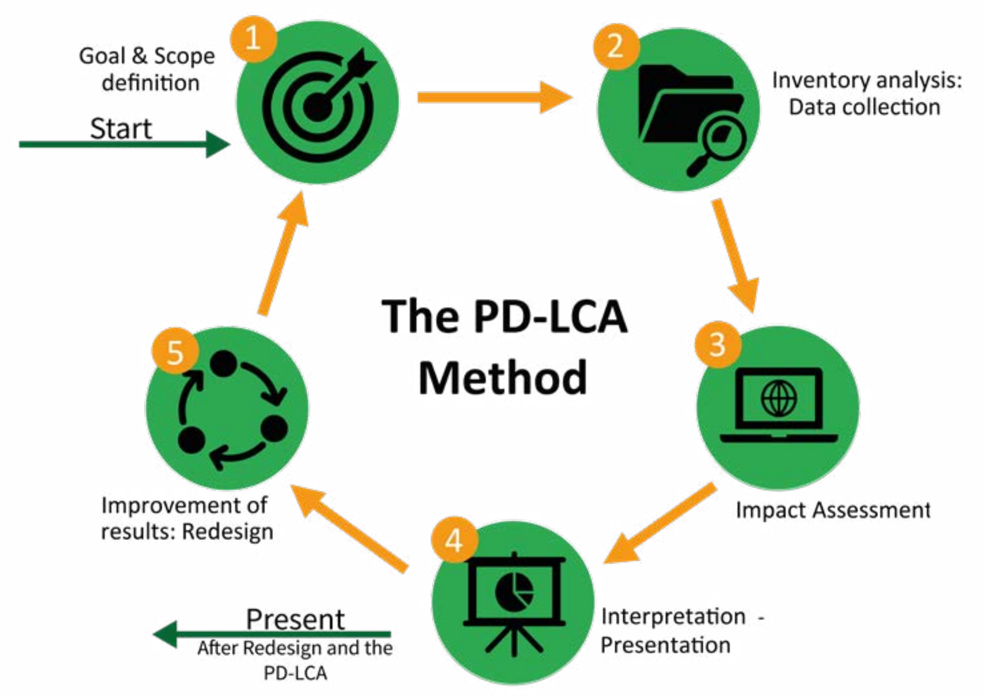


Figure 15 The PD-LCA Method

6.1 The Method Design

The PD-LCA method differs from the current LCA framework with the most crucial addition, redesign. This stage is necessary because design iterations are needed to improve a product to better meet requirements. A design process is not as linear as the methods show; mistakes are made during design, while it is better to make those mistakes earlier in the development process to keep the impact and costs low. Making those mistakes is crucial to identify which elements do not meet requirements and improve the product for better results. Changing the design of a product in the iteration and concept phase is better than when the product is already on the market [17].

Besides the addition of redesign, the PD-LCA has a circular structure which makes it possible to improve the design and to redo the assessment to lower the environmental impact and to have better results. The continuous incremental process flow helps the user maintain structure and direction to create the best sustainable results. The user maintains ownership when reviewing and improving a concept. Thereby, the method is designed to stand out by using contrasting colours and symbols to explain the function of the stage. Therefore, the flow of assessment and the bright green and orange colours, create an attractable, simple, and valuable method.

6.2 Method Application

Figure 16 visualizes the PD-LCA method in its output structure. In addition to Figure 11, the method needs explanatory information to understand the meaning and use of each stage. The Life-cycle assessment needs to follow all the steps accurately otherwise the results are unreliable. The users need to put the asked information in and the program that supports the PD-LCA method will calculate to show the output. The steps of the PD-LCA are elaborated in the following enumeration.

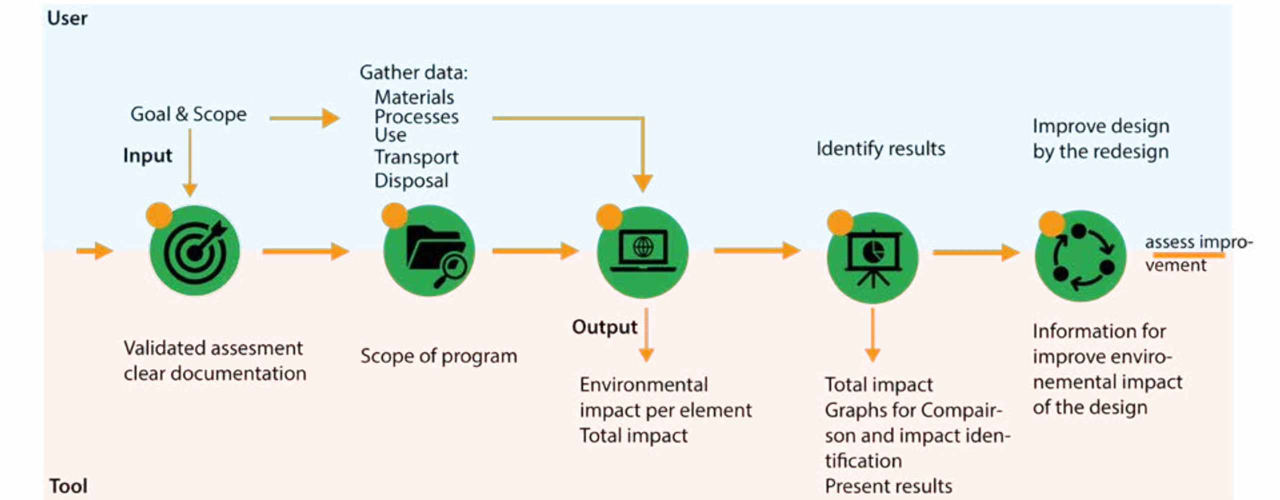


Figure 16 In and output structure of the PD-LCA method

1. Goal and Scope

The LCA begins by defining the objectives of the assessment. At this stage, the objectives and scope are defined to indicate the breadth and depth of the assessment. This step is about why, what and for what the user wants to determine the environmental impact of the products. Within the objective, the unit of function is an essential element. The user must explain what function the system/product provides. It is a quantitative measurement of function [53]. It refers to the inputs and outputs related to the system within the defined life-cycle (in years). If the unit of the function is equal, it is fair to compare products based on their impact. If the FU is not set equal, the results are biased.

2. Inventory analysis

The data to be collected by the user for the assessment are defined in the inventory analysis. The variety of inputs is determined by the type of material, the processes required, the area of transportation and the use and disposal of the product. In the inventory analysis, the scope of the program is defined to make the assessment faster and easier for the user by limiting the options of the data. The scope may differ for manufacturers as products are different, knowledge varies, and the influence of product design may change. The scope can be defined per program but is also influenced in applying a measurement method. Section 4.2.3 explains some of these methods. Measurement methods use different research to define their database. These data vary in scope, quality, and usefulness for assessment. Therefore, the purpose and scope guide the assessment to determine which parts of the life-cycle are essential to include and which are not. The assessment focuses entirely on the influence of product developers in the process to consider the options accessible to them.

3. Impact Assessment

The life-cycle impact assessment assesses the impact of the gathered inventory. The purpose and scope already determined the depth of the study and the impact categories. In this stage the user fills in the data of the product's life cycle in the tool or program. The results are generated by the inventory and the type of measurement method. The results are shown in a type of classification, for example, global warming potential, acidification, and human toxicity. However, this characterization factor also depends on the measurement method. Some measurement methods have large databases, and the characterization factor can be chosen, but other methods only have one type of factor.

4. Interpretation & Presentation

In the interpretation and presentation, it becomes clear which product and which life-cycle phase has the most impact. The comparison of results show the impact according to the two products or concepts. Though the results can roughly be compared to other examples to become more understandable by putting the result into perspective. The user can then choose which part to improve in the redesign phase. When the user has already done an iteration of a product and gone through all the stages before, the user can also choose to present the results.

5. Redesign

The redesign aims to show the user the problematic areas and to focus on product aspects that can be improved. The redesign shows to the user that even minor changes can have a significant impact. At the same time, the redesign supports the user to identify the most impactful life-cycle phases. After making changes to the design, the product should be reassessed to determine the impact again. This can be examined until the user is satisfied with the results or can no longer change the product.

6.3 The Sustainability Methods in Product Development

Figure 15 visualizes the PD-LCA method in its output structure. In addition to Figure 12, the method needs The PD-LCA aims to fill this void by quantifying the sustainability of a product between the end of the ideation phase and just at the beginning of the detail phase, as shown in Figure 17. The method makes LCAs available within the essential development stages to reduce harmful emissions to the world. The method does require support from a program to quantify sustainability by calculating environmental impact. That program should follow the stages of PD-LCA but can also apply other existing sustainability strategies to support the PD-LCA method. For example, to help the user reduce the impact, the awareness strategies of the R-method and the DfE could be applied for redesign. The product labelling could also be created for displaying the results to make them more understandable. The developer of a LCA program is still free to decide how to achieve the goals that are set in the PD-LCA method. The method is essential to support research into the development of LCA programs or tools suitable for making sustainability quantifiable for product development. The PD-LCA method is a sustainable product development method needed to make valuable changes within academic research and sustainable concept development.

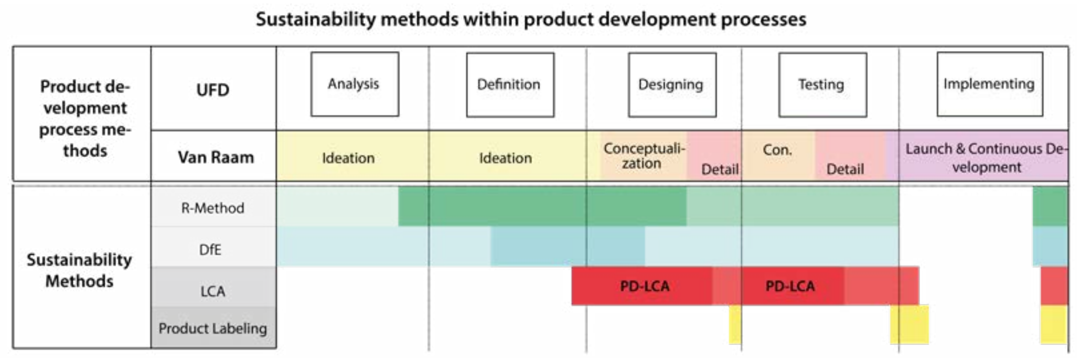


Figure 17 PD-LCA method's use within the product development stages

6.4 The Conclusion of the PD-LCA

The PD-LCA method makes the quantification of sustainability accessible within the earlier stages of product development to support sustainable product development. The method follows the flow of development by assessing and improving the environmental impact of the concept. It adheres to the knowledge of product developers and makes environmental assessment accessible for them. Yet, the method must be applied within a program to be tangible and accessible for manufacturers, such as Van Raam, to use and add value.

7 THE PRODUCT DEVELOPMENT SUSTAINABILITY ASSESSMENT TOOL

The Product Development Sustainability tool is developed to determine the environmental impacts of product concepts through the PD-LCA. The tool its name is STAT, which is a creative abbreviation of Sustainability Assessment Tool. The STAT is intended for product developers who have limited experience with LCAs. The STAT provides information before, during and after the concept assessment. It is a digital tool that provides product developers with a platform to apply sustainability within the phases of product development. The PD-LCA is the basis for the STAT solution, and the STAT is the developed solution to assess sustainability for decision-making.

7.1 The STAT

The STAT is a tool that supports a product developer in quantifying sustainability through concept comparison. It was developed for stationery products, intended for product developers who influence product design. When a product is purchased, the user can ask the manufacturer for more information about the product's emissions or must clearly state that the element is being purchased. The quality of the results depends on the quality of the assessment and therefore the user should pay attention to all PD-LCA steps that the STAT includes. The quality also depends on the measurement method, program, and scope of the assessment.

7.1.1 The Program and Measurement Method

The STAT is developed in Excel and uses the Eco-indicator 99 as its measurement method. Excel was chosen because the programme is accessible to many, uses low-level interactions and can make calculations based on background data and data that the user can enter. The programme can limit the user's choices within the tool. The current tool needs adaptations to be accessible to the market. Due to the time constraints, Excel is used. Excel is not the best programme for UX design and therefore for improvements, it is recommended to develop the tool by programming online, this also gives opportunities for better UX design. On the other hand, the target audience is familiar with the program, and this lowers the threshold to use the tool.

The STAT also needs a measurement method to assess the environmental impact of a product within, the eco-indicator 99 is used. This measurement method was chosen by comparing different methods according to three functions: accessibility, data quality and ease of use. Attachment F explains the measurement methods and assesses them against the three functions. The evaluation showed that two methods best met the functions, namely the Ecolizer 2.0 and the Eco-indicator 99. The Eco-indicator 99 was chosen because it has only one characterisation factor, the mPt, but it is possible to convert the results to CO^2-eq to facilitate comparison. Since 1 mPt is equal to 1/1000 Pt and 1 Pt is approximately equal to 7.9 kg CO^2-eq [63]. The measurement method is also accessible, updated in 2008 and easy to understand. The method does not of high quality, but it provides sufficient information in the internal decision-making of product development to determine the sustainability of products. Consequently, the measurement method has been integrated into the tools database to use and visualize the data within STAT.

7.1.2 The Scope of the Tool

The STAT is primarily aimed at assessing products for their environmental impacts according to the PD-LCA method, but the tool also provides sustainability information that can be used at any stage of the development process. The information is provided by displaying the data set by category to shop the (non-) harmful, (non-) recyclable materials & processes of the eco-indicator 99. The tool uses references in the database where the user can find more information on sustainability in product development. In addition, the Rs method and the DfE are also explained in the STAT to show some other methods that users can apply. The STAT is thus more than just a product assessment tool, but also a platform to find the necessary information on sustainable product development.

In the PD-LCA, the inventory is explained as the phase where the scope of the programme is determined; this scope is also integrated into the STAT to fit the target audience. The STAT limits the choices the user has to make in the life-cycle phases to make the assessment more convenient and easier. The scope is based on the options provided by the eco-indicator 99 as data to make the options suitable for the development influence of the target group. Product developers do not have much influence on the choice of transport or type of disposal. They do have influence on where a product comes from and whether it is possible to recycle the product. The use of a product is mainly influenced by the use of electricity, although this study focuses on parts that do not use energy but may wear out during their lifetime. Use is incorporated into the material and process as the number of parts needed within the expected life of a component. Therefore, these steps focus on those options that the target group can define. To show all the options and how the PD-LCA works, products are assessed of the case study in section 7.3.

7.2 The STAT Structure

The STAT makes sustainability available and accessible for product development through a structured method, visualized in Figure 15. The STAT includes design strategies, life-cycle assessment, the company's vision, and sources for additional sustainability information. The figure shows many elements, all divided into sheets. Each sheet has multiple options for directions to other sheets. The taskbar is always accessible, and life-cycle stages are available in starred sheets. Within the taskbar, the library is underlined. The library contains all additional information with a list of sources. Resources are referenced throughout STAT to give the user more details. The resource list can be modified and added to provide a more comprehensive and complete library.

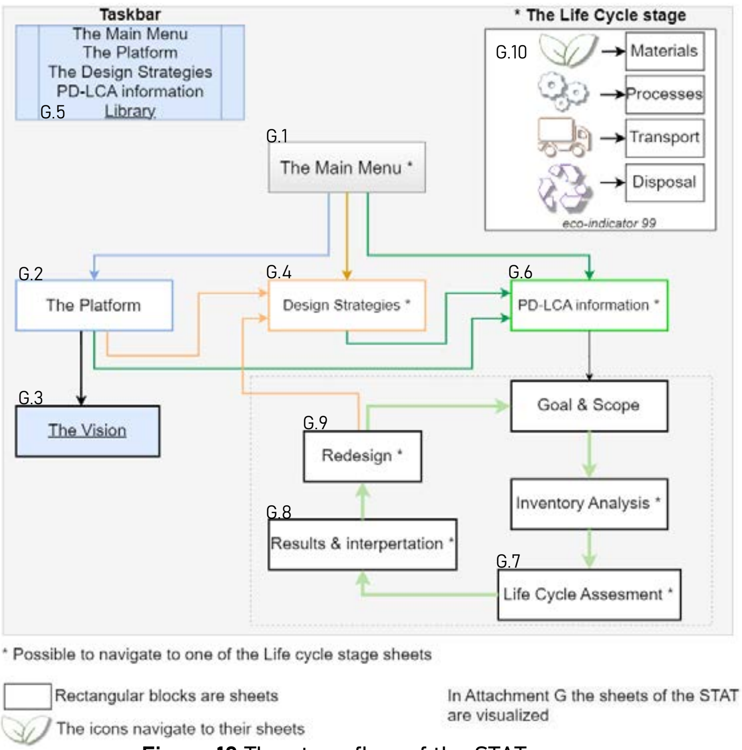


Figure 18 The stage flow of the STAT

The main flow of use starts with the main menu that leads the user to the three segments visualized in Figure 18. In Appendix G, the sheets of the STAT are visualized to give more insight into the tool. The first option is the platform, which explains the STAT and the vision of the program. The platform also provides brief information on the design strategies and the PD-LCA method. The design strategies explain the importance of including eco-factors as a developer. These strategies are the R's method, DfE and LCA. The information is supported by the library for more information. The primary purpose of the tool is PD-LCA assessment. Before assessing an LCA, the PD-LCA explains its purpose and the usage process. The project can then be started to indicate the impact of the product. An example of such a project is explained in the next section.

7.3 Case Study: The STAT products assessment

To show how STAT applies its PD-LCA, two Van Raam chairs are used in the assessment. The chairs were chosen because they all have an essential function on tricycles. However, the chairs are fully developed products and not concepts, but due to time constraints, no concepts were developed for assessment. Though it is important to visualize the use of the STAT and the applied PD-LCA method. The case study example shows the essential steps and pitfalls for inexperienced users as they may make mistakes that affect the quality of the result. The two products assessed and compared are the Ballet and the Easy Rider 3 (ER3) seat, shown in Figure 19. The Ballet was one of Van Raam's earlier generation of seats and the ER3 seat is one of the latest models of the best-selling tricycle at Van Raam. The Ballet is a simple seat with only a few parts. The ER3 is more comfortable but uses more parts and is more expensive. It is interesting whether the Ballet or the ER3 scores better in terms of environmental impact. In previous research by a student, the seat of the ER3 was found to be not as sustainable by GRANTA's Edupack eco [65]. Therefore, the expectation is that the Ballet will have less impact than the ER3 seat.

Figure 19 Van Raam: The ER3 seat and the Ballet

7.3.1 The Scope & Goal

The assessment starts by defining the scope and purpose of the PD-LCA. Table 4 defines the assessment. Using a Functional Unit (FU), the purpose should be defined to clarify which parts or products are being compared according to the FU. The products or features are designed to perform one or more functions, which can be identified as a sentence and the Functional Unit. For example, for a bicycle seat and an office chair, the unit of function may be someone weighing 85 kilograms who can sit on the chair for 10,000 hours under normal conditions. The FU enables comparisons of different types of products. However, the FU can be a pitfall in determining the Scope & Goal. If the user is not sure if it is listed correctly, more information can be found in the reference within the tool.

Table 4 Case Study: The Scope & Goal defining of starting a project in the STAT

General	*Project*	Environmental impact assessment of the Ballet and Comfort seat
	Date	08-05-2022
	Product or Component 1	The Ballet
	Product or Component 2	The Easy Rider 3
	Author	Rixt van der Leij

Goal & Scope definition	*Goal*	Compare the products to identify their impact against another.
	Scope	The seat with the backrest and the attachment to the frame.
	Function Unit	For a general person (85 kg) to use the seat for 10000 hours under normal circumstances.
	Life-cycle Unit in years	10

7.3.2 The Inventory Analysis

To determine the focus of the assessment, the inventory must be analysed. The inventory analysis explains the scope of the platform. The scope is user-focused and developed according to the needs and spheres of influence of the product developers. Figure 20 visualizes the inventory analysis of the STAT. The inventory analysis identifies the information needed to assess the environmental impact of a product. In doing so, the user only needs to collect the information within the boundaries, such as shown in Attachment H.1. As at any stage, the user should be aware that an incorrect assessment will affect the validity of the results. Acceptability can be checked by other product developers. Collecting the right information is crucial for assessing the effect of the product.

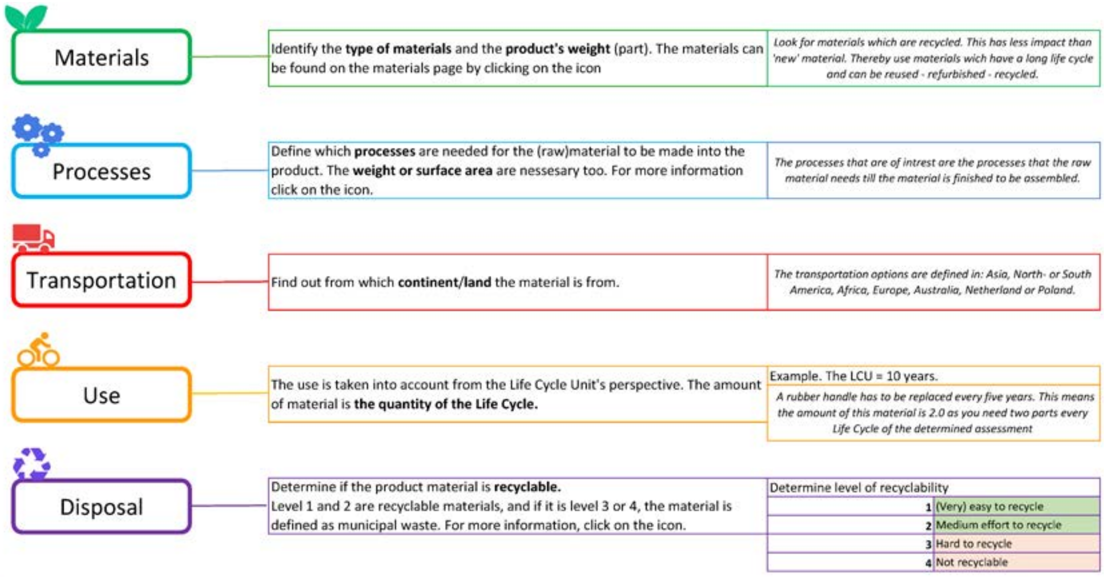


Figure 20 The scope of the assessment of the PD-LCA tool within the STAT

7.3.3 The Assessment

Assessment is the stage where the user fills in the data collected from the analysis. In the assessment, the user starts by entering the names of the product parts, followed by the type of material the person can select from the option list. The quantification within the life-cycle is the 'use time' the part may have. In the case of the Ballet in Table 5, the bottom cushion estimates half the expected life of the chair; for this case, the quantity is entered as two. Then the user also must include this amount in the process because the part must be made twice as long, while having an additional environmental impact. The other assessment steps are visualized in Attachment H.2.

The user goes through each life-cycle stage by filling in the inventory analysis data. In some cases, the material is in the database is not available for assessment. The user should mention this in the comments and can find a similar material or better leave it blank and put a question mark and continue with the assessment. If the assessment is completed correctly, the results can be printed in a pdf to preserve the data.

The results are visible when all information is completed, as shown in Table 6. The total results are shown in Points (Pt) and are translated to CO^2-eq. The End of Life (EoL) potential is used in eco-indicator 99 and shows the potential of a component to be reused through recycling. If the user designed the product to be fully recycled, the recyclability rate would be 100%. In the case of the Ballet, the product has a recyclability rate of 22%. The EoL potential has a negative value because the user supports other manufacturers' choice not to use virgin raw material. Therefore, it is even better to use recycled materials as a resource in the assessment, as this reduces the number of points and therefore the environmental impact. The full results are visualized in the results sheet.

Table 5 The Assessment of the Ballet in the STAT

	Name part	Type of materials *	Material *	Quantity per Life-cycle *	Measure unit in kg *	eco-Indicator 99	Result	Comments
1.1	Seat	Plastic	PUR energy absorbing	1.00	2.7	490.0	*1323.00*	
1.2	Cushion top	Plastic	PUR flexible block foam	1.00	0.036	480.0	*17.28*	
1.3	Top Nylon	Plastic	PA 6.6	1.00	0.112	630.0	*70.56*	
1.4	Cushion bottom	Plastic	PUR flexible block foam	2.00	0.096	480.0	*92.16*	
1.5	Bottom nylon	Plastic	PA 6.6	2.00	0.292	630.0	*367.92*	
1.6	Bottom attachment for slide	Ferro Metals	Steel high alloy	1.00	1.22	910.0	*1110.20*	
				Total in kg	**4.456**	Total (mPt)	**2981**	

Table 6 Short results of the product assessment of the Ballet

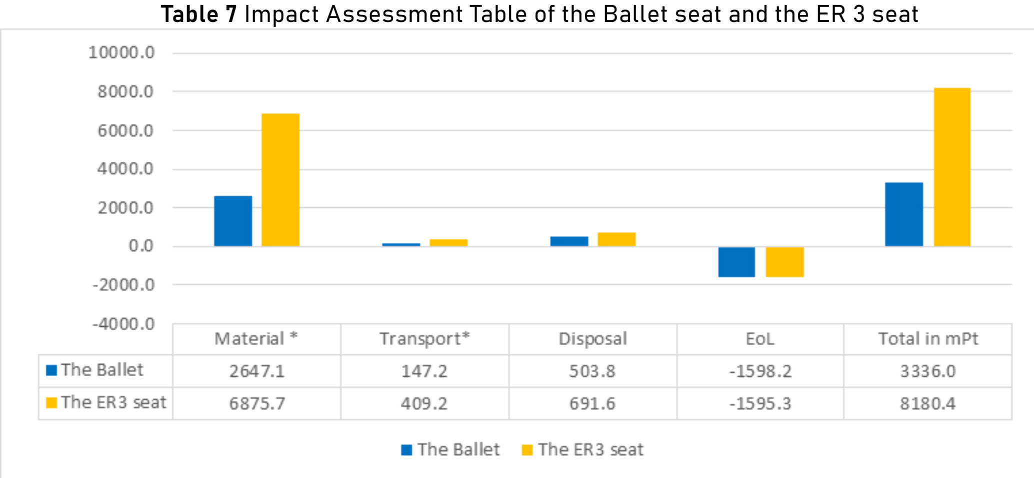
	Results product	Results End Life Potential
Total mPt	3354.4	-750.4
Total Pt	3.4	-0.8
Recyclability Rate		22%
Life-cycle impact per year in mPt	335.4	
Approximately CO^2-eq kg	27	

7.3.4 The Results

The results of the environmental impact assessment are visible in graphs showing the assessment results as shown in Table 7 and Appendix H.3. The results are visualized in a block and circle diagram. It becomes clear that the materials have the largest impact withiHn the total emission. In addition, the results are compared with the number of trees and the number of car kilometres. One of the main requirements was to make the environmental impact understandable by using standard features for comparison. The comparison with trees is designed to see how many trees are needed to make the product net zero. The trees are calculated based on adult trees that can absorb approximately 25 kg CO^2-eq per year [66]. The number of kilometres driven per car is meant to understand the impact of the product by something understandable that many people use to get to work.

The impact of the results should be compared for decision-making. The ER3 seat has double the impact of the Ballet seat. This result indicates that the ER3 needs quite a bit of redesign to improve the product, or the Ballet is chosen but also needs to be redesigned. So, it does not matter which concept is chosen, as the redesign is needed to improve the product. The assessment is not entirely fair, as the ER3 seat has a sliding system built in and the Ballet did not have that system assessed. In the FU, the sliding system was not built in, but in the ER3 seat it is. When assessing the results, other decision factors such as cost, quality and comfort must also be considered. This remains important because the product must fit into the company's social, economic, and environmental coherence.

Table 7 Impact Assessment Table of the Ballet seat and the ER 3 seat



7.3.4 The Redesign

Redesign is the most essential part of the PD-LCA, as the user must look at the impact of the product to see how the impact on the environment can be reduced. The redesign aims to show the user the problem areas and focus on aspects for improvement. The redesign sheet shows that a small adjustment can have significant effects, and that every little bit counts to make the redesign work. For example, a product is improved by 200 mPt and the product is sold 1,000 times a year. If the company's sales' grow by 40 percent a year, as in Van Raam's case, that's 70,000 products around the world in 10 years. The 200 mPt or 0.2 Pt becomes 14,000 Pt, equivalent to 100-tonne kg CO^2-eq That's the same emissions as driving around the world 21 times. So, a small improvement can have a big impact.

The assessment of the redesign is determined by Rs. The sheet contains six steps to follow. At the same time, they identify the most impactful life-cycle stages. In most cases, the materials are the problem, as new materials score high in mPt in the eco-indicator 99 method. The second step is to identify the part with the most impact and see if the user can modify that part. The third step is to go through the circular economy stages of the Rs. The R's contain questions for the user to answer and thereby rethink the product's prupose and identify the area's to adapt. The Redesign is partly shown in Table 8 and the complet Table is shown in Attachment H.4 (Table 21).

If all the steps are completed, the products' redesign can be assessed to identify the improvements. The improvements can be saved in a pdf as the STAT will not save the assessed products, for example, the Ballet seat. The product has a low recyclability rate as it uses PUR, which is not recyclable. By changing the material and rethinking the way of the attachment of the bottom slide to the seat, the seat has pressured thread in it to attach the two parts with bolts and nuts. The Ballet was the best concept choice, but it can still be redesigned to improve the product's environmental impact. Assessing the Ballet's redesign with recyclable material, such as ABS, increases the EoL by 20% and decreases the impact by 200 mPt. Hence the redesign can also be helpful for other decision factors for decision making. By limiting the parts, the company can save money. Therefore, it is possible within the presentation to print the results and use the graphs for a presentation during the decision-making meetings.

Table 8 A part of the Redesign assessment Table

Step	Questions to answer			Yes/No
1)	Which Life-cycle Stage has the most impact?			
2)	Which aspect of that stage has the most impact?		Is this logical and necessary?	
3)	Go by the Circularity strategies to determine improvement areas.			
3.1)	R0	Is it possible to Refuse a part?		
		Are all elements in the product necessary?		
		If yes: Why are those necessary?		
	R1	Can you Rethink the situation for the product?		
		Can you increase the time of Use?		
		Can you increase its durability? (not everything needs to be as durable when the product is disposed of. The durability is		
		Can you make the product to be easy to maintain?		
		Can you make the product (parts) out of one material?		
	R2	Can you Reduce Materials, Processes, Transport, and Disposal?		
		Can you use Recycled Materials?		
		Do you need a particular material, or are there other possibilities?		
		Can you decrease the weight or volume?		
		Can you reduce the number of options? To create more modular.		
		Can you use processes with less impact?		
		Can you design for Packaging? To decrease packaging use.		
		Does it even need packaging at all?		

7.4 Case Study: User Tests

The STAT was tested by three target users at Van Raam to assess the tool's requirements. The tests were examined when the STAT was still in development, therefore some of the results were used to improve the design, within time constraints. The tests provide more insight into the features of the tool that do or do not work for quantifying sustainability. In addition, understanding the results is important because they need to be applicable for decision-making. The user test explored four topics: user expectations, UX design ease, PD-LCA assessment of quantifying product lifecycle, and estimation of essential requirements. The questions and the results of the user tests are described in Attachment J.

The user test starts with users' expectations of the instrument without seeing it. Expectations were high because they thought, or hoped, that the tool contained the best sustainable option for a chosen material. The STAT cannot, as the user must adjust based on the values and results. In addition, another expectation was that when in doubt when choosing between concepts, the results of the tool could be the deciding factor. The second topic of the user test was to identify the tool's user interface by finding certain features in the STAT. The navigate through the tool took the user some time to find the assigned citation or answer to the question. The UX design must be improved or another program then Excel is needed to optimize the flow of navigation. However, because of time limitation the user did not read everything. This can be improved for other user tests. In the third topic the user had to assess two products of Van Raam. However, because of time constrains the complete assessment was not possible by the user to do. Because of that, the user went through all the steps with already having the information filled in. The users were enthusiastic about the system and happy with the results. One of the users made it clear that the PD-LCA redesign sheet needed to be improved, as that sheet is the link between the tool and the design strategies, library and PD-LCA results together. This idea lead to the redesign sheet as mentioned in 7.3.5 and in Attachment G.9.

At the end, the users had to rate the STAT according to the most essential requirements. In general, the STAT scored well, with a 3.5 out of 5. The best assets of the tool are the display of the results and its understanding. Though this was for the product developers, as for decision-making moments the results must be made easier and better placed in context. The UX design can be improved, as some features were difficult to find in the tool. The redesign sheet also needed improvement, and some materials and processes that are not available are used within the product manufacturing. Especially the going back button they missed. However, the users were pleased with the results of the PD-LCA method and the application of the tool.

7.5 The Conclusion of the STAT

The STAT makes it possible to define the environmental impact of a concept or product to understand and improve a product to become more sustainable by applying more circularity in the design. The STAT is adaptable to the manufacturer to add its vision and goals, update the library for more resources about sustainability, and explain more about important sustainability methods. The STAT is the solution to make sustainability accessible and suitable for product development and improvement. The STAT makes applying LCA's comprehensible, but the context and validation of the results need further investigation to be easy and applicable for presenting sustainability within decision-making.

8 THE INTERPRETATION AND VALIDATION OF THE ENVIRONMENTAL IMPACT

The PD-LCA in the STAT makes it possible for product developers to extract the environmental impact of a concept or a product. However, the product evaluation needs to be more tangible to be applicable for decision-making. This chapter focuses on the third sub-question: **How can a product's environmental impact support sustainable choices in decision-making?** To achieve a clearer view of the environmental impact, product labelling could be applied. This was mentioned, in Chapters 3 and 4, as a method to easily present and understand results on to base decisions. The validation of such a label must be high enough to trust when making decisions. Therefore, the results are also compared to other LCA programs to identify the reliability of the STAT's results. In addition, the application of sustainability methods is elaborated within the product development process and its decision-making.

8.1 Presentation of Results

During the user tests, there was noted that the results needed to be made tangible, as simply comparing the concepts does not tell how much impact the component has compared to the entire product. To better understand the impact of a product, one of Van Raam's best-selling tricycles was assessed with the use of the STAT. The assessment identifies the environmental impact of Points and CO^2-eq.

8.1.1 The Life-cycle assessment of the Easy Rider 3

The Easy Rider 3, seen in Figure 21, is assessed by the STAT to identify its environmental impact. The STAT is not designed to assess complete products, but it is possible to assess parts of the tricycle in the tool over multiple assessments, and for different product concepts. The estimate of the environmental impact from the assessment is suitable for comparisons between product concepts. The Easy Rider 3 is assessed without battery and attachments. Appendix I specifies the segments and parts of the tricycle for the inventory analysis. The data was collected from a 3D model in SolidWorks and by enquiry of Van Raam's R&D Engineers. The subdivision of the inventory and results made the assessment of the ER3's impact more accessible and gave a good picture of the impact per part. The assessment resulted in a score of 32 Pt (based on the Eco 99) for the Easy Rider 3, which roughly translated to 260 kg CO^2-eq.


Figure 21 Van Raam: The Easy Rider 3

Because the ER3 is assessed on its environmental impact, product components can now also be compared in terms of what impact a component has overall. For example, if the Ballet seat were on the ER3, the bike would have 15% less environmental impact in comparison to the previous concept. This is a significant difference. It also became clear in the ER3 assessment that after the seat, the rear frame has the highest impact. The bike also uses a lot of materials in its design and is heavy at 48 kilos. The weight of the materials also determines the impact on the environment, which is why reusing or reducing materials is important to Reduce the environmental impact.

8.1.2 The Product Labelling

The impact of the complete product, as the ER3, provides referencing for other products and parts to understand the distribution of the impact. With these results, it is clear to identify that the ER3 seat has a high impact, as a part, compared to the total impact. Besides identifying the impact of the segments, the trike's impact can be a reference to set up in-house labelling (A – E label) of the impact of trikes. As mentioned before, there are sustainability labels for use products, but it is possible to create a label only meant for company use, to easily show the impact of a product. In Table 9 the label is visualized. It is made by defining the current situation as a D label and then by making assumptions around the results the label is established, of the ER3. Though, it helps to understand the quantification of sustainability and to set goals to improve bi and tricycles as the company wants to improve its rating. This e-labelling makes it possible to define the short-term goals, which are essential to make for manufacturers to make sustainable changes.

Table 9 The Easy Rider 3 product labelling

Eco-Label Product	Pt	Kg CO^2-eq	Recyclability Rate in %
A	< 20	<150	60<
B	20-25	150-200	50-60
C	25-30	200-240	40-50
D	30-35	240-280	30-40
E	35-40	280-320	<30

The label can also be established for the products with the same function, such as the assessed seats. The four seats of Van Raam are assessed it their life-cycle impact: The Ballet, ER3 Seat, the F2G Seat and the Comfort Seat. The inventory data is shown in Tables 15, 16, 25 and 27 and the results of the assessment are shown in Attachment K.2. To generate the category label the best seat can score a B or a C, whereas the worst score is an E. The Ballet has the lowest environmental impact and receives a B, while the Comfort Seat receives a C. The Easy Rider 3 seat will get an E label. As mentioned before, such a label is only meant to be used within the company and not for marketing purposes, as the label is not verified. This is because the definition of the label is based on the assessment of one company's product portfolio and not the entire market of products. Also, the STAT is not verified in its reliability, and as mentioned in 7.5.3 only products with the same FU can be compared. However, it can be possible to discuss such labelling within meetings with multiple competitors or with the NEN or ISO, just as Auping did with the retrieval of mattresses. All in all, product labelling can be created by multiple PD-LCAs by using the STAT.

8.2 Reliability of the Results

To make decisions based on the results of the STAT, the tool must have realible data. Attachments L and M assess the PD-LCA method and the STAT in accordance with their requirements. The method and tool meet the requirements, but improvements are required. As previously stated, the UX design could be improved, and the validity of the eco-indicator 99 could be investigated further.

As a result, the STAT results are compared to other LCA programs. The STAT results determine the eco-label, but in addition to the user test, the STAT results must be verified to ensure validity and reliability of the results. Especially when major decisions are made based on the generated data. Although it is not intended to be as specific and accurate as LCA programs such as GaBi, the results should be accurate. The eco-indicator 99 measurement method is generic and was updated in 2008, so it lacks some options that manufacturers use today.

One product is tested with several tools to see if there are any significant differences. Table 10 summarises the results of all assessments found in Attachment M.3. The evaluation gives a first impression of the tool's reliability. The total impact is quite different, with the Eco-It the product emits 108 kg CO^2-eq, the GRANTA 91 kg CO^2-eq, and the STAT 74 kg CO^2-eq. The values between the Eco-It and GRANTA differ as well, particularly in the disposal phase. The material and process phases of the STAT differ the most, leading to lower results. The calculated impact is less than that of the other tools Furthermore, to identify even more significant differences, it would be advantageous to evaluate even more products using the tools for more extensive research. However, this does not negate the fact that the STAT is a useful comparison tool. As long as the designer considers that it shows a more positive representation of reality.

Table 10 The environmenal impact of the ER3 seat by the Eco-It, GRATNTA Edupact and The STAT

Life-cycle stage	**Eco-It** **IPCC 2007 & ReCiPe**	**GRANTA Edupack** **Eco Edupack**	**The STAT** **Eco-indicator 99**
Material	9,9 Pt / 91 kg CO^2-eq.	72,8 Kg CO^2-eq.	8 Pt / 63 Kg CO^2-eq
Process		15,4 Kg CO^2-eq.	0,4 Pt / 3,1 Kg CO^2-eq
Transport	0,3 Pt / 2,1 Kg CO^2-eq.	2,6 Kg CO^2-eq.	0,3 Pt / 2,4 Kg CO^2-eq
Dispose	0,7 Pt /14 kg CO^2-eq.	0,5 Kg CO^2-eq.	0,7 Pt / 5,5 Kg CO^2-eq
Total	10,9 Pt / 108 Kg CO^2-eq.	91 Kg CO^2-eq.	9,4 Pt / 74 Kg CO^2-eq
End of Life potential	//	-28,5 Kg CO^2-eq.	-2,7 Pt / 21 Kg CO^2-eq

8.3 Application of Sustaianbility Methods in the product development process

Not only is the presentation of the results of the environmental impact essential, but also how to support sustainable choices in decision-making. Sustainability should become a factor in decision-making when the results of the STAT are considered in meetings. As explained in sub-sub-sections 3.2.5 and 4.1.5., product labelling can be an easy way to understand and support defining short-term goals. The results of the STAT can be used to motivate product developers to improve the calculated impact and to improve the product label to a greener level.

Within the product development process, several methods and tools are appropriate to make sustainability assessable and implementable. Each development phase is important to develop products with less environmental impact and more circularity of materials and product use. Even before developing, a company must apply a sustainability analysis to understand its strengths and improvements according to the TBL before applying sustainability methods, as in section 3.5. By looking at the design method, the UFD, different sustainability methods are suitable which are shown in Figure 22.

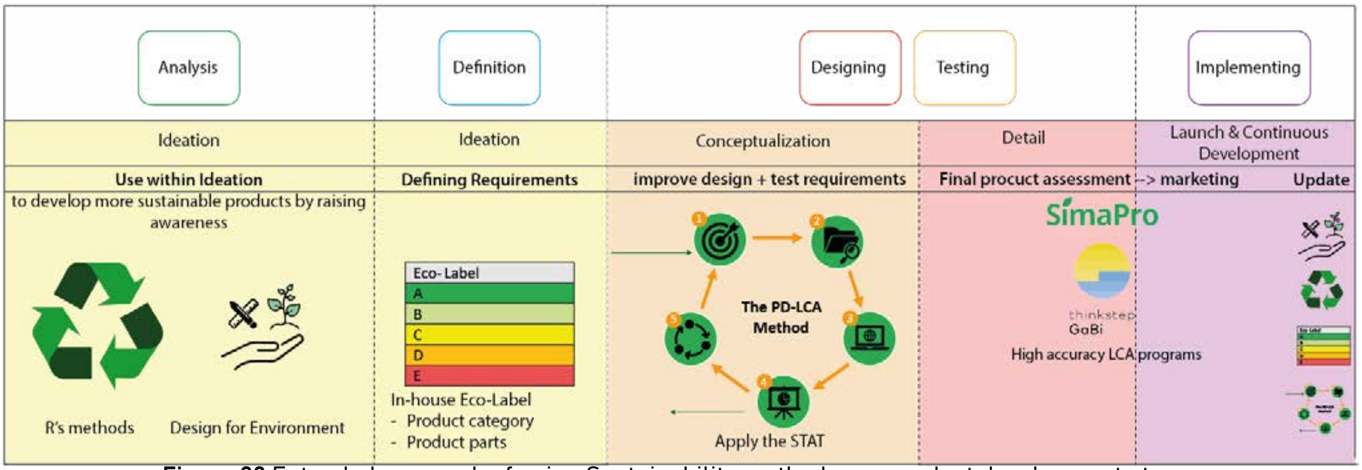


Figure 22 Extended approach of using Sustainability methods per product development stage

In the ideation, it is difficult to quantify sustainability because the product is not yet defined, but awareness-raising methods such as the Rs and the DfE are applicable. The methods help to remind product developers of sustainability. However, before starting a new development process, current products within the product portfolio should be assessed by the PD-LCA in the STAT to establish internal product (part) labels. The ecolabel can then support the definition of SMART eco-requirements for a new project. Then, within the conceptualization phase, the STAT together with the PD-LCA can be used to compare concepts to one another and products from the portfolio. For decision moments, the results can be presented by the eco-label. In the detail phase, the PD-LCA in the STAT is less suitable because this tool does not focus on details. However, other LCA programs that are more comprehensive can be used to determine the total environmental impact of the product, which can be used for marketing purposes. The programmes are challenging and difficult to assess the LCA of a product, so this can be outsourced, but the product developer must collaborate to support the correctness of the data. Within continuous development, all methods are essential for staying up-to-date and being reminded to think about the sustainability aspect of a product. So, to implement sustainability in all stages of the product development process, different methods and tools are needed to develop a product that includes sustainability for decision-making.

8.4 The Chapter Conclusion

The findings of this chapter can answer the third sub-question: **How can the environmental impact of a product support sustainable choices in decision-making?** Environmental impact can be determined by assessing a concept or product in STAT using the PD-LCA method and the application of eco-indicator 99. To support sustainable choices, it must be clear whether something is sustainable or not. Therefore, product developers can create an internal stop sign environmental label to put the results of an assessment in a clear context. This eco-label is only meant for decision-making within the company and has no marketing value. Such a label supports a clear visual view of sustainability and can therefore be used to compare other assessment values, such as costs, comfort, and safety. The establishment of a label is not included in the STAT but can be determined from its results. The environmental impact can thus be converted into its eco-label, which indicates the degree of sustainability compared to other products (parts).

9 CHANGE MANAGEMENT

Abrupt changes can bring chaos and uncertainty to the implementation of something new this must be managed to ensure a smooth transition. The PD-LCA method and the STAT are suitable solutions but if a company does not want to implement them, there is no improvement. Within this chapter, the focus is to answer the fourth sub-question: **What is required to implement sustainability as a decision factor in a company?** The change is to make the stakeholders, such as product developers, the management, and the board of directors, aware of why, and how to apply sustainability within the development process. The chapter explores the literature on change management to understand the focus points for implementing any changes.

9.1 A Company's Vision

Changes can create uncertainty but they are needed to sustain as a company [37]. This is also because the planning for change differs from change implementation within a company. With the implementation of the STAT, a new element is introduced. Some changes gain value and improvement but other changes fail and cost more money and time. The approach to the change is essential in succeeding by having open communication with involved stakeholders. Thereby, there should be clear goals and reasons for the change [67]. These goals should be determined by the board of directors as they have the vision in which direction the company is heading. The company's vision is closely connected to the adaptation and acceptance of changes.

The board can push specific changes to managers and employees. They also have a symbolic value to employees when they perform a plan for change [68]. The people that are involved in the change should be informed of the adaptation as they can also help in the transition by involving them in the development of the change plan [69-71]. Involving the stakeholders provides insight into their capabilities, needs, and influence within the change process. Those involved need to know why the change is needed and its urgency [71]. If people have a complete view of the coming change, they are more willing to engage in the transformation [72]. It is possible to make one or more people responsible for the change, as Auping did by hiring a person who did the sustainability change. It can be a group effort and help get more people on board.

To structure the transition, Lewin's model provides a grip on managing a change within a company [73]. The model explains that analysis needs to be done on the current situation. Only then can the change be planned; this is the unfreezing stage. After that, the plan can be executed, and transformation can take place. Then, in the final stage, the new situation can be frozen again, and the new factor becomes part of the routine. The method is short and structured and creates a clear approach to the people that are involved in the transformation.

9.1.1 Structure of the Company

The approach of the implementation can differ according to the type of company, its size, and the influThe approach of the implementation can differ according to the type of company, its size, and the influence of the hierarchical structure. Larger companies tend to have more hierarchical structures. Employees have less to say in things, and change happens from the top down, as visualized in Figure 23. Smaller companies with a less hierarchical structure can implement change in a bottom-up manner. Within this research, the focus is on manufacturers that are medium-sized with a less hierarchical structure [74]. Therefore, a bottom-up approach is possible. However, the bottom-up approach is complex because employees must invest time in the change, which can be difficult if no time is set aside. The top-down ap-

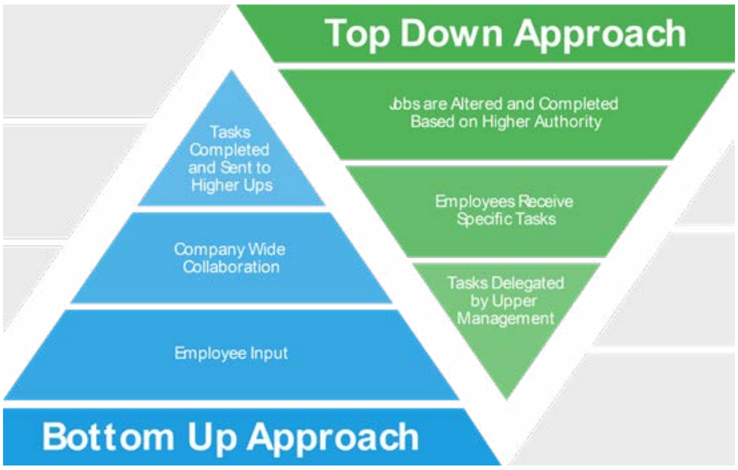


Figure 23 Bottom-Up and Top-Down approach [8]

proach can create resistance, especially among employees who must adapt. Combining the two approaches gives more room to achieve a positive outcome, both for the board and the implementation for the product developers.

The combination of approaches goes hand in hand with communication, such as conversations, to understand the values and objectives of both parties. To make sustainable changes for the company, the board of directors must approve, and the developers must at least accept it. The board's goal is to achieve a better market standard to promote their investment in the environment. The problem is that investment comes with risks and costs. Product developers want and need to do their job, and their goal is to deliver a good product in a good social environment. Adaptation is accepted if it adds value. The problem is that time must be set aside to assess and apply a new product evaluation factor. These values should be considered when planning the transition.

9.1.2 Engagement & Influence of people

To ensure the transformation, urgency needs to be created to make people aware of the problem and the solution. By applying the AIDA method it is possible to convince people to change their way of thinking to something that they want and need [4]. The method is designed from a marketing perspective but can also be used for change management. The method follows four steps to change the needs of the target group. First, they are made aware of the problem; second, interest is aroused, such as for the STAT; third, the desire to use the product or tool needs to be created; and finally, the action to implement it and change the processes.

In addition to the AIDA method, the areas of influence of people must be defined to know who is affected, involved and responsible for the transformation. By determining the people's involvement, it becomes evident who plays which part in the transition. Some people need to be only made aware, which are engaged, others have an influence on the adaptation, and some are in control and must take the action. Therefore determining someone's circle of influence support the understanding of areas of involvement of people [16].

In Figure 24 the circle of influence and the AIDA method are combined to show how the approach to the structure of change can be executed. However, before executing the changes it first needs to be clear who is engaged, has influence and is in control of the change. If this is not stated well, the change will be more difficult as people do not know their position within the adaptation. In the execution, the engaged people must be made aware of the problem to change while the people with influence must have an interest in the purpose and the goal and the people of control must take the action to achieve this. The control can be one manager that is leading the change and working together with someone on the board of directors, such as Auping did.

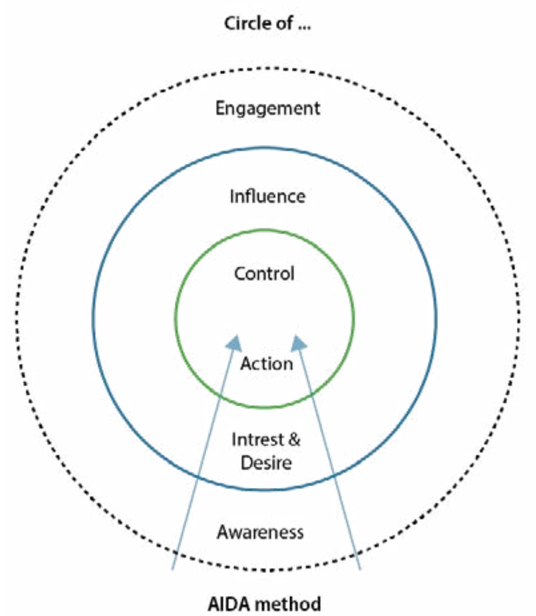


Figure 24 The circle of influence and the AIDA method combined to structure change [16] [4]

9.2 Implementation of Change

To execute the change, the company must have a vision for sustainability, a clear structure of a top-down bottom-up approach, and a project definition of peoples' involvement in the change. The preparation is as important as the execution. However, the execution will not always go as planned, which needs to be considered. In the execution communicating is key to getting people on board with the change. The people must understand why, when, and how the change is planned. Though every situation, the people, and the environment are different, there is no best way to manage change in a company, but some focus points are essential.

9.2.1 The Involvement of Actions

Interviews and workshops can be set up to create a space for people to give their opinions and ideas. It is important at such meetings to have a structure like an agenda and to give the participants a heads-up to prepare for the meeting. The target group needs to be made aware and create an interest and desire to want to adjust. For this goal, the workshops can include the AIDA model as guidance [4, 75]. The creation of awareness differences per company, but suited examples that are understandable within their day-to-day working activity or personal life could support the awareness. It is important to summarize the results to make the goals clear and to update people that could not attend. Making notes and clearly defining the result of the meeting helps to document and to remind the target group of the outcomes, which keeps the communication clear.

While implementing the change, obstacles must be eliminated to ensure an easy transition. The obstacles can be anything that causes time delays or makes it impossible to implement the change. From the stakeholders, motivation is essential. This can come from internal or external factors, or it can occur when people do not have any motivation to cooperate. People are not an obstacle but an opportunity to improve the change plan. Therefore, it is essential to go into a conversation and ask why the person does not want to integrate into the process. Take criticism seriously by listening to and talking about the problem [70]. People like to be rewarded for their effort. Therefore, providing support within the adaptations and creating small achievements can motivate the employees to adapt slowly towards the intended situation. This can be done by a small gesture such as a compliment from the board of directors, or a more significant gesture of extra money or a department activity.

9.2.2 The Change becomes part of the process

After the implementation of sustainability support in decision-making, the situation can be refrozen, as the Lewin's model stated. Therefore, the change is applied in the current development process and becomes a standard. The change of a process can take months or years, before including sustainability as an assessment factor in the product development process [73]. The refreeze of the situation can promote the implantation of sustainability factors. The company is transitioning to creating fewer environmental impacts by creating products.

However, implementing sustainability to support decision-making is not the finish line of becoming a circular consumption manufacturer. Only the first step is set to make the transition, but there is more to change by taking more steps. Unfreezing, changing, and refreezing of the process is needed again within the transition to maintain continuous improvement toward a reduced environmental impact. When a company adopts a circular development method, it faces both expected and unexpected challenges. These challenges are shown in the Van Raam Case Study, where the literature is implemented within the environment of a company.

9.3 Case Study: Making Sustainable Changes

To make sustainable changes, the adaptation needs to be managed by working together with the product developers and the board of directors. This is established by having interviews, meetings, and workshops. The main goal of the change is to make the stakeholders aware of the environmental problems, and the linear economy and to show that implementing the STAT is necessary to translate the SDGs into smaller short-term goals. As mentioned before, the implementation of the change at Van Raam happened simultaneously with the development of the PD-LCA and STAT. This means that it was not completely possible to introduce the usage of the tool. The developers at van Raam were very interested in the results, and they provided valuable feedback on the usage of the tool. Even though the research was limited in time, the ownership of the tool was transferred internally for further implementation within Van Raam.

9.3.1 Determining the Companies Vision

One of the problems Van Raam encounters in implementing sustainability is that the expectations of the board of directors and the product developers do not align. As illustrated in Figure 24, to tackle this challenge, it must be apparent what function someone has in this transformation. As Van Raam grows, the company will become more adhered to a top-down strategy. As a result, the board of directors must recognise that they are essential in implementing changes. As a result, a meeting was held to inform them of the situation. One of them agreed to join one of the workshops to support sustainable changes and to discuss the board's and product developers' needs and expectations.

The workshops were established to ensure a smoother transition by making the stakeholders aware of the urgency of the environmental problems. Some were internally motivated, others needed to be convinced and some did not want to participate. The four workshops follow the AIDA method to convince the stakeholders. These are elaborated on in Attachment N. One of the aspects to not only raise awareness within the workshops was to give the stakeholders a 'kneuzen plant' [79]. These are plants that are saved from being disposed but they need a little more care. They were placed on their desk, to be daily reminded to apply sustainability. The workshops demonstrated, through an assignment, that the stakeholders were unaware of their areas of engagement, influence, or control. To address this, the company must explicitly define these aspects to make better changes. Nonetheless, the workshops, plants, and assignment raised awareness to think about sustainability in a variety of ways.

9.3.2 Shift of Ownership

Because of this time limitation, the ownership of the change and the further implementation of sustainability are transferred to the knowledge domain of "Sustainability" of Van Raam. This domain is established in March 2022 and exists out of four people that have an interest in tackling sustainable issues at Van Raam. They are now taking the main lead on sustainable development not only within product development but also in supporting other departments for sustainable decision-making. The domain achieves clarity within the roles of the change. The domain has control, as well as the board of directors whereas the other stakeholders have influence or engagement, depending on the type of adaptation.

The STAT is transferred to this domain by a presentation about its use. They lead the future change and implementation. Although the STAT still requires changes and management has yet to achieve long-term change, the first step in the transformation has been taken. Sustainability is becoming a part of daily activities as a topic of debate and as 'kneuzen plant' to be a symbol of the company's direction to a sustainable future.

9.4 The Chapter Conclusion

Overall, this change management research can provide a solution to the last sub-question: **What is required to implement sustainability as a decision factor in a company?** To make changes possible a company should first define two aspects. The company's vision about sustainability and the stakeholders that are involved in the transformation. Though, companies differ within a top-down, bottom-up or both, the board is essential in steering the people to their vision. They should lead the company and they are responsible for changes. It is possible to give others control of the change and they can ensure that their vision is met. By having someone that is taking the lead this person can guide and structure the change. This person can identify the people that are involved and affected by the change. It is essential to have a plan and clarity of the reasons why, how and when the change is applied. Keeping the stakeholders up to date and listen to their ideas will increase their willingness to adapt. Not everyone has motivation to make changes as some do not agree or do not want to take part. It is essential to listen to them and their point of view while having an open attitude.

To be successful in the implementation, stakeholders must understand the urgency of the change, as this promotes readiness for change. As a result, workshops can be organised to show them the current problems and potential solutions. Changing something takes time, and one or more people should lead and control the change while maintaining close contact with the board of directors. Only then would it be suitable to implement a sustainability decision factor, the in-house eco-label. To incorporate the STAT into the product development process, and the eco-label in decision-making meetings, there must a clear vision, well-defined stakeholders, a sense of urgency to transit and plenty of time.

10 DISCUSSION

This research demonstrates how sustainability can be integrated and made measurable for decision-making in product development. The sustainability integration was facilitated by change management while the solution was developed. To make sustainability measurable for the target group, the PD-LCA method and the assessment tool STAT have been established. The results of the research have been demonstrated in this thesis, but some results are unexpected or affected by limitations. Therefore, the results are discussed regarding their validity and feasibility.

10.1 The Uncertainties of the LCA

There are many uncertainties when assessing a product's life-cycle, such as the limitations of parameters, the different measuring methods, and how the data is implemented by the user. These limitations will influence the outcome, but it is not yet stated to what extent this influence has in making decisions. Multiple aspects are hard to measure and define in the case of certain products. As there are subjective feelings, the truthfulness of the results is not always easy to measure. Therefore, it is interesting to know and to research, whether the effect of these uncertainties is insignificant enough to be allowed to base choices on.

The research stated numerous times that the results are not intended for marketing purposes and that the purpose of the research is to define sustainability and use this to set and meet short-term goals. The STAT makes the user aware of the impact of certain decisions in a simple but valuable way. The measuring method could be updated if another resource is made available. More research is needed into the volatility of making decisions and how this works in practice. Also, human error will always be an unavoidable factor, but when LCAs are applied by two or more product developers, the details must become more unified. The measuring methods will be updated and adapted to the current knowledge and use of certain life-cycle parts. The solution of quantifying sustainability with the STAT is certain enough to be used within the company but not for marketing purposes, as public blame on the manufacturer must be avoided.

The PD-LCA method was developed within this research and needs more research to prove the method fits other product development-related cases. The method follows its requirements, but improvements and assessments are needed to support the method. The STAT uses the PD-LCA method, but other LCA tools could also use the method to make product LCA and improvements better suited to the developers of products. The STAT is the result of such a tool, but it would be interesting to have more developments on such a tool based on the PD-LCA method to optimize the assessment for the user.

10.2 Quantification of Sustainability

Further, the focus of research is to quantify sustainability, which is done by defining the environmental impacts and then decreasing these impacts through a redesign. Reducing environmental impact is not the only way to develop more environmentally friendly products. The reuse of materials is important, as is product durability and the possibility of disassembly for reuse. What constitutes sustainable design has several perspectives. In this study, environmental impact is taken to understand the impact of the different life-cycle stages, and from there, product developers learn not only to reduce the impact but also to look at it from other perspectives through the DfE's and R methods. Sustainability is extensive, but the PD-LCA and STAT make it accessible to define the environmental impact within the earlier stages of the development process. There are many more solutions within LCA programs. However, this research enables product developers to incorporate assessment into their development process and add value.

The meaning of sustainability was mentioned to include the coherence of social, economic, and environmental assets of a company. Within the research, the direction was chosen to focus on the environmental asset to make sustainability quantifiable, as this element is hard to define and follow in the requirements, as the research and the case study stated. However, for further research, it would be of interest to know how to define social and economic sustainability for a product development process and its decision-making.

10.3 Application for other manufacturers

The results of the research should apply to manufacturers other than the case study, but there are some limitations within the research for other manufacturers. The research targets product developers from one company who have similar backgrounds. The target group includes product developers with different functions. Nevertheless, using more case studies would improve the validity of the research. In different case studies, change management research will be different because companies, product developers, and stakeholders are not the same. A different approach would be needed for the transition. This study examined literature that could support other manufacturers, as the core needs of change management still apply. Communication is essential in all the changes that are made.

Another aspect to mention is using STAT for other manufacturers. STAT uses the eco-indicator 99, which has a limited database. The available data is not suitable for all manufacturing companies. To improve the data, more simplified data should be made accessible, or contracts should be signed with companies, such as PRé Sustainability, to make the data available. However, the simplicity of the current data makes LCA easy and fast for product developers, which is the main requirement of the tool. The same applies to Excel as the interface. The program is not the best in terms of its UX, using another program to create the STAT would make the UX design better for users. The STAT is in its infancy and therefore needs further development. This development should improve the tool by meeting requirements that are not yet fully met. While the STAT is the first step for product developers to apply LCAs, more research is needed to know for sure whether the STAT applies to other manufacturers.

11 CONCLUSION

This research solves the problem of transitioning to a more sustainable company by adhering to the SDGs. This requires, defining sustainability and clear short-term goals. This can be accomplished by defining a product's environmental impact of a product in an easy, understandable, and valuable way that supports sustainable product development. As a result, the STAT was created, which applies the PD-LCA approach to perform an LCA and define the environmental impact of concepts or products in CO2-eq and milli points. Not only is defining the impact important, but a developer can create a product that has less impact by redesigning and using the R's method and DfE in every stage of the development process. However, by making sustainability quantifiable it becomes accessible. The value of quantification can be created when comparing concepts and products according to the company's product portfolio. Understanding the company's impact on its portfolio shows the major impact areas that must be tackled when redesigning the product or when a new product is developed. Therefore, the main impact areas need to be decreased to create valuable environmental changes.

The findings of the research and the answers to the sub-questions, which were answered during the thesis, form the answer to the main research question:

How can sustainability be integrated and made measurable for decision-making in product development?

Sustainability can be made measurable by applying the PD-LCA method in STATs within the concept phase. For decision-making in product development, an internal eco-label is needed to set requirements and short-term sustainable goals. All this needs to be put into practice by the guidance of change management where the urgency of the transition must be created and open discussions on the subject.

The stakeholders who are involved in the change, such as product developers, managers, and the board of directors, must be made aware of the urgency of the change for more sustainable products. Raising awareness and creating a space of discussion for sustainable ideas and solutions can help to make the transformation easier and more graspable for the stakeholders. The solution to making the first steps towards following SDGs and achieving a more sustainable company can be found by doing a sustainability analysis, which can show the strengths and improvements of a company according to the TBL. This supports making changes that are valuable and suitable for the manufacturer.

The developer has the most influence in reducing environmental impact and developing for the environment during the ideation process. The Rs method and the DfE support the developer by rethinking the situation and showing that circularity is possible. Small changes can have a big influence, and the developer must be motivated and supported in this process by the manager or board of directors. To assess sustainability within product development, it must be implemented in the requirements list. A SMART requirement is more easily met and, therefore, the eco-label can define the goal for the product development aims.

In the product conceptualization phase, a product developer can assess a product life-cycle by applying the STAT when wanting to know the concept's environmental impact or to compare concepts to identify which product to choose. Sustainability is a part of the design process; therefore, iterating a concept by sustainability redesign must be done when applying the STAT. The greatest impact can be achieved by reducing the amount and type of material used, as this accounts for the majority of a product's environmental impact. The STAT results of a product can be compared to other concepts with similar FU, and the results can also be approximated to an existing product in the company's portfolio. The extent to which the target has been met can be determined by comparing the results to the requirements and the company's own eco-label. If it is not met, more redesigns will be required to meet the requirements.

Thus, implementing sustainability is the first step in improving a manufacturer's business by shifting from a linear to a circular model, using fewer materials, and reusing them. The SDGs must be met within eight years, so significant changes are still required. These goals can be met more easily by implementing the STAT and using product eco-labelling. Thereby, the PD-LCA and the STAT assist a manufacturer in becoming more resilient for the future by achieving social, economic, and environmental coherence.

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13 TABLE OF ATTACHMENTS

A Results of Interviews of the Product Developers at Van Raam

The Conduction of the Interviews

The interviews took place in 2022 between 27 October and 10 November. The interviews lasted between 45 and one hour. Depending on the amount of time the participant had available. The interview's objectives are to get to know the target group, ascertain Van Raam's TBL for sustainability, and determine their needs in order to specify the type of support to be provided for sustainable evaluation. The interviews are thorough and significant because they provide support for various aspects of the research. In order to create a summary, each interview was transcribed.

The same format was used for all the interviews. Starting with the interviewee's educational background, professional background, and path to Van Raam. These elements determine whether the target group is diverse or cohesive. The interviewees had to identify Van Raam's advantages and improvements within the TBL sustainability cohesion in the second section. The TBL can identify the areas of the business that require improvement in order to become more resilient. They had to describe their sustainability vision in the third section, which helped determine whether they were internally motivated to change or whether they required external motivation. In the fourth step, they had to specify their requirements and goals for the creation of a tool that could quantify sustainability's environmental component.

Each interview was summarised per person. Due to privacy concerns, the positions of individuals are not disclosed, and since the business is expanding quickly, it is more important to know who is in that position now than when they held it previously.

Interview Questions

Part 1 Current situation 10 mins
*Let's introduce myself, I'm Rixt etc. nice that you were at the workshop etc.
*Explanation of the conversation
What is your position at Van Raam (what is your specialism) (what tasks)?
How long have you been working at Van Raam?
What did you do before Van Raam? (study or work)
Why did you come to work at Van Raam? (What appealed to you?)
What does your 'standard working week look like'?
What are important moments (annual)?
With whom do you mainly work with?

Part 2: Sustainability in the company 10 min
How does Van Raam apply sustainability in the company (Social, economic and environmental)?
How are these values applied in the design processes? Where do the interests lie?
How are they applied in new developments in the company?

1. New bicycles (Easy rider how did that process go)
2. New methods
3. New people new features

Part 3: Own view on sustainability
What shocked you the most when you saw something about sustainability? (Something in the news, what you have seen, read, or heard)
What do you think would be good about Van Raam that you appreciate? (Looking 3 values)
    What do you think they do well?
What do you think could be improved in the company according to the 3 values?
    Have you also noticed that when applying / designing with the Easy Rider?
What are the problems in decision-making?
    What kind of information would help with this?
    What would you like to know better?
Do you ever look at the durability of a product part?

Part 4: Support to define sustainability
Explanation of what the purpose of the research is and that a method and support will be developed.
What do you think about this problem?
How can current products be qualified in terms of sustainability?
What do you think the support/tool should be able to do?
Would a tool be an addition to your work?
1. If so, how?
2. If not, who do you think could do it?
Do you know tools that support sustainability in product development?
1. Have you already used tools that you know?
Interesting values
What values would you like to know that come from a tool?
1. How do you envisage these values?
How much time do you think this should take? (Time vs precision)
Where do you think the focus of the support should be?
What do you think is most important to Van Raam?
What would add the most value?
Would it be useful if a support is customizable as the company has different processes?

Junior Engineer (JE)

Pre- Van Raam
The Junior Engineer did his studies in the Automotive industry in Aalten. The JE did an internship at Mueller, a manufacturer of milk and beer tanks. In this internship, not much of his studies came to pass. JE always worked on bicycles at home, mainly because of the corona. Then the JE graduated with an assignment at Van Raam. JE's mother works in healthcare, so she was familiar with the company. JE worked on the rear wheel of the Fun2Go. By putting the wheel into Solidworks and doing tests in the model programme. The spoke tension.

Van Raam
The Junior Engineer now works at van Raam for two months. The JE works on the real integration of the JE's research in the graduation assignment. By using the wheel spokes machine. Next to that main project, the JE does smaller tasks for the other Engineers if they need something to be designed. Such as gears or the chain guard.

Social	Economic	Environment
+Possibility to learn. As a student as well as an employee.	- The availability of product parts is difficult	+ Looking for more sustainable materials -> coming from R&D
+ Good atmosphere but with many new people the atmosphere does change	- Making choices other than availability	- We need to focus more on our waste
- More schooling is needed (for new mechanics and eco-sustainable)	- R&D spending -> It is about the profit of products.	±
- More rules and areas of specialisation -> a shame for prototyping		

Sustainability
Some people think about the recyclability of plastics. Some parts are recyclable, but the JE has no idea if the products are recycled. That was also missed by the JE in the study, which is unfortunate. The JE believes that laws should be changed to encourage companies to produce more sustainably. Only profit is still considered at the larger corporations. Van Raam's pure profit margin is not as high as that of multinational corporations. The government provides subsidies to Van Raam. As a result, R&D has more freedom to carry out their duties. The JE does not take into account design sustainability. Only recyclable plastics are permitted. In doing so, the JE is not taught about what is sustainable in school or at Van Raam. What are the best options?

The JE had no idea Solidworks had a sustainability tool. The JE was taken aback because he had no idea it existed. The JE was unfamiliar with sustainability tools. Even though the JE has only recently graduated from Higher Vocational education. The JE wouldn't mind using a tool if it suits within Van Raam.

Support to define sustainability
- What are we, as Van Raam doing to be sustainable?
- Graphs and overview would be nice
- Three concepts that are possible and then use the tool to see which concept is the most ecological positive.
- Only use the tool if the material of strength is equal
- Solidworks would be nice, but it is easy to use.

Engineer (3D printing) (E3DP)

Pre- Van Raam

Engineer 3D Printing is from Aalten and studied Mechanical Engineering at Saxion in Enschede. In the minor, the ER3P also completed a premaster's degree in technical physics. The E3DP was impressed by the Saxion's practicality and performed a stage at Van Raam. They learned about the company from E3DP's mother, who works in healthcare. 3D printing was and still is the participant's hobby. The study's internship was on how to redesign the metal print group. The graduating assignment for this intern was at Kaak ten Borg. Whereas the E3DP continued with metal printing, this time the interviewee created a 3D design for a heat exchanger (40% more efficient use). This design is used by the company. The assignment programmed an optimal method for allowing the computer to calculate the best strategy.

Van Raam

The participant is now employed as an engineer in 3D modelling. The E3DP oversees the technology centre and the 3D printing area. The participant has been with the company for over two years, beginning in the printing department. This had to be set up to be used to produce bicycles. However, technology and 3D printing have advanced significantly. As a result, the interviewee began a personal development process to determine his passions and qualities. This was necessary after the company grew significantly and pressure and desire decreased. About 80% of the time was spent managing print production, and the remaining 20% was spent on research. E3DP preferred it the other way around. He was attending events in order to discover and develop new techniques, among other things.

The E3DP collaborated extensively with Employee Tech Centre and, on occasion, Montage Engineer Specials. However, MEs are in the tech centre to scan parts to ensure that the details are of high quality. In addition to them, the JE is in the tech centre. As a result, the production engineers are also involved in the communication. The E3DP has an impact on printing and determining whether something can be 3D printed. The participant must also examine the frameworks to ensure that they meet the production requirements.

Social	Economic	Environment
+ Family company	+ Tech Centre -> checking products in design & quality	- Unknown waste disposal of some products (batteries & 3d print dust)
+ Ahead in norms as NEN & ISO in three-wheelers	+ High-quality products -> checked by norms	- Buying from Asia
± Inhouse production can be even more	+ Your plastic solutions is of Van Raam	- Too less knowledge in the company about this sector
- Miscommunications -> waste in tons stored somewhere in the building, and no one knows what to do about it	- Focus on own function can be more on the research and pioneering instead of managing the 3D printers	- Transport to Poland -> Varsseveld and Poland again.
	- Efficiency improvement & in housing	

Sustainability

Even if many parts are manufactured in-house, Van Raam can reduce transportation significantly. Many parts are still sourced from Asia, which is neither sustainable nor efficient. For example, frames made in Poland are checked in Varsseveld before being returned to the manufacturer. Using 3D printed powder to create Nylon tread for other 3D printers.
The JE had no idea Solidworks had a sustainability tool. The JE was taken aback because he had no idea it existed. The JE was unfamiliar with sustainability tools. Even though the JE has only recently graduated from Higher Vocational education. The JE wouldn't mind using a tool if it suits within Van Raam.

Support to define sustainability

- Giving grades per bike
- Heavier is not always better
- Where is the energy from?

Senior Engineer Montage (SEM)

Van Raam

When the Senior Engineer Montage was 19, he began working at Van Raam. The SEM is from Nijverdal and attended the LTS, where the participant was a metal and electrical specialist. The SEM has undergone many changes in the last 35 years. The SEM was Van Raam's sixth employee in 1985. There was a crisis this year. Bicycles were made by one person back then, and the production rate was much slower. It was more about company survival back then. Van Raam was able to expand due to government compensation. Because Van Raam is a family business, the working environment is pleasant. There is constant change and innovation. They are not afraid to face technical difficulties. Because the company is financially stable, there is more time for these things these days.

The SEM manages day-to-day tasks and projects involving multiple disciplines. To create or improve bicycles. The SEM creates mechanics' work preparation manuals. These are drawings or pictograms with brief explanations. These manuals are more complicated for special bikes.

Social	Economic	Environment
+ Ecological building Customer focus	+ Ecological building Good wealth gives more room for innovation	+ Ecological building
± Good atmosphere but with many new people the atmosphere does change	+ 3D printing	
- More schooling is needed (for new mechanics and eco-sustainable)	- Too much of a growth -> too much sometimes to handle	
- More rules and areas of specialisation -> a shame for prototyping		

Sustainability

The SEM says the procurement department can start looking at the carbon footprint of product components, as transport has a big impact. By being more sustainable, the customer cannot bear the brunt of creating more eco-friendly bikes. So, comfort and usability should be the same or even better. The SEM recommended looking at the Gogab. To change that design because the body is polyester and could have a redesign to be more durable.

Support to define sustainability

- Only use if it is necessary or very informative to use
- Needs to have added value
- Life-cycle Analysis (especially the transportation)
- Put demands in PVE (List of Requirements)

Process Engineer Montage (PEM)

Pre- Van Raam

The Process Engineer Montage conducted research in Arnhem Industrial Product Design. The PEM did research, design, and technique for the minor at a sailmaker company. Life&Mobility agreed to provide a graduation spot. The topic was to investigate wheelchair seats which are equipped with sensors to see how people sit in order to prevent blister forming on the sit areas. The company did not make a future match. As a result, Jolien was contacted, and the PEM began working for Van Raam in the Research and Development department.

Van Raam

The PEM began at Van Raam 3.5 years ago. The participant started with designing chain guards to optimise assembly processes There is not much time to prepare for assembly, primarily optimising current bicycles for more efficient assembly, so that the technician has the correct information. The PEM also aids in the establishment of new lines for more mass-produced products such as the Easy Rider 3. As a result, the PEM is the point of contact for any mechanical issues. The emphasis is on the Product and Process. Is it possible to produce the product in batches? The mechanic is the PEM's user. The PEM communicates with many people in the company.

Social	Economic	Environment
+ Excellent atmosphere as a family company	+ Market leader in the production	+ Market leader in the production
- More guidance needed for students	+ Much investment in production technics (Tech Centre)	- No room/time to brainstorm or to think about the ecological side of a product (part)
	± Focus mainly on output	- Can be more ecological grow
		- Still using plastic cups

Sustainability

Van Raam's means of production are up 36% and profanity is up 50% year on year. This is not always a good thing, as more people are needed in some areas of the business. This aspect of the business can help to improve eco-sustainability. In design, cost reduction is critical. When something is changed (redesigned), it becomes more expensive, and old parts are discarded.

Van Raam has the option of returning the bikes to the factory for disassembly. Or have someone else do it for Van Raam. To set a good example for competitors. Making your own parts will also be beneficial. Because the pollution level is much higher when parts are imported from Asia. 3D printing is an excellent example of in-house, fully sustainable production that produces only the features that are required (no inventory needed). Change must be prompted from on high.

Support to define sustainability

- What are the possibilities, and what is the yield of it?
- Material options
- Technique options
- Who has which specialism
- For new bicycle designing
- Efficient producing
- Knowing the whole life-cycle -> what happens?

Lead Engineer (LE)

Pre- Van Raam

At the Han in Arnhem, the LE studied Industrial Product Development. Following the study, the LE began working at QDP, an injection moulding design firm. QDP's designs were created by employees, and the products were manufactured in Asia. It was time for a change after many years. The LE knew who to contact for a job interview because of his connections as QDP to Van Raam. The LE has now been at Van Raam for over two years.

Van Raam

The lead engineer began as a generalist engineer. The individual's knowledge of injection moulding could be very useful in the job. Van Raam has taken over Your Plastic Solutions. The LE is in charge of the Balance project. The LE is also involved in cargo bikes through policy groups or the NEN

Social	Economic	Environment
+ Good quality of life in the company	+ Economic secure	- The vision needs to be reset that recycling is essential and that costs are not the overall motive
+ Community development	- Difficult to get the parts from distributors	- Not getting the materials back in the loop of recycling
+ Good smart growth	- Use of resources	- Parts bought in Asia

Sustainability
The participant was astounded by the impact of fishing on aquatic life. The LE no longer eats fish because the LE believes that it is insignificant to endanger more aquatic life. The "low hanging fruit" is critical for the LE because it is relatively "easy" to change. These plastics, primarily recycled plastic, are appropriate for Van Raam's products. The powder 3d printer waste can be used to make filament or nylon string 3d printer. More can be found throughout the life-cycle. Additionally, 'general' waste can be separated. Because the LE is well-versed in plastics, it already considers which material is the best fit and most sustainable.

Support to define sustainability
- Make it as relevant as possible
- What happens, and what is the process -> clear
- The background knowledge can help with designing
- Details are not required
- What impact does a production technique have?
- Consider transportation.

Product Management Design (PMD)

Van Raam
The PMD works at van Raam for 2.5 years. The participant already graduated at Van Raam as a student. The PMD created a new design for Fun2Go. The goal was to create a bike without a chain, something that could be driven wirelessly. The participant studied IPO in Enschede and worked as a designer at Van Raam after graduation. The PMD creates the aesthetics of the bicycles. For example, stickering and drawing sketches for the bikes. By beginning with sketching the ideas in Sketchbook, and then an engineer sketches 3D in Solidworks. One aspect of this job is the design, and the other is product management which conducts market research. The PMD was speaking with sales and dealers who had encountered issues with the bike or other ideas. The PMD conducts this research to determine what is required in the market. They will then create products and find solutions. This was done in collaboration with the engineers. In addition, there are guiding groups. These groups meet with representatives from various departments to discuss new bikes or additive parts solutions. They all represent their function of brainstorming and deciding what is and is not interesting to do.

Social	Economic	Environment
+ Take each other into account	+ In the Netherlands, Van Raam does well with the WMO	+ Laws that help to be ecological
+ Good company in the quality of life for employees and the end customer	+ People will buy the product (high importance and improve quality of life)	- Many improvements needed in the knowledge
+ Is still room for improvement	- A shame that the products are so expensive (especially compared to 2-wheel bikes)	- It is not taken seriously to make ecological parts
	- Improvement for other countries that do not have the social payment for Van Raam bikes	- View of that eco is more expensive
		- That's how it was, and that's how we do it

Sustainability
The PMD believes that much improvement is needed in the ecological area's sustainability. More knowledge is required, but some of the parts can be recycled. It would be ideal if someone took the lead on environmental sustainability. The 'low hanging fruit' can be implemented first. In the PVE, requirements list, use sustainability. Some product components do not need to be able to exist indefinitely. Then the participant would like to see what other opportunities are available.

Many people are acting in the same way they always have. It's a shame to pass up new opportunities. The current design prioritises product availability over environmental sustainability. However, environmental concerns must not come at the expense of the user.

Support to define sustainability
- Critical parts are different -> categorise types of product parts
- Look at the PM and the engineers
- Designing with knowledge (get information before designing)
- Function, looks, methods, materials (in a general way include this).'
- Fair competing

Montage Engineer (specials) (MES)

Pre- Van Raam
Montage Engineer Specials studied Industrial Product Design atthe Saxion in Enschede. The internship was at Van Raam during the third year. The task was to create a digital user manual for Opair. This took place within Solidworks composer. The MES devised a method to reduce the chain case for the Fun2Go from eight separate parts to three. The graduation project was at NOVA. This was a small business where the MES worked on a machine tool that created safety lines to prevent wear.

Van Raam
The MES returned to Van Raam after graduation. Things have changed quickly in the 4.5 years at Van Raam. Different R&D departments are in another location. The work is close to the work floor as a MES. The MES collaborates closely with the PEM and the montage team leader. All of the questions on the job can be asked of the interviewee. Following that, the individual creates one-of-a-kind bicycles. Orders for these specials are also increasing. There aren't many drawings or instructions with the specials. As a result, the MES creates instructions in addition to the design. The MES, 3D Engineer, PLE, and Jaap operate the 3-D scanner in the Tech Centre. The PLE and the LE submitted applications for the specials. They go to the customer if they require a bike that Van Raam does not have in stock. The application is sent to the MES, which determines whether it is feasible and how much time and money will be required for the invoice. The PLM that the MES must now work with makes the job more difficult. The interviewee believes that while this is currently annoying, it will improve in the future.

Social	Economic	Environment
+ Taking good care of personal (fruit, treats, activities)	+ Becoming more independent as a company (your plastic solutions)	+ Solar Panels
+ Education (cursus)	+ Innovative actions (motivation of the managing board)	+ The wish is there, but the clue how to do it is not there yet
+ A lot is possible, but you must be assertive	- R&D projects become more challenging to make a design and build it in 3D	- Use of a lot of paper manuals
- A lot of new people bring a different atmosphere (&corona)	- Too much growth because of the demand in the market	- Not getting the materials back in the loop of recycling
- Too much pressure on your work	- Too much pressure on projects	

Sustainability
The MEP was taken aback by the current state of the environment. The price of gasoline continues to rise. The raw materials are depleted. Nature documentaries highlight the issues that nature faces because of environmental impacts. It's not going so well. Customers, on the other hand, do not ask about sustainability. They are pleased with the product, which is primarily concerned with the price.

The MEP thinks that Van Raam must not waste material. The critical driver must not be saving money on everything. However, Van Raam feels that they are already better than a car manufacturer and comparing with that makes it useless.

The MEP thinks it is not easy to look at a sustainable way. As it takes time, the customer will pay the money, and the bikes are already costly. As the company, we can look at transportation and localizing. One example of +/- in innovation and sustainability is the 3D printer. The water waste from the cleaning of the parts needs to be separated. This was not known before we bought the 3D printer as the company of those printers said that this was no problem.

Support to define sustainability
- Mostly look at the development and maybe redesign
- Look at where there is a choice to design more sustainable
- Decision three with categories of critical
- For the whole life-cycle, begin -> end
- Gaining knowledge
- Hard evidence

Montage Engineer (Poland) (MEP)

Pre- Van Raam
The MEP attended the Han in Arnhem. The participant worked in mechanical engineering there. The MEP worked on a solar boat during and after his studies. The MEP interned at Q Concepts, where the participant made parts for aviation, sailing, and drones. The participant constructed a hydrofoil. Following that internship, the MEP began working at Hesling. This company employs approximately 80 people and manufactures bicycle parts. They are experts in injection moulding. This is primarily intended for city bikes. The MEP worked on the product moulds here. It took a lot of communication with China to get those moulds. Though the atmosphere was not what the person was used to after several years, it was time to look for something else.

V**an Raam**
Since June 2021, the MEP has worked at Van Raam. The person's interests and the atmosphere are much better. The MEP's task is to be the point of contact for the Easy Rider & Fun2Go. This is with line coordinating as with communication the person, talking with assembly logistics and the Senior Engineer Montage. Next to the daily questions and the projects, the MEP is also the contact for Poland.

Social	Economic	Environment
+ Good atmosphere in a lovely building	+ Solar Panels	+ Solar Panels
+ Nice college's	- Too much demand and too fast for the tricycles	- Not much that is known of what Van Raam does in this area
+ Vision of the company is clear	- Not enough personal as for R&D area's	
- Workload becomes higher with more demand		

Sustainability
The entire process of climate change is irreversible. There is much more to learn about sustainability in the company. As a result, it would be beneficial if sustainability was taught in schools. Then you'll be able to make a difference in the future.

Support to define sustainability

- Van Raam has its database in solid works of materials
- Material identification what is there in the market possible?
- Reuse of products what does that have in influence
- More personal interest connection
- Process three as a hold on -> as a large poster for in the office

Manager R&D (MR&D)

Pre- Van Raam

Prior to Van Raam, the MR&D studied mechanical engineering for a few years before pursuing a career in business administration. Following graduation, the MR&D began working at NPS, now Marrell. The MR&D provided quality care and provided ample opportunity for personal development in the workplace. Project evaluation and process improvement were both tasks. The MR&D then travelled to Kamarun to assist a local organisation in becoming more efficient in sponsoring and training people to improve agriculture. Following that, the participant worked as a quality engineer at an iron foundry, where he examined process risks. Then five years at Sanovo, which manufactures egg sorting machines. In the end, there was no room for changing the policies because they no longer suited the company. It was a shame to leave because there was a positive work environment.

Van Raam

A network connection brought the MR&D to van Raam a year ago. By beginning the job, the MR&D examined how processes work and how to define or optimise them, from project initiation documentation (PID) to final technical documents. The PVE's decisions are supported by the MR&D. The first concept phase of the PVE has begun. The MR&D collaborates with numerous departments. Product management, montage planning, PLM meetings, service, production, and assembly are all included. The MR&D examines how the team functions and who is best suited for specific tasks. To make use of everyone's strengths. The participant notices that people in Van Raam have a lot of freedom. This suits some people, but others frequently

Social	Economic	Environment
+ Van Raam has a good name as a company	+ Large prosperity by growing 30% per year	+ Sgreen) product, the bike is better than an alternative (car) for the target group
+ Looking after each other	+ Worldwide perspective for transport	- Improvement in processes can be better
± Freedom	+ Aging target group increases economic growth	- Create more awareness as there is now no one that takes care of this
± (too) much growth	+ 3D printing and tech center	- Transportation is a fundamental problem
	± (Too) much growth	
	- Profit at the expense of innovation	

Sustainability

In sustainability, there is still a lot to improve. Especially the systematic ways as the company are growing. The process needs to begin somewhere. The MR&D thinks that Product Management has a lot of influence on the stainability as they are responsible for making up the PVE. Thereby the PLE can overview the requirements to use more sustainable product materials and processes.

Support to define sustainability

- Taking into account the whole life-cycle
- Concrete -> something to use
- Maybe look at also packaging in the design process. What will that have a fa footprint?
- Your plastic solutions -> reuse of own plastics that we don't use
- Integration in PLM would be nice

Project lead Engineer (PLE)

Pre- Van Raam

In Enschede, the Project Lead Engineer completed an HBO study in mechanical engineering. The PLE may have wanted to conduct a Physio study. However, the technical side was more interesting than the people side. The PLE interned at Life and Mobility, where he worked on scoot mobiles. The PLE even went to Australia to work in mechanical engineering during the study. Because this was unsuitable, the PLE turned to Van Raam for the graduation assignment. The PLE's mother worked in Varsseveld and knew Van Raam, so the company was familiar with internships in the Netherlands. Following graduation, the PLE pursued a one-year business administration program.

V**an Raam**

The PLE completed the O-pair as a graduation project within van Raam. Particularly on the stability and function. Based on that, the interviewee created a prototype to test the O-pair against those requirements. In 2013, the PLE started as a Junior Engineer. The PLE worked on drawings and small tasks with five people in R&D. After that, EasyGo became a project that had to be made production-ready after the design was completed by the Graafschap College. At the time, production methods were much more hands-on, such as making the mould for the frame. In the company, a lot of analysis and norms were not followed. Much more is now noted and checked by regulations. As an example, consider the ISO 9001 technical approval paper. Since the new building opened in 2019, the products have been assembled in a line. The current Easy Rider is made by hydroforming and was expected to sell 3000 units in its first year. As a result, we must now consider how to make things more efficiently, quickly, easily, with less material, and so on. The PLE is now the primary designer of the Fun2Go, which is expected to be a more mass-produced product than a chat or a Twinny. As a PLE, you have many options for when to pursue or abandon an idea. It has a lot to do with experience and gut instinct. Every project has issues that you must learn from. Because of longer delivery times, the purchase marketing must buy something for more than a year or two. The budget is roughly set in the PVE, the requirements list. If the PLE wishes to spend more, the manager of R&D can approve.

The PLE collaborates with the LE and the Manager R&D. This is primarily for norms and risk analysis. It provides advice to montage engineers and the Fun2Go project. The PLE will begin working at the Ideeenfabriek in December. Instead of only drawing online, the workplace has more freedom to build something and do more in physical trials. The details are more minor and important, and the PLE prefers the trial-and-error method. Returning to the beginning of 2013, the company.

Social	Economic	Environment
+ Family-owned company give good work atmosphere	+ Decisions focused on the sustainability of the company	+ Fitting environment laws
+ Supporting good causes	+ Innovation hub sponsoring	+ Sustainable building
+ Parties, trips, everyday fruit	+ Tech Centre & 3D printing	+ Looking for closer to house production
+ Local interacted	±(Too) much growth in production numbers	- Too much emphasised what Van Raam does well (such as the sustainable building)
	- Innovative processes don't necessarily make the product more innovative	
	- Not much time to research the innovation within projects	

Sustainability

Things that seek more connections in the community are more sustainable. Not only in terms of environmental benefit (fewer emissions), but also in terms of social and economic well-being. Still, many product parts are purchased in Asia. However, what is the most effective way to be sustainable? What exactly does it entail? The PLE is willing to consider more sustainable product parts but does not know how to do so in many cases, aside from more local production.

Support to define sustainability

It would be nice to know what simple things could be done to change the impact of a tool. 'Low hanging fruit.' As a result, the recyclability of product parts is required. That is a step in the right direction. What materials can be recycled? Biological materials cannot always withstand the elements for more than ten years. A tool for recognising sustainability would be beneficial. It is necessary to understand the costs associated with it, and most importantly, how much it may cost. Take a look at management. If you introduce sustainability, function, price, design, and quality will be considered. Compromise will have an impact on what element?

- The tool must display the product's emission. The engineers will already handle the costs and material mechanics. They are now doing the same thing.
- Include the emissions in the PVE.
- Inform people about which processes have which effects on emissions (lasering, casting, punching)
- What does a gazelle emit? Comparison to well-known products of competitors
- Using the tool with an ex. three concepts -> which is a better choice in sustainability

Product Manager (PM)

Pre- Van Raam

At the University of Twente, the PM studied Industrial Design Engineering (IDE). The graduation project for the bachelor's degree was with SoWeCare's medical instruments. The PM created workplace instruction manuals. The process improvement was fascinating because there were numerous communication errors. In many cases, the lack of communication was the source of the problems. This is what the Prime Minister prefers. So, as part of his master's degree, the PM studied Management of Product Development as well as some medical subjects from biomedical engineering. To see and feel things more from the user's point of view. The master's thesis was completed at Roessing R&D e-health. Using Adobe XD, create a tool for communication in the company when elements change and why they need to change.

Van Raam

The PM was hired last year after applying for an open solicitation at Van Raam. The function includes designing from the user's perspective and creating a well-defined set of requirements to assist the designer and engineers in producing a good product. The PM considers everything from what the customer requires or desires to how that can be translated into a product. What does the bike require? Are modifications required, or is a new solution for producing a new bike available? Product Management is involved as the project's main lead until the part of a requirements list. The Engineer will then take over. However, project managers will be involved in project groups or steering committees. The PM connects

Social	Economic	Environment
+ lets's all cycle -> slogan	+ Large growth (good: more technological trials and buying (3d printer)) (bad: too fast and too less at R&D.)	+ Van Raam makes necessary bikes and not additional hobby bikes, which makes the ecological side of the manufacturing not of interest to the customer
+ Good at taking care of employees	- Focus on production	+ Second hand or leasing is an excellent opportunity, maybe not for van Raam but for a dealer connection
+ New college that focuses on social elements	- Long delivery times -> different suppliers (ex. Envio)	+ To define requirements of CO^2 or elements to be more sustainable in design
+ Communication even through all levels of employees. One team.	- Long-range planning could be improved	+ Not the one to solve the problems but to participate in being aware and doing so in the process of design/engineering
- Becomes harder to be one team with the fast growth of the company	- Need to keep cost price low, but selling prices become higher	- Not much sustainable push in the company, more focus on innovation

Sustainability
The participant is astounded by the natural perspective of climate change. The effects of increased heat and pollution in the sea are primarily to blame. The PM wishes to be more sustainable in their ideation and design but does not wish to take the lead in this regard. The managing board must advocate for the inclusion of requirements on the list. It would be ideal if someone in the company took the initiative to examine the sustainability of products and product parts. In addition, customers, according to the PM, are not yet interested in the bike's sustainability. They primarily require the three-wheeled bike. As a result, the cost and ease of use take priority.

Support to define sustainability
The PM mentioned that it would be useful to have an overview of where the majority of the company's profit is made. 'Low hanging fruit.' The entire life-cycle is appealing, and one wants to know if something is more environmentally sustainable.

Conclusion

Pre- Van Raam
The majority of the target group studied Mechanical Engineering or Industrial Product Design at Saxion or the Han. During their studies, many students worked as interns at van Raam. Many people from the 'Achterhoek' like to say they live in this area. The majority of the employees were already interested in cycling or human interaction and designing for it at the time. Jolien did well in approaching many people for a job. The tasks' functions and responsibilities vary greatly, from speaking with customers to beginning the ideation process to finally preparing it for production and assembly.

Van Raam
The tasks' functions and responsibilities vary greatly, from speaking with customers to beginning the ideation process to finally preparing it for production and assembly. However, more research and another meeting with each department are required to define this. So, Product Management, R&D Engineering and R&D Assembly are yet to meet.

Everyone liked the environment and the people in the workplace. The open communication and the family business gave them positive energy. Table 12 summarises the results of this section. Van Raam is socially and economically powerful, according to the target group. With market equity, innovations, and a growing business. Van Raam went from a struggling business to a thriving one. There is a significant technological push, which people are pleased with. Aside from the positive aspects, participants discuss how the company could improve. This is mostly about environmental sustainability. Other than a sustainable building, none of the participants could think of anything else. The most frequently mentioned issue is that Van Raam purchases many parts in Asia that could be obtained more locally. When purchasing in Asia, price is an important consideration. Separating waste and reusing materials, according to interviewees, would already help. They claim a lack of knowledge in this area and a push from management. Van Raam's long-term strengths and improvements are depicted in Figure 10 in Section 3.5. The dotted circles represent the desired focus sizes for a long-term business. This suggests that Van Raam's priority should be environmental sustainability rather than social sustainability.

The TBL

Social

Engineers and designers are optimistic on Van Raam's social viability. The company looks after its employees and customers. On the shop floor, open communication is also valued. Furthermore, the company is active in the Varsseveld and surrounding communities. However, the company's atmosphere is changing because of its rapid expansion. The company hires many new employees. Development also increases the pressure on engineers because they must do more work with fewer resources. Because new employees are not always properly trained, there is sometimes more training in production assembly. Because of the company's size, there is more miscommunication or no communication. People with knowledge leave from time to time, and not everything is documented. A new structure of PDM and PLM makes people more confused about their work.

Economic

Van Raam is growing (too) quickly, according to participants. This has both positive and negative implications. Van Raam benefits from financial security and can invest in new technologies and capabilities. The disadvantage is that production cannot keep up with R&D. This puts additional strain on projects and day-to-day performance. As a result, the economic circles are nearly the same size. Because employees expressed their dissatisfaction, the improvement circle has grown slightly larger. Van Raam's economic sustainability, on the other hand, is fixed. Van Raam invests in 3D printing, and the Tech Centre uses technology to present its products. These techniques also help to improve its own part production. Your Plastic Solutions is an good example of local manufacturing. However, a large portion of it is still sourced in Asia. This could be done in Europe as well, but the cost is critical. The majority of investment is in innovation and techniques. People believe that more money should be invested in R&D and project development. To determine what technology adds value to manufacturing and assembly. Van Raam also sells internationally and has a manufacturing and assembly facility in Poland. These countries are not all financially supported by the government. They may find the products to be prohibitively expensive. The price of new bikes is also rising. As a result, the products are restricted to the upper-class.

Economic

The size of the Environment circles differs significantly. This indicates that Van Raam has fewer environmental strengths and more room for improvement. Van Raam's strengths, on the other hand, are in social and economic sustainability. According to interviewees, Van Raam's building is environmentally friendly due to sound insulation and several rooms with appropriate temperatures. Solar panels are also installed on the structure. Van Raam manufactures a (green) product because a bicycle is more comfortable than a car. Although the rationale for not investigating the environmental impact has taken its place. Because the product is both expensive and necessary for the user, it is unlikely that their customers and users are concerned about sustainability. As a result, it is not (yet) possible to reuse or remanufacture the parts. Sustainability is included in the requirement list, shown in Attachment D. However, this requirement is frequently not met due to other, more critical conditions. It has been forgotten. People in general do not see the environmental aspects that Van Raam does.

Table 12 The Social, Economic and Environmental values of Van Raam

Social	Economic	Environmental
A clear vision of the company -> let's all cycle -> slogan	Good wealth gives more room for innova-tion.	Looking for more sustainable materials -> comming from R&D
Van Raam has a good name as a com-pany	In the Netherlands, Van Raam does well with the WMO	Ecological building (Solar Panels)
Supporting good causes (smart hubs, Local interaction)	People will buy the product (high im-portance and improve quality of life)	Fitting environmental laws that help to be eco-logical
Socially sustainable representative in Van Raam (Walter)	Tech Centre -> checking products in design & quality	Close to house production (more working on this)
Communication even though all levels of employees. One team.	High-quality products -> checked by norms.	Second-hand or leasing is an excellent oppor-tunity, maybe not for van Raam but a dealer connection.
Good in taking care of employees (fruit, treats, activities, education, self-develop-ment, students, freedom)	Considerable prosperity by growing 30% per year	Not the one to solve the problems but to partici-pate in being aware and doing so in the process of design/engineering
looking after each other Family-owned company gives good work atmosphere	Worldwide perspective for transport	(green) product, the bike is better than an alter-native (car) for the target group
Good company in the quality of life for em-ployees and the end customer Ahead	Decisions focused on the sustainability of the company	The wish is there, but the clue how to do it is not there yet
Customer focus	Innovation hub sponsoring	We need to focus more on our waste
norms as NEN & ISO in three-wheelers	Becoming more independent as a company (your plastic solutions)	Unknown waste disposal of some products (bat-teries & 3d print dust)
(too) much growth (creates a different at-mosphere by a lot of new employees & corona)	Innovative actions (motivation of the manag-ing board)	Less interest from the customer as it is their primary goal to be mobile again
A lot is possible, but you must be asser-tive	(Too) much growth in production numbers	Buying from Asia (Transportation is a cru-cial problem for pollution)
Inhouse production can be even more	The availability of product parts is difficult.	We could define requirements of CO^2 or ele-ments to be more sustainable in design.
The focus on the own function can be more on the research and pioneering than on managing the 3D printers.	Making choices other than availability	Too less knowledge in the company about this sector
Miscommunications-> waste in tons stored somewhere in the building, and no one knows what to do about it.	Long-range planning could be improved.	Transport to Poland -> Varsseveld and Poland again
It becomes harder to be one team with the fast growth of the company	The focus of its function can be more on the research and pioneering instead of manag-ing the 3D printers.	Many improvements are needed in knowl-edge about this sector
The workload becomes higher with more demand.	Need to keep cost price low but selling prices become higher	It is not taken seriously to make ecological parts.
More schooling is required (for new mechanics and eco-sustainable)	A shame that the products are so expensive (especially compared to 2-wheel bikes)	View of that eco is more expensive
More rules and areas of specialisation -> a shame for prototyping	Improvement for other countries that do not have the social payment for Van Raam bikes	That's how it was, and that's how we do it
	Too much a growth -> too much sometimes to handle	Use of a lot of paper manuals
	Significant growth (good: more technological trials and buying (3d printer)) (wrong: too fast and too less at R&D.)	I am not getting the materials back in the loop of recycling.
	Too much pressure on projects	Improvement in processes can be better.
	Not much time to research the innovation within projects	Create more awareness as there is now no one that takes care of this
	Innovative processes don't necessarily make the product more innovative.	Too much emphasized what Van Raam does well (such as the sustainable building)
	R&D projects become more challenging to make a design and build it in 3D	Not much sustainable push in the company, more focus on innovation
	Profit at the expense of innovation R&D spend-ing-> is about the yield of products.	
	Focus on production	
	Efficiency improvement & in housing	

Sustainability Assessment at Van Raam

The interviews with the target group assisted in determining how Van Raam works on sustainability and how the target groups view sustainability in their work. The only component of the bicycle that was considered sustainable at the time was a bamboo tray. More than half of respondents believed that employers and management should push for the implementation of sustainability. They do not consider assessing the product's recyclability to be a critical task. They mention that product disposal is on the list of requirements but is also overlooked. When asked about their influence in decision-making, many pointed to each other as decision-makers to release. At least two of the eleven respondents were aware of a life-cycle analysis tool, such as the Solidworks eco tool. The others were unaware of its existence. Van Raam's product development is not focused on or specialised in sustainable design. As a result, they have extensive knowledge of materials, processes, and design considerations. Although there is still much to learn about incorporating sustainability into decision-making.

Sustainable view

- The participants were astounded by how the environment is changing and what this means for all life on Earth
- Sustainability is not (yet) a vital factor of the company. The company focuses mainly on innovation and production.
- The currently designed parts that are sustainable are the bamboo tray and the battery can be recycled. Though not all participants knew the story of how the battery is recycled. Nobody knows what happens in the other parts. It is up to the end user to decide how to dispose of it. Van Raam's design priorities are comfort, strength, price, and availability. Sustainability is still not taken seriously.
- What's interesting is that multiple participants say that customers don't ask about the product's (eco)sustainability because they need the product and don't ask for'more.' As a result, the SLE stated that eco-design should not be at the expense of user comfort.
- More than half believe that an environmental push is required from the manager or the board of directors to allow designers and engineers to develop more sustainable products. They believe that focusing on the product's recyclability is not a critical task for them. It may become a component of design and engineering, but it will not be the primary focus. The PM suggested that one person be involved in projects representing sustainability and examining the product's life-cycle.
- When establishing the PVE, requirements list, consider the product's and product parts' sustainability.
- What is remarkable is that many people point fingers at each other in order to influence others to be more environmentally conscious. They believe this is one side that can wield power, but not as much as another. On the other hand, they believe it must be pushed by the management or the managing board. They must motivate and guide them to consider environmental sustainability.
- Van Raam is trying to produce more locally. More parts can be made in-house by having Your Plastic Solutions (YPS) and 3D printers. Many factors are being purchased in Asia and sent to Van Raam in Varsseveld. This transportation finds many interviewees of one of the significant ecological problems. They think more structure and more inhouse production are needed to solve this problem. On the other hand, this problem in Asia makes people less assertive about changing their designs. As they think the transportation is the major problem.
- When the interviewees saw the Sustainable tool of Solidworks, only two people were familiar that the device existed. This was the PLE & the SEM. However, no participants have never used the tool.

• Low-hanging fruit -> is the most impact and easy • Requirements needed in the PVE • Clear overview of the results • Comparing concepts for sustainability • Only use the tool if there is room to look for other options (strength) • Easy to access and use • Giving marks per bike • Heavier is not always better • Only use if it is necessary or very informative to use • Life-cycle Analysis (especially the transportation)	• Needs to have added value • Put demands in PVE • Whole life-cycle taking into account • Maybe look at also packaging in the design process. What will that have a footprint? • Your Plastic Solutions (YPS)-> reuse of own plastics that we don't use • Integration in PLM would be nice • Graphs and overview would be nice • Three concepts that are possible and then use the tool to see which concept is the most ecological positive.

B The Visualization of R-methods Van Raam

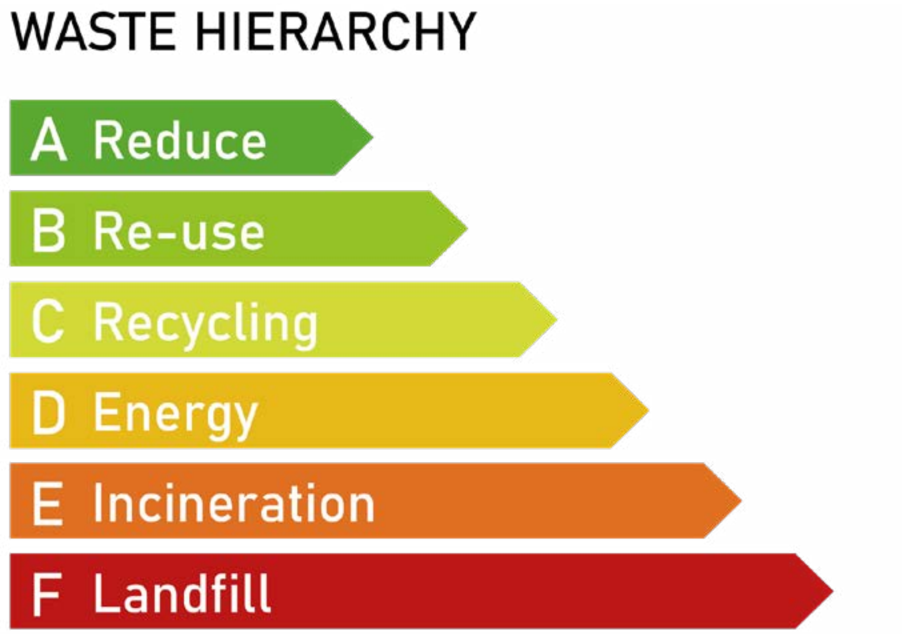


Figure 25 The Ladder of Lansink based on [48]

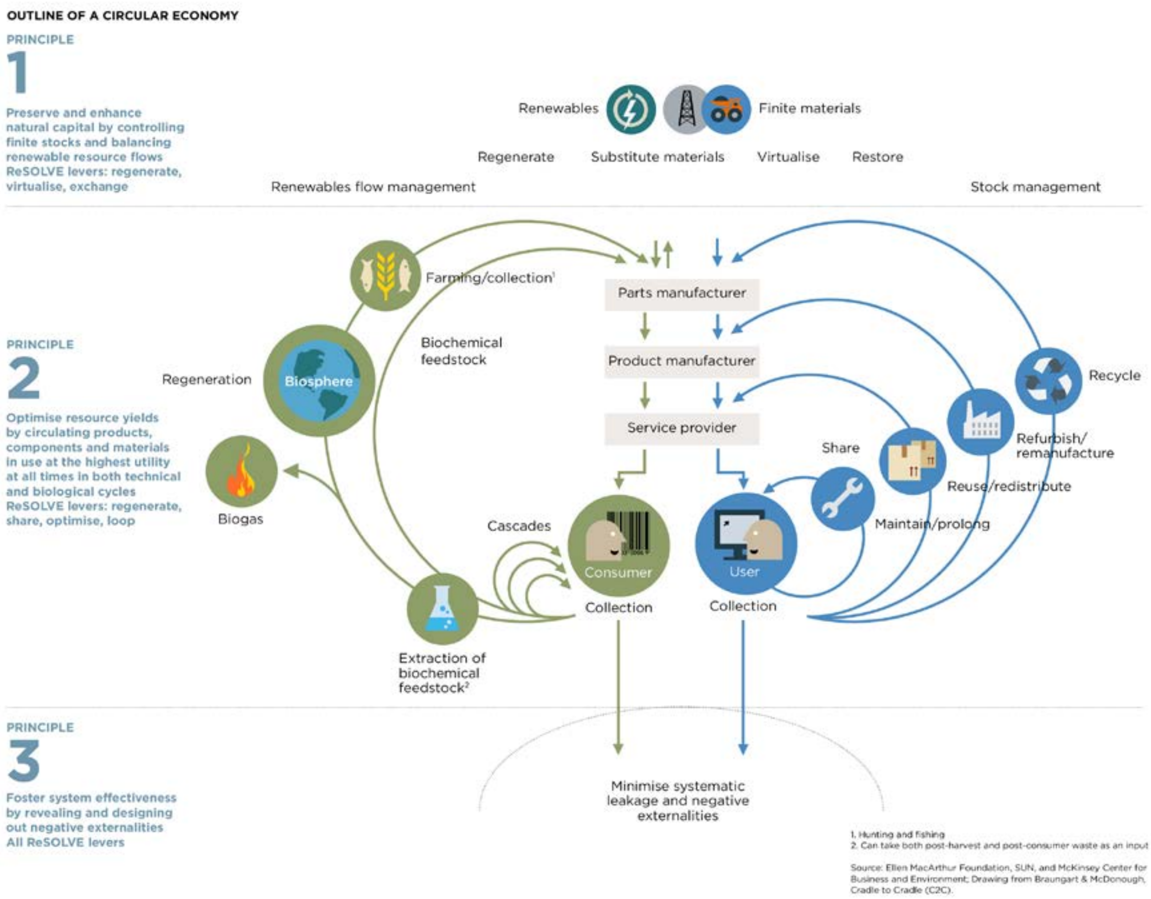


Figure 26 The Butterfly Model or the 7R's [6]

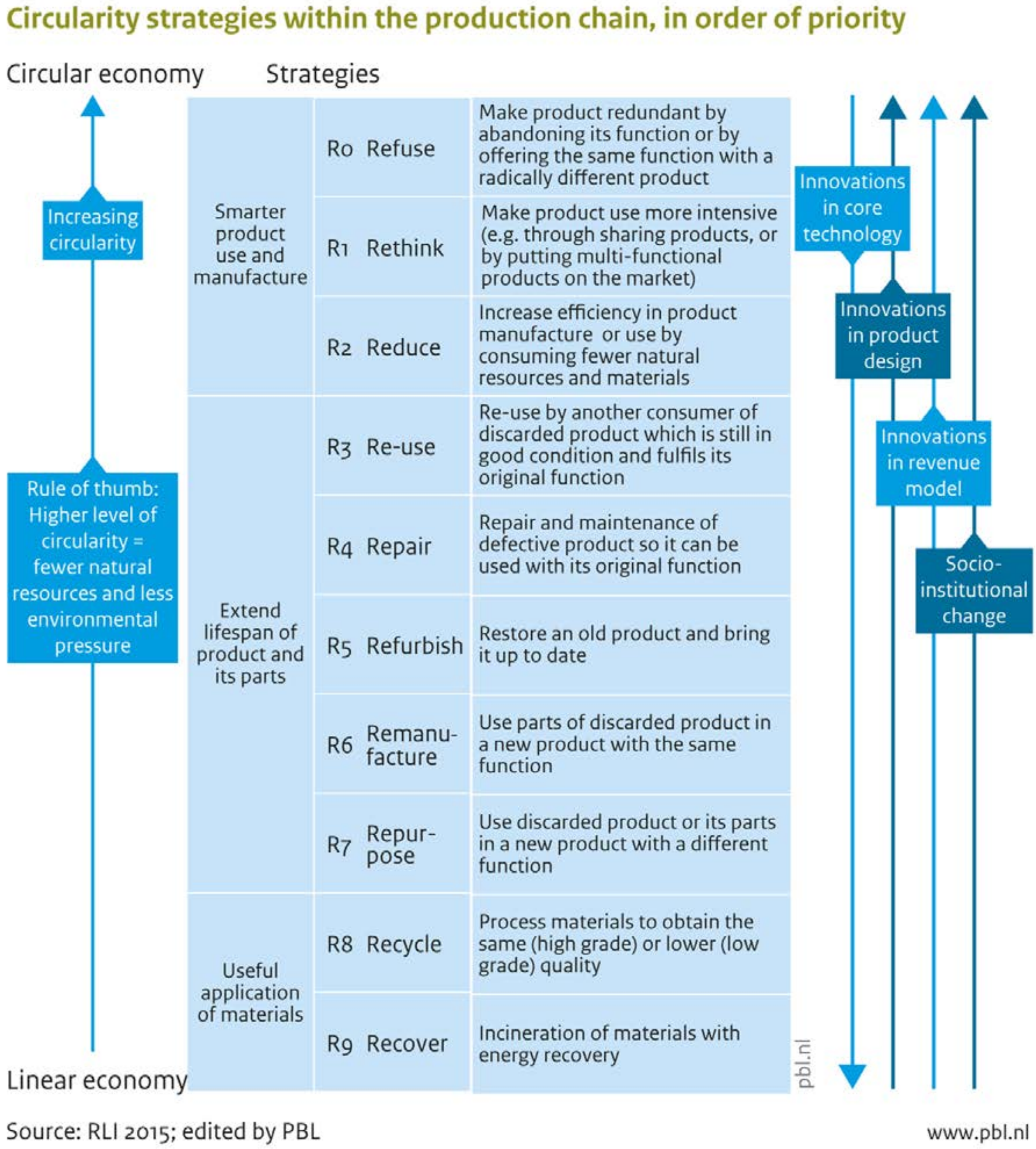


Figure 27 The 9 R's for increasing circularity [1]

C Van Raam Product Development Proces

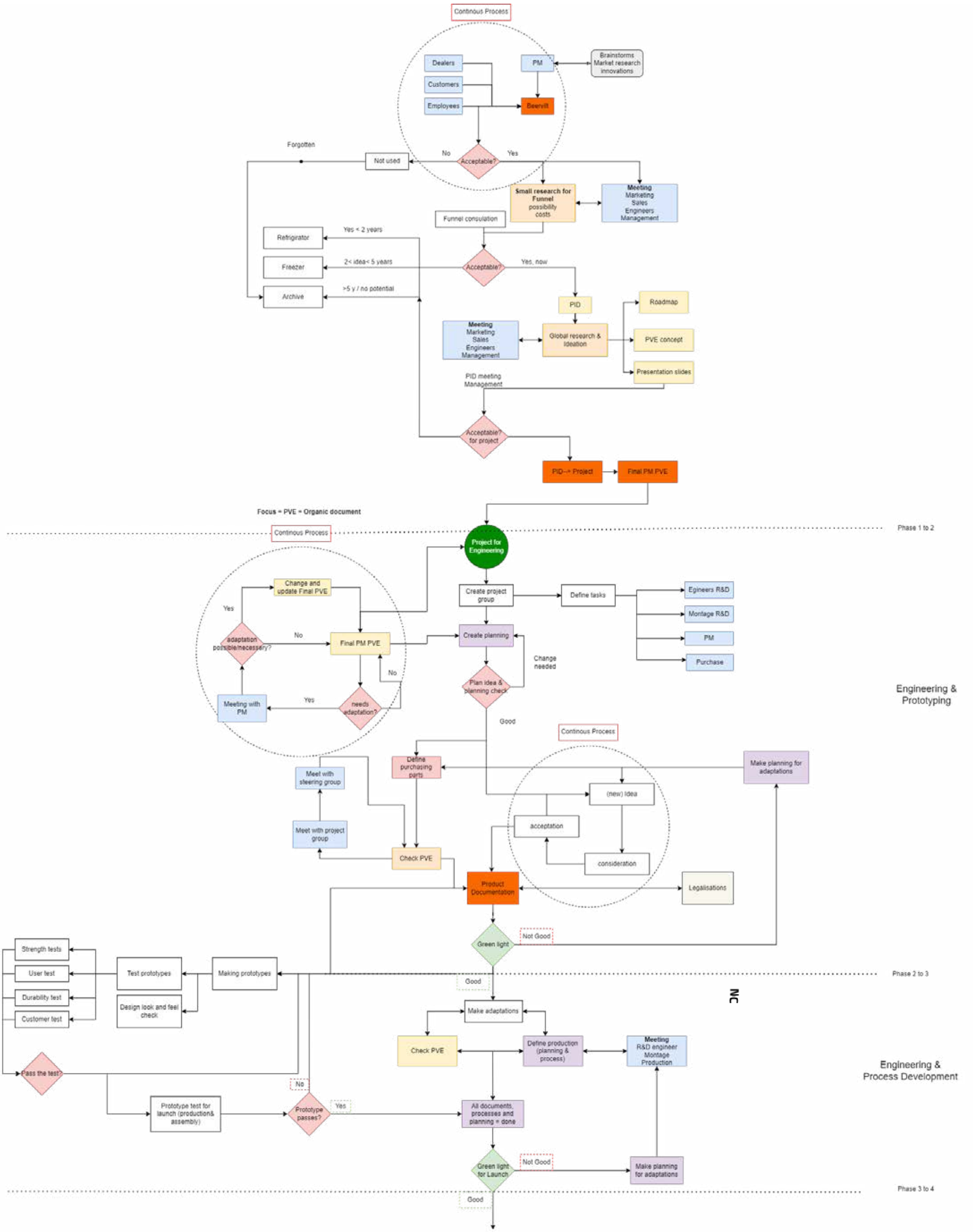


Figure 28 The established Product Development Process of Van Raam by meetings with PM, R&D Engineer and R&D Montage

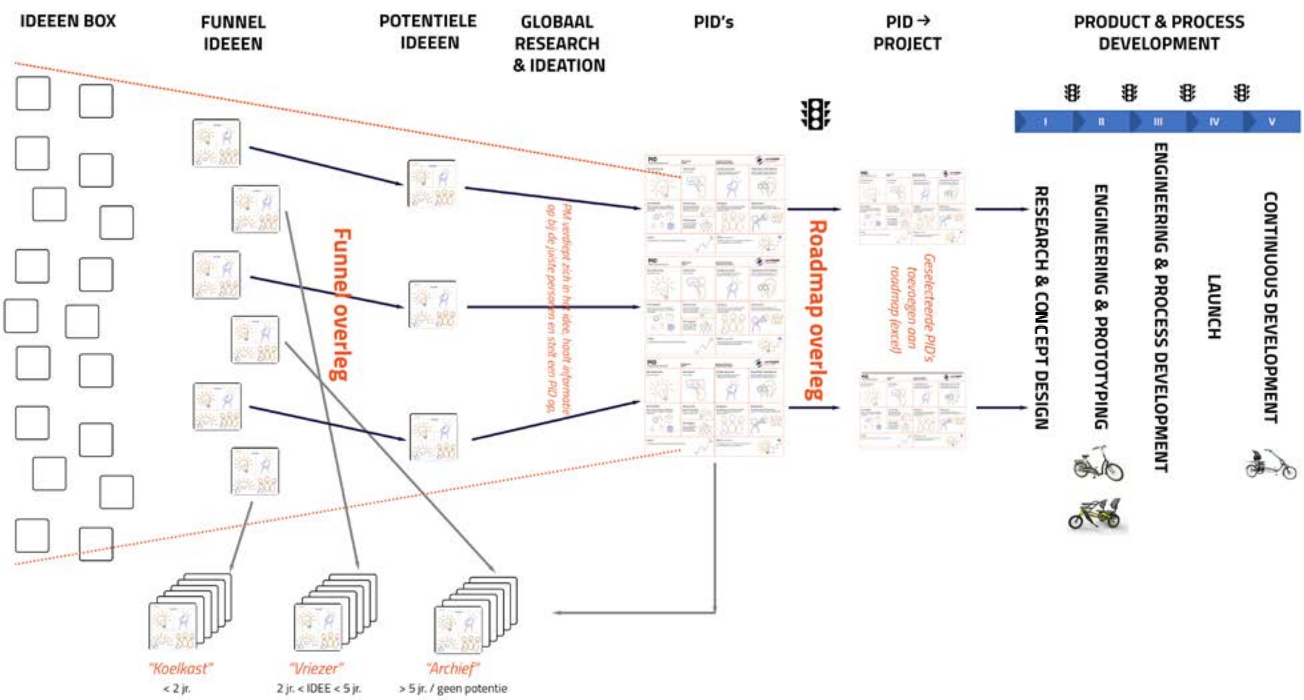


Figure 29 The Product Development Funnel at Van Raam

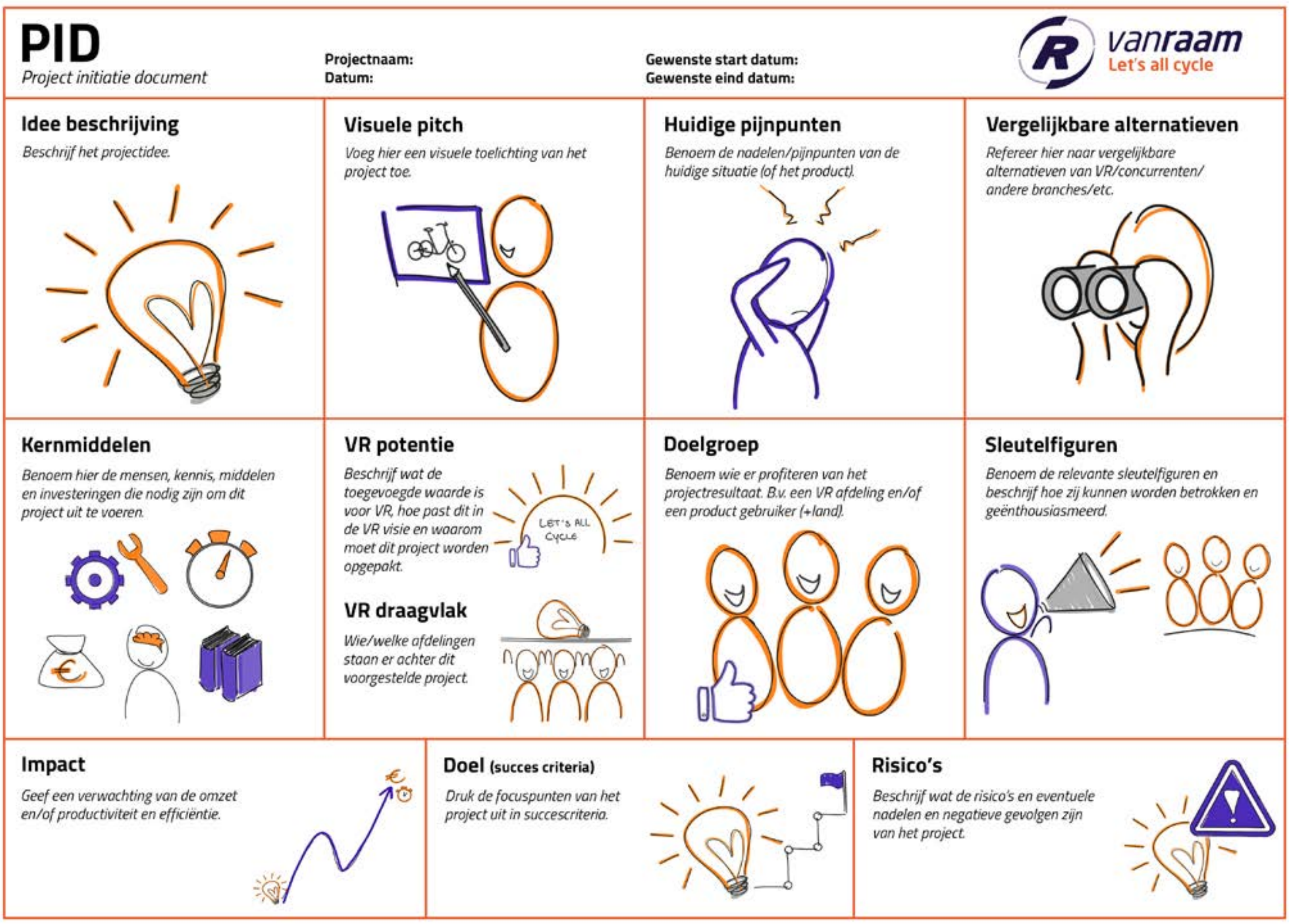


Figure 30 The Project Initiation Document (PID) Poster Presentation of Van Raam

D The Requirements list of Van Raam A

Last updated on April 15, 2014

Requirements are placed in an Excel file. The list is not actively used as the product managers did not know of this existence. However, they do use the elements that are incorporated into this list.

Use/Performance/Ergonomics

1. What is the (intended) target group, are there physical peculiarities to the (specific) users that affect the use?
2. What main and secondary functions does the product have to perform (cycling, braking)?
3. What requirements does observe, understanding, handling, operating, etc. place on the product?
4. What functional properties should the product have?
5. How long should the product last (economically and technically), how is it tested?
6. How intensively is the product used?
7. Is maintenance necessary and available and by whom is it done; what level of knowledge does this person have?
8. Which parts should be (easily) accessible?
9. Which forms of failure and consequences for functioning should certainly not occur?
10. What can be the risk of defects in functioning?11. Disturbing noises during use?
11. Wear and tear of intensively used parts, maintenance of these?
12. How is it cleaned (sandy path, mud, incontinence etc.)?
13. What use tax must be considered during the product process (person and luggage)?
14. Are the functionalities designed for maximum ease of use?
15. Weight of the bike, does that limit its use?

Safety

1. Does the bike (including all accessories) meet the requirements within the risk inventory and evaluation?
2. Can the user or mechanic get hurt while using or setting up the bike?

Surroundings

1. What environmental influences is the product subject to during use (temperature, vibrations, moisture, etc.)?
2. UV resistance

Design

1. Van Raam on the bike, where?
2. Standard color and option colors. Which frame parts are painted in which colours?
3. Frame sticker location

Geometry

1. Does the use set limits on maximum dimensions and weight? (Sheds, cycle paths, transport in the car?
2. What user limitations affect the geometry of the product?

Value

1. Will an existing product be improved? Then analyze the functions of the existing product. Or is a new product being developed?
2. What will be the specific characteristics or properties of the product?
3. What is the added value for the user? What are the USPs?
4. Where should the new product improve competing products?
5. What quality tests is the product subjected to inside and outside the company?
6. What preferences for colour, shape and finish do consumers or customers have?
7. What are the characteristics of the van Raam product line, within which the product must fit?
8. Does the current and future product range impose requirements on the product?
9. What are the views in “society” regarding the product?
10. Should certain materials be used or not (e.g., in relation to safety or environmental impacts)?
11. How big is the development budget (one-off costs for moulds/moulds etc)?
12. Does the staff have sufficient knowledge, or do they need to be trained or do we have to outsource parts of the development?

Standards/Law/Legal

1. What relevant legislation is there in the field of the new product? Lighting, braking etc.
2. Which of Raam standards are there in the field of the new product? Do new standards need to be developed?
3. For which design, production and use errors can the producer be held liable?
4. Should special provisions be taken, regarding the safety of users and non-users?
5. What comes out of patent and patent research?6. Are all aspects explained in the manual (product liability)

Production/manufacturing

1. Does it have to be produced internally or externally (complexity)?
2. Is the required quality and constancy feasible internally?
3. How big is the expected batch size?
4. How long is the product (expected to be) produced?
5. What technology goes and can be used?
6. Should a new technology be developed?
7. Should standardization in the company or industry be considered?
8. Strategy for production, which one is used?
9. Has standard parts been used as much as possible?
10. Does production set limits on maximum dimensions and weight?
11. What environmental influences is the product subject to during manufacture (temperature, vibrations, moisture, etc.)?
12. Are there (long) periods during manufacture in which the product is stored? Does this call for specific conservation measures?
13. Module production/variations on as few moulds as possible?
14. Does production/manufacturing set limits on maximum dimensions and weight? (Paint shop, internal transport?)

Transport/logistics

1. What environmental influences is the product subject to during transport (temperature, vibrations, moisture, etc.)?
2. Are there (long- term) periods during distribution in which the product is stored? Does this call for specific conservation measures?
3. What are the requirements for transport during production, and to the place of use?
4. Is packaging necessary and, if so, what should the packaging protect against?
5. Does transport set limits on maximum dimensions and weight?
6. Are there any specific requirements for the means of transport?
7. When choosing packaging and choosing the means of transport, has attention been paid to the stability and optimal space filling?

Sales/marketing/business administration

1. What is the size and growth of the market
2. What should the product cost, given the prices of similar products?
3. How long is the product (expected to be) produced and sold?
4. Where is the product located in the life-cycle and what does this mean for the design process?
5. Who are the competitors and what are the characteristics and behaviour of these competitors?
6. How will the product be sold and promoted?
7. Who are the current customers and what partnerships are there?
8. What are the requirements for distributors and brokers?
9. What are the requirements for final assembly outside the factory, installation, connection to other systems and learning to handle and operate the product?
10. When are the product photos, leaflets and manual made?
11. When will the product be introduced (trade shows/customers/season)?
12. Which USPs are needed marketing-wise?
13. Are there customer-specific requirements for the product?
14. Is a new marketing strategy needed?

Disappear

1. Do the chosen materials have a long service life?
2. Can the chosen materials be recycled?
3. Are the materials and parts separable for waste disposal

E

LCA Programs

Multiple programs can perform a LCA with different types of data. However, not all the programs have the same method and data that is needed for the input. In a research of Su and Casamayor, 2013 they reviewed more than 20 tools on its use [62]. This assessment gave the results that for different stages of a product development process there are different tools suited. However, they also identified that there was not a complete suited tool for the ideation and concept phase.

Therefore, according to some important requirements of this study an analysis is performed. Four general LCA programs are investigated in its potential. The programs are: Granta Edupack 2020, Gabi Education 2021, Solidworks 2021 Sustainability tool and eco-it 1.4. Sima Pro is not taken into consideration as the ability to investigate this program is too low. With the demo 30 days version the program has not enough features working to perform an LCIA. These programs where accessible for students or as a demo for a couple of days. The results of the LCA program's assessment are visualized in Table 13.

Table 13 The score of LCA programs according to the requirements

Requirements	Open LCA	Granta	Solidworks	GaBi	Eco-it
Clear and easy UX	--	+/-	+/-	--	+
Feedback for improvement of result	-	+/-	--	-	-
Easy overview of database	--	+/-	-	--	+
Easy to use	+/-	+	+	--	++
Gives background information of calculations	-	++	-	+/-	-
Low Expertise level	-	+/-	--	--	+
Possible to assess a concept product	+	+	-	--	+
Compare Concepts	+	+	--	--	-
Quality of data	+	+/-	+/-	++	-
Low in costs	?	?	?	?	?
Data can be stored	+/-	+	+/-	+	+
Follows LCA steps	+/-	-	-	+	+/-
Adaptation of data	++	+	-	++	-
Clear results	-	+	-	-	+/-
Presentable results	+/-	+	+/-	-	+
Total points (Between the -30 and 30 points)	**-4**	**9**	**-11**	**-10**	**3**
The grade of the program	**4.3**	**6.5**	**3.1**	**3.3**	**5.5**

When the programmes are compared, it is clear that Solidworks, GaBi, and open LCA are not suitable for manufacturers to easily define sustainability within their product concepts. Since it has too many options and a large data space, and it is more difficult to use in product development. Solidworks is inexpensive for Van Raam but can be expensive for companies that do not already use Still, the program is unsuitable because it requires a 3D model of the part, which is not always the situation for concept comparison. Granta and Eco-It perform better, but not particularly well.

F LCA Measurement Methods

A measurement method to quantify the impact of products is required for the development of a LCA tool. Since the 1990s, various methods have been developed. A few methods are included for comparison within these three assessment areas: accessibility, data quality, and ease of interpretation and use. More information on the differences between specific measurement methods is established in a research review, as each method has different possibilities and qualities [76].

Different characterization factors are used in the measurement methods to quantify the impact of a specific element. The methods are not only useful for quantifying sustainable products, but they can also be applied to any type of emission, such as heating your home or car pollution. The methods define the impact of a specific assessed element by using mid and/or endpoints. Climate change, ozone depletion, and groundwater acidification are all possibilities. These midpoints or endpoints can indicate how much influence that element has on those various points. Each measurement method has a different mid-point and end-point, and some only have one end-point [76]. It is critical for this research that it is usable in the tool and of sufficient quality to be valuable, as well as simple to implement and explain.

To carry out an LCA for product development, a measurement method is required to quantify a product's life-cycle by its material, process, transportation, use, and disposal. Table 14 defines and evaluates multiple methods based on the three criteria discussed above. The name of the measurement method and the country of origin are listed in the table, along with their accessibility, quality, and ease of use. The goal is to find a method that is both accessible and simple to use. The methods that achieve this goal are the Eco-indicator 99 and the Ecolizer 2.0.

Table 14 The evaluation of the accessibility, quality, and ease of use of Quantification methods

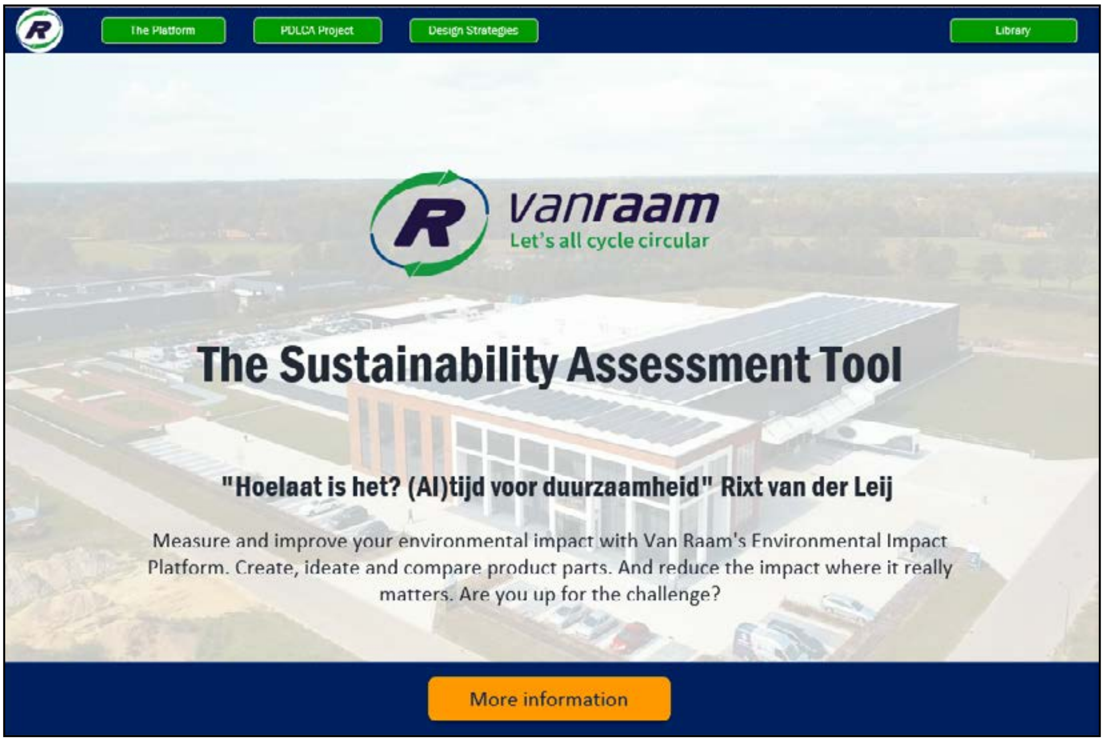
Quantification Method	Country	Accessibility	Quality	Ease of use
ReCiPe (2016)	Dutch	No	High	Low
Eco-Indicator 99	Dutch	Yes	Low/medium	High
CES EduPack Eco	Japan	Yes/No (Only students)	High	Medium
Impact 2002+	Switzerland	No	Medium	Low
CML	Dutch	No		Low
Ecolizer 2.0	Dutch	Yes	Low/medium	High

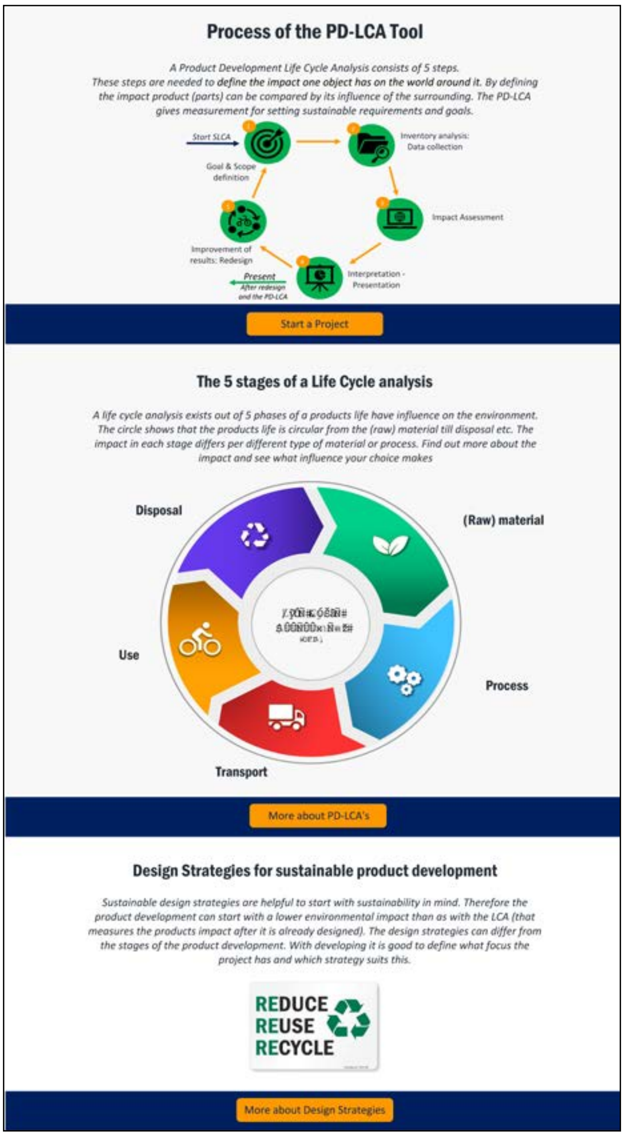
The Ecolizer 2.0 and the Eco-indicator 99 are the best measurement methods for assessing sustainable products. Because these methods only have one endpoint, all types of emissions are gathered to one number, their accuracy is low. This is because the methods only use one endpoint, which is defined as a milli point (mPt). In one endpoint, the normalisation and weighting of the various measured impacts are established. The results are not as viable as with other methods. These methods, on the other hand, have accessible data that can be implemented into a tool and visually show its calculations.

The tool can support either of the two methods. The Ecolizer 2.0 has the advantage of including many processes, and the method is based on the Eco-Indicator 99. It is newer than the Ecolizer, having been developed in 2005. The Ecolizer 2.0, on the other hand, has a lot of undetermined data or generalising the data because they know the exact measurements. It has a lot of options that are difficult to translate into a tool [77]. The Eco-indicator benefits from the fact that it was created by a well-known company, PRé Sustainability, which also created ReCiPe. The ReCiPe method is widely used in LCAs around the world. The Eco-indicator 99 can also perform a rough calculation to convert mPt to CO^2-eq. This is because 1 mPt equals 1/1000 Pt and 1 Pt equals 1/1000 of a European's emission in 1993, 7900 kg CO^2-eq [64, 78]. As a result, 1 Pt is approximately equal to 7,9 kg CO^2-eq. The disadvantage is that it lacks Ecolizer 2.0 datasets and is therefore more out of date. The Eco-indicator 99, on the other hand, better meets the needs of product developers because the data is more clearly defined. The method does not have too many or too few options, and the results can be converted to CO^2-eq, making it easier to compare the emissions of other products. So, the Eco-indicator 99 is chosen to apply within the LCA tool.

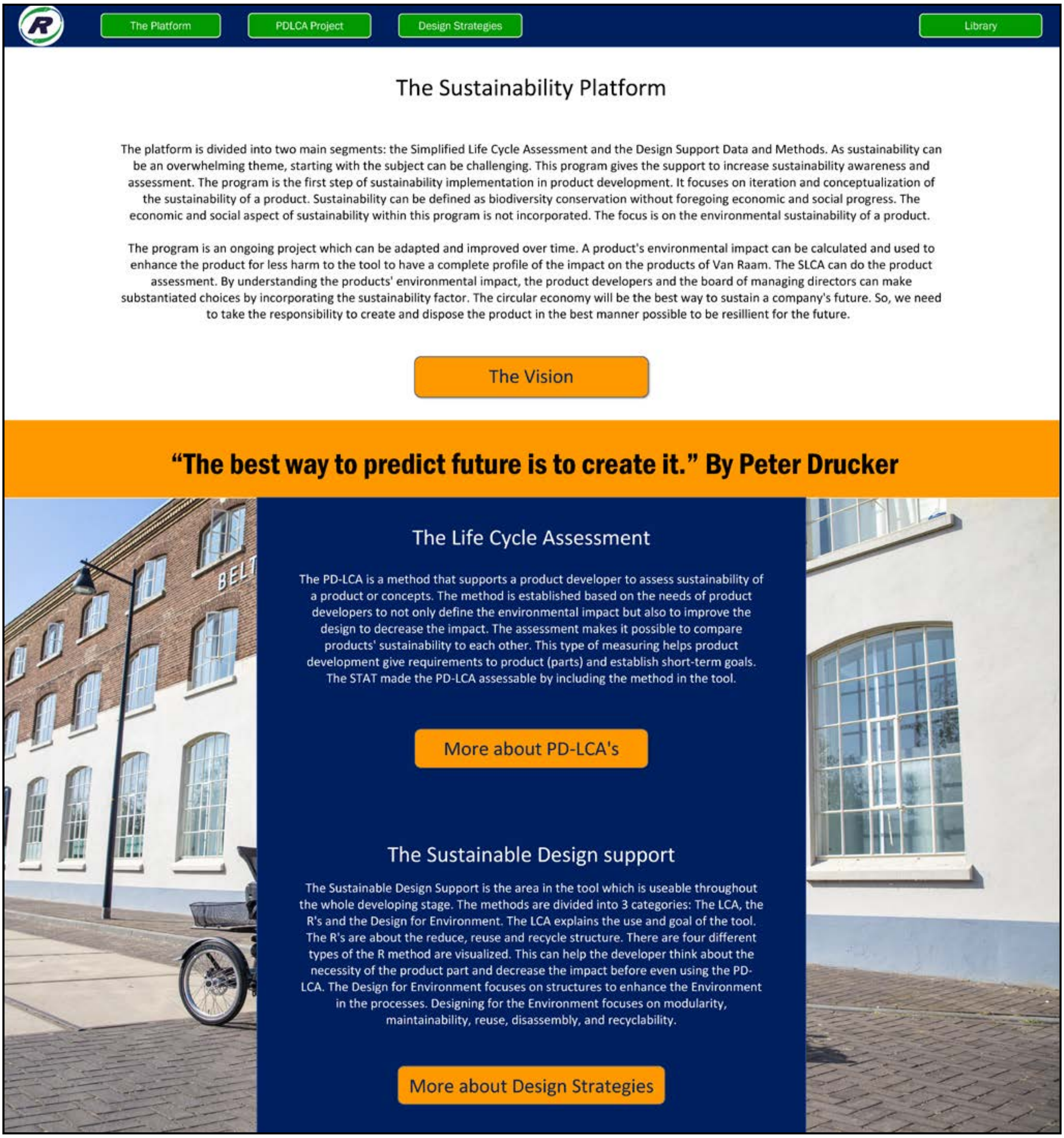
G The Sustainability Assessment Tool

G.1 The Main Menu





G.2 The Platform



G.3 The Vision of a Manufacturer

The Platform | PDLCA Project | Design Strategies | Library

Vision of Van Raam

As Van Raam develops a sustainable form of modern-day mobility, Van Raam has its vision toward innovation and connecting with the customer and the surrounding economy. The bikes bring independence and freedom to the user. Because everyone needs to be able to cycle: ***Let's All Cycle.***

Van Raam is committed to working as sustainable as possible. The factory is virtually energy-neutral by using solar panels, 25 sealed ground sources, heat pumps, LED lighting, the most modern insulation and triple-A glass. In the factory, there is a very consistent waste separation in paper, iron, plastic, tires, powder, batteries, chemicals, oil/water, cleaning cloths and toners [51].

Van Raam has a broad vision with the critical elements of availability, ambassadors, connection, innovation and digital factory.The circularity, development, and target group are incorporated within the board. As seen on the vision board, the whole environment is green. Van Raam wants to help people in a sustainable way. However, the goals on measuring and increasing environmental sustainability are challenging. Thereby, this platform is created. The platform is the first step in improving the products to generate fewer emissions to harm the environment.

The focus upon the Sustainable Development Goals

In 2019 a workshop is done to define the focus points for Van Raam as vision for the sustainable development and its goals [50]. The report resulted in the following SDG's:

3 Good Health and Well Being
8 Decent work and economic growth
9 Industry, innovation and infrastructure
10 Reduce Inequalities
11 Sustainable cities and communities
12 Responsible consumption and production *
13 Climate action *
17 Partnership to achieve goals

* The platform focusses upon these SDG's

The Tool Research Focus

Rixt van der Leij created the tool, with her research focusing on defining sustainability in product development to a measurable aspect that aids decision making. Jolien Heeman initiated the study because she was a product developer who noticed that sustainability was not a factor that developers considered. Despite the fact that there was a start with the definition of SDG focus points and two previous student studies. This, however, did not last. Rixt's research was not only focused on making sustainability measurable. She also brought the product development team with her to inspire, motivate, and activate them to include sustainability in their sphere of influence. This tool, along with a report, paper, and presentation, is the result of the research. You can get more information about the research from Jolien Heeman or the Knowledge Domain

G.4 The Design Strategies

The Platform | PDLCA Project | Design Strategies | Library

Sustainable design Strategies

Designing sustainable can be very easy. You are probably already within the product development.
Thinking of less materials, less waste more recyclability.
Their are many elements and strategies to develop more sustainable. One of those is the Life Cycle Analysis.
In this page sustainable design strategies are explained in what they do and how to use it.

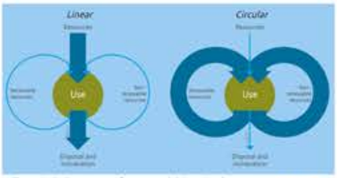


Figure 1: the large reuse of raw materials in a circular economy (PBL, 2019a)

The goal for sustainable design is to increase the circularity of the product. Currently Van Raam has a linear economy. The raw materials are processes are used to create a product and at the end of life the product is landfill or incinerated. The goal of having a circular economy is to use renewable materials and reuse materials or parts (recycled/reuse) [10]. In this economy the natural loop of a life is sustained. This gives Van Raam perspective to still exist in the coming 500 years.

Influence as Product Developer

As a Product Developer there is many influence to develop a more sustainable product. As 80% of the impact is determined in the Concept and Detailed Design. This high influence comes in collaboration with other department and management. Though the developer is in charge of this area of design. So create it together!

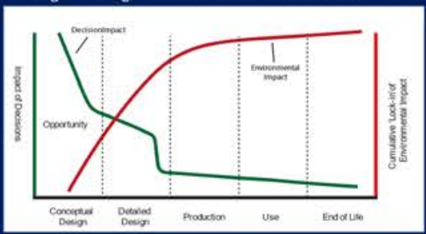


Figure 2: The impact of a Developer over time in the Decisions and Environment (Han et al, 2021)

With having influence there are opportunities to decrease the impact from the beginning of the development process. Such as implementing product initiations which are focussed upon decreasing the product's impact or calculating the possible impact of a project.
In the detailed design, smaller choices can be compared to determine the impact of both options. Whereas at the product presentation the complete product can be calculated in it's impact.

But first look at the Principles of Sustainability in Design.

The Sustainable Design Principles

The Cambridge Dictionary explains that sustainability is the idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment.
To design with the environment in mind there are multiple methods, strategies or principles. To choose a strategy that fits your project, you can fill in the development method tool. It helps you to focus upon the environmental changes you want to make!

Product Life Cycle

The Life cycle of a product can give much information in optimizing and improving a products ecological impact. To understand this impact a life cycle assessment (LCA) can be performed [21,22,24].

Life Cycle Assessment (LCA) explained - PRé Sustainability (pre-sustainability.com)

The PDLCA
Identify where to improve the product
Compare Products by its impact
Set goals and create more sustainable products.

When the LCA is performed a good view of the products impact visible & the area of impact is visible in numbers of mPt.

Material	- Reduce material weight or volume - Look for materials with less impact and comparable properties - Use recycled material - Use non-toxic materials - Use Non-exhaustible materials - Use materials efficiently

The R's

The R's method is a method to decrease the amount of waste by looking at aspects to prevent the waste from existing. Thereby the method implies to extend the life cycle by for example recycling. The R's helps you to ask yourself whether what you are doing is necessary and whether it can be done differently. The amount of R's are go from general to more specific aspects. So, choose a method that fits to your project.

The 3R's waste management

Reduce - Reuse - Recycle (markmuirarchitect.com)

The 3R's are the most commonly known method. Reduce is to rethink if you need something and if you can cope with less. Reuse means to see if you can reuse the part t to elongate the life cycle. Whereas Recycle is to give the element a second life by processing it to another make it destined for something else.

The 6R's waste management

Development Process

Design for Environment
This design method is the umbrella of the other processes that you can implement. The advantages of ***DfE*** are cost reductions, reduced business and environmental hazards, expanded business and market potential, and compliance with environmental standards The complete design for environment can be large and too much as a developer to integrate all [13 - 17]. That's why focussing upon sub parts can make it easier. Some of the aspects are:

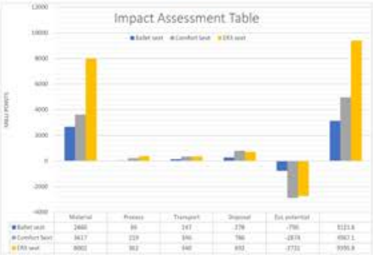
Design for Modularity (DfMod.)
Design for Maintenance (DfMain.)
Design for Reuse (DfReuse)
Design for Disassembly (DfD)
Design for Recyclability (DfRec.)

Design for Modularity
Designing for modularity has environmental benefits. As the method aims to break a product's architecture into independent units.
1. This makes it easier for developing. As the parts can be worked on independently.
2. The parts are easier to reuse and dethatched
3. It is efficient as the units are multiple used and less other parts are needed to be made or bought [18].

Design for Maintenance
This method focusses upon developing products that are easy to maintain and to repair when needed. To make the maintenance as little as possible the bike can enhance its life cycle. And when needed the maintained is easy to do [47].

Material	- Reduce material weight or volume - Look for materials with less impact and comparable properties - Use recycled material - Use non-toxic materials - Use Non-exhaustible materials - Use materials efficiently
Manufacturing	- Find comparable processes with lower impact - Use Less production processes - Manufacture yourself or close by to have insight in the processes used - Use processes with minimal material waste - Clean/low energy consumption - Few/clean production consumables
Distribution	- Get the products from suppliers around the area - Have efficient logistics by designing the product for easy transportation - Design the product for Less packaging /Design for transportation/
Use	- Find parts that have a higher efficiency of electricity use - Make sure the product does not create harmful micro plastics - Create durable or easy to maintain parts - Make the product modular and adaptable within the product structure
Disposal	- Making a part mono material makes disposal easier - Reuse the product - Disassembly of different materials - Think of the chains that dispose your waste - Recycling is one of the last resources next to incineration

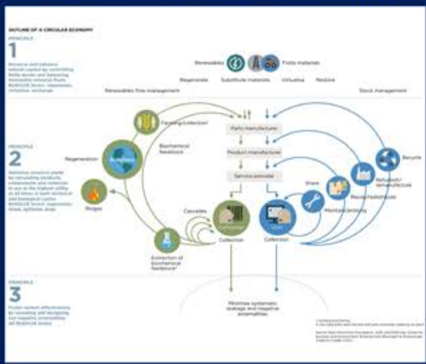
An Example: The LCA of three seats from bikes at Van Raam. As visualized the highest impact is the ER3 Seat. Especially within material use the impact is major. More external examples are: [23,24]



More about LCA's

The waste Hierarchy is defined by Ad Landsink. A Dutch politician. The goal is to prioritise the green factors and avoid the least preferred red elements. The reduce and reusing waste are the top priority (avoidance). Recycling and high-quality energy recovery is the second priority (recovery). The least preferred is burning waste and dumping waste on landfills (disposal) [46].

The 7R's for a circular economy



The Ellen MacArthur foundation works to accelerate the transition to a circular economy. The foundation works with businesses, academics etc. The butterfly diagram above tries to capture the essence of the circular economy. The diagram is divided in 3 principles:

1. Focuses on preserving and enhance natural capital.
2. Is to optimise resources yield by circulating products.
3. Designing out negative externalities. (reducing damage and pollution)

The method is quite extensive and covers the complete life cycle for increasing the sustainability. The report about this diagram is advised to read trough. [9,11]

Design for Maintenance

This method focusses upon developing products that are easy to maintain and to repair when needed. To make the maintenance as little as possible the bike can enhance its life cycle. And when needed the maintained is easy to do [47].

Design for Reuse

The principle behind reuse is to keep products functional and attractive for as many users as possible and for as long as possible. Products don't only get discarded when they fail or break. To improve the chances of reuse:

1. Durability of materials and connections.
2. Ease of maintenance and repair.
3. Standardization, compatibility, and adaptability.
4. Product attachment and trust. [14]

Design for Disassembly

The ability to disassemble supports the maintenance, reuse & recyclability of the product (part). The disassembling generates value to the parts. For current product the method can be used to measure the time it takes to disassemble the whole bike. This identifies what takes the most time and what processes are difficult to carry out [48]. For the design process the ways to attach parts need to be defined. Some examples:

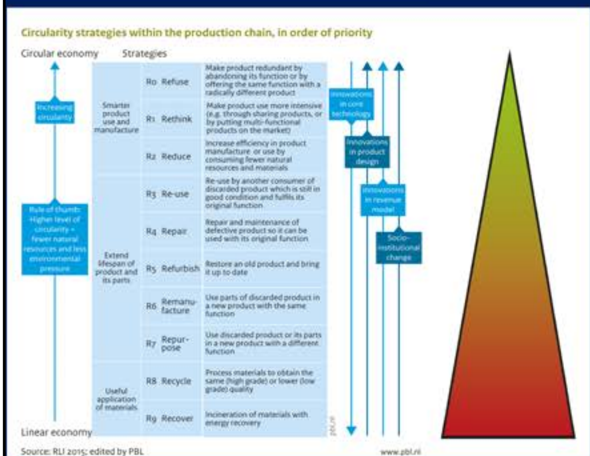
- the fewer parts, the less to take apart (also with fasteners)
- Easy use of tools for disassembling
- Don't use glue
- Avoid welding of different types of material.

Design for Recyclability

Design for recycling aims at the ability to recover the materials for additional use. This method is the last option of the material to use. Within development the products recyclability can be defined. The reachability rate (%) of the products impact. Next, to the materials recyclability the ease for disassembling plays a part. If different types of material cannot be (easy) detached the probability of recycling decreases. Thereby the value of the part plays a part too. If the material is valuable the product will be more likely to be separated and used for recycling.

The best way to decrease a products impact on the environment is to use recycled material [19].

The 9R's for circularity



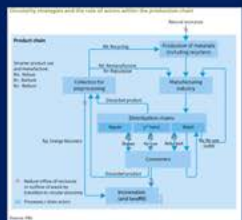
The 9R's is a method of the RLI, a council for the environment and infrastructure. The method is derived from the Ladder of Lansink and has as the other R's the same purpose of using less resources and consume less in the product chance and to make the economy more circular [7-9].

The left figure shows the strategies from R0 to R9. The lower numbers have a high circularity focus whereas the high numbers have low circularity.

On the right the figure shows the strategies placed in a production chain. As circularity has multiple factors in a chain to be responsible of the strategies.

Questions you can ask to create a more circular economy are:

- Does the consumption of primary materials decrease in absolute terms?
- Does the design take reuse and recycling into account?
- Is the proportion of hazardous substances in products decreasing?
- Are products used more often or for longer periods of time?
- Do materials retain their value and undergo high-grade recycling



G.5 The Library

The Platform | PDLCA Project | Design Strategies | Library

The Library

The library is a database with a section for storing interesting documents, videos, or websites. This aids in the search for information on your topic. In addition to the documentation database, there is an impact assessment tool database. This information can be found by clicking on the icons of the various life cycle stages.

	Theme	Company	Title	Type	Language	The link	Year	Comm
1	CE	Circular Economy	Explaination video of Circular Economy	YouTube	Dutch	[illegible]	2017	
2	CE	Ellen Mac Arthur	Explanation video of Circular Economy	YouTube	Eng.	[illegible]	2011	
3	CE	European Environment Agency	Explanation video of Circular Economy	YouTube	Eng.	[illegible]	2017	
4	CE	PwC Switzerland	Explanation video of Circular Economy	YouTube	Eng.	[illegible]	2021	
5	CE	Ted Talk	The Circular Economy: A simple explaination	YouTube	Eng.	[illegible]	2018	
6	CE	RLI	Circular Economy; from Wish to Practice	Report	Eng.	[illegible]	2015	
7	CE	PBL	Circular Economy: Measuring Innovation in the Product Chain	Report	Eng.	[illegible]	2017	
8	CE	PBL	Circulaire Economie: Innovatie meten in de keten	Report	Dutch	[illegible]	2017	
9	CE	Ellen Mac Arthur	Towards a Circular Economy	Report	Eng.	[illegible]	2015	
10	CE	Kenniskaarten	Circular Economy	Website	eng. & Dutch	[illegible]	2019	
11	CE	Ellen Mac Arthur	Plastics & Circular Economy	Website	Eng.	[illegible]	2017	
12	CE DfReuse	UT Delft	Engineering Design for Circular Economy: Design Strategies for Reuse	Youtube & Book	Eng.	https://ocw.tudelft.nl/course-lectures/2-2-1-design-strategies-reuse/	2021	
13	DfE	Mattias Lindahl	Environmental Effect Analysis (Dfe)	Paper	Eng.	http://www.aeki.se/eea_eng.pdf	1997	
14	DfE	Goverment of Canada	Design for environment	Website	Eng.	[illegible]	2011	
15	DfE	Eco Matters	Tool for designing reusable products & packaging	Website	Eng.	[illegible]	2021	
16	DfE	Daniel Fitzgerald & Jeffrey Herrmann etc.	Design for Environment (DfE): Strategies, Practices, Guidelines, Methods, And Tools	Paper	Eng.	[illegible]		
17	DFE	Johannes Behrisch, Dr mariano Ramirez etc.	Application of ecodesign strategies amongst Australian industrial design consultancies	Paper	Eng.	[illegible]	2008	
18	DfMod.	Monique Sonego a, Marcia Elisa Soares Ech	The role of modularity in sustainable design: A systematic review	Paper	Eng.	[illegible]	2018	
19	DfRec.	Kosuke Ishii	Modular Design for Recyclability Implementation and Knowledge Dissemination	Book	Eng.	https://www.nap.edu/read/6322/chapter/11#109	2001	
20	DfV	R. Wever & J. Vogtländer	Design for the Value of Sustainability	Paper	Eng.	Wever 2014	2014	
21	LCA	spark-sx	Principles of Life Cycle Assesment	YouTube	Eng.	[illegible]	2017	
22	LCA		Product Life Cycle assesment	YouTube	Eng.	[illegible]	2015	
23	LCA ex.	Eco Invent Centre	Implementation of Life Cycle Impact Assessment Methods	Paper	Eng.	[illegible]	2007	
24	LCA ex.	Singh, Vishavdeep	Life Cycle Assessment of Ammonia Production Methods	Book	Eng.	[illegible]	2015	
25	LCA ISO	ISO	ISO-14040, Life Cycle Assessment Principles and Framework	Paper	Eng.	[illegible]	2006	
26	LCA ISO	ISO	ISO-14041, Life Cycle Assessment Goal and Scope Definition and Inventory Analysis	Paper	Eng.	?	?	
27	LCA ISO	ISO	ISO-14042, Life Cycle Assessment Life Cycle Impact Assessment	Paper	Eng.	[illegible]	1999	
28	LCA ISO	ISO	ISO-14043, Life Cycle Assessment Life Cycle Interpretation	Paper	Eng.	?	?	
29	LCA ISO	ISO	ISO-14044, Life Cycle Assessment Requirements and Guidelines	Paper	Eng.	[illegible]	2006	
30	LCA ISO	APEC & Ministery of Korea	Life Cycle Assessment: Best Practices of ISO 14040 Series	Review Paper	Eng.	[illegible]	2004	
31	LCA ISO	Matthias Finkbeiner, Atsushi Inaba etc.	The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044	Review Paper	Eng.	[illegible]	2006	
32	LCA Methods	Green Delta	LCIA methods	Report	Eng.	[illegible]	2015	
33	LCA Methods	Sima Pro	Database Manual for Methods	Report	Eng.	[illegible]	2020	
34	LCA Tool	Rossella Lugliettia , Paolo Rosa	Life Cycle Assessment Tool in Product Development: Environmental Requirements in D	Paper	Eng.	[illegible]	2016	
35	Pro. Label.	CTM Admin	The Importance of Product Labeling	Website	Eng.	[illegible]	2020	
36	Pro. Label.	European Union	About the energy label and ecodesign	Website	Eng.	[illegible]	2021	
37	Pro. Label.	Lidl	Eco-Score	Website	Eng. & France	[illegible]	2020	
38	SPD	J.C. Weenen	Towards Sustainable Product Development	Paper	Eng.	Doc.	1995	
39	LCA Tool	Friesland Campina	RESPACKT anymation	YouTube	Eng.	[illegible]	2020	
40	CE Goals	Rijksoverheid	Monitor Klimaatbeleid: Bijlage bij de Klimaatnota	Tool	Ned.		2021	
41	Tool	FoodFootprint	Food Footprint Calculator	Website / Tool	Eng. & Ned	https://foodfootprint.nl/		
42	LCA Method	OVAM - Openbare Vlaamse Afvalstoffenma	Ecolizer 2.0	Tool	Eng.	[illegible]		
43	LCA FU	consequential-lca	Defining the functional unit	Website	Eng.	[illegible]	2015	
44	LCA FU	Danish Ministry of the Environment	The Product, Functional Unit and Reference Flows in LCA	Paper	Eng.	https://www2.mst.dk/udgiv/publications/2004/87-7614-233-7/pdf/87-7614-234-5.pdf	2004	
45		Ji Han, Pingfei Jiang and Peter R. N. Childs	Metrics for Measuring Sustainable Product Design Concepts	Paper	Eng.	https://www.mdpi.com/1996-1073/14/12/3469/htm#B16-energies-14-03469	2021	
46	6R's	Recycling.com	Ladder of Lansink	Website	Eng.	https://www.recycling.com/downloads/waste-hierarchy-lansinks-ladder/		
47	DfMain.	University of Twente; Winik Mulder Jeroen I	Design for maintenance: guidelines to enhance maintainability, reliability and supporta	Paper	Eng.	[illegible]	2012	
48	DfDis.	Nederland Circulair	DESIGN FOR DISASSEMBLY Principes voor klimaatsystemen	Report	Ned.	[illegible]	2016	
49	LCA Method	Pré-Sustainability	Eco-Indicator 99: Manual for Designers	Report	Eng.	https://pre-sustainability.com/files/2013/10/EI99_Manual.pdf	2013	
50	SDG	United Nations	Sustainable Development Goals of the UN	Website	Eng.	https://sdgs.un.org/goals	2015	
51	Company	Van Raam	Sustainability at Van Raam	Website	Eng. & Ned	Circular and sustainability policy of Van Raam | Van Raam	2021	

G.6 The PD-LCA information

The Platform | PDLCA Project | Design Strategies | Library

Life Cycle Analysis (LCA)

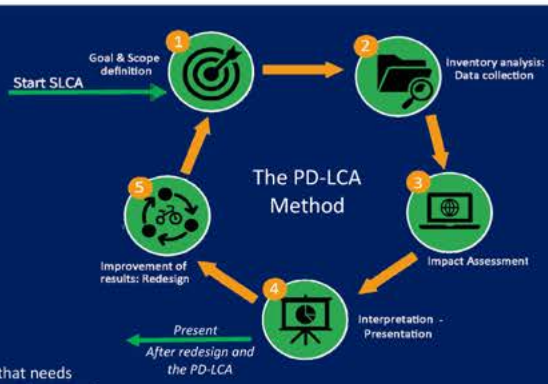
A life cycle analysis maps the impact of a product over its entire lifecycle. The environmental impact includes the harm the product material, process, transport, use and disposal has on its surroundings. This life cycle is within every product or product part different. It isn't easy to compare products on their environmental impact. However, a car and a bicycle can be compared when using the same function. For example, the Function unit of bridging a distance of 10 km per day. Though with the assessment of the SLCA, it is possible to compare different types of products.

The tool in the sustainability platform uses the PD-LCA method (Product development life cycle anlaysis). This PD-LCA tool's distinction from other life cycle assessment programs is that the tool focuses on product developers that develop in a conceptual stage. Current life cycle programs are complicated, and hard to identify a product's environmental impact. The PD-CA makes product assessment easier and focuses on the redesign to improve a product by iterations. The numbering of the environmental impact is determined by using the eco-indicator 99 method. This method gives the ecological value of materials processes etc. in milli points (mPt). mPt's are 1/1000 of a Pt. Whereas a Pt is 1/1000 of the general emission of one European in 1993 (7891 kg Co2 eq.) [49]. To assess a product's environmental impact a project can be started.

Start a Project

The Method

The process flow of a Life cycle assessment is visualized on the left. The framework shows the stages of the assessment of an SLCA. The main goal is to determine the environmental impact of a product for decision-making. The core element of the SLCA tool is to compare concepts based on their impact. However, products' can be individually assessed and improved. Within the SLCA framework, the improvement of results is the most essential part. [34].



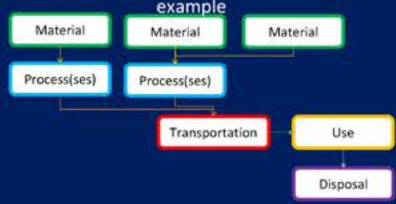
Goal and scope

The first step of an PD-LCA is to define the study's objectives with the aims and the scope that needs definition. For the breadth and depth of the assessment. The indented reason, the audience, the use of the results. The Function Unit is the function delivered by the system/product. It is a quantitative measure of the function. It references the inputs and outputs related to the system within the defined life cycle (in years).

Inventory analysis

The product's life cycle inputs and outputs are identified in this stage. So the material type, the processes needed, the country of transportation, and the product's use and disposal. The inventory is essential to collect all the data, making the impact assessment fast and easy. The data quality is critical for having a good and trustworthy LCA. Be aware of what the impact assessment has as options. Tools and methods are limited for assessment. The goal and scope help identify which elements of the life cycle you consider and which ones you leave out because of the frame. In the picture on the left, an LCI is shown as an example of how the flow of a product is defined.

Life Cycle Inventory (LCI) - Flow model example



Impact Assessment

The life cycle impact assessment assesses the impact of activities that are investigated. The data of the LCI are used to identify the impact in areas. The goal and the scope definition defined the depth of the study and the impact categories. Within the LCI, the classification is needed of which impact categories to evaluate. For example, Global Warming Potential, Acidification and human toxicity. Then the characterization factor is required. This factor relativities the contribution of each type of emission to the impact categories. The last part is the Normalization and Weighting. This step is not mandatory but is used to
Within this LCA tool, these processes are already incorporated. By using the **eco-indicator 99**. This method already classified the impact categories, the characterization factor and the Normalization and Weighting all to one number (see the database for the eco-impact).

Interpretation

The data is assessed and shown by graphs and comparisons in the interpretation stage. The results are compared with the number of threes and the kilometres of driving by car. The results are therefore understandable by something many people use or comprehend. A table shows the impact per life cycle stage within the comparison of products. Then the user can choose the best possible concept(s) for going through the redesign stage.

Redesign

The redesign aims to show the user the problem points and focus on product aspects that can be adapted for improvement. The redesign sheet shows the user that a slight modification can have significant effects. Every little bit counts to do the redesign. At the same time, they are identifying the most impact of the life cycle stages. The sheet includes six steps to go through. Suppose the user went through all the steps. The user can redesign the product to create another life cycle assessment to identify the improvements.

Start a Project

G.7 The Life-cycle Impact Assessment

The Platform | PDLCA Project | Design Strategies | Library

Impact Assesment Calculator

1

General

Project	The assessment of the seats portfolio at Van Raam
Date	01/11/2022
Product/ Component	The Ballet
Author	Rixt

Goal & Scope

Goal	To identify the impact of the ER3
Scope	Only the seat with backrest, without attachment to the frame.
Functional Unit	For a general person (85 kg) to use the seating for 10000 hours by regular cir
Life Cycle Unit	10

3

	Name part	Type of materials *	Material *	Quantity per Life Cycle *	Measure unit in kg *	eco-indicator 99	Result	comments
1.1	Seating	Plastic	ABS	1.00	2.7	400.0	1080.00	
1.2	Cushion top	Plastic	PUR flexible block foam	1.00	0.036	480.0	17.28	
1.3	Top Nylon	Plastic	PA 6.6	1.00	0.112	630.0	70.56	
1.4	Cushion bottom	Plastic	PUR flexible block foam	2.00	0.096	480.0	92.16	
1.5	Bottom nylon	Plastic	PA 6.6	2.00	0.292	630.0	367.92	
1.6	Bottom attachment for slide	Ferro Metals	Steel high alloy	1.00	1.12	910.0	1019.20	
1.7								
1.8								
1.9								
1.10								
		Total [mPt]			4.356		2647.12	

	Name process	Type of Processes *	Process *	Quantity per Life Cycle *	Measure unit *	eco-indicator 99	Result
2.1		Plastics	React.Inj.Moulding-PUR	1.00	2.7	12.0	32.40
2.2		Plastics	React.Inj.Moulding-PUR	2.00	1.E-01	12.0	3.17
2.3		Metals	Pressing	1.00	0.1	23.0	2.30
2.4		Metals	Shearing/stampin-steel	1.00	0.4	0.0	0.00
2.5							
2.6							
2.7							
		Total [mPt]					37.87

	Name transport	Transport*	Type		Measure unit kg freight *	eco-indicator 99	Result
3.1		Asia	Boat		4.356	33.8	147.21
3.2		Netherlands	Truck		0	4.5	0.00
3.3							
3.4							
		Total [mPt]					147.21

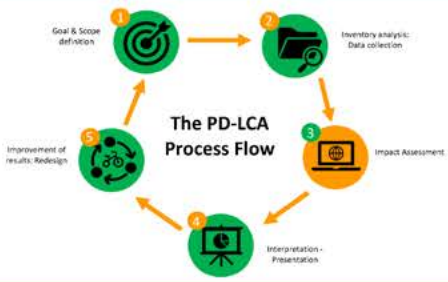
	Name type of disposal 1-4	Disposal	Type*	Quantity per Life Cycle*	Measure unit in kg *	eco-indicator 99	Result	EoL potential	comments
4.1		ABS	Recycling ABS	1.00	2.7	86.0	232.20	-847.8	
4.2		PUR flexible block foam	Incineration PUR	1.00	0.036	2.8	0.10		
4.3		PA 6.6	Municipal waste Nylon	1.00	0.112	3.1	0.35		
4.4		PUR flexible block foam	Incineration PUR	2.00	0.096	2.8	0.54		
4.5		PA 6.6	Municipal waste Nylon	2.00	0.292	3.1	1.81		
4.6		Steel high alloy	Recycling Steel high alloy	1.00	1.12	240.0	268.80	-750.4	
4.7		0							
4.8		0							
4.9		0							
4.10		0							
		Total [mPt]					503.80	-1598.2	

	mpt/year
Lifecycle impact per year	333.6

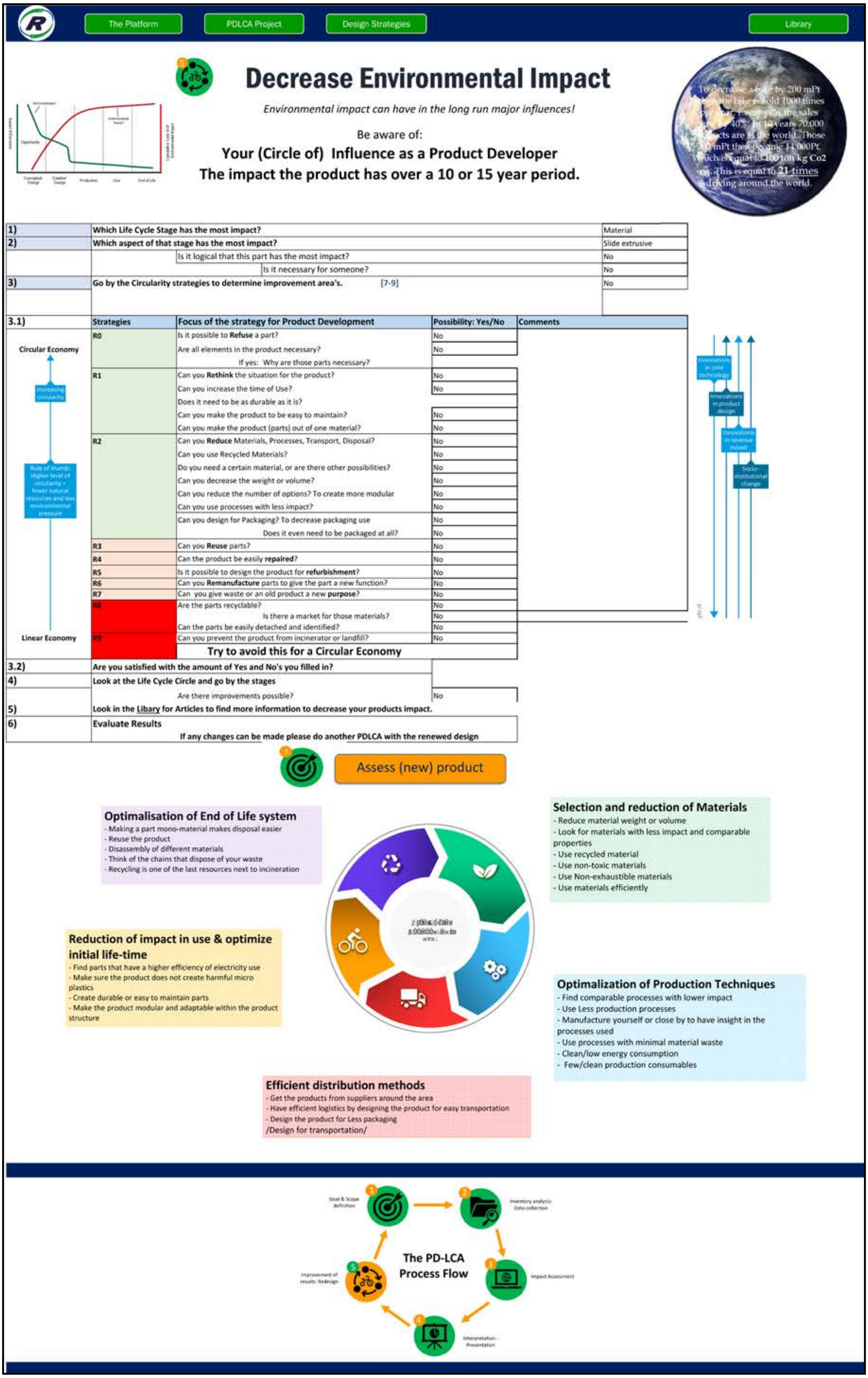
* You must fill in the rows with an apostrophe

4

See Results	Total Mpt	3336.0	-1598.2
	Total Pt	3.3	-1.6
			-48%



G.8 The Results



The Platform
PDLCA Project
Design Strategies
Library
Decrease Environmental Impact
Environmental impact can have in the long run major influences!
Be aware of:
Your (Circle of) Influence as a Product Developer
The impact the product has over a 10 or 15 year period.
1) Which Life Cycle Stage has the most impact? Material
2) Which aspect of that stage has the most impact? Slide extrusive
Is it logical that this part has the most impact? No
Is it necessary for someone? No
3) Go by the Circularity strategies to determine improvement area's. [7-9] No
3.1) Strategies | Focus of the strategy for Product Development | Possibility: Yes/No | Comments
Circular Economy
R0 Is it possible to Refuse a part? No
Are all elements in the product necessary? No
If yes: Why are those parts necessary?
R1 Can you Rethink the situation for the product? No
Can you increase the time of Use? No
Does it need to be as durable as it is?
Can you make the product to be easy to maintain? No
Can you make the product (parts) out of one material? No
R2 Can you Reduce Materials, Processes, Transport, Disposal? No
Can you use Recycled Materials? No
Do you need a certain material, or are there other possibilities? No
Can you decrease the weight or volume? No
Can you reduce the number of options? To create more modular No
Can you use processes with less impact? No
Can you design for Packaging? To decrease packaging use No
Does it even need to be packaged at all? No
R3 Can you Reuse parts? No
R4 Can the product be easily repaired? No
R5 Is it possible to design the product for refurbishment? No
R6 Can you Remanufacture parts to give the part a new function? No
R7 Can you give waste or an old product a new purpose? No
Are the parts recyclable? No
Is there a market for those materials? No
Can the parts be easily detached and identified? No
Linear Economy
Can you prevent the product from incinerator or landfill? No
Try to avoid this for a Circular Economy
3.2) Are you satisfied with the amount of Yes and No's you filled in?
4) Look at the Life Cycle Circle and go by the stages
Are there improvements possible? No
5) Look in the Libary for Articles to find more information to decrease your products impact.
6) Evaluate Results
If any changes can be made please do another PDLCA with the renewed design
Assess (new) product
Optimalisation of End of Life system
- Making a part mono-material makes disposal easier
- Reuse the product
- Disassembly of different materials
- Think of the chains that dispose of your waste
- Recycling is one of the last resources next to incineration
Selection and reduction of Materials
- Reduce material weight or volume
- Look for materials with less impact and comparable properties
- Use recycled material
- Use non-toxic materials
- Use Non-exhaustible materials
- Use materials efficiently
Reduction of impact in use & optimize initial life-time
- Find parts that have a higher efficiency of electricity use
- Make sure the product does not create harmful micro plastics
- Create durable or easy to maintain parts
- Make the product modular and adaptable within the product structure
Optimalization of Production Techniques
- Find comparable processes with lower impact
- Use Less production processes
- Manufacture yourself or close by to have insight in the processes used
- Use processes with minimal material waste
- Clean/low energy consumption
- Few/clean production consumables
Efficient distribution methods
- Get the products from suppliers around the area
- Have efficient logistics by designing the product for easy transportation
- Design the product for Less packaging
/Design for transportation/
The PD-LCA Process Flow

G.10 The Materials

The Platform | PDLCA Project | Design Strategies | Library

Production of ferro metals	Sort Low to high		Recyclable?
in mPt per kg	Indicator	Description	Recycling impact factor
Cast iron	240	Casting iron with > 2% carbon compound	60
Converter steel	94	Block material containing only primary steel	24
Steel	86	Block material containing 80% primary iron, 20% scrap	24
Steel high alloy	910	Block material containing 71% primary iron, 16% Cr, 13% Ni	240
Steel low alloy	110	Block material containing 93% primary iron, 5% scrap, 1% alloy metals	24
Production of non ferro metals (in milli points per kg)			
Aluminium 100% Rec.	60	Block containing only secondary material	60
Aluminium 80% Rec.	156	Block containing 80% recycled material and 20% primary (most common in use)	60
Aluminium 0% Rec.	780	Block containing only primary material	60
Chromium	970	Block, containing only primary material	152
Copper	1400	Block, containing only primary material	152
Lead	640	Block, containing 50% secondary lead	76
Production of plastic granulate (in milli points per kg)			
ABS	400	Acrylonitrile butadiene styrene	86
HDPE	330	high density polyethylene	86
LDPE	360	low density polyethylene	86
PA 6.6	630	Nylon	86
PC	510	poly carbonate	86
PET	380	Polyethylene terephthalate	86
PET bottle grade	390	used for bottles	86
PP	330	polypropylene	86
PS (GPPS)	370	Polystyrene, general purposes	86
PS (HIPS)	360	Polystyrene, high impact	86
PS (EPS)	360	Polystyrene, expandable	86
PUR energy absorbing	490	cushion foam, pentane blown	
PUR flexible block foam	480	for furniture, bedding, clothing	
PUR hard foam	420	used in white goods, insulation, construction material	
PUR semi rigid foam	480	foam insulation or in dashboards	
PVC high impact	280	Without metal stabilizer (Pb or Ba) and without plasticizer (see under Chemicals)	86
PVC (rigid)	270	rigid PVC with 10% plasticizers (crude estimate)	86
PVC (flexible)	240	Flexible PVC with 50% plasticizers (crude estimate)	86
PVDC	440	for thin coatings	
Production of rubbers (in milli points per kg)			
EPDM rubber	360	Vulcanised with 44% carbon, including moulding	
Production of packaging materials (in milli points per kg)			
Packaging carton	69	CO2 absorption in growth stage disregarded	19
Paper	96	Containing 65% waste paper, CO2 absorption in growth stage disregarded	32
Glass (brown)	50	Packaging glass containing 61% recycled glass	51
Glass (green)	51	Packaging glass containing 99% recycled glass	51
Glass (white)	58	Packaging glass containing 55% recycled glass	51
Wood board	39	European wood (FSC criteria); CO2 absorption in growth stage disregarded	19
Wood massive	6.6	European wood (FSC criteria); CO2 absorption in growth stage disregarded	

More information about the ecolizer 2.0 Click here [42]

Did you know that the way we produce, consume and dispose of our products and our food accounts for 42% of U.S. greenhouse gas emissions?

The material list
All the possible materials in the tool are defined here with its impact. The higher the score the more impact the material has.

Selection and reduction of Materials
- Reduce material weight or volume
- Look for materials with less impact and comparable properties
- Use recycled material
- Use non-toxic materials
- Use Non-exhaustible materials
- Use materials efficiently

H Assessment of Seats

H.1 The Inventory Analysis

The Ballet Seat

Table 15 The Life-cycle Inventory of the Ballet

Name of part	Specified name	Material	Amount	Weight in gr	Process	Recycla-ble?
Seat	Seat	Pur	1	2700	Injection mould-ed	No
	Cushion top	Low pur	1	36	Glued to Nylon	No
	Top Nylon	Nylon	1	112	Stitched	No
	Cushion bottom	Low pur	2	96	Glued to Nylon	No
	Bottom nylon	Nylon	2	388-96=292	Stitched	No
Bottom attach	Bottom at-tachment for slide	RVs	1	1120	Laser and bended	No
			Total weight	**4456 gr**		

The ER3 Seat

Table 16 The Life-cycle Inventory of the ER3 seat

Name of part	Specified name	Material	Amount	Weight in gr	Process	Recy-clable?
Bottom	Plastic seat inside	PA6CF15	1	427 gr	Injection mould	No
		PUR	1	4945 gr	Injection mould	No
Back lean-ing	Outer sides back leaning	Nylon	1	1600	Injection mould	Yes
	Mesh of back leaning	Nylon	1	480	?	?
	Back support	Nylon	1	1051 gr	Injection mould	Yes
RVS at-tachment	Backrest at-tachment	Stainless steel	1	748gr + 363gr + 67 gr	Casting	Yes
	Bottom montage	Stainless steel	1	1203 gr	Laser and bending	Yes
Shifting	RV	Alumini-um	1	1564	Extrusi-on	Yes
			Total weight	**12448 gr**		

H.2 The Ballet Assessment Data

Table 17 The Process Assessment of the ER3 Seat

	Name process	Type of Processes *	Process *	Quantity per Life-cycle *	Measure Unit *	eco-Indicator 99	Result	Comments
2.1	Seat inj. Mo.	Plastics	React.Inj.Moulding-PUR	1.00	2.7	12.0	32.40	
2.2	Cushions	Plastics	React.Inj.Moulding-PUR	2.00	1.E-01	12.0	3.16	
2.3	Bottom attach	Metals	Pressing	1.00	0.1	23.0	2.30	
2.4	Bottom attach	Metals	Shearing/Stamp-in-steel	1.00	0.4	0.0	0.00	
						Total in mPt	38	

Table 18 The Transport Assessment of the ER3 Seat

	Name transport	Transport*	Type		Measure unit kg freight *	eco-Indicator 99	Result	Comments
3.1	Ballet	Asia	Boat		4.456	33.795	150.59	
						Total in mPt	150	

Table 19 The Disposal Assessment of the ER3 Seat

	Name part	Disposal	Type	Amount	Measure unit in kg	Indicator	Result	EoL poten-tial	Comments
4.1	Seat	PUR energy ab-sorbing	Incineration PUR	1.00	2.7	2.800	7.56		Not recyclable
4.2	Cushion top	PUR semi-rigid foam	Incineration PUR	1.00	0.036	2.800	0.10		Not recyclable
4.3	Top Nylon	PA 6.6	Municipal waste Nylon	1.00	0.112	3.100	0.35		Not recyclable
4.4	Cushion bottom	PUR semi-rigid foam	Incineration PUR	2.00	0.096	2.800	0.54		Not recyclable
4.5	Bottom nylon	PA 6.6	Municipal waste Nylon	2.00	0.292	3.100	1.81		Not recyclable
4.6	Bottom attachment for slide	Steel high alloy	Recycling high steel alloy	1.00	1.12	240.000	292.80	-750.4	
						Total in mPt	297	-750	

H.3 The Results of the PD-LCA

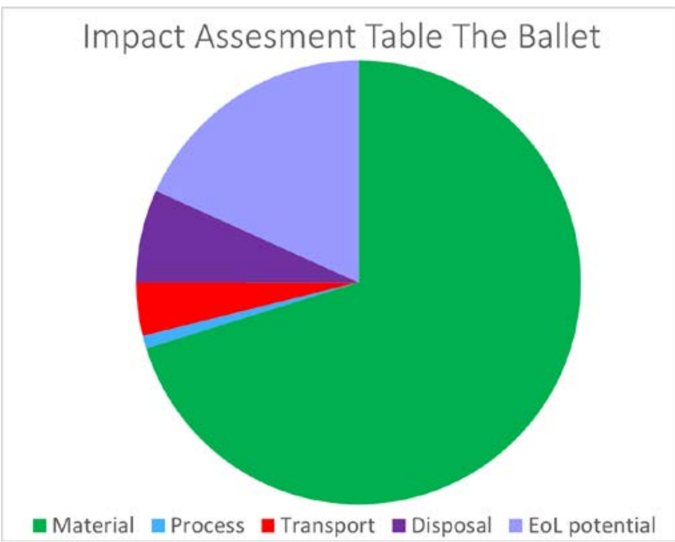


Figure 31 The Impact Assessment Division of the Ballet

Table 20 Impact Comparison of Trees and Cars

	Number of trees needed to be Net Zero	Equal to km driving by benzine car
Ballet Seat	1	217
Comfort Seat	2.6	532

H.4 The Redesign steps

Table 21 The Redesign Steps in the STAT

Step	Questions to answer			Yes/No
1)	Which Life-cycle Stage has the most impact?			
2)	Which aspect of that stage has the most impact?		Is this logical and necessary?	
3)	Go by the Circularity strategies to determine improvement areas.			
3.1)	R0	Is it possible to Refuse a part?		
		Are all elements in the product necessary?		
		If yes: Why are those necessary?		
	R1	Can you Rethink the situation for the product?		
		Can you increase the time of Use?		
		Can you increase its durability? (not everything needs to be as durable when the product is disposed of. The durability is		
		Can you make the product to be easy to maintain?		
		Can you make the product (parts) out of one material?		
	R2	Can you Reduce Materials, Processes, Transport, and Disposal?		
		Can you use Recycled Materials?		
		Do you need a particular material, or are there other possibilities?		
		Can you decrease the weight or volume?		
		Can you reduce the number of options? To create more modular.		
		Can you use processes with less impact?		
		Can you design for Packaging? To decrease packaging use.		
		Does it even need packaging at all?		
	R3	Can you Reuse parts?		
	R4	Can the product be easily repaired?		
	R5	Is it possible to design the product for refurbishment?		
	R6	Can you Remanufacture parts to give the part a new function?		
	R7	Can you give waste or an old product a new purpose?		
	R8	Are the parts recyclable?		
		Is there a market for those materials?		
		Can the parts be easily detached and identified?		
	R9	Can you prevent the product from incinerator or landfill?		
	Try to avoid this for a Circular Economy.			
3.2)	Are you satisfied with the amount of Yes and No you filled in?			
4)	**Look at the Life-cycle Circle and go by the stages;** Are there improvements possible?			
5)	**Look in the Library for Articles to find more information to decrease the impact of your product.**			
6)	**Evaluate results ;** Please do another PD-LCA with the Renewed design if any changes can be made.			

I The Easy Rider 3 by the STAT

I.1 The Easy Rider 3 Impact Inventory

Table 22 The Easy Rider 3 Impact Inventory

Product parts	Product sub parts	Sub- sub parts	Material	Weight/ surface	Processes	Recyclable or not
1. Basic frame	1.1 Frame hydro		Steel	4394 0,45m2	Coated, hydroformed, extruded, bended	Recyclable
	1.2 Connection to back part		Steel	842	Casting	Recyclable
	1.3 Connection front fork		Steel	856	Coated and casted	Recyclable
			Total weight	**6092 gr**		
2. The Swing arm	2.1 The protection cap		Abs	303	Injection moulded	Recyclable
	2.2 The back frame	Chrome alloy part construc-tion	Chrome alloy (Low alloy steel)	4951	Extruded Weld-ed	Not Recycl.
		Steel part	Steel	1941	Extruded	Not Recycl.
	2.3Electric motor support + seat	Right and left	High alloy Steel	1797	Bended and Milled	Recycleble?
	2.4 Accu slide	The case	Aluminium	860	Bended	Recyclable
		The back	ABS	44	Injection moulded	Recyclable
		The print plate	Multi mat	400	Resin	Not Recycl.
	2.5 Chain span-ners		Steel	450	Casted	Recyclable
	2.6 Spring/ damper	Damper	Steel	695	Casted?	Not Recycl.
		Spring	Steel	380	Extruded	Recyclable
	2.7 Motor		Steel	280 116 214	Plate Casting Extrusion	Not Recycl.
			Alu	1392.33	Milling	
			Copper	50	?	Recyclable
	2.8 Gear hub	Casing gears	Steel	752	Casting	Not Recycl.
		Casings gear hub	Alu	739		Not Recycl.
			ABS	400		Not Recycl.
	2.9 The back axis		Steel	1156 547 114	Extrusion	Not Recycl.
	2.10 The front axis		Steel	400		Recyclable
	Total weight			**15293 gr**		
3. Front frame	Front fork		Steel	1901 0.13 m²	Extrusion Powder paint	Recyclable
	Steering frame	The steer	Aluminium	140	Extrusion	Recyclable
		The beam + pur-chase piece	Aluminium	756	Extrusion & cast-ing	Not Recycl.
		Universal joint	Steel	155	Casting	Recyclable
	Connection cap front		ABS	140	Injection moulded	Recyclable
	'emergency' brake		ABS	55	Injection moulded	Recyclable
	Handles		Rubber	120	Moulded	Not Recycl.
	Hand brake	Combined mate-rials!	Steel	200 gr		Not Recycl.
			Total weight	**2756 gr**		

4 seat	Bottom	Inner firmness	PA6CF15	427	Injection mould	Not Recycl.
		Soft seat	PUR	4945	Injection mould	Not Recycl.
	Back leaning	Outer sides back leaning	Nylon 30% Fibre	1600	Injection mould	Recyclable
		Mesh of back leaning	Nylon	480	?	?
		Back support	nylon fibre	1051	Injection Mould	
	RVS attachment	Backrest at-tachment	Stainless steel	748 + 363 + 67	Casting	
		Bottom mon-tage	Stainless steel	1203	Laser and bend-ing	Recyclable
	Shifting	RV	Aluminium	1564	Extrusion	Recyclable
			Total weight	**12448 gr**		
5 Pedal and chains	Chain	The bicycle chain	Low alloy steel	300	Sheet production	Not Recycl.
		Back chain'	rubber	330	Sheet production	Not Recycl.
	Pedal	Crank	Stainless steel	593*2	Casting	Recyclable
		Gear	Stainless steel	116	Sheet production	Recyclable
		connection	Stainless steel	300	Casting	Recyclable
		Chain cage	ABS	300	Injection moulding	Recyclable
		Pedal	ABS	107*2	Injection moulding	Not Recycl.
			Total weight	2746 gr		
6. Wheel (x 3)	Hub		Aluminium	442	Casting and milling	Recyclable
	Inner tube		Rubber	103	?	Not Recycl.
	Tire		Rubber	613	?	Not Recycl.
	Spokes		Stainless steel	150	Extrusion	Recyclable
	Fenders		ABS	160	Injection mould	Not Recycl.
	Rim		Aluminium	1097	Extrusion	Recyclable
			Total weight	**3* 2565= 4595 gr**		

In the assessment, the 'use' is set to one. This means that within the life-cycle expectancy, which is in this case 10 years, only one part is needed and is expected to maintain for those 10 years.

Figure 32 The Easy Rider 3 product assessment segments

I.2 The Results of the Impact Assessment of the ER3

Table 23 Impact per Product Part of the ER3

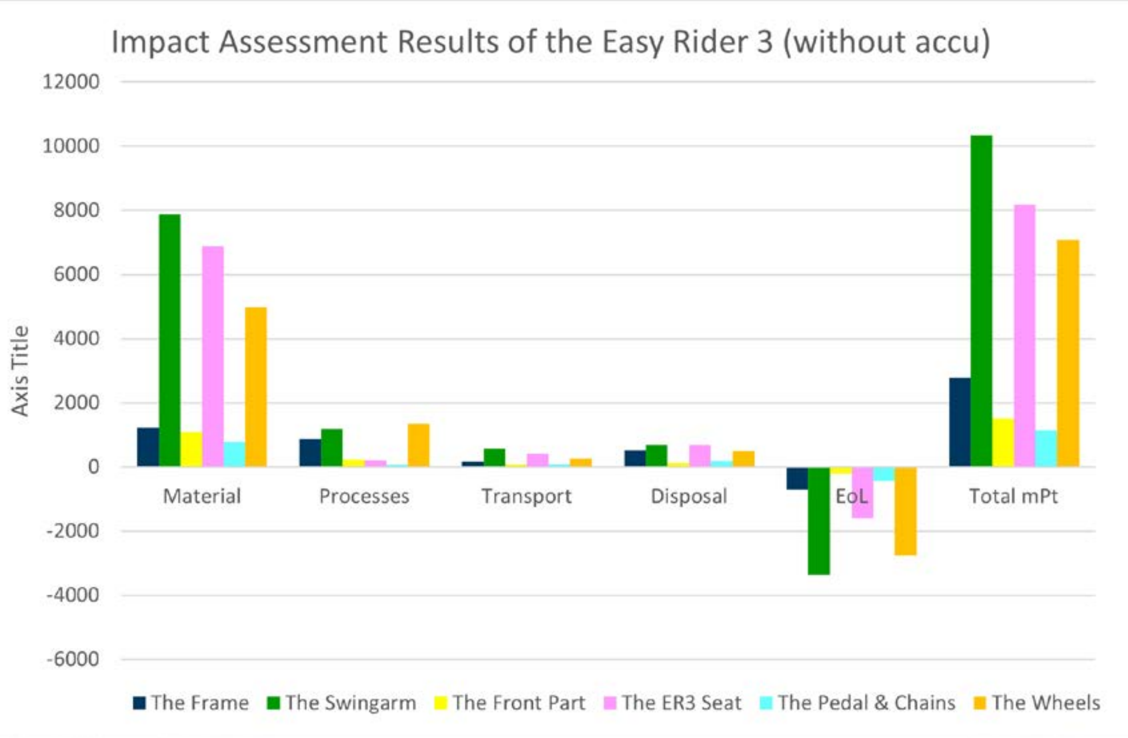


Table 24 Impact per Product Part of the ER3

	The Frame	The Swin-garm	The Front Fork	The ER3 Seat	The Pe-dal & Chains	The Wheels	Total in mPt	Total in Pt
Material	1218	7883	1081	6875	784	4976	23943	23.9
Processes	863	1195	230	203	70	1353	4074	4.1
Transport	176	567	87	409	93	260	1524	1.5
Disposal	517	698	121	691	193	498	2719	2.7
EoL	-701	-3354	-204	-1595	-432	-2748	-10160	-10.2
Total mPt	2775	10343	1519	8178	1140	7087	32259.7	-
Total Pt	2.8	10.3	1.5	8.2	1.1	7.1	-	32.3
Recycling Potential	25%	32%	13%	20%	38%	39%	29%	29%
Weight	6.092	18.008	2.7561	12.448	2.746	7.695	49.7 kg	
Pt per kg	0.5	0.6	0.6	0.7	0.4	0.9	0.6	

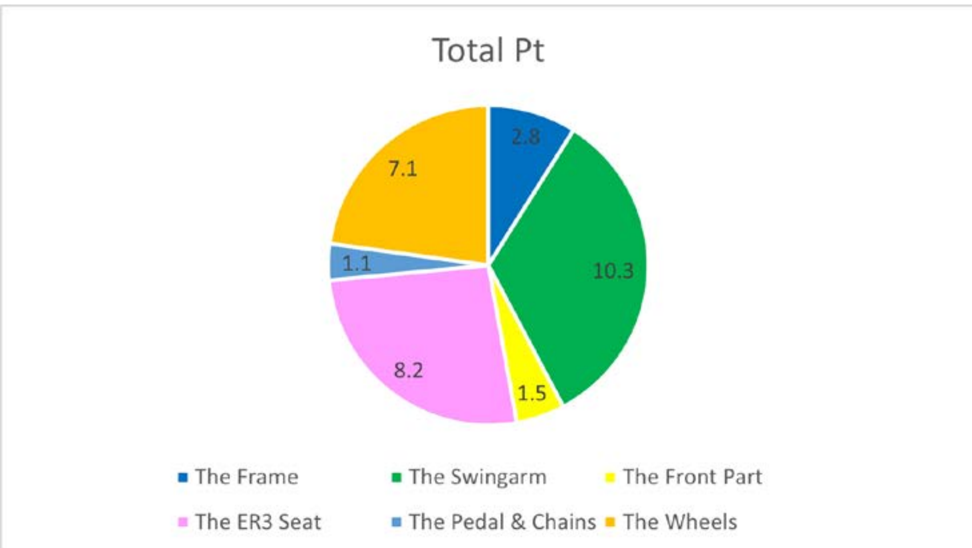


Figure 33 Impact per Product Part of the ER3

J User Tests

J.1 The Test Plan

Test persons: Lead Engineer (LE), the Product Management Design (PMD) and the Manager R&D (MR&D)
Date: 10-03-2022 till 24-03-2022
Place: Ideeënfabriek
Materials: 2 computers + a screen and pen and paper
Quantitative useability testing: measuring user experience with data.
Moderative usability testing: seeing how the user uses the tool is better to be around. To completely see where the tool flows well and were not. Especially for additional questioning for the feedback of the tool.

Goal & Scope
1. Getting feedback about the flow of the tool and what is already going well and what can be improved
2. Whether the core elements are clear
3. The convenience of the tool by going through the requirements

The User Test Questions

Phase 1: Questions in advance
- What do you expect from the sustainability platform?
- What is the most important aspect of such a platform for you?
- What do you think of such a platform?
- What is interesting for you as a product developer?
- Would you apply it daily, weekly, monthly?

Phase 2: Go through the tool
Try to find the area where you can find:
- Find the page that is about sustainable design.
- Find a YouTube clip that explains how an LCA works.
- Can you Figure out how much more impact a truck has versus a boat.
- What options does the LCA tool have within waste processing?
- Find out where the reason is why this tool was developed.
- What does DfD mean?
- What do the icon with 3 gears mean and do?
- Where can you Figure out how to reduce impact in your design.
- What is a Milli point?

Phase 3.1: Assessment without data.
- Why use a life-cycle analysis?
- How would you start the LCA?
- What would you do next?
- How would you collect the data?
- How would you fill in the details?
- How would you define the results?
- What are you looking at to reduce the impact?
- What do you miss in the tool to understand the flow?

Phase 3.2 Assessment with data

The ER3 Seat

Table 16 The Life-cycle Inventory of the ER3 Seat

Name of part	Specified name	Material	Amount	Weight in gr	Process	Recy-clable?
Bottom	Plastic seat inside	PA6CF15	1	427 gr	Injection mould	No
		PUR	1	4945 gr	Injection mould	No
Back lean-ing	Outer sides back leaning	Nylon	1	1600	Injection mould	Yes
	Mesh of back leaning	Nylon	1	480	?	?
	Back support	Nylon	1	1051 gr	Injection mould	Yes
RVS at-tachment	Backrest at-tachment	Stainless steel	1	748gr + 363gr + 67 gr	Casting	Yes
	Bottom montage	Stainless steel	1	1203 gr	Laser and bending	Yes
Shifting	RV	Alumini-um	1	1564	Extrusi-on	Yes
				Total weight	**12448 gr**	

The F2G Seat

Table 25 The Life-cycle Inventory of the F2G Seat

Name of part	Material	Weight in kg	Process	Trans-port	Life-cy-cles	Waste
Seat cushion	EVA	1.15	Injection mould 1	China	2	1
Backrest	PA6 GF Glas gevuld nylon	0.81	Injection mould 1	China	1	1
Cover cap	PA6 GF	0.04 8	Injection mould 1	China	1	1
Backrest frame (mesh is stretched into it)	PA6 GF	1.47	Injection mould 1	China	1	4
Mesh	Nylon met PE	0.2	Weaving	China	1	3
Seat bowl	PA6 GF	1.22	Injection mould 1	China	1	1
Cantilever extrusion	Alu 6061	2,59	Extrusi-on	China	1	1
Cover	PA6 GF	0.01	Injection mould 1	China	1	1
Seat lock	RVS 1.4301 (AISI type 304)	0.32	Lazer cutting and edging	The	1	1
Pressure spring	Blad-veer RVS 301	0.01	Purcha-se part	?	2	1

The data of the F2G seat was provided by the Product Manager Design, as this person was interested in the product's environmental impact.

Questions

- What is easy to fill in? & what is difficult?
- Is the flow of filling out suit?
- Is information missing? / too much
- Is data missing? / too much
- Is it clear what the results are?
- How would you proceed with these results?
- What would you do to redesign a chair?
- How would you go about that?
- What are you missing?
- Tell the good and the not so good points

Phase 4: The Requirements

Not at all	Partially not	Mediocre	Excellent	Good	Terrific
0	1	2	3	4	5

o Do you find the tool easy to use? (0-5) Why?
What could be better/different?
o Do you think the platform is clear? (0-5) And why?
What are you missing/are you missing too much?
o Do you think the LCA process is clear? (0-5) And why?
What are you missing/are you missing too much?
o Does the tool speak for itself? (0-5) And why?
o Does the tool fit Van Raam's processes? (0-5) And why?

o Is the tool easy to implement do you think?
o Is the design of the tool attractive?

Note: The participant has seen the programm before, so he or she is familiar with it.

J.2 The Results

The results of the three user tests are gathered for improvements. The user test results were divided into four phases, and the reactions are written down in sections. The users did point out important features that could be improved. The redesign sheet, for example, was not yet completed and thus lacked connection to the other elements of the tool and the program. More remarks are provided in the sections that follow.

Phase 1: Questions in advance

The tool, according to the lead engineer (LE), would provide biomaterial alternatives. The user had previously seen the tool and knew that this was not the case. The user, on the other hand, would like to have this feature. The LE did struggle to define what the user expected. Because desires and needs are not the same thing. As a result, the LE is having difficulty making decisions. LE makes designs and developments available as Product Management (PM) completes them. Because the PM's design sketch influences the user, the LE only considers those materials. Aside from that, the LE met with Your Plastic Solutions (YPS) to discuss how they can implement sustainability in the company. Since YPS was acquired by Van Raam, the plastic parts are also manufactured at YPS.

The second user then expects the platform to provide the environmental impact of the part's profile. The function is thus to compare parts in order to better identify with the concept. The users' goal is to raise employee awareness. The program should be simple to use and should not fail to meet the user's expectations.

Product Management is the third user. The individual anticipates that the programme will assist them in making honest decisions through equal comparison of concepts. Especially when choosing between concepts, the tool can be the deciding factor. The programme can help the user gain more knowledge about sustainability, and it raises awareness among both the user and the company. The user anticipates that the tool will be better suited for R&D Engineering because the PM is more concerned with drawing and less with material. The materials are not defined by User 3. However, the program could provide more information and inspiration for sustainable design.

Phase 2 Going through the tool

During this phase, users were required to navigate the tool in order to locate specific features and provide a solution to the question. Overall, users took some time to locate the element within the tool. In several situations, they knew the solution before looking it up in the application. When the search took too long, the users were aided by pointing them in the right path. The LE went quite fast through the program to find the features. The YouTube clip was harder to find as it was not directly clear that the user needs to go to the library for this information. The reason for the development of the program was also more difficult to find. Then the LE thought the scope and the function unit were difficult to distinguish.

The difficulty with this assessment was that it was difficult to detect minor pieces within a few clicks within the time constraint. Because the application was created for product developers who did not use an LCA. Therefore, the users needed more time to find the answers to the questions as the tool provides much information for low-experienced LCA users. Though, at the end everyone could give an answer to the questions.

Phase 3 The Program Product Assessment

The Lead Engineer was pleased with the product evaluation flow. However, he emphasised the need of keeping the user in mind. As an example, consider the delivery of product components. The engineer has no idea where it is coming from, especially if it is a purchased part. As a result, the selections must be simple and limited in order to facilitate assessment. Then, with the materials, he discovered that neither EVA nor the current state of Aluminium (80% recycled) were available. This reduces the legitimacy and accessibility for the product developer. The LE mentioned creating a sense with the statistics when displaying the findings. The points do not convey as much information as referring to the number of plants and the distance travelled in a car. The results are then understandable to the user. The LE also mentioned that the redesign document needed to be better organised. The LE needs a strategy with actions to follow and to know which parts the user may improve the product with. The user must maintain control, but the program will guide them to their goal.

The manager R&D has matching arguments with the Lead Engineer, but the manager did not go into specifics. The MR&D noted that the redesign checklist was crucial to remind the user to think about product enhancement. The MR&D indicated that he could implement the instrument for requesting the impact of items with design freezes. Overall, MR&D was impressed and believed it could work. The MR&D already had suggestions for improving and broadening the scope of sustainability. The Product Manager Design was then delighted about the STAT results. Because the inventory is time demanding, the assessment requires some effort. However, the results are suitable for decision-making. The tool's user interface might be improved.

In the third phase the users went through the PD-LCA steps. Because of time concerns there was not time to fill in all the parts by the user themselves.

Phase 4 The Requirements

Within the phase the most important requirements were put forward to identify which elements need improvement and which are already well developed. The users each gave a grade from 0-5 and this resulted in an overall score of 3,3, which is shown in Table 19.

The requirements are (partially) met. However, adjustments are still required to make the redesign more integrated to the overall PD-LCA process and the other sustainability strategies. The tool's design scored higher than predicted because Excel features design flaws that can be used to optimise the UX design. The manager indicated that the tool would be quite valuable, and that as the manager, the STAT might be mandated for decision-making situations. This would aid implementation. Overall, users like the STAT, and with slight adjustments, such as the redesign sheet, the tool will be more complete.

Table 26 Assessment of the Requirements according to the Users

Requirements	User 1	User 2	User 3	average
Ease of use	2	3	3,5	2,8
Clarity of platform	4	3	4	3,7
PD-LCA process clarity	3	4	4	3,7
Tool ease	1	4,5	3	2,8
Tool implementation in process	4	2	3	3
Tool design	4	4	3	3,7
Total	**3**	**3,9**	**3,4**	**3,3**

K The LCA of the Product Portfolio seats of Van Raam

K.1 The LCI of the Comfort Seat

The Comfort Seat

Table 27 The Life-cycle Inventory of the Comfort Seat

The Part	The Name	Material	Weight in gr	Processes	Disposal
Bottom seat	'cushion'	PUR	2510	Injection mould	Not recy-clable
	Support	Wood	360		Not recy-clable
	Connection to bolds	Wood	753	Sawed	Not recy-clable
Back	Frame back	Stem	1744	Extruded + welding (6cm)	Recyclable
	Cover	Nylon	1922 gr (cloth)	Stitched	Recyclable
	Velcro's	Nylon	1186	Glued	Recyclable
	Connects elcro's	ABS?	12.3 g * 8		Recyclable
Attach-ments	Back to bottom	Stainless steel	243	Casted	Recyclable
	Bottom for slide	Stainless steel	1019	Lasered and bended	Recyclable
	Connect bottom to slide	Stainless steel	390	Laser and bended	Recyclable

K.2 The Results of the PD-LCA

Table 28 Impact Assessment Results of the Seat Portfolio of Van Raam

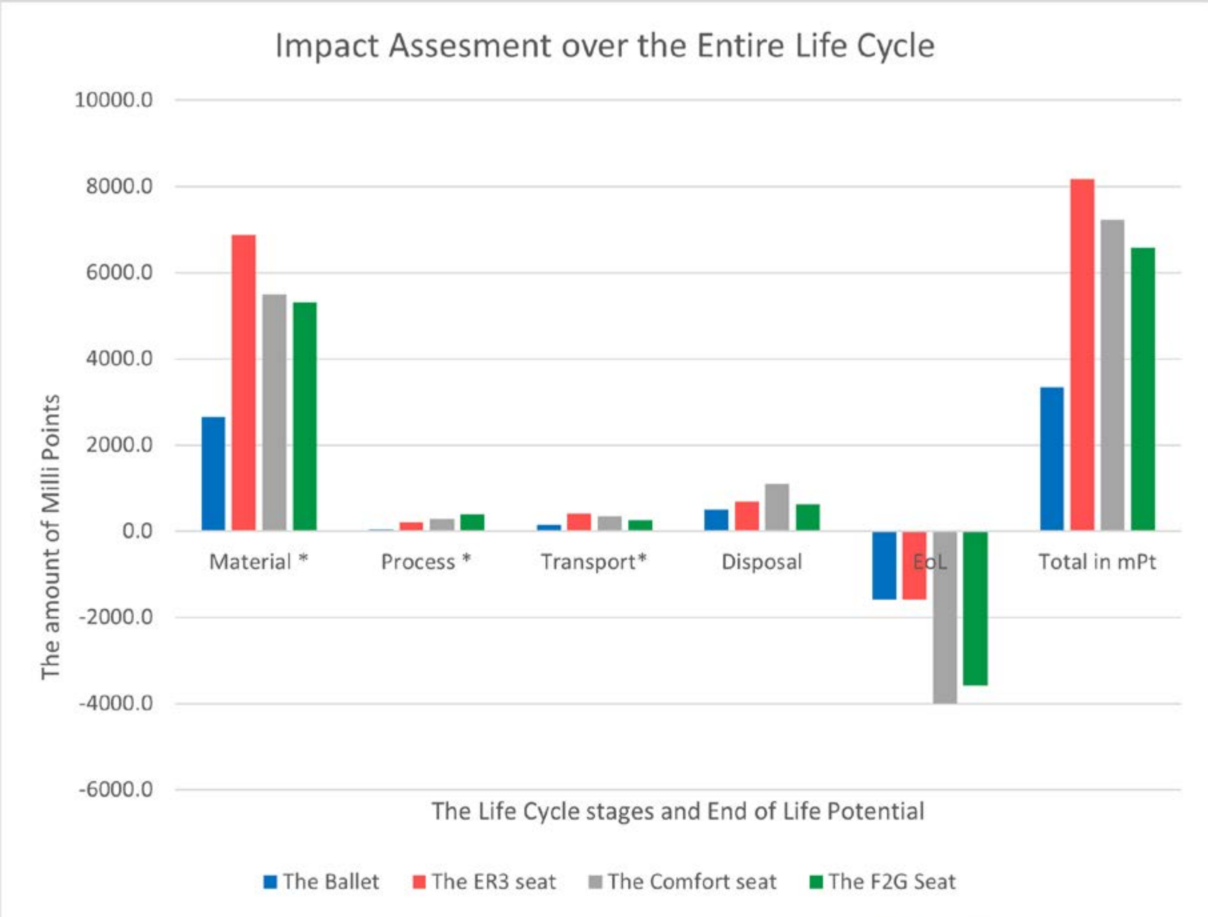


Table 29 Impact Assessment of the Seats Portfolio of Van Raam

	Material	Process	Transport	Disposal	EoL	Total in mPt	Total in mPt + EoL	Total in Pt	Impact per year
The Ballet	2647.1	37.9	147.2	503.8	-1598.2	3336.0	1737.8	3.3	112.4
The ER3 seat	6875.7	203.9	409.2	691.6	-1595.3	8180.4	6585.2	8.2	146.3
The Comfort seat	5498.80	284.98	345.57	1100.87	-3996.96	7230.2	3233.3	7.2	139.6
The F2G Seat	5307.74	393.21	254.84	619.55	-3582.87	6575.3	2992.5	6.6	135.0

L Requirement assessment of the PD-LCA

Table 30 The Requirements Assessment of the PD-LCA

	Requirement	Specification	(1-5)*	Assessment
General	*Focus on product development*	The target group for this method are product developers that almost finished their studies or work as a product developer (Product Management, Engineering, R&D)	2	2
	Focus on manufacturing of physical manufacturable products	Products that are made and designed by the company to define the material, processes, transport, use and disposal of physical use products.	4	3
	Is applied within the conceptualization stage of the product development process	The assessment of concepts that are determined in its materials, processes, transport, use, and disposal	1	1
	The process needs to create added value	The product developer can identify the environmental impact and redesign to lower this impact.	5	4
	Explanation of the method	Shortly notify the product developers of the purpose of every stage	4	3
	Method description	Make the product developer understand the use, goal, and purpose of the method	3	2
Use	*Meant for concept comparison*	The results have meaning when it is compared to other elements that are understandable	4	3
	Makes use of circular iterative process	The method is circular as product improvements are supported	2	2
Function	*Easy and accessible life-cycle assessment*	Include clear steps and is appealing for the user	4	3
	Precise start and end points of the LCA	The start of the method and the end must be clear by using visuals as icons	2	1
	The redesign is needed for a more sustainable product	Follows iterations to improve the product by including a redesign stage and assessing a product again after redesigning	5	5
Design	Attractable and remarkable method design	Use of colours, Figures, and text to show the steps of the methods used	3	2
		Total	**40**	**31**

Because the LCA framework was insufficient, the PD-LCA was created to assist product developers in improving and assessing a product's environmental impact. As a result, in section 5.1, requirements for developing the PD-LCA, which is explained in Chapter 6, Figure 15, were established. The PD-LCA is evaluated according to the requirements in this section to determine if the requirements still apply for any improvements within the scope of the research. In Table 30 the PD-LCA method's requirements are assessed. The method received 31 points out of a possible 40, which is adequate, but improvements are still required.

The PD-LCA method is suitable for product evaluation by product developers because it incorporates product improvement through redesign while adhering to the qualitative LCA stages. The method includes information about its purpose, significance, and application. Though improvements could be made because the method must be tested twice because the user must redesign the product or concept before presenting the results. The PD-LCA adheres to product developers, adds value, and is appealing..

M Requirement assessment of the STAT

Table 31 The Assessment of the STAT according to the Requirements

Type	Requirement	Specification	(1-5)*	
Gen-eral	The tool can be used in a digital environment	On a computer	2	2
	The tool provides information on sustainability	For product developers in companies that design and develop manufacturing of use goods	4	4
	Data can be adapted.	When there is an update or change in the measurement method, data can be adapted	2	1
	The process flows in the program are informatively supported	The user can click on an icon to get more information about the step	3	2
	The data can be stored	Saved in the program or by PDF print	1	1
	The tool makes use of a sustainable measurement method	More specifications are established below**		
	There is a database for easy access to suitable sources	The database is connected to the other parts of the tool as the LCA	3	3
	Provides background information on calculations	Provides information on how the calculations are done	2	2
	The tool makes life-cycle assessment easier for product developers than the current LCA programs	The tool scopes the input needed for information, so the user has only the choices they influence, and those matters	5	4
Safety	The tool can only be found in the data folders of the manufacturer	Online the program cannot be seen without a code or password (encrypted)	1	1
	Security is ensured by not storing data in the program	Results must be stored separately from the program at the company's internal cloud	2	2
	The tool cannot be modified 'just like that.'	Code encrypted to adjust 'background' data	2	1
Use	Easy to use	A Life-cycle Assessment can be filled in, in five to twenty minutes (data collection excluded)	4	4
	A low threshold to use	Accessible for all situations in the product development process	5	3
	Easy implementation	The tool is added to processes as a requirement	3	2
	Used alongside the current process and program of design	Little adaptability needed to use the tool	4	3
	Few computer skills are needed to use the program	The program requires basic computer skills	5	4
	The user is guided through the program.	The steps are self-explanatory and are explained where necessary.	4	3
	The tool makes use of the product development LCA method	The tool assesses an LCA according to the method	4	4
	Can compare concepts within one flow of assessment	Multiple conceptual products can be assessed and then compared by its results, all within the program	2	2
	It is possible to assess a conceptual product in the program	The data inventory is possible within the conceptual knowledge of the product, which means that a couple of materials, processes, and transport is known and the general idea of its use and disposal.	4	4
Func-tion	The tool provides support on how to reduce the impact of a product	Advice by design structures, recycling or the reuse of materials is made applicable	4	3
	The tool provides information about the environment for sustainability materials & processes	Basic knowledge of the program	3	2
	Making LCA results understandable and usable	A clear vision of the results through graphs and comparison which can be understood by the stakeholders	3	3
	The tool can be adapted toward the company's goals & vision	Data is customisable by Van Raam employees	2	2
	Focus on eco-sustainability in the tool	Warming, water, acidification, acidification, health	3	3
	The tool is an interactive system.	The program responds to choices that are made / information that is chosen or filled in	3	3
	The tool is simple but creates reliable added value	Concrete steps and process flow is created by making the assessment accurate within detail	3	3
	Data from the program connects to current manufacturing processes	The materials, processes, transport, disposal, and end-of-life potential.	3	3
	The tool supports sustainability for iteration and conceptualization stages	Design strategies are incorporated within the program.	2	2

Design	Visually appealing	Using colours, clear contrasts, and graphs, visualize as much as needed	2	1
	The tool is designed as a website page	The tool looks like a webpage with a taskbar and interaction features	3	2
	The results must be understood within one view	The results are visualized and put into context which is viewed in one page	3	3
Legal	The results are meant for internal use.	The results of the tool are not meant for marketing and promotional purposes	3	3
		Total	**100**	**85**

Sustainable measurement method **	Accessible	Available for use	5	5
	Easy to understand	Simple calculations with understandable characterisation factors such as CO^2-eq or mPt	4	3
	Reliable	Data is qualitative and verifiable by literature.	3	1

M.2 The Results of the Assessment of the Requirements list

The STAT was created to help product creators quantify sustainability using the PD-LCA technique. Table 19 lists the tool's requirements. The criteria list specifies the conditions that the tool must meet. The STAT receives 85 points out of a possible 100. As these conditions are accomplished, the tool fully or partially meets all of them. The requirements could be scored based on the results of the user tests and case studies. The review was carried out per category, which is stated below, to identify which improvements are required.

The General

Overall, the requirements are met because the STAT is made in a digital environment, the tool gives information for the user to apply an LCA, and therefore using Excel and eco-indicator 99. Because it focuses on users' knowledge, the tool makes LCAs easier than current LCA programs. However, some requirements are not entirely achieved, such as the data; it is configurable but difficult to manage. This might be enhanced by employing a programmer to improve the Excel utility or, even better, programming the tool by coding. Within the time constraints, however, Excel is best suited for doing calculations and displaying findings. However, the goal of developing a tool to assist product development in quantifying and implementing sustainability has been met.

The Use

The application of the STAT focuses on ease of implementation, provides guidance, and establishes thresholds via the PD-LCA. These prerequisites can be met with success. Product developers discovered during user testing that the tool is simple to use with a few Excel abilities, provides decent guidance, and can be utilised in conjunction with the present product development process. The only challenging criteria is the simplicity of adoption across the company. Especially given the effort that goes into raising awareness and generating interest and desire before there is any action of use. This is also challenging, according to users. Change does not occur automatically, especially in significant transitions, but it does occur with a new sustainability assessment factor. Because this takes time and effort, the requirement was not fully met.

The Function

The application of the STAT focuses on ease of implementation, provides guidance, and establishes thres-
The tool's weakness is the usage of Excel, which complicates the design and safety standards. Within the scope of expertise and capabilities, an attempt is made to ensure design and safety. The STAT was created by the author, who had no prior expertise creating a high-quality application. It is feasible to pay someone to improve the UX design through programming. For example, the tool is not on Van Raam's network, and the data is easily manipulated because it is not guarded or inscribed. The STAT, on the other hand, delivers the necessary information as well as visually understandable results to users.

The Sustainable Measurement Method

The scope's dependability was determined by comparing the outcomes of an evaluation of ER3, Eco-it, and Granta Edupack. These two programs are used with the same evaluation level and are (part-time) available. The impact of a product is assessed by the three program instruments to guarantee that the quality of the STAT instrument's results with the eco-indicator 99 is acceptable. The comparison resulted that the STAT is valid and can be used for decision-making within product development. Especially when the company makes only use of one tool, which is the STAT.

The Conclusion

The STAT specifies the environmental effect of a concept or product for internal decision-making. However, because only one case study is used, more research is required to define the appropriateness for other firms. For product developers, the STAT makes LCAs accessible and understandable. Because the sustainability measurement method is not of high quality and does not have many materials and processes to employ, more study into other measurement methods or collaboration with PRé Sustainability to obtain the ReCiPe method is also an option. Finally, the STAT meets the requirements and is applicable for manufacturers to use in their product development process.

M.3 The Validation of data of the STAT

To evaluate the validity of the STAT's results, the ER3 seat is assessed within three LCA program or Tool, Eco-It, GRANTA Edupack, and the STAT. The ER3 seat is used in accordance with the Inventory indicated in Attachment H.1 (Table 15 & 16), Attachment J.1 (Table 25) and, Attachment K.1 (Table 27). The results are shown in Figure 34 - 36. The main difference is that the aluminium used is not 100% recycled aluminium, but rather aluminium. As a result, all the assessment numbers are higher than the PD-LCA performed of the ER3 in Attachment H. The assessment in Attachment H was adjusted as during the user testing, a product engineer stated that 80% of the aluminium is recycled and 20% is new, so the data of 100% and non-recycled aluminium is more out of date.

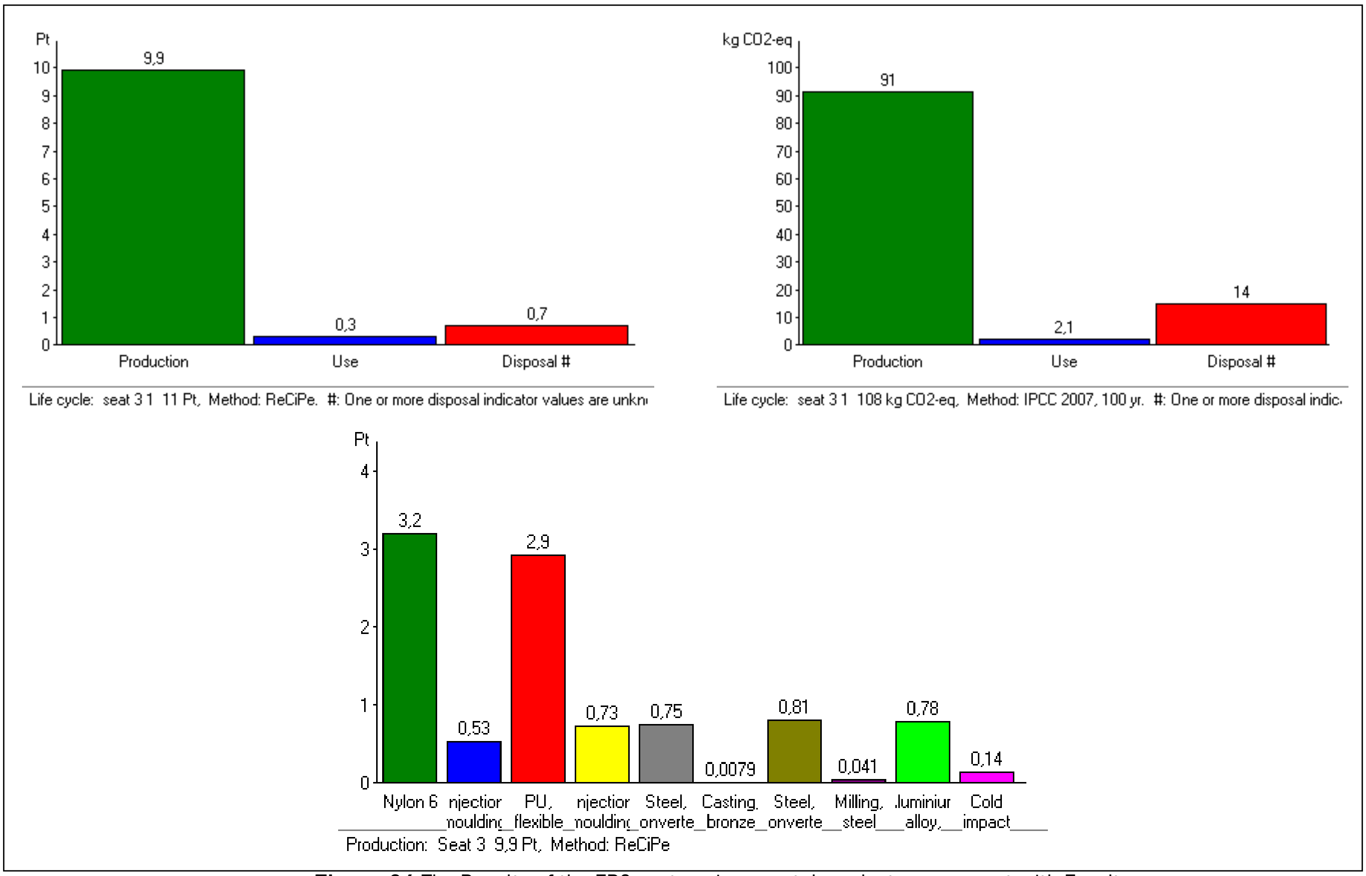
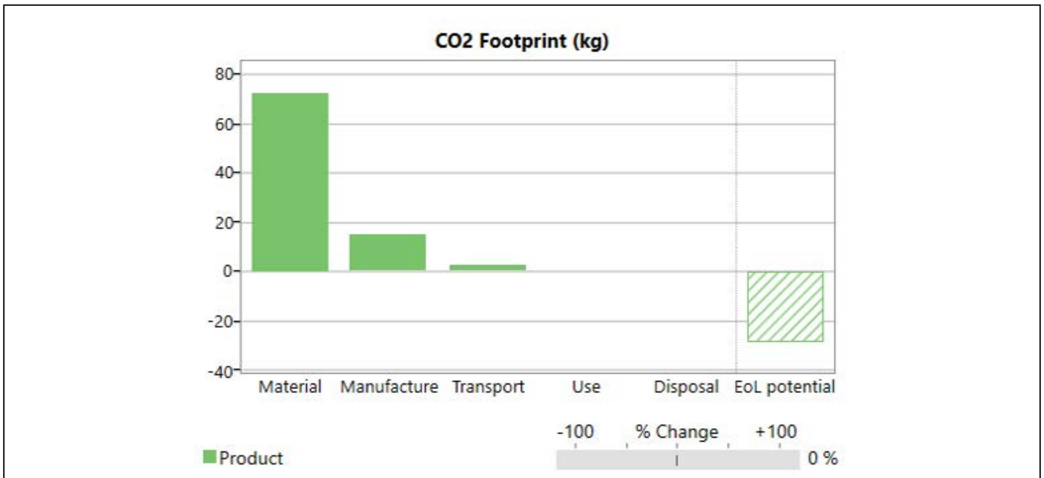


Figure 34 The Results of the ER3 seat environmental product assessment with Eco-It



Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	1,38e+03	85,0	72,8	79,7
Manufacture	200	12,3	15,4	16,9
Transport	35,8	2,2	2,58	2,8
Use	0	0,0	0	0,0
Disposal	7,62	0,5	0,533	0,6
Total (for first life)	**1,63e+03**	**100**	**91,3**	**100**
End of life potential	-723		-28,5	

NOTE: Differences of less than 20% are not usually significant. Page 1 / 3

See notes on precision and data sources. woensdag 16 februari 2022

Figure 35 The Results of the ER3 seat environmental product assessment with GRANTA Eco EduPack

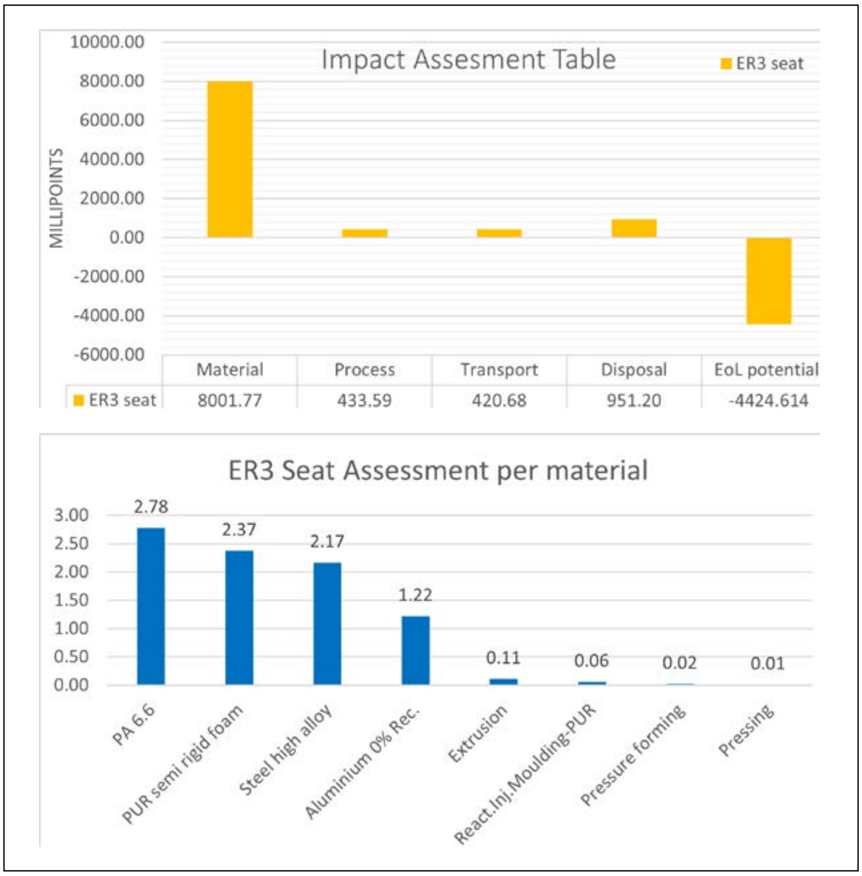


Figure 36 The Results of the ER3 seat environmental product assessment with the STAT

As the results are comparable and do not differ much. Thereby the method is applied and approved for use within the tool. It should be noted that these programs are not equivalent to GaBi and SimaPro as these programs have more detailed and better quality results but are not within the scope of the research [55].

N Workshop Summaries

N.1 Workshop 1

The focus of the first workshop was to show the general environmental problems and the effect these have on people, also in their day-to-day lives. Therefore, an assignment was given and a quiz to test their knowledge about the subject. For the assignment, they had to rate food according to its sustainability. This is challenging as the user does not know what, in this case, sustainability includes and, more importantly, which factors play a role, such as CO^2 emissions, water, or land use, and how much each factor matters about the other. This is also the case when the sustainability factor is added to decision-making along with the current factors. The products are shown in Figure 37 as well as the parts of the ER3 that they needed to rate within sustainability.

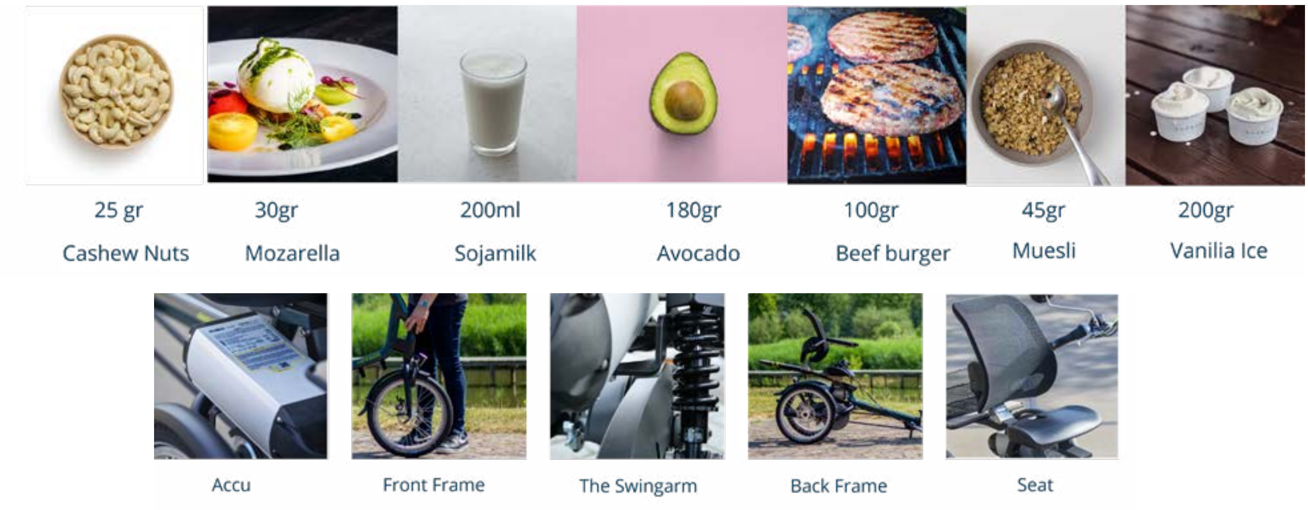


Figure 37 Rating Sustaiabilty with food and the ER3 product parts

In addition, the participants were shocked by how the linear consumption model pollutes the earth and how the earth is contaminated by us. Some already have an internal motivation as their interest in the theme is high, while others have a more critical mindset. The results of the assignment are summarized in an email which is shown in Attachment M. After every workshop the people that participated can be reminded of the results of the workshop as the stakeholders that could not attend are notified of the subjects and results.

N.2 Workshop 2

For the second workshop life-cycle analysis was explained as to how this could support sustainable product development. The workshop was able to increase interest and desire as people became more curious about the possibilities of STAT development. Although in the workshops, the LCA was explained by an example of a coffee machine, which was not very clear to the participants. The example could better be within their knowledge area, such as a bicycle. To create awareness and interest in sustainability it must be recognizable and understandable for them and therefore using examples from the real world will help.

Another element in the workshop was the Eco Footprint test. This was interesting for them to see but not very understandable as the results were hard to interpret and compare to more understandable examples. To create a daily awareness of sustainability, all the stakeholders were given a plant to take care of. The plants were 'kneuzenplanten', these plants were otherwise thrown away but are still good only they need more care [76]. The second workshop did not yield the best results as the topic was too complex, and for the assessment of a life-cycle analysis, the PM did not match the level of detail for assessing a product. Though, it became clear that LCA's are only suitable for R&D engineers and production.

N.3 Workshop 3

For the third workshop, the target groups had to determine their influence on change for sustainability. They had to complete an assignment to define something they could change to make something more sustainable. The assignment had to be presented in a one-minute pitch during the third workshop. The results were valuable, as the target group had good ideas. However, those changes were within their circle of Engagement rather than within their influence or control. With this assignment, it became clear that people find it hard to identify the impact they can have. Especially from their function, it is not clear in which elements they engage, have influence or are within control. This makes it harder to make changes in a company which is growing. Understanding your strength and significance in decision-making is tial to making changes. In Figure 38 one of the results of this assignment is shown. This web is made by a PM, and this can be used for decision-making, from the PID to the Project. Within the web, the importance of factors can be defined for that project, and requirements can be set for them. A discussion ensued in the workshop about what influence participants have in the product development process. Unfortunately, not many people showed up at this workshop because of other short-term interests. So, a fourth workshop was organized to clarify the outcome of the meeting. Only e-mailing the important results did not work well, because people did not completely understand what the problem was. With the extra meeting, the discussion created a platform to improve and identify their circle of influence. Communication is crucial to conveying the right information.

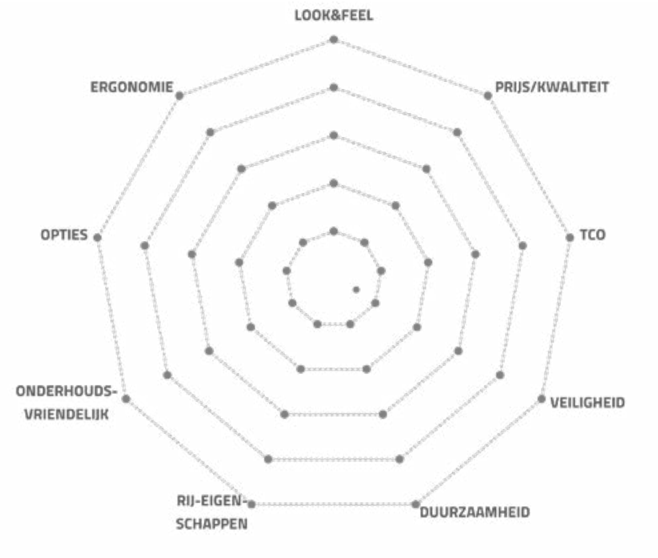


Figure 38 Results of the personal assignment PM: The assessment factors for rating importance

N.4 Workshop 4

Before the fourth workshop, a meeting was convened with the manager and board of directors to convey the urgency and awareness of implementing sustainability. The board of directors were not present in the workshops, but they still need to be made aware of the problem. They are important for motivating product developers to change their processes. One of the board members joined the fourth workshop to express their support and explain the urgency. This support from the board is essential for sustaining change and implementing sustainability.

This last workshop was focused on the circle of influence, again with the assignment of the target group to show everyone that to make changes this must be done within someone's circle of influence or control. The change to create awareness is established by these workshops. There has been made space to create the implementation of STAT with the PD-LCA. Whereas the inhouse-eco labelling supports the sustainability factor for decision-making. Though, because of time limitations, the use of the LCA tool and eco-label is not seen within the companies' practices.