LIGHT MATERIALS FOR ELECTRIC VEHICLES

IEDGE TOOLKIT GUIDELINE

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[1] PU = Public

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LIGHT MATERIALS FOR ELECTRIC VEHICLES

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Date	Version	Author	Comment
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LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
iEDGE	Integrated Eco-Design Guideline and Evaluator
RiT	Requirements identifier Tool
EQFD	Eco-design Quality Function Deployment
KPI	Key Performance Indicators
Requirements	Used synonymously for ‘High-Level requirements’ in the context of this report
WP	Workpackage
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
GHG emissions	Greenhouse Gas emissions

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PUBLISHABLE SUMMARY

This report contains the guidelines of the iEDGE toolkit, which is used in eco-design methodology, the results of the LEVIS demonstrator use cases and the evaluation of the LEVIS partners using the toolkit. Eco-design methodology is used during the first stages of a design process by identifying opportunities to improve integration of eco-design and circular economy principles into a new design. The iEDGE toolkit aids the designers applying the eco-design methodology. The toolkit is specifically designed for the LEVIS project but can be universally used for all kinds of products and is not specific only for automotive applications. The partners involved in the design process of the LEVIS demonstrators used the tool and provided feedback which is documented in this report and is used to improve the toolkit.

This deliverable report contains the following main sections:

- The context of the iEDGE toolkit and how it was developed. (Chapters 1 and 2)
- The Guideline to accompany the iEDGE toolkit. (Chapter 3)
- The results of the assessment performed by the demonstrator partners by use of the iEDGE toolkit. (Chapter 4)
- Conclusions and recommendations derived from the process of adopting an eco-design approach and the toolkit. (Chapter 5)

The LEVIS eco-design methodology and iEDGE toolkit was designed by conducting thorough literature research and create an inventory of possible methods and tools that could be used for the LEVIS demonstrators. It was decided to use a combination of different tools that seem to fit well within the goals of the LEVIS deliverables. These tools have been adopted to be used within one toolkit which covers all the steps of the eco-design methodology. The toolkit itself contains 5 steps which has to be followed:

1. **Frame the context** of the design environment by setting objectives and choosing a benchmark product.
2. **Identify scope and (high-level) requirements.** This is done by using the RiT (Requirements identifier Tool) checklist to guide the brainstorm session in finding potential impact related concerns and bottlenecks of the benchmark product. From the RiT Checklist high-level requirements and corresponding Key Performance Indicators (i.e., KPIs) can be formulated. In addition, the EQFD (Eco-design Quality Function Deployment) tool is used to set priorities for KPIs. These priorities ranking is used later in the performance evaluation.
3. **Create a baseline and set a target.** The performance evaluation tool (located in the EQFD sheet) is used to score the benchmark performance and to set the target. This input is used by the tool to automatically provide a suggested strategy and KPIs to focus your improvement direction on.
4. Create an **inventory of improvement options** and perform a **feasibility assessment**. The inventoried improvement options are analysed for their effects on different life cycle phase and impact areas, which results in low or high-risk improvement options. The feasibility assessment is then performed to determine whether the improvement is suitable for the new design or not.
5. **Performance Evaluation of the new design.** The new design goes under the same performance evaluation tool as the benchmark product and target. This results in a visual overview of the performances in a radar chart.

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Assessment Results – The demonstrator results and evaluation with the iEDGE toolkit often showed similar remarks concerning the usage and results shown by the toolkit. All partners needed personal guidance during the project but were still able to finish the assessments and gain results. The toolkit proved to be of value for the design process, where multiple improvement options were documented and after analysis proved to be increase the performance of the product design. During the process some insights were gained in how to improve the toolkit. Some of these improvements already have been put through in the new version of the toolkit and are shown in the use case in the appendix. Other improvements and suggestions are documented in this report.

Conclusions and Recommendations – The eco-design methodology and iEDGE toolkit proved to be valuable to the partners and the design process of the demonstrators. New insights and information were gained which helped in the process of generating improvements options for the new design. However, some improvements in both the usage of the toolkit and the toolkit itself can be made to perfect the eco-design methodology. Adopting eco-design into the 'business-as-usual' design process demands additional time and effort and requires becoming acquainted with a new area of expertise, it is recommended to allow for this. The iEDGE Toolkit and Guideline aims to support in the early stages of the design and is therefore primarily a qualitative assessment, however, integration with the performance of full LCAs (Life Cycle Assessment) and LCC's (Life Cycle Costing) is possible to create an extended version that also includes a quantitative assessment.

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1. INTRODUCTION

This report contains the guidelines to the iEDGE (integrated Eco-Design Guideline and Evaluator) toolkit, which is used in eco-design methodology, and the results of the application of this toolkit to the LEVIS demonstrators.

1.1. PURPOSE AND TARGET GROUP

The purpose of this deliverable is to integrate eco-design into the early stages of the development of the LEVIS demonstrators. To aid the partners that develop the use cases, the iEDGE toolkit and accompanying Guideline is created. The toolkit is based on multiple methods and tools that have been designed and used by universities and researchers specialised in eco-design. While several approaches provide very useful and on topic means for improvement, they approach design decisions only from a focus on improving environmental (and social) impact. With the iEDGE toolkit we aimed to provide a means to identify improvements considering the four main focus areas for product design: Environmental, Economic, Technical and Social. Based on this objective, components from existing methods have been adapted to create a comprehensive approach for practical application.

iEDGE was created to be an aid in supporting the integration of eco-design and related circular economy principles in the early stage of the decision-making process for a product's design. It provides a means to come to a set of key (eco)design principles to focus on, considers all focus areas and is underpinned by justifications for design decisions going forward.

The toolkit aims to help the design team identify potential impact-considerations across the four focus areas of the current (benchmark) product and arrive at a strategy to design a new improved product to reduce the key impacts. The toolkit is therefore best applied from the very first stage of the design process, namely the problem analysis and the discovery phase.

Because the LEVIS project had already determined 'Lightweighting' as its key objective to run like a thread through the project's work, the purpose of the iEDGE toolkit for LEVIS in particular is to:

- provide a sense-check on the decision-making process in the early stages of the demonstrator product designs,
- to validate whether the high-level requirements and corresponding KPIs are fit for purpose, and
- provide the opportunity to identify additional impacts and opportunities for improvement the project partners may not (yet) have been fully aware of.

N.B: For this project deliverable report and the iEDGE toolkit and Guideline, whenever we use the term 'requirement' we are referring to 'high-level requirements'. High-level requirements are typically formulated in a qualitative manner (i.e., not quantified). The reason for this is the fact that the iEDGE tool and guideline addresses the early stages of a product's design and therefore it is very difficult (if not impossible) to formulate sensible *quantified* requirements, particularly when the new design is likely to adopt innovative solutions.

Although the toolkit is created as part of the LEVIS project and requires it to be a useful and effective tool for the demonstrator partners, it was our objective to create a tool which is, in principle, product or sector independent. Therefore, the target audience for the toolkit and guideline is not limited to companies in the LEVIS project nor the automotive supply chain. The most likely primary users of the toolkit are designers; however, the best effect is achieved when designers also involve and/or consult

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colleagues with other roles or even (supply chain) partners who can provide complementing expertise and insights to varying aspects of a product's lifecycle.

Designing a product is a profession in its own right and often requires specific sector or product considerations. Similarly, other stages of a product's life cycle require expertise from a variety of specialists. Therefore, iEDGE does not presume to replace any expertise nor is it a tool for the design of the product itself.

1.2. CONTRIBUTIONS OF PARTNERS

Table 1 depicts the main contributions from project partners in the development of this deliverable. The key contributing partners have been the WP1 Lead and the partners primarily responsible for the demonstrator cases. Partners that are linked to any of the demonstrator cases for their specific expertise have not been directly involved in Task 1.2 but are aligned via Task 1.1 and 1.3.

Table 1 Contributions of Partners

PARTNER SHORT NAME	CONTRIBUTIONS
LEAR	Workpackage lead "Demonstrator development", alignment with task 1.1 and 1.3 and provide input and feedback in different stages of the development of the toolkit
MERSEN	Provide input and feedback in different stages of the development of the toolkit, as well as applying it in the early stage of the design process for their demonstrator product, the Battery Busbar.
YOVA	Provide input and feedback in different stages of the development of the toolkit, as well as applying it in the early stage of the design process for their demonstrator product, the Battery Box.
MARELLI	Provide input and feedback in different stages of the development of the toolkit, as well as applying it in the early stage of the design process for their demonstrator product, the Suspension Control Arm.
TOFAS	Provide input and feedback in different stages of the development of the toolkit, as well as applying it in the early stage of the design process for their demonstrator product, the Cross-Car Beam.

1.3. DEVIATIONS FROM THE PLAN

The original plan was executed accordingly, and no deviations were made during the process of the deliverable.

1.4. LINKS WITH OTHER WPS

The impact of eco-design and circular principles are inherently present throughout a product's lifecycle and therefore the work done in Task 1.2 affects and has interdependencies with various other tasks and Workpackages. Table 2 below provides a summary indication of these relations.

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Table 2: Workpackage and task relationship

WP OR TASK	RELATION
WP1	Task 1.2 is part of this Workpackage. The most direct relations are with Task 1.1 as the iEDGE toolkit provides a set of (most relevant) case specific eco-design principles through its prioritised improvement options results. This is a crucial building block for the design strategy's foundation going forward. The results of Task 1.2 will be also integrated in Task 1.1's Specification Reports (D1.1), to apply the eco-design principles into the refining of the requirements and the specifications that the demonstrator has to fulfil. It should carry through into the Validation Methods Reports (D1.2) where tests will determine if defined specifications are (sufficiently) met and the ensuing tasks in this Workpackage
WP5	This Workpackage addresses end-of-life stage, in particular the development of appropriate methodologies for disassembly, reuse, and recovery of parts from the end-of-life multi-material structures. Eco-design and circular economy consider all lifecycle stages of a product, which inherently includes the end-of-life stage. The assessment performed with the iEDGE toolkit includes the considerations of impacts and potential improvement options for this category. The level of impact or the extent of improvement may differ per product, either because of a product's characteristics or because of a decision to prioritise other considerations.
WP6	This Workpackage will focus on the valuation of environmental (LCA) and technoeconomic impacts (LCC). This includes the quantification and comparisons of the environmental impacts of the proposed LEVIS vehicle modules against their benchmark alternatives, as well as the cost impact of material choices, production, manufacturing, and end-of-life processes. Additionally, the potential for replication, further improvements and overall effect is assessed. Logically, the use and output of the iEDGE toolkit lie at the foundation of the design's improvement effect. The performance assessments in this Workpackage will identify this effect.

Although the effects of eco-design and circular principles are also expected to resonate within

- WP2 (Materials design and development),
- WP3 (Manufacturing and assembly technologies) and
- WP4 (Structural integrity, long service-life reliability, and structural health monitoring),

the key aspects of Task 1.2. will be integrally embedded into the 'Specification Report' coming out of WP1. This includes the integrated design strategy, with the case-specific eco-design principles, and are expected to be adopted into the tasks performed under these Workpackages.

It should be noted that the lead and contributing partners of each of the above mentioned Workpackages are therefore expected to follow these design requirements or are able to substantiate or support the reasons for any deviations that occurred in the later stages of the design process.

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2. APPROACH TO ECO-DESIGN FRAMEWORK

2.1. OUR APPROACH

Before the iEDGE toolkit was created and the case specific eco-design methodology was formulated, preliminary research was conducted to identify necessary eco-design categories and suitability for LEVIS and to create a shortlist of existing eco-design methodologies and tools.

A literature study provided the shortlist of the eco-design methodologies and tools. These methodologies and tools were then filtered based on:

- Level of information provided.
- Availability of use-guidelines/manuals.
- Initial indication of level of quality / source(s) and usefulness for LEVIS setting.
- Addresses all life cycle categories for product design.

The filtered methods and tools were then analysed based on certain criteria to see potential strengths and weaknesses. Based on these strengths and weaknesses, a methodology is proposed. There were four methodologies that were analysed:

- Methodology for Ecodesign of Energy-related Products (MEErP) ((EU directive 2009/125/EG)
- Design for Sustainability (Brezet, H. & van Hemel, C. 1997)
- Design for Environment (Sanyé-Mangual et al. 2013)
- EcoDesign Pilot (Wimmer et al. 2004)

2.2. A COMBINED METHODOLOGY: IEDGE TOOLKIT

In order to produce an eco-design methodology that is suitable for the LEVIS demonstrators, multiple tool components are used from the previous mentioned methodologies. These tools have been adapted to be able to combine them together to create a logical workflow. The tools that have been used are the following:

- The checklist questions from Design for Sustainability.
- The EQFD form the EcoDesign Pilot.
- The performance evaluation and strategy wheel from Design for Sustainability.
- The improvements inventory and feasibility study Design for Environment.

This combination of tools should help the user to identify the eco-design principles (improvement options/ideas) that are specific and most to their case and company strategy (or objectives). The Requirements identification Tool (RiT) Checklist Questions guides the user in their initial brainstorm session to identify the impact landscape of the benchmark product, which helps them to set requirements and KPIs, do a (benchmark) performance evaluation, and assess possible improvement options. This information forms the basis of rest of the tool. The EQFD is a great tool to assess the importance of the KPIs that have been set, while the performance evaluation and strategy wheel helps to steer the designer into the prioritised design direction. The improvements inventory and the feasibility check tool are used to analyse and filter out possible improvement options for the new design.

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2.3. ECO-DESIGN FRAMEWORK

The iEDGE (Integrated Eco-Design Guideline and Evaluator) toolkit, which is used in eco-design methodology, consists of the 5 steps shown in Figure 1.

The **first step** is framing the context of the eco-design assessment. During this step, objectives which play a key role in a company's strategy are identified. These can range from objectives related to a company's mission (its 'raison d'être') or relate to more practical matters such as legislation or certifications that need to be met. Additionally, a benchmark product is selected. This step provides the outline within which the product's design is taking place.

The **second step** is to identify the scope and requirements. During this step, the RiT Checklist is used as a brainstorm tool to explore the impact landscape of the benchmark product. This can be used afterwards to identify requirements and KPIs. The EQFD (Eco-design Quality Function Deployment) tool is then used with the requirements and KPIs to rank the performance and analyse the relationship between them. This step results in an overview of the current areas of highest impact of the benchmark product and an importance ranking of the KPIs.

The **third step** is to create a baseline and set a target. The EQFD performance evaluation tool is used to evaluate the benchmark product and perform a qualitative assessment. After this, the projects ambitions can be set by evaluating the target scores. This results in an indication of design (life cycle) categories to focus improvements on.

The **fourth step** is to create in inventory of improvement options by exploring possible ideas, which are then assessed on their feasibility. The possible improvement options are explored within the selected focus design categories listed in the Strategy Dashboard based on earlier steps. The options are analysed to assess the possible effect on each life cycle category. The feasibility assessment is then performed, and design priorities are chosen. This results in a shortlist of feasible improvement options for the new design.

The **fifth, and last step** is to evaluate the expected performance score of the improved design in the EQFD and compare improvement levels against the targets and the baseline. This results in a visual overview of the performances and provides a justification of the case-specific (product) eco-design principles. These form the foundation for your detailed design.

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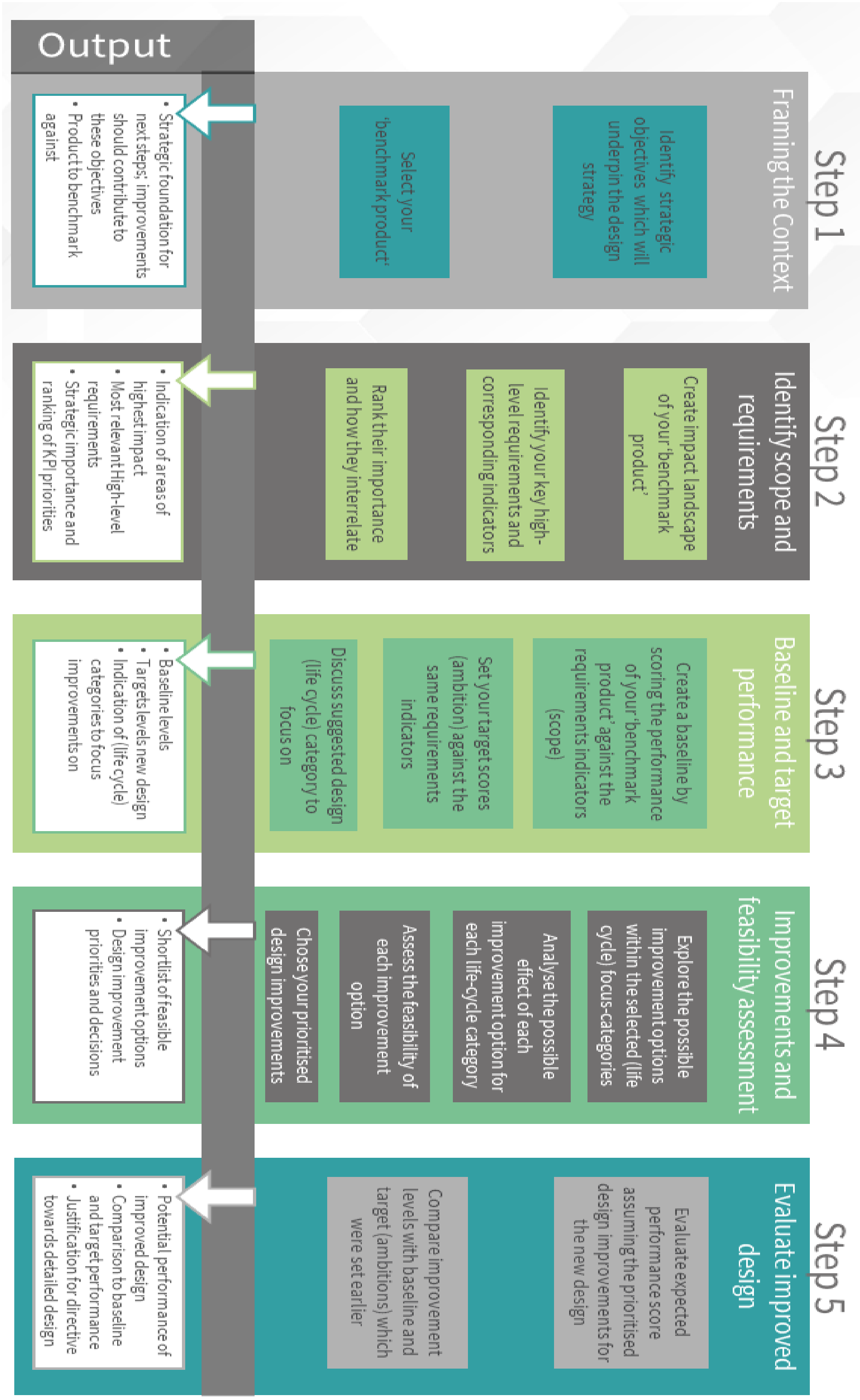

Figure 1: LEVIS 'iEDGE' Roadmap (main steps)

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3. INTEGRATED ECO-DESIGN GUIDELINE AND EVALUATOR

3.1. STEP 1. FRAMING THE CONTEXT

3.1.1. STRATEGIC OBJECTIVES

The first step of the IEDGE (integrated Eco-Design Guideline and Evaluator) toolkit is to set the context in which the design team will operate. This is using the home page (Figure 2) and the “Framing the Context” (Figure 3) sheet. This will be a very broad assessment and it is not needed to go into specific or quantified objectives. It is very important to keep in mind that the objectives can relate to environmental, economic, technical, and social aspects. There are three frames in which the team will operate:

- The (internal) organisation objectives. These are the current ambitions of the whole organisation, which are often linked to its missions and visions. For example, ‘Achieve climate-neutral operations by [ABC]’ or ‘Deliver first class quality products to our customers’.
- The societal trends and objectives. These are the trends that are currently ongoing in society that the company wishes to meet or consider. For example, ‘Use renewable energy’ or ‘increase local employment’.
- Compliance objectives. These are the important legislations, standards, or certifications that the product (and therefore any improvement) needs to comply with. Think of elements such as certain industry safety standards or environmental certifications such as ISO14000 that you either need or wish to uphold.

The toolkit provides three spaces per ‘frame’ (see Figure 3), more can be added, but it is advised to keep the number of objectives small and broad. Additionally, there is space on the right columns for comments, in which it is possible to share links or small descriptions of the objectives. These objectives set the context for the whole project and the design team can revisit this tab from time to time to help steer the design process in the direction which is in accordance with the objectives.

LEDGER	
Company name	Demo4Wheels
Project Title	P215/65R15 Wheel rim passenger vehicle design with eco-design principles
Project Leader	A. Demo
Product ID	TESTCASE1
Start Date	07/07/2021
Sign-off Date	
Sign-off signature	

Figure 2: Use case, eco-design project (home page)

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Listing of overarching key ambitions, goals and obligations underpinning the design decisions

	Organisational objectives (Internal)	Comments
A	Deliver high quality products to our customers	Link company website, mission statement
B	Achieve net-zero emission production in 2040	Link company website, objectives
C	Be a job provider for local community	Have good relations with our surroundings
	Trends and societal objectives	Comments
D	Transition to renewable energy	In line with Paris Agreement
E	Change to circular economy	Less waste and material security
F	<insert here>	
	Compliance objectives	Comments
G	Compliance ISO 90001, 14001	Wish to maintain certification
H	Compliance EU Regulation No 124	Legal requirement
I	<insert here>	

Figure 3: Use case, framing the context - objectives

3.1.2. BENCHMARK PRODUCT (OR COMPONENT)

The last step of framing the context is to choose an existing product for your benchmark. This benchmark product will be important for the whole design process, since this will be used to determine requirements, KPIs, what your comparative baseline is and how improvement options compare to this. A benchmark product can be either an older or existing model/version within your own company or a comparative product (or a product with a similar base-function) available in the market.

Based on the objectives that have been set in the “Framing the context” tool, market research can be done to identify a comparative product in the current market. It is important to use the objectives that have been previously set when choosing a benchmark product to compare your own new design to. Try to pick products and/or companies that share similar base-function(s), target audiences and values as your own. This will help set a higher quality baseline which will benefit the quality of the eco-design process. It will help you to better understand the details of its impact and as such the improvement ideas. Figure 4 shows the documentation process in the iEDGE toolkit.

Description and specifications of the benchmark product

Benchmark product	
Product name	Wheel4Bench
Model	X1
Manufacturer	Bench2Wheel
Serial no./product ID	W4BXX001
General description	Aluminium rim for high end passenger electric vehicles.
Justification (why this product as benchmark)	Bench2Wheel shares the same organisational and societal objectives as Demo4Wheels. The benchmark product (W4BXX001) has the same target audience as the TESTCASE1.
Picture(s)	

Figure 4: Use case, benchmark product description

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3.2. STEP 2. REQUIREMENTS IDENTIFICATION AND SCOPE

3.2.1. FOCUS AREA CATEGORIES EXPLAINED

The iEDGE toolkit helps the designer to integrate the four different aspects of the product into the design process. At the heart of eco-design and circular economy lies the objective to include what is conventionally considered to as ‘externalities’ into the producer responsibilities approach. This way, a socially responsible, sustainable, and feasible product can be made.

The four focus area categories are:

Environmental
The environmental area focusses on the emissions and waste that occur during the life cycle of the product that can harm the environment or human health. Sometimes this can be confused as an impact to the social focus area. However, as will be explained further, there is a difference. As a rule of thumb can be used, if the emissions or waste can be quantified in terms that it can be used for Life Cycle Assessment, then it is categorised as “Environmental”.

Economic
The economic area focusses on all the monetary costs during the life cycle of the product that influence the purchase costs of the whole product, or the waste handling costs. Societal costs (by for example, damage to forestation) do not fall under this category but are reflected under environmental.

Technical
The technical area focusses on all the mechanical and functional properties of the product. This includes for example the thermal capacities of the materials, the strength, but also features that are influenced by these properties, like the safety usage of the product, which can be assigned to the tensile strength, flexibility and/or other mechanical properties.

Social
The social area indicates the impact the product or the business operations of the product has on the supply chain’s workforce and local communities. This focus area aims to ensure that the product is produced and used in an ethically sound way, by for example, improving the working conditions or reducing poverty in the area of production.

3.2.2. DESIGN (LIFE CYCLE) STRATEGIES EXPLAINED

The iEDGE toolkit is largely based around the design (life cycle) strategies. All strategies (except strategy 6) are based on the different life cycle categories of the product. By dividing the products life cycle in these five categories, it is easier for the design team to pinpoint the strong and weak points of the benchmark product. The design team is then able to concentrate on these aspects and focus their effort here regarding the most effective improvements options for the new design, hence the name “design strategies” but they are sometimes also referred to as categories in this report. The sixth strategy allows for the possibility of focussing on ‘added value’ on top of the product’s base function(s). The design (life cycle) strategies are explained below and examples of improvement options per strategy are provided.

Material selection

This strategy focusses on the type of materials and surface treatments that have been chosen by the design team. Examples are:

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a. Choice of recycled materials
b. Choice of recyclable materials
c. Low-energy content materials

Mining and Production

The second strategy focusses more on the production techniques used for the product itself, including the mining process of the materials that are needed. Production techniques are of course often correlated to the materials that are used and the substances or resources needed during production.

The production process affects the costs, technical specs, working conditions and the environment through loss of raw material and waste. It should be applied not only to the production processes of the parent company, but also of its suppliers. For example, the company could insist that their suppliers have certain certifications.

Transport and Distribution

This strategy ensures that the product is transported from the factory to the retailer and users in the most efficient manner. This also includes the transport from mine to production facility as well as transportation between different facilities (e.g., production and assembly sites). This strategy relates to the packaging used and the mode of transport for supply chain logistics.

Examples of optimised transport and distribution systems are:

a. Less/cleaner/reusable/biodegradable/compostable packaging
b. Energy-efficient and low (or zero) carbon transport modes
c. Local suppliers and customers

Utilisation (First and Extended use)

This strategy includes attention to the fact that some products need consumables to operate (energy, water, filters, etc.). It should also cover aspects such as the need or ability for maintenance, repair, upgrades, and refurbishment etc. The strategy in this life cycle design category is to design the product in such a way that the product minimises waste materials and emissions during use or to increase the ease and access for maintenance or repair, without shortening the lifetime of the product itself, ideally even extending it. It can also be designed in such a way that is easier to dismantle and replace worn or outdated parts in order to create a “refurbished” or “upgraded” product.

Examples of optimised utilisation are:

a. Fewer consumables needed for use
b. Modular design
c. Waste reduction during use
d. Lower energy consumption
e. Higher reliability
f. Easier maintenance and repair
g. Long-term availability of parts

End-of-life (Recovery and disposal)

This design strategy focusses on the product after its initial lifetime. It aims at ensuring proper waste management and reusing valuable product components and materials.

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Examples of optimizing end-of-life systems:

- **a.** Recovery of reusable parts which can be used for repairs for still functioning products
- **b.** Recovery of the materials which can serve as materials for new products for downcycling, recycling or upcycling)
- **c.** Recovery of materials which can biodegrade
- **d.** Safe incineration for the purpose of recovery in form of energy (from circular economy perspective this is the least favourable option)
- **e.** Safe storage in landfill (from circular economy perspective this should not occur)

Added functional value

The last design strategy focusses more on the function of the product system and the way it fulfils a need rather than the physical product. The questions in the RiT Checklist related to this strategy focus therefore more on the functional level of the product.

The decision to focus on this design category, is usually made prior to the product development process. This decision could potentially change the business itself rather than the product. Examples of adding the functional value could be:

- **a.** Shared use of the product.
- **b.** Integration or consolidation of functions.
- **c.** Functional optimization of the product.
- **d.** Dematerialization by replacing material products with immaterial substitutes. (e.g., using sensors for digital twins to minimise late repairs and need for replacements of materials/components).

3.2.3. EXPLORING IMPACT LANDSCAPE OF A PRODUCT (TOOL – RIT CHECKLIST)

The RiT Checklist (Figure 5 and Figure 6) is a tool that helps to create an inventory of potential impact, benefits, and bottlenecks of the benchmark product. It is designed to map out the landscape of impacts triggered by (potentially) relevant questions for the life cycle categories. This inventory will serve as the foundation for designers. The output in response to the questions from the checklist can be used by the design team in several categories of the eco-design methodology and it is therefore advised to put considerable thought in this stage of the eco-design process. It is also recommended to keep in mind the objectives listed under 'framing the context'. It can be used to establish a set of requirements and KPIs, which are aimed at avoiding unwanted impacts while stimulating desirable benefits. These requirements and KPIs form the bases for the next steps (i.e., the performance evaluation of the benchmark product, setting targets and assessing improvement options).

The RiT Checklist is, at its core, both a guided brainstorm with the design team and a means to document this brainstorm. It may be advantageous to invite colleagues from outside the design team (i.e., a sustainability manager, finance officer, legal expert) to bring in multiple (organisational) perspectives.

The questions in the left column (see Figure 5) are designed to guide the team in life cycle thinking on an environmental, economic, technical, and social level. Some questions (e.g., "Where is the biggest cost impact associated to used materials (why)?") may only be relevant for the economic focus area category. Other questions (e.g., "What would dematerialization mean?") can be answered on multiple focus area categories. It is of course not compulsory to address every question in the checklist but be

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sure not to dismiss a question too quickly. It is also entirely possible that during the process of the brainstorm, new questions pop up. If this occurs, a new row can be inserted within the most applicable life cycle category to document the additional question (and its corresponding output).

The strategy for answering the questions is to keep it concise and to keep in mind the goal of the assessment (analysing the potential impact, benefits, and bottlenecks of the benchmark product and to use that to set the requirements). It is advised to give a two-part answer, the "what" and the "why". So "what" is the impact of the product in this area, and "why" is this important, problematic, or normal. Important to keep in mind is that the RiT Checklist does not directly ask the designer for a quantitative answer (e.g., "The production costs of this product is 200 euros") but rather steers in a way of thinking that helps you to explore the impact landscape of the product. The intent of the question is to consider if the impact is relatively high or not as a means to how relevant the impact is. It is advised to limit yourself to accessible expert knowledge when performing this assessment.

	Environmental	Economic
1. Material selection		
What types of materials are used, and what impacts may be related to them:	Aluminium	Alumnium, relatively cheap
Where is the biggest cost impact associated to used materials (why)?		Aluminium, Only materials used.
Consider the (relative) energy intensity of mining the(se) material(s)		
What is the likelihood that the mining of these material(s) generally require (potentially) dangerous procedures?		
Are there potential indications of ethical supply chain risks?		
Where is the material coming from? (consider transport of the material)	Bauxit mine Australia, Transport by ship	Bauxit mine Australia, high tranport costs
Does the material require specific type of transportation (procedure)?		
Relative distances to transport		
What are considerations of critical properties of the materials?		
Known for certain necessary properties		
Any specific (such as surface) treatment needs		
What are the current (other) considerations for the material choices?		Low costs
What would potential dematerialization mean?	Re-use/recycle old rims	Less material potentially lowers purchase costs?
How well does the material lend itself to reduce without losing properties?		
Does the product use virgin (raw) materials or recovered (raw) materials?	Exclusively virgin materials, no recycling facility at place.	

Figure 5: Use case, RiT Checklist environmental and economic

Technical	Social
Aluminium, maintains strength and durability	
	Bauxit mine Australia, relatively good working conditions
Solid state, every transportation option is possible.	
Paint, to decrease corrosion and look esthetically pleasing	
Lightweight, strong and durable	
Structural optimization for efficienty purposes	

Figure 6: Use case, RiT checklist technical and social

3.2.4. (HIGH-LEVEL) REQUIREMENTS AND KPIS (TOOL – RIT CHECKLIST)

The preceding brainstorm and resulting inventory should provide a clear understanding of the impact landscape to be able to discuss and identify (find consensus on) which requirements are needed or most relevant for the new product. These requirements are specified below the Checklist questions (example in Figure 7 and Figure 8). They are broad indications on what the expectations are of the new product for different types of stakeholders. These stakeholders all deal with the product in different categories of the life cycle, and for one or more focus areas (environmental, economic, technical, or social). These requirements are not meant to be formulated in a detailed or quantified manner. For example, instead of stating "20% reduction on CO_2 emissions" a more general approach would be "Produce less CO_2 emissions".

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The requirements can be filled in per life cycle category and per focus area category. It is not required to fill in every blank cell in the form. It is advised to provide no more than four requirements per life cycle category. However, if more than four are needed, extra requirements can be added. Be aware that the EQFD – Boundary Conditions Strategy then also needs to be edited and a row needs to be inserted.

Next, you need to define KPIs that are linked to the requirements. The KPIs do need to be formulated in a way which makes it possible to measure or compare, if not in units / percentages, formulate it as a different measurable value. If you cannot, you most likely need to reconsider the way the requirement was formulated. Keep in mind that just simply providing a unit (e.g., %, euros, kg, etc.) is not sufficient, since this does not describe how the KPIs helps to meet the requirements. The KPI should be formulated in such a way that it is linked and specific to the requirement. However, it is still possible that different requirements can share the same KPI. For example, "Less waste" and "Less use of virgin plastics" can share the KPI "% virgin materials". It is also possible that a requirement may be relevant to more than one design (life cycle) categories but require different KPIs. For example, "Improve recyclability" may need the KPI "% virgin material" in the Material Selection category but "% recovered raw material" in the "End-of-Life" category.

These KPIs will be used in a later stage in the design process to evaluate the benchmark product, setting targets, and the new product design outline. Similar to the requirements, there is a recommended (manageable) number of KPIs to be defined. However, it *is* possible that one requirement warrants more than one relevant KPI in the *same* category. For example, a requirement for 'Generate less waste' could involve both the use of recycled material and the use of bio-based materials, both relevant for the Material Selection category. If you decide to add extra KPIs, then the EQFD – Boundary Conditions Strategy needs to be edited and a column needs to be inserted in the next step.

Provisional Selection for EQFD	High-level Requirement	Indicator
1. Material selection	Use of recycled aluminium	% virgin material
2. Mining and Production	Use less energy during production	Energy consumption (kWh)
	Produce less greenhouse gas emissions during production	GHG emissions (kg CO2 eq.)
3. Transport and Distribution	Less plastic use for packaging	Kg plastic
4. Utilisation (First and Extended use)	Lightweigth product	kg product
5. End-of-life (Recovery and disposal)	Energy use during melting proces	Energy consumption (kWh)
6. Added functional value		

Figure 7: Use case, requirements and KPIs environmental

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High-level Requirement	Indicator	High-level Requirement	Indicator	High-level Requirement	Indicator
Possibility to re-sell-re-buy	Lifetime rim (years)	Long life-time	lifetime rim (years)		
Low material costs	costs in euros				
				Amount of incidents uring production	# incidents
				Good labour right standards in supply chain	percentage of suppliers in the chain certified with 'X'
Less product waste due to scratching	Waste /1000 rims produced				
		Lifetime/durability	Corrosion		
		Strong product	N/m2		
		Heat dispersion optimization	W/(m2K)		

Figure 8: Use case, requirements and KPIs economic, technical and social.

3.2.5. STRATEGIC IMPORTANCE OF BOUNDARY CONDITIONS (TOOL – EQFD)

The requirements and KPIs form the basis of your product's boundary conditions. Once they are specified, you can move to the EQFD (Environmental Quality Function Deployment) - Boundary Conditions Strategy tool. The EQFD – Boundary Conditions Strategy is a means to interlink all the defined KPIs and the requirements. Using this technique, the proportional relevance (weight) of the performance KPIs can be defined (see 3.2.5.1 and 3.2.5.2). The relations or dependencies of an KPI to one or more requirements can be stronger than others and will carry more weight going forward. Keep in mind that the requirements and KPIs need to be manually copied from the RiT Checklist tab into the EQFD. It is also possible that while manually inserting the requirements and KPIs, some adjustments can be made.

N.B. It is possible to consolidate (or bundle) recurring requirements or KPIs or to leave out those who are deemed marginal. However, make sure this is a conscious and well-considered decision because consolidating requirements or KPIs has a direct impact in the way the focus suggestions are calculated for the topic they relate to. Equally, the decision to not consolidate similar requirements or KPIs will give the topic more weight in the calculation. The decision whether or not to make any adjustments all depends on how important you consider this topic to be.

As can be seen in Figure 10, in the EQFD, the KPIs are placed under "focus area categories" and "subcategories". The focus area categories cannot be changed, but the subcategories are suggestions. The current suggestions are considered common categorisations for performance KPIs for typical products. The design team is able to delete or replace the already pre-existing subcategories or add a new one. Note that the latter needs to be done manually by adding a column and the format for cells in these columns need to be copied from the previous column.

3.2.5.1. IMPORTANCE RATING

The first step is to give a 1 (low) to 5 (high) importance rating to the Requirements. There is an extra column added to give the user the opportunity to provide a short justification description of the chosen importance rating (see Figure 9). A justification could be a reference to a strategic objective from "Framing the Context" or an important realisation from the RiT Checklist brainstorm.

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Design (life-cycle) strategies ↓	Importance rating	Justificication	High-level requirements - (What) ↓
1. Material selection	3	User requirement	Low material costs
	5	High-end product	Long life-time
	4	Social objectives	Use of recycled aluminium
2. Mining and Production	2	Social objectives	Use less energy during production
	5	CSR (corporate social responsibility)	Amount of incidents during production
	4	CSR (corporate social responsibility)	Good labour right standards in supply chain
	5	Organisational objectives	Produce less greenhouse gas emissions during production
3. Transport and Distribution	4	Social objectives	Less plastic use for packaging
	2	Social objectives & cost reduction	Less product waste due to damaged goods
4. Utilisation (First and Extended use)	5	User requirement & social objective	Lightweigth product
	5	User requirement	Strong product
	1	User requirement	Possibility to re-sell or re-buy
	4	User requirement	Durability
5. End-of-life (Recovery and disposal)	4	Social objectives	Energy use during melting proces
6. Added functional value	2	Tyre lifespan for user	Optimization of heat dispersion

Figure 9: Use case, EQFD importance scoring requirements.

3.2.5.2. RELATIONSHIP SCORING

The second step is to score the strength of the relationship between the requirements with the KPIs (Figure 10). The relationship scoring is based on the degree on which the KPI impacts the realization of the requirements. The tool requires the user to use a 4-step scoring structure from 0 to 9, where 0 means no relationship, 1 means weak relationship, 3 means medium relationship and 9 being a high relationship between the KPI and the requirement. If the user accidently puts in a different number, an error pop-up will occur.

3.2.6. OUTPUT: KPI RELEVANCE SCORE

When the importance rating and the relationship scoring is provided, the tool will automatically calculate the Strategic Importance Score (Figure 10), which indicates the importance and the priority ranking of a specific KPI in relation to the other KPIs. The Strategic Importance Scoring will be important for the performance evaluation in the next step because this will be used in the calculation process for the total performance of the benchmark, target, and new design products.

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This example shows the EQFD boundary conditions and how it could be used. In Figure 9, the high-level requirements that were made in step 3.2.4 are copied into the EQFD. Every high-level requirement has been given an importance rating based on their relative importance. Figure 10 provides an example of the relationship scoring of step 3.2.5.2. In this example, there is GHG emissions share multiple relations with requirements, which results in the highest importance score.

Subcategories	Ecological				Mining & production	Use & disposal	
Key Performance indicator (How) → / **High-level requirements - (What) ↓**	% virgin material	Energy consumpion (kWh)	Amount of wrapping material (Kg plastic)	GHG emissions (kg CO2 eq.)	Investment costs (euros)	Wasted products /1000 rims produced	Add optional requirement
Low material costs	0	0	0	0	9	0	
Long life-time	1	3	1	9	1	0	
Use of recycled aluminium	9	1	0	3	3	0	
Use less energy during production	0	9	0	3	1	0	
Amount of incidents during production	0	0	0	0	0	0	
Good labour right standards in supply chain	0	0	0	0	1	0	
Produce less greenhouse gas emissions during production	3	3	1	9	1	1	
Less plastic use for packaging	1	0	9	1	1	9	
Less product waste due to damaged goods	0	1	9	3	1	9	
Lightweigth product	0	3	0	1	1	0	
Strong product	0	0	0	0	3	1	
Possibility to re-sell or re-buy	0	0	0	0	3	0	
Durability	0	0	0	1	0	0	
Energy use during melting proces	1	9	0	3	1	0	
Optimization of heat dispersion	0	1	0	1	1	0	
Strategic importance score	64	107	64	141	90	64	0
Importance %	6%	11%	6%	14%	9%	6%	0%
Priorities rank	**7**	**4**	**7**	**1**	**5**	**7**	**14**

Figure 10: Use case, correlation scoring high-level requirements and performance indicators & strategic importance score.

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3.3. STEP 3. BASELINE AND TARGET PERFORMANCE

3.3.1. BASELINE EVALUATION (TOOL – EQFD)

In the EQFD tab, the "Performance Evaluation" tool can be found (Figure 11). This tool will be used to score the performance of the benchmark product, target, and the new product idea. The scoring is a qualitative assessment (1 to 5, where 1 is a low performance and 5 is a high performance against the KPI). To determine your scores for the benchmark product (which serves as your baseline), you can use the questions and answers from RiT Checklist as it should reflect the product's impact landscape. You can of course also consult colleagues with specific expertise or other sources. As it can be seen in the example provided in Figure 11, when a KPI did not receive any (significant) relationship scores to the list of requirements, and thus has a "zero" strategic importance score, the corresponding cells in the performance evaluation section are automatically coloured in red. These cells do not have to be scored.

The **first step** of the performance evaluation is to assess the **benchmark** product. This assessment will become your baseline. Again, the RiT Checklist questions and the answers that are provided by the design team can be revisited for inspiration on how to score the benchmark product. Keep in mind that it is not needed to score every criterion for every life cycle category. In the example of Figure 11, the hypothetical benchmark product does not use toxic materials. Therefore, it is not possible to give the corresponding 'material selection' strategy a 'low' or 'high' performance score. When this is the case, simply score it a "0". The tool does not take zeros into account when calculating the average, so it will not affect the outcome of the total score of the benchmark product, target and new design.

3.3.2. SETTING YOUR PERFORMANCE TARGET (TOOL – EQFD)

The **second step** of the performance evaluation is to determine the **target** performance. In effect, here you determine your ambition level. To set your targets you can consult the strategic objectives that were listed in the first step of the eco-design methodology or the requirements.

3.3.3. OUTPUT: KPI PERFORMANCE DELTA & STRATEGY DASHBOARD

When the benchmark and target performance have been evaluated, the performances per design (life cycle) category are automatically calculated. This is shown under the performance evaluation as "Output: KPI performance delta" and visualised in the "Strategy Dashboard" sheet. The "Output: KPI performance delta" shows the difference between the benchmark and the target performance multiplied by their Strategic Importance Score. This provides an overview on which KPI scores worst compared to the to the target considering each life cycle category of the product. The higher the score in this table, the larger the performance-gap (e.g., delta) is between the benchmark product and the target.

The sheet "Strategy Dashboard" provides an overview of the total performances of the product per design (life cycle) category (example in Figure 12). This gives a quick insight in which life cycle category the benchmark product lacks the most. Additionally, a spider diagram is provided in the same sheet to give a visual representation of the difference between the target and benchmark performance (Figure 15). Each can also be viewed in a separate spider diagram.

After the performance evaluation of the benchmark and targets are set, the improvements options can be explored. The strategy dashboard is designed to help steer the design team in the direction where the benchmark product falls short and thus in which areas improvements could make the biggest difference towards the target.

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Firstly, the strategy dashboard provides *suggested* design focus categories (Figure 13), in order of importance (which means, difference between benchmark performance and target). It is however possible to decide your own focus design categories, which can be done in the strategy dashboard (Figure 13). It is recommended to select a maximum of the three most important categories to focus on. However, if so desired, additional categories can be added (insert row and copy the drop-down list from the cell above). In the comments' box you can note down your reasons for the deviation from the suggested categories.

Secondly, the dashboard provides 5 suggested focus KPIs (Figure 14). These KPIs are automatically suggested from "Output: KPI performance delta" and based on the chosen design (life cycle) strategy. These KPIs can be used to formulate possible improvements options, since it provides an insight on what aspects to focus on.

The figures below show the examples of the baseline and target performances, and how the scoring of the EQFD -Performance Evaluation (Figure 11) results in the overview that is provided in the Strategy Dashboard (Figure 12). In this example, the mining and production of the benchmark product does not show any wrapping material, which is why they scored 0. This example also shows that, based on the output of the strategy dashboard, a suggested focus for the strategy (Figure 12) and the KPIs (Figure 14) is provided. A visual overview of the scoring of the benchmark product and the target is also provided (Figure 15).

	Key Performance indicator (How) →	% virgin material	Energy consumpion (kWh)	Amount of wrapping material (Kg plastic)	GHG emissions (kg CO2 eq.)	Investment costs (euros)	Wasted products /1000 rims produced	Add optional requirement
Design (life-cycle) strategies ↓	**Product - (Which) ↓**							
1. Material selection	Benchmark performance	1	2	0	2	5	0	
	Target	3	4	0	5	4	0	
	Improved design							
2. Mining and production	Benchmark performance	1	1	0	1	3	5	
	Target	4	4	0	5	3	5	
	Improved design							
3. Transport and Distribution	Benchmark performance	0	3	1	2	4	3	
	Target	0	3	4	3	4	4	
	Improved design							
4. Utilisation (First and Extended use)	Benchmark performance	0	0	0	0	3	0	
	Target	0	0	0	0	4	0	
	Improved design							
5. End-of-life (Recovery and disposal)	Benchmark performance	1	2	0	1	4	0	
	Target	4	5	0	4	4	0	
	Improved design							
6. Added functional value	Benchmark performance	0	0	0	0	0	0	
	Target	0	0	0	0	0	0	
	Improved design							

Figure 11: Use case, performance evaluation

Design (life-cycle) strategies ↓	Performance scoring		
	Baseline design	Target	Improved design
1. Material selection	2,7	4,0	
2. Mining and production	2,7	4,1	
3. Transport and Distribution	2,8	3,6	
4. Utilisation (First and Extended use)	3,1	4,1	
5. End-of-life (Recovery and disposal)	2,3	4,2	
6. Added functional value	3,0	4,0	

Figure 12: Use case, total scoring strategy dashboard

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OUTPUT: Suggested focus	
No. 1	5. End-of-life (Recovery and disposal)
No. 2	2. Mining and production
No. 3	1. Material selection

DECISION: Chosen focus	
No. 1	5. End-of-life (Recovery and disposal)
No. 2	2. Mining and production
No. 3	3. Transport and Distribution
Comments: Material selection in this case not a real possibility since the available options are scares and not feasibile.	

Figure 13: Use case, suggested and chosen design category focus

OUTPUT: Suggested top 5 focus KPIs					
5. End-of-life (Recovery and disposal)		2. Mining and production		3. Transport and Distribution	
No. 1	GHG emissions (kg CO2 eq.)	No. 1	GHG emissions (kg CO2 eq.)	No. 1	Amount of wrapping material (Kg plastic)
No. 2	Energy consumpion (kWh)	No. 2	Energy consumpion (kWh)	No. 2	GHG emissions (kg CO2 eq.)
No. 3	% virgin material	No. 3	% virgin material	No. 3	Wasted products /1000 rims produced
No. 4		No. 4	Percentage of suppliers certified	No. 4	
No. 5		No. 5	# incidents	No. 5	

Figure 14: Use case, suggested top 5 focus KPIs

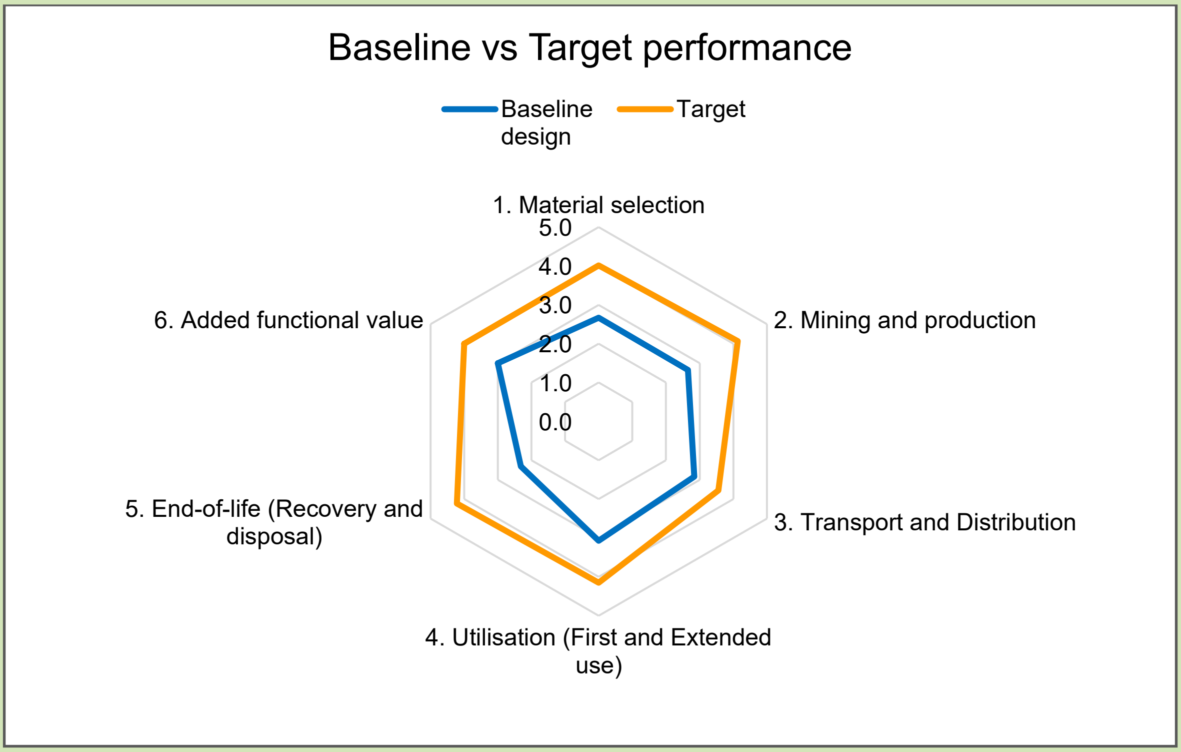

Figure 15: Baseline vs Target performance

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3.4. STEP 4. IMPROVEMENTS AND FEASIBILITY ASSESSMENT

3.4.1. IMPROVEMENTS BRAINSTORM (TOOL – IMPROVEMENTS & FEASIBILITY)

This section is, in effect, also intended as a brainstorm exercise. The idea is to consider any possible improvements and to not discard any off the bat. The collected improvement options can be listed in the "Improvements & Feasibility" sheet. It is advised to filter out the table by going to the left column under "Design (life cycle) categories" (see Figure 16) and select the (three) focus design categories via the drop-down list button.

It is possible that during the process of the Eco-Design methodology, several improvement options have already sprung to mind. To further assist with the brainstorm session, the RiT Checklist questions can be consulted again. The questions and answers there could provide further inspiration for possible improvement options. The top 5 KPIs of the strategy dashboard are also shown here for extra support during this assessment.

In the table (Figure 16) under "Improvements options" the name of the improvement option that is created by the designer can be filled in here. Under "Application description" a short description (what, how, where etc.) can be provided to give a bit more context about what and how or where you intend to apply it.

The right column "Intended KPI effects" is used to document which KPIs the option is supposed to improve. This cell contains a list of the previously assessed KPIs. Multiple KPI can be selected from the dropdown menu by selecting a different KPI in succession. To delete a KPI in the cell, just simply re-select this KPI a second time and it will be removed from the list.

3.4.2. EFFECT ON DESIGN CATEGORIES (TOOL – IMPROVEMENTS & FEASIBILITY)

The next step is to analyse the possible implications this improvement option would have on all the design (life cycle) categories and the four focus area categories (see Figure 17). The purpose of this step is to consider the possible implications could have beyond its intended KPI effect. For example, the user may come up with an idea that decrease the emissions of the product, but as a side effect greatly increases the investment costs during production.

For every combination (design category and focus area category), it is possible to choose between either 'positive', 'neutral', 'negative' or 'unknown'. The explanation of these effect category indicators is shown in Table 3. The table also provides some extra space to document the reasoning behind the scoring of the effects.

Table 3: Explanation effect category indicators

Effect category indicator	Meaning
Positive	The effect of the option is expected to perform better compared to the baseline.
Negative	The effect of the option is expected to perform worse compared to the baseline.
Neutral	Option has either insignificant or no effect at all.
Unknown	Effect not possible to predict.

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3.4.3. FEASIBILITY ASSESSMENT (TOOL – IMPROVEMENTS & FEASIBILITY)

The third step is to check to actual feasibility and desirability of the improvement options in order to come to a priority list for the improvement options. Figure 18 provides an example of the feasibility assessment. Both the columns under feasibility and desirability are drop down menus.

The options under the feasibility assessment are:

- Feasible short-term,
- Feasible long-term (used when for example the technology progress or prices are not yet at a stage where it can be used for the new design, but it is likely to change in the future),
- Unfeasible
- N/A (not applicable or not available).

The 'Impact risk level' is automatically chosen based on the analysis that has been performed in the previous step. When a new idea has many negative effects, this option will be set to 'High Risk'. If there a lot of expected positive effects, it will be set to 'Low Risk', with approximate equal negative, positive or many neutral effects, the Risk is set to Neutral. The tool automatically sets an improvement option to low priority when it is labelled either high risk, unfeasible or long-term feasible. Otherwise, it will be set to high priority. Keep in mind that the tool does not take into account any weighing of the focus areas and life cycle categories. It could be entirely possible that improvement options have a negative effect in most focus areas and life cycle strategies but is still selected for the new design due to the positive effect it has on areas that are deemed more important to the designer.

Finally, the design team has the option to choose whether the actual improvement should be included in set of eco-design principles for the new design. Since it is possible that multiple options are feasible and desirable, but not all improvement options are fit to be addressed simultaneously. This last action makes sure that only the chosen improvements options will be assessed and designed for the next step, the performance evaluation of the (future) new design. There is room for justification notes on the left column.

3.4.4. OUTPUT: (ECO-)DESIGN IMPROVEMENT PRIORITIES

The final output of this exercise is a complete inventory of all improvement options. This overview has multiple functions.

- First of all, the improvement options for the new design are listed with a summary indication of the effects on the focus area categories. This can be used in the evaluation of the new design.
- Secondly, by using this tool, the reasoning behind certain design choices is documented and can be revisited later in the design process.
- Lastly, by having this overview, the design team can always save these ideas for later use. For example, the improvement ideas that where feasible in the longer term may not be selected now but could be in future product design processes.

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These figures show examples of the inventory of improvements, effects analysis and feasibility assessment for the mining and production category. Figure 16 shows an example of improvement ideas for the material design category that has been chosen as focus in step 3.3.3. Figure 17 then shows an example on how the effects analysis could look like. The table is designed in such a way that at first glance it is already noticeable which improvement option has more positive effects than others. As can be seen in Figure 17, improvement option 2.0 has more negative effects then the other improvement option. In this example (Figure 18), all options are of high priority. However (as the justification notes suggests), in this case it is only feasible to choose one improvement option at the same time for the new design. Therefore option 2.0 is not chosen as part of the new design.

Design (life-cycle) strategies	Top 5 KPIs	No.	Improvement option	Application Description	Intended KPI effect
2. Mining and production	GHG emissions (kg CO2 eq.) Energy consumpion (kWh) % virgin material Percentage of suppliers certified with 'X' # incidents	2.0	Use recycled aluminium	Instead of using only virgin material, mix it with a "X" percentage of recycled material when folding and casting the aluminium	% virgin material, GHG emissions (kg CO2 eq.)
		2.1	Change brand surface treatment	Use a brand of surface treatment that ensures certifications of good labour rights across the supply chain.	Percentage of suppliers certified with 'X'
		2.2			

Figure 16: Use case, inventory improvement options

Effect on design (life-cycle) categories					
Design categories	Environmental	Economic	Technical	Social	Reasoning
1. Material selection	Positive	Negative	Negative	Positive	Positive environmentlale effect cause less virgin material is needed. However, decreases over time the purity of the aluminium rims which decreases the technical spects. Also costs increases.
2. Mining and production	Positive	Negative	Negative	Positive	
3. Transport and Distribution	Neutral	Neutral	Neutral	Neutral	
4. Utilisation (First and Extended use)	Neutral	Neutral	Neutral	Neutral	
5. End-of-life (Recovery and disposal)	Neutral	Neutral	Neutral	Neutral	
6. Added functional value	Unknown	Unknown	Unknown	Unknown	
1. Material selection	Positive	Negative	Positive	Positive	A new brand is more expensive, but it does provide certainty on that the requirement for good labour conditions are met. Brand also protects the rim better against corrosion.
2. Mining and production	Neutral	Neutral	Positive	Positive	
3. Transport and Distribution	Neutral	Neutral	Neutral	Neutral	
4. Utilisation (First and Extended use)	Positive	Neutral	Neutral	Neutral	
5. End-of-life (Recovery and disposal)	Neutral	Neutral	Neutral	Neutral	
6. Added functional value	Unknown	Unknown	Unknown	Unknown	

Figure 17: Use case, analysed effect of improvement options

Design priorities: Selecting your case-specific eco-design principles				
Feasibility	Impact risk level	Priotity	New design choice	Justification notes
Feasible-short term	Neutral	High Priority	No	Desirable and feasible, but not enough investment money available when combined with other design improvement options.
Feasible-short term	Low risk	High Priority	Yes	

Figure 18: Use case, feasibility assessment and design priorities improvement options

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3.5. STEP 5. EVALUATE PERFORMANCE OF IMPROVED DESIGN

This is the final step of the IEDGE toolkit. At this stage, the design team should already have (a) high priority list (i.e., a shortlist) of improvement options to focus on for the new design. The next step is to evaluate the improvement options that have been chosen for the new design. This step aims at assessing how the new design is expected to perform in comparison to the benchmark and the target.

3.5.1. NEW DESIGN EVALUATION (TOOL – EQFD PERFORMANCE EVALUATION)

For the performance evaluation of the new design, the EQFD – Performance evaluation is again used. In this tool, the previous performance evaluations of the benchmark and target are still shown. The new design can now be directly evaluated per KPI in comparison to the target and benchmark performance. The effects analysis performed in step 3.4.2 (the 'Effect on design (life cycle) categories' section) should provide a reasonable understanding of the expected performance of the new design.

3.5.2. OUTPUT: STRATEGY DASHBOARD – PERFORMANCE SCORES OVERVIEW

After the performance evaluation of the new design, the total score is automatically calculated and shown next to the performance of the baseline design and target in the Strategy Dashboard, which is again presented as a radar chart to give a visual overview of the final scoring. Additionally, the Strategy dashboard shows a list of the improvement options that have been chosen for the new design. These improvement options are now called **"Set of Eco-design principles (new design)"**.

If indeed this final scoring is deemed satisfactory, the set of improvement options, with corresponding requirements and KPIs, that have been assessed will act as your core (eco-design) principles for when proceeding to the actual product design in detail.

Should the final scoring not be satisfactory, either not sufficiently meeting the target you had set or perhaps even scoring worse than the benchmark product, in one or more design categories, you have two possible routes:

1. You can choose to accept this outcome, perhaps because the scores in other design categories sufficiently compensate the lack of improvement in other ones.
2. You can revisit the improvements and feasibility assessment tool to reassess the possible improvement options within the corresponding design categories.

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The use case shows how the scoring for the new design is performed in the EQFD (Figure 19), how this is represented in the strategy dashboard (Figure 20 and Figure 22) and how this provides the final outcome, the eco-design principles in Figure 21. The radar chart (Figure 22) gives a visual representation of the expected performance of the new design compared to the target and benchmark. In this example it can be clearly seen that the new design is an improvement over the benchmark product. The new design exceeds the targets during the "Transport and Distribution" stage but shows still room for improvement in others.

Design (life-cycle) strategies ↓	Key Performance indicator (How) → / Product - (Which) ↓	% virgin material	Energy consumpion (kWh)	Amount of wrapping material (Kg plastic)	GHG emissions (kg CO2 eq.)	Investment costs (euros)	Wasted products /1000 rims produced	Add optional requirement
1. Material selection	Benchmark performance	1	2	0	2	5	0	
	Target	3	4	0	5	4	0	
	Improved design	1	2	0	3	3	0	
2. Mining and production	Benchmark performance	1	1	0	1	3	5	
	Target	4	4	0	5	3	5	
	Improved design	1	1	0	1	3	5	
3. Transport and Distribution	Benchmark performance	0	3	1	2	4	3	
	Target	0	3	4	3	4	4	
	Improved design	0	4	4	4	2	5	
4. Utilisation (First and Extended use)	Benchmark performance	0	0	0	0	3	0	
	Target	0	0	0	0	4	0	
	Improved design	0	0	0	0	3	0	
5. End-of-life (Recovery and disposal)	Benchmark performance	1	2	0	1	4	0	
	Target	4	5	0	4	4	0	
	Improved design	1	2	0	1	4	0	
6. Added functional value	Benchmark performance	0	0	0	0	0	0	
	Target	0	0	0	0	0	0	
	Improved design	0	0	0	0	0	0	

Figure 19: Use case, performance evaluation baseline, target and new design

Design (life-cycle) strategies ↓	Performance scoring		
	Baseline design	Target	Improved design
1. Material selection	2,7	4,0	3,1
2. Mining and production	2,7	4,1	2,9
3. Transport and Distribution	2,8	3,6	3,9
4. Utilisation (First and Extended use)	3,1	4,1	3,8
5. End-of-life (Recovery and disposal)	2,3	4,2	2,4
6. Added functional value	3,0	4,0	3,0

Figure 20: Use case, Strategy Dashboard

Product specific (eco-)design principles			
Id.	**Life cycle strategy**	**Improvement option**	**Requirements related KPIs**
2.1	**2. Mining and production**	Change brand surface treatment	Percentage of suppliers certified with 'X'
3.0	**3. Transport and Distribution**	Use strong wooden boxes with foam on the inside walls for packaging	Amount of wrapping material (Kg plastic), Wasted products /1000 rims produced

Figure 21: Use case, output product specific (eco)-design principles

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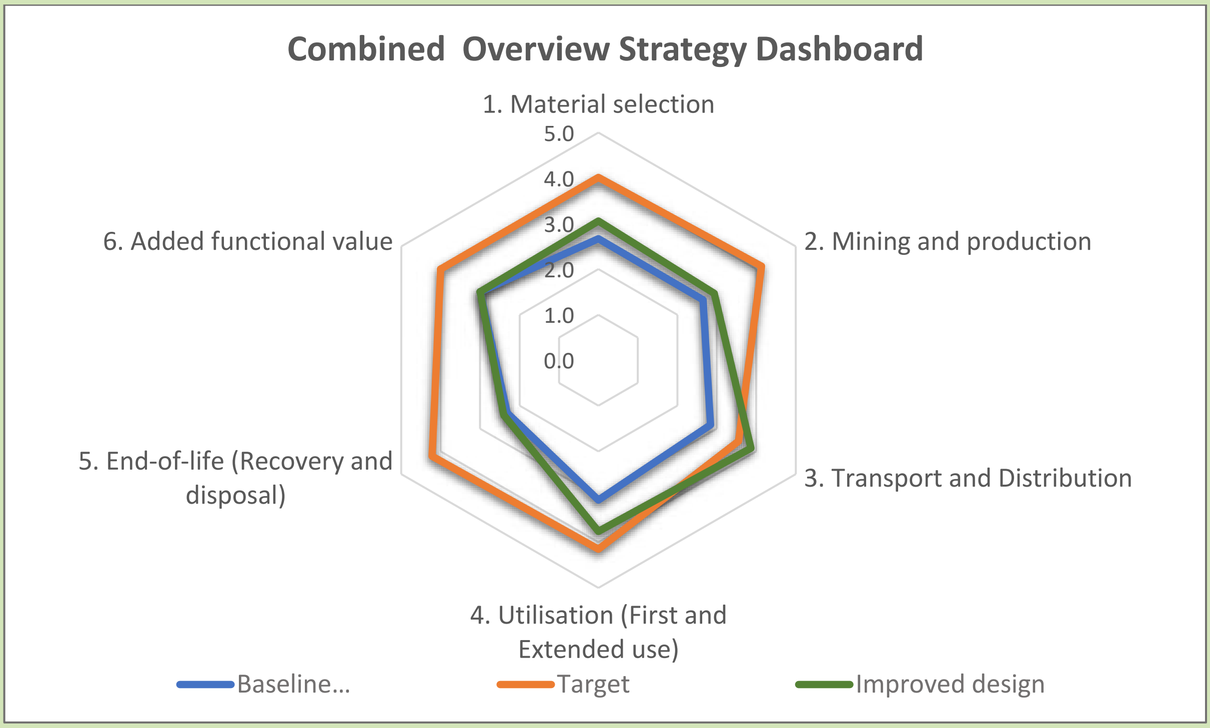

Figure 22: Use case, overview Strategy Dashboard in radar chart

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3.6. LIFE CYCLE ANALYSIS

As indicated in section 1.3, this project task (1.2) has strong links to WP6, in particular the Life Cycle Analysis (LCA). Whereas the eco-design toolkit (and this corresponding guideline) is primarily focusing on the early stages of the design process to help steer towards the most effective and strategically relevant design-decisions, the LCA's purpose is to perform a comprehensive and in-depth environmental impact assessment of a product. This requires having detailed knowledge of its final design.

While it is of significant valuable to understand which impact areas to (best) focus on in an early stage of the design process, there are no such exact details available yet of an (improved) design. Herein lies the key different between this iEDGE toolkit and an LCA. The iEDGE toolkit is a qualitative assessment which aims to support design decisions at the start of the process and facilitates aligned with a company's overarching strategic objectives, whereas the LCA is a detailed quantitative analysis.

One can approach a Life Cycle Analysis in (mainly) two different ways:

- First option is to perform an LCA only on the product (as it is) for the purpose of understanding and quantifying the exact environmental impact of this particular product (design).
- Second option is for the purpose of making a comparison between two products, which share functionalities, to understand which has a better environmental performance for whichever reason this may be desirable to know.

One important reason for wanting to make a comparison is to validate whether a new design indeed performs better than an older design (which is then used as a 'benchmark'). For the LEVIS project we will need to quantify and compare the environmental impacts of the proposed LEVIS vehicle modules against their benchmark alternatives in WP6 and therefore requires the second approach.

For the LEVIS project, the LCA (and Life Cycle Costing) is scheduled after task 1.2 is completed. The iEDGE toolkit is therefore designed to be useable independent of an LCA. However, it is possible to seek more integration with LCA (and possibly LCC), which we have elaborated on in Section 5 (Conclusions and Recommendations). Revisiting the assessment once the detailed design is complete and an LCA has been performed. Not only can you verify whether the new design indeed has a better environmental performance, you can also use the LCA outcomes to retrace your steps and learning from past mistakes, future (eco-)design processes could be improved. Depending on the level of detail you documented in the RiT Checklist and various comments sections, this can be a very helpful exercise to retrace why decisions were correct, or less so.

N.B. Keep in mind that if an LCA indicates the impact related to a design decision(s) turns out to be different from what you had anticipated, this does not necessarily mean the decision was entirely wrong. Other aspects, from an economic, technical, or social perspective, may be part of the reason why a trade-off was preferred. Another reason could be that a possible improvement to mitigate this impact was simply not yet feasible at this stage, etc. If, however, the outcome of the LCA is deemed 'unacceptable' moving forward, revisiting the iEDGE toolkit can be an equally helpful exercise to understand how you can improve the decision-making in the early stages of design.

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4. DEMONSTRATOR RESULTS AND EVALUATION

In this chapter the results for the LEVIS demonstrators, from using the iEDGE toolkit and guideline, will be discussed and analysed. The evaluation covers three aspects:

- The actual results of the toolkit as final (project task) output for the demonstrators, including the case specific eco-design principles (i.e., the baseline, target and (forecasted) new design improvements performances),
- The input from the demonstrator partners in the individual steps of the iEDGE toolkit; how do these relate or compare to each other and whether anything in particular stands out from this (i.e., Key Messages),
- The experience from the demonstrator partners about the use of the toolkit and its accompanying guideline (including the support from Cenex NL).

Each demonstrator will first be analysed separately in sections 4.1 to 4.4, and is followed by an overarching evaluation of the process as a whole in section 4.5.

N.B. It is important to keep in mind that the demonstrators used an older version of the toolkit than the one is presented in the Guideline and its Use Case. Based on intermediate and final feedback from some of the partners several bugs and improvements have already been addressed in the newest version, which has also been integrated into the Guideline section of this report.

The improvements that have been made to the new toolkit, and are thus not reflected in the results based on the version the partners used, are the following:

- Additional space for documentation in the “Framing the Context” and “Improvements and Feasibility” sheet.
- Additional space for documentation on the Benchmark product (see chapter 3.1.2).
- Rephrasing of the checklist questions to help the brainstorm process.
- Additional information in the “Strategy Dashboard” on the Suggested top 5 focus KPIs (see chapter 3.3.3).
- “Desirability” has been changed to “Impact risk level” in the “Improvements and Feasibility” step. Additionally, instead of manually choosing whether the improvement options are desirable or not, the toolkit automatically provides the impact risk level of the improvement options (see chapter 3.4.3)

4.1. DEMO 1 RESULTS: SUSPENSION CONTROL ARM

The assessment for Demonstrator 1 (suspension control arm) was performed by Marelli. Marelli identified the following (Table 4) as their key objectives for the context of the design decisions:

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Table 4: Objectives Marelli

Organisational objectives (Internal)	
A	Reduce product environmental footprint
B	Reduce energy consumptions
C	Provide customer with top class solution
Trends and societal objectives	
D	Reduce CO2 emission
E	Circular economy approach
Compliance objectives	
G	Iso 14001

This indicates that the objective for the energy consumption related to their product (as part of the company's (extended) environmental footprint) is on par with their objective to continue to provide top quality products to their customers. However, they are also looking towards the future and are aiming to take steps to ensure their products will be better suited for a circular economy (as an up-and-coming trend), while maintaining their reductions in CO_2. To manage their company-wide environmental responsibilities and performance they use ISO14001 practices and certification, among the others.

4.1.1. RIT CHECKLIST & EQFD – REQUIREMENTS AND KPIS

The results of the RiT Checklist are in line with the objectives that have been highlighted earlier. CO_2 emissions, energy consumption and recyclability are mentioned several times, both as important impact considerations and potential areas of improvements, and where the benchmark product is lacking.

Within the RiT Checklist, energy consumption as a high impact area for their (own) benchmark product is recognised for multiple stages of its life cycle, for example relating to the type of materials being used and the production process consisting of several steps at different 'working stations'. The product cannot be repaired due to safety (structural integrity) reasons. Because of this the (benchmark) product is made with the intention to last for the whole vehicle life. In case of damage (e.g., because of an accident) it is possible to replace the product. However, it is not very easily separated from the rest of the vehicle because of the way it is fixed to the knuckle and to the suspension subframe with bolts and interface elements like the ball joint and bushings. Once the vehicle reaches end-of-life, there is generally no time to lift the vehicle and unscrew all the bolts to separate the part. In the current situation (where the steering column is a metal part), it is likely also not considered necessary since the rest of the vehicle is also made from metal, which means everything could be crushed together. From a circular economy perspective, it is not ideal if a vehicle component that is potentially still perfectly fine is disposed of, but other factors are likely superseding this route. Also, safety levels do need to be assured for reuse and it could require extra steps to ensure the component could still be used. However, the necessity for disassembly could change when the steering column is made out of non-metal materials. From the formulated requirements and KPIs the partner seems to be looking for (other) ways to positively influence the life extension and end-of-life practices in relation to emissions, serviceability, and recycling.

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Based on the RiT Checklist, Marelli formulated the following requirements and KPIs for the EQFD:

Design (life-cycle) strategies ↓	High-level requirements - (What) ↓
1. Material selection	Less waste
	Mechanical Performances
	Price per kg
2. Mining and Production	Reduce energy consumptions
	Improve environmental footprint
	Amount of injuries during production
	Safest work environment
3. Transport and Distribution	Energy-efficient low carbon transport modes
	Non compliant sample reduction
4. Utilisation (First and Extended use)	Less emission damaging human health
	Lightweigth solution to decrease use-phase impact
	Serviceability
5. End-of-life (Recovery and disposal)	Open Loop recycling
	Less emission damaging human health
	Energy use for material recovery
6. Added functional value	Enhance part functionality

Figure 23: Formulated requirements by Marelli

For these requirements Marelli defined the following KPIs across multiple subcategories:

Environmental				Economic		
Ecological		Human health		Mining & production	Use & disposal	
% of virgin/ primary material	GWP index [kg Co2 equ]	Primary energy demand (PED)	Packaging weigth	Cost per kg	Number of non compliant parts	Credits and debts at EOL
Technical				**Social**		
Mechanical			Protection	Ethical supply chain	Employee Health & Safety	
Durability	Product weigth	No. of years	Safety monitoring	ISO certified suppliers	No. of incidents per year	

Figure 24: Defined KPIs by Marelli

Interestingly in the original version of the results of the demonstrator, the KPIs that revolve around the circular economy and GHG emissions objectives were scored the 1st and 3rd most important KPI's in the EQFD, the primary energy demand KPI was only 9th most important (out of 13). Durability of the product as well as Lightweighting of the packaging and the product itself were found relatively important. For the KPIs related to these impact areas, it was mostly the strong relationship with other important (environmental) requirements (GHG emissions and energy consumption), which gave them a high Strategic Importance Score. Since the RiT Checklist indicates that the product does not require specific high-quality packaging this begged the question on whether this was a conscious decision. However, after consulting with Marelli, they reviewed the toolkit which changed the Strategic Importance Scoring. This decreased the importance of the Packaging weight and increased it for the "GWP index" and "N of years (durability)" KPIs.

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4.1.2. BASELINE & TARGET PERFORMANCE

The baseline & target performance of Demonstrator 1 (suspension control arm) are shown Figure 25. Based on the earlier input given in the tool the Dashboard shows a priority suggestion to focus on possible improvements for the “Utilisation”, “Material selection” and “Mining and Production” design (life cycle) categories. This was confirmed by the designer - in the Chosen (design) focus - albeit in a slightly different order of importance (see Table 5). These three design strategy categories all have a similar performance delta (benchmark performance versus target performance), but that of the “Utilisation” category is slightly higher. This larger difference can likely be explained by the fact that this category has less KPIs listed in comparison to the other two focus strategies). This means that the bad performances of the benchmark, in for example the “Product weight” KPI, has a relatively larger impact on the average score, ranking it higher for the suggested focus.

Table 5: Chosen focus Demo 1

DECISION: Chosen focus	
No. 1	4. Utilisation (First and Extended use)
No. 2	2. Mining and production
No. 3	1. Material selection

When looking at the individual scoring of the performance evaluation of the benchmark product, most KPIs were scored equal or only one point lower than the target to the target. With the exception of the KPI Product Weight, which had a two-point difference with the target in both Material Selection, Utilisation. This is the main reason why these two were suggested for as focus strategies. It is remarkable that, even though some KPIs were deemed as very important based on the Strategic Importance Score, they still have a relatively low target in the Performance Evaluation. Most noteworthy example is the KPI “% of virgin/primary material”, which collected the highest Strategic Importance Score, but scored a target of 3 out of 5 (only one higher than the benchmark score of 2). An ambition to change the core material altogether may be the reason why they decided to not set the target for this KPI very high yet. It could be revisited as a possible design improvement in future. The consequence of setting a lower target is that Material Selection scored lower.

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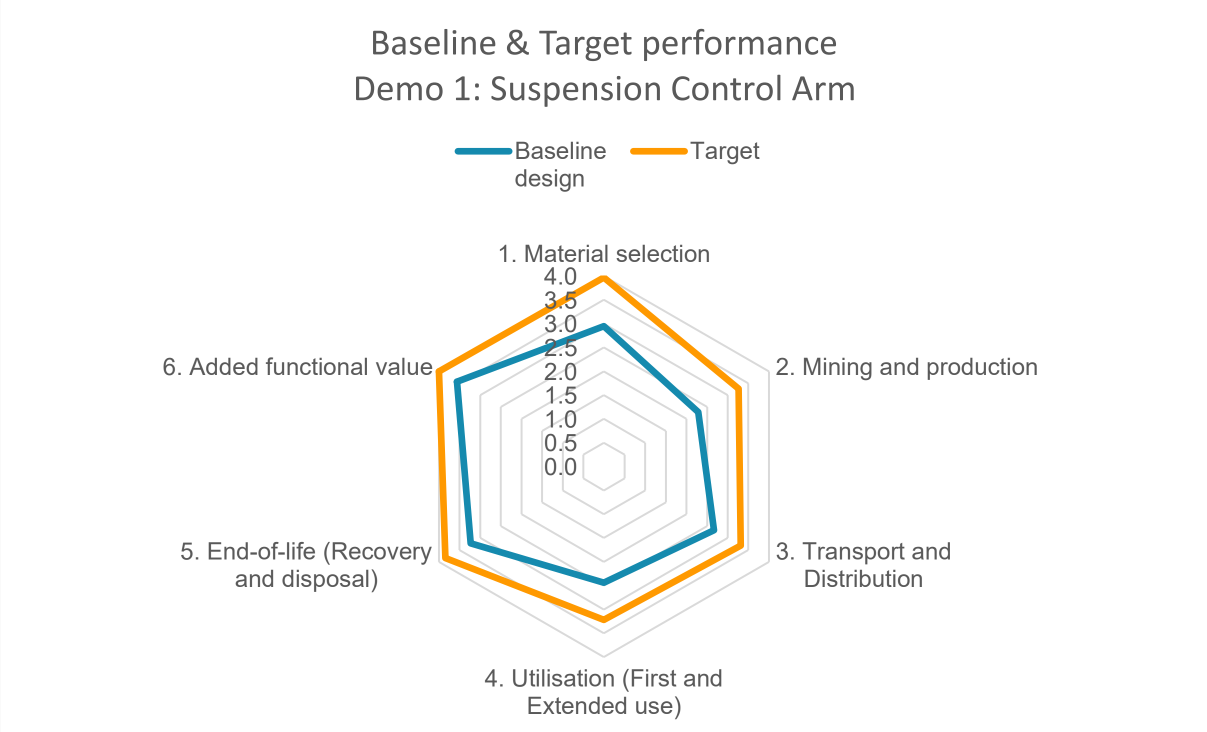

Figure 25: Baseline & Target performance Demo 1: Suspension Control Arm

4.1.3. IMPROVEMENTS & FEASIBILITY

Considering above, their improvement options do consider the 'downstream' lifecycle categories by addressing aspects of serviceability, energy consumption and enabling a better recycling loop by focusing on the (lifecycle) design strategies. Through the selection of different material, they also expect to improve the product's related energy consumption upstream.

All of the improvement options were focused on the environmental KPIs. Interestingly, no improvement option in the Material Selection strategy was focused on the Packaging weight where the difference between the benchmark and target performance was largest. Also, no improvement option addresses the most prioritised KPI, the "% of virgin/primary material". There are several possibilities as to why this is the case. Firstly, which KPIs are scoring highest in their need for improvements was initially not clearly enough highlighted. The version of the iEDGE toolkit the partners worked with did not yet have a "Suggested KPI focus" table and this has now been added in the updated version of the toolkit (see Annex 7.3.6). Another reason may be that the user did consider improvements that could address these particular KPIs but (subconsciously) dismissed them as unfeasible or not as desirable and filtered these out when documenting improvement options.

Each of the improvement options were found feasible in the short term and desirable for the designer and were chosen for the new design. It is noteworthy to mention that all improvement options relate to efforts to reduce material weight. Although it is not entirely unexpected in a project with a primary focus on Lightweighting, but what makes it interesting is that the selected improvement options are not based on this one singular focus.

4.1.4. RESULTS

The final results of DEMO 1: Suspension Control Arm are shown in Figure 26. It is clear that the improvement options are scored significantly better than the benchmark product, in all categories.

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Interestingly, the only two design life cycle strategies that meet the targets, are the categories “end of life” and “added functional value”, which were not chosen as focus strategy.

Looking at the individual results, some of the KPIs, especially in the technical and costs areas, show a decrease in performance. This is also shown when looking back at the improvements & feasibility sheet, where the improvement options show negative effects in these areas.

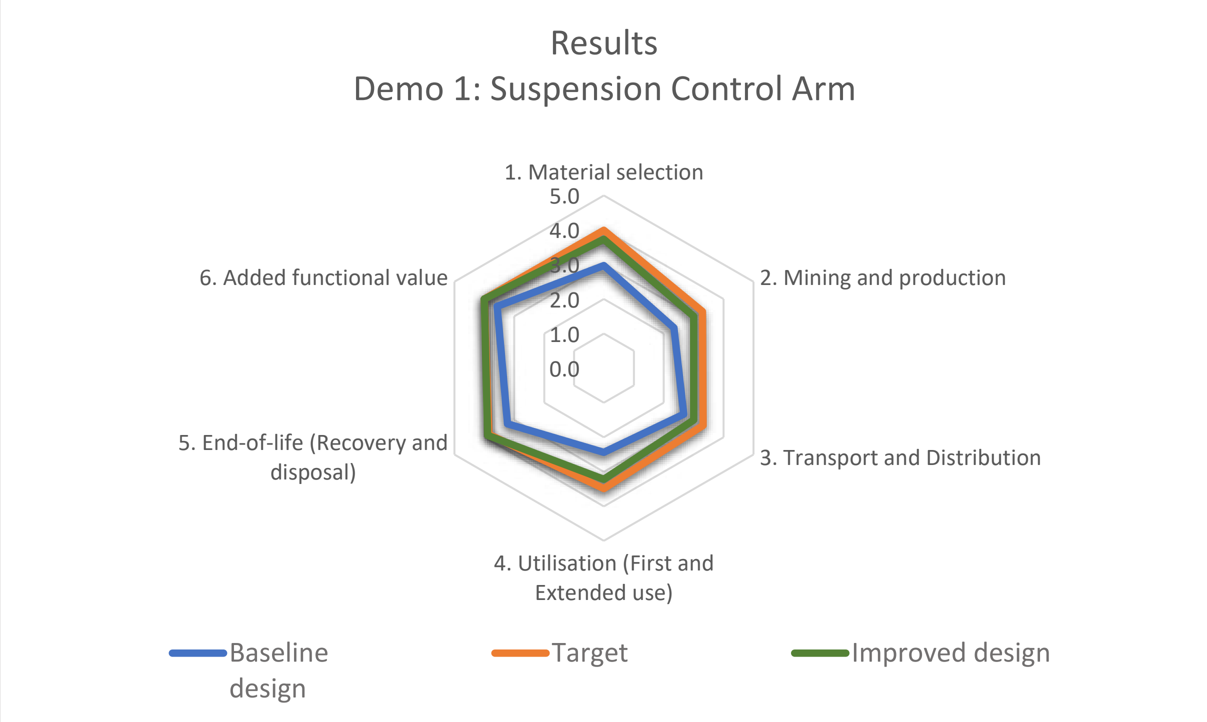

Figure 26: Results Demo 1: Suspension Control Arm

4.1.5. KEY MESSAGES

- Requirements with strong links to “Utilisation” in combination with the relatively high target (compared to baseline) resulted in it being ranked first as suggested life cycle strategy focus.
- The KPIs linked to the improvement options are different from those who had the largest performance evaluation delta. Although the partner stands by their improvement choices, they were not aware of this difference. This suggests the tool could provide extra guidance in this area. This has been added to the new version of the toolkit by visualizing the KPI with the largest performance delta.
- The data in the toolkit indicates the designers looked beyond the LEVIS scope area of lightweight solutions. Suggesting that the toolkit does stimulate users to also look for solutions on other (more vulnerable) impact areas. To stimulate this more the new version of the toolkit now specifically lists the KPI with the largest performance delta.
- The partner has explored the effects of the improvement options beyond their intended KPI effect and over multiple categories of the life cycle of the product. Indicating that the tool (possibly by the “Effect on design (life cycle) categories” part in the “Improvements and Feasibility” sheet) provided additional insights into the effects of their suggested improvement options for the new design.
- To ensure logic and proportionality in the different scoring exercises, it can be highly beneficial for the toolkit user(s) to do a ‘sense-check’ after each section.

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4.2. DEMO 2A RESULTS: BATTERY BOX

The results of demonstrator 2A (battery box), were performed by YESILOVA. Yesilova's organisational objectives are shown in Table 6. By raising these points as objectives, it is clear that the company is dedicated to making environmentally conscious products.

Table 6: Objectives YESILOVA

Organisational objectives (Internal)	
A	Creating environment friendly and lightweight solutions
B	Contributing sustainability
C	Through usage of recyclable light metals
Trends and societal objectives	
D	Usage of renewable energy (solar panels, etc.)
E	Contributing innovation and cooperation/synergy with products developed
F	Usage of recycled materials, less energy and emission waste
Compliance objectives	
G	ISO 9001/ IATF 16949/ ISO 27001/ ISO 14001

4.2.1. RIT CHECKLIST & EQFD – REQUIREMENTS AND KPIS

The RiT Checklist was used extensively, and every requirement listed in the EQFD clearly originates from the checklist. This suggests that the RiT Checklist was effective as a brainstorm mechanism. Whether or not it actually came to new insights and requirements depends on the evaluation of the partner (chapter 4.5).

Based on the RiT Checklist, Yesilova formulated the following requirements and KPIs for the EQFD:

Design (life cycle) strategies ↓	High-level requirements - (What) ↓
1. Material selection	Increased recyclability Lower emissions during production Light Material Usage
2. Mining and Production	Lower energy consumption during production
3. Transport and Distribution	Lower transport costs
4. Utilisation (First and Extended use)	Safety Lower Running Costs
5. End-of-life (Recovery and disposal)	Increased recyclability Increased reusability
6. Added functional value	More energy

Figure 27: Formulated requirements by Yesilova

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For these requirements Yesilova defined the following KPIs across multiple subcategories:

Environmental		Economic		
Ecological		Mining & production	Use & disposal	
Recyclable % mass	CO2,CO,NOx,HC emissions	Production Energy Efficiency (%)	running costs €	recycling profit €
Technical				
Mechanical			Protection	
Weight Reduction % mass	Energy Density (kWh/kg)	Sealing performance	Structural integrity	

Figure 28: Defined KPIs by Yesilova

When looking at the importance scoring of the KPIs, it is interesting to see that there is one KPI that scores significantly higher than the others, which is the Recycle % mass KPI. This is in line with the company objectives (Table 6) and it was referenced to several times in the RiT Checklist as an important impact factor (for example for purchase decision). However, it is surprising that it scores a lot higher than the energy density and the structural integrity KPIs, which relate to the main and auxiliary functions of the product (contributions to energy storage and safety). The reasoning behind this is suggested in the impact landscape of the RiT Checklist, which indicates that the recyclability (and other environmental requirements that have a relationship with this KPI) of the product is a larger bottleneck or concern of the current benchmark product.

4.2.2. BASELINE & TARGET PERFORMANCE

The baseline and target performance of Demo 2A are shown in Figure 29. What stood out was the relatively small difference between the performance of the benchmark and target for the "Recyclable mass" KPI, even though in both the RiT Checklist and the EQFD highlights "Recyclable % mass" as an important KPI. It was recognised as a potential bottleneck for the benchmark. Yet, the performance of the benchmark product was scored only slightly worse compared to the target for this KPI. This can be explained by the fact that the requirement corresponding to this KPI ("Increased recyclability") is considered twice in the life cycle category of the product, the "Material Selection" and the "End-of-Life" category, making it automatically twice as important (double strong relationship scoring). "Increased recyclability" as requirement warrants different KPIs for the two life cycle categories, in that the product would need to be both constructed using recycled materials (Material Selection) and be recycled back into raw material (End-of-Life). This makes it perfectly reasonable to keep the target low in both categories to balance the (weight) importance in the priority calculations.

Table 7: Suggested focus Demo 2A

OUTPUT: Suggested focus	
No. 1	4. Utilisation (First and Extended use)
No. 2	6. Added functional value
No. 3	1. Material selection

The Suggested focus strategies (Table 7) were adopted as the Chosen focus strategies by the designers. It is noteworthy that, with the exception of Material Selection, the KPIs for these lifecycle strategies are primarily linked to Requirements in the Technical focus area. These KPIs are strongly dedicated to lowering costs for service and maintenance. If these costs are lowered, this could also help to extend a product's life, but this was not identified in the RiT. In the EQFD (next step) multiple KPIs from the

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RiT seem to have been bundled as "Running Costs". Consequently, this benefit of the improvement option may not have been noticed as a positive 'environmental' effect. This illustrates the importance of the brainstorm (and documentation in the RiT Checklist) as well as being conscious of effects when bundling KPIs. An alternative approach could have been to keep "Lower running costs" as the Requirement and see whether they could formulate KPIs for different (main) focus areas. For example, for Environmental "Ease of Repair" (qualitative) or "Time to Repair" (quantitative) and for Economic "€ to Repair".

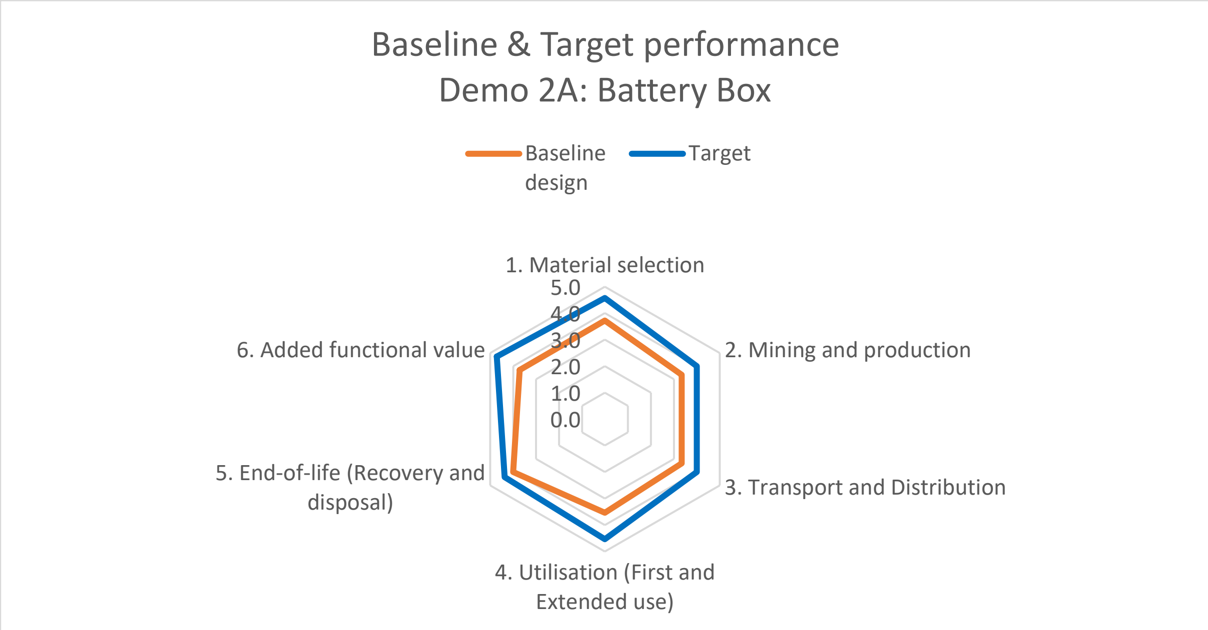

Figure 29: Baseline & Target performance Demo 2A: Battery Box

4.2.3. IMPROVEMENTS & FEASIBILITY

The improvement options assessment of Demo 2 shows some similarities to that of Demo 1. Like Demo 1, improvement options do not address the KPI with the highest priority, the "recyclable % mass". It was later explained by the designer that, even though they were aware this was the KPI with the highest priority, they knew that the benchmark product already scored close to the target objective. Which is the reason they decided to focus on other KPIs for improvement options

There were also no "unfeasible" or "undesirable" improvement options, it does give the impression that any improvements options which may have come up but is almost immediately considered not feasible, they are simply not documented. There can be various possible reasons for this to happen, ranging from time constraints to just simply not being used to document these as part of the thought process. However, it is important to note that one of the goals of this toolkit is to document the decision-making process, making it important to write all possibilities down so the information (and resulting decision) can always be consulted again later.

In this case, most improvement options were not focused on improving the environmental KPIs. This is in line with the remarks made in 4.2.2., where only the "Material Selection" recognised requirements for the environmental focus area. While we believe the designer does in fact consider environmental impact as part of these requirements, especially since the organisational objectives strongly favoured the ambition to create environmentally conscious products, this is not as clearly documented.

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For this Demo, several improvement options were documented in all three design life cycle strategies. They focus on the main and auxiliary functions, the safety and energy storage KPIs and are intended to have an effect on the same KPIs across multiple design life cycle strategy. Yet, for the exercise "Effect on design (life cycle) categories" they opted to only provide an effect-indication for the area to which the KPI was linked in the EQFD. For example, for (the earlier bundled) KPI "Running costs", only effects in the Economic area were provided for the different design (life cycle) strategies.

For the new design, all the improvement options were deemed Desirable, but some were only deemed Feasible in the long term, therefore receiving a Low Priority. Those with a high priority chosen for the new design, were the solutions focusing on the running costs and the safety of the battery box.

4.2.4. RESULTS

The results of Demo 2A: Battery Box are shown in Figure 30. It is clear that the new design indicates an improvement in all but one ("End-of-Life") design life cycle strategy. The two design life cycle strategies that meet the targets ("Mining and Production" and "Transport and Distribution"), were initially not suggested nor selected as focus strategies. This is because they are affected by only three KPIs: Emissions, Production energy efficiency and Recycling profit. The Recycling profit seemed to have already met the target. The fact that there is an improvement in the performance of the Emissions and Production energy efficiency, while they were not selected amongst Intended KPI effect, suggests the improvement option must have additional positive effects when doing the performance evaluation.

As was mentioned before, although the strategic objectives prioritise creating environmental products, the improvements focused mostly on the "Running costs" and "Safety" KPIs. However, the improvements for the new design are expected to reduce emissions, primarily due to the fact that in the "Material Selection" category should result in lower emissions during "Mining and Production". This improvement focus also means that the KPI with the highest Strategic Importance Score (recyclable % mass) was not improved in the performance evaluation. This would also explain why the design life cycle strategy "End-of-Life" saw no improvement at all compared to the benchmark product. The only KPI that effected this score (since the benchmark already met the targets in other KPIs) was the "recycle % mass".

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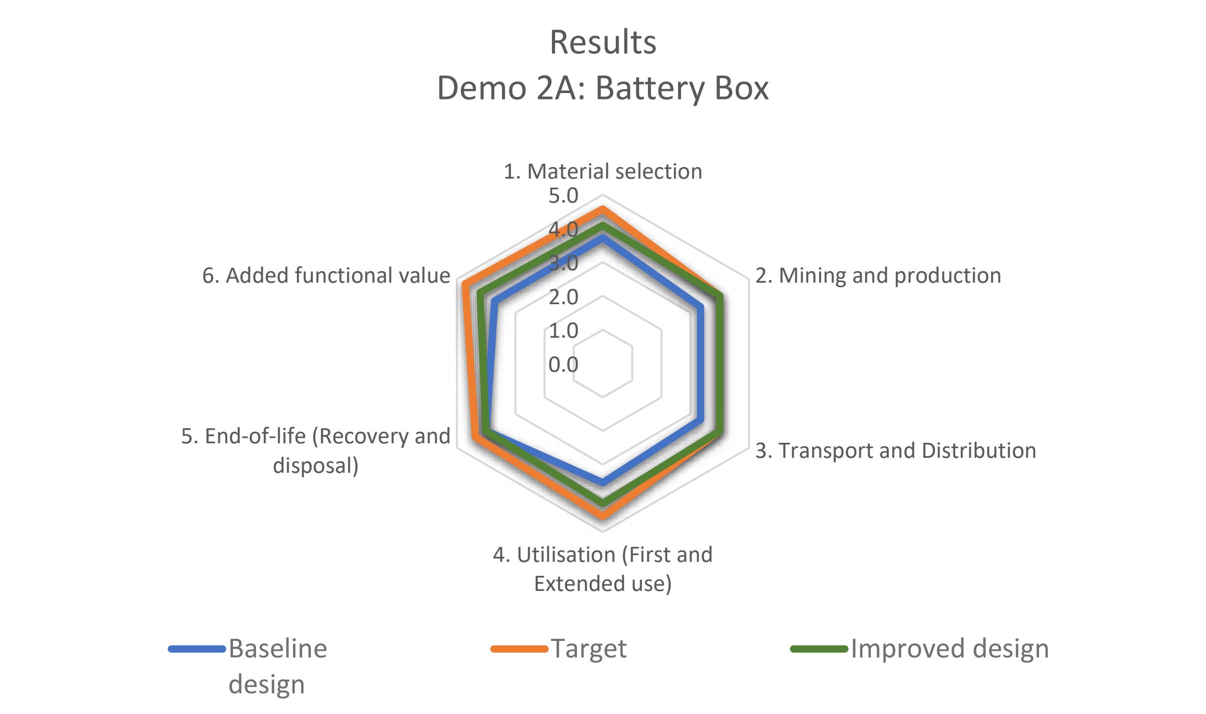

Figure 30: Results Demo 2A: Battery Box

4.2.5. KEY MESSAGES

- A high use of the RiT Checklist possibly led to new insights for identifying requirements and corresponding KPIs
- The RiT Checklist and EQFD suggested that in this Demo case the environmental KPI were deemed more important than the functional (technical) KPIs. Suggesting that concerns, risks and/or bottlenecks were found during the RiT Checklist assessment.
- The KPI that could have benefited most from improvement was not addressed in inventory of possible improvement options. However, it was explained this was a conscious decision as the partner chose to keep the target for this similar to the benchmark and focus on other improvement areas.
- The Improvements inventory showed no unfeasible improvement options. This suggests part of the thought process to identify improvement options was not documented.
- The toolkits performance evaluation scoring suggests that additional beneficial effects of the improvement options were spotted.
- The bundling of KPIs needs to be done with careful consideration, since this increases the risk of missing certain additional positive or negative effects during the performance evaluation.

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4.3. DEMO 2B RESULTS: BATTERY BUSBAR

The assessment of demonstrator 2B (battery busbar), was performed by MERSEN. The objectives of MERSEN are shown in Table 8. MERSEN focusses on a combination of environmental aspects and maintaining producing high-quality products. Additionally, the reduction of raw material use is a key focus. This sets the context in which they work in and set their requirements.

Table 8: Objectives Mersen

Organisational objectives (Internal)	
A	Reduce GHG emissions by 20% in 2025
B	High quality products
Trends and societal objectives	
D	Use renewable energy
E	Reduce raw material consumption
F	Reduce energy consumption (water / electricity)
Compliance objectives	
G	REACH
H	ISO 14001

4.3.1. RIT CHECKLIST & EQFD – REQUIREMENTS AND KPIS

Since the objectives of DEMO 2B mostly revolve around the environmental performance, it is interesting to see in which section of the tool these resonate. Although there seems to be little information referencing to this area in the RiT Checklist, there is a strong link when looking at the KPI importance priorities.

Based on the RiT Checklist, MERSEN formulated the following requirements and KPIs for the EQFD:

Design (life-cycle) strategies ↓	High-level requirements - (What) ↓
1. Material selection	REACH / RoHS Compliance Recycled/Biosourced materials Local purchasing
2. Mining and Production	Low energy consumption processes Reduce raw material consumption
3. Transport and Distribution	Reusable packaging Local purchasing
4. Utilisation (First and Extended use)	Higher repairability Higher reliability Modular design
5. End-of-life (Recovery and disposal)	Recovery of materials for new products Easier dismantling
6. Added functional value	Integrated monitoring : Predictive maintenance

Figure 31: Formulated requirements by MERSEN

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For these requirements MERSEN defined the following KPIs across multiple subcategories:

<table>
<tr><th colspan="5">Environmental</th></tr>
<tr><td colspan="2">Ecological</td><td colspan="3">Human</td></tr>
<tr><td>% virgin material</td><td>Emissions of Eq CO2</td><td>REACH Compliance</td><td colspan="2">% Recyclable materials (%) - Ecological</td></tr>
<tr><th colspan="3">Economic</th><th>Technical</th><th>Social</th></tr>
<tr><td colspan="2">Mining & Production</td><td>Use & Disposal</td><td>Mechanical</td><td>Ethical supply chain</td></tr>
<tr><td>Total Electricity consumption</td><td>Production Throughput</td><td>Raw material consumption (g/parts)</td><td>Est. lifetime including second life (y)</td><td>Distance Purchasing plant - production plant</td></tr>
</table>

Figure 32: Defined KPIs by MERSEN

It is noticeable that most of the questions in the RiT Checklist are either left out or are not related to the topics of the objectives, GHG emissions, (renewable) energy consumption and raw material consumption, while there are several requirements and KPIs formulated that do link to these objectives. These KPIs (GHG emissions, total electricity consumption and raw material consumption) are also the 1^{st} 2^{nd} and 4^{th} priority according to the EQFD. This suggests parts of the 'brainstorm', which resulted in the Requirements and KPIs, were not documented. Therefore 'justification' for them will be more difficult to retrace in hindsight.

Three (out of the nine) KPIs that are not directly linked to the objectives. These KPIs are however mentioned in the RiT Checklist, which suggests that they were deemed important after the brainstorm session of the RiT Checklist.

4.3.2. BASELINE & TARGET PERFORMANCE

The baseline and target performance of the Battery Busbar is shown in Figure 33. It is clear that the difference in performance between target and the benchmark is quite large, especially in the "Mining and Production" category and the "End-of-Life" category of the product. Looking at the individual scoring of KPIs, it shows that the KPI CO_2 emissions is the largest contributor to this target gap. This correlates well to the strategic objectives as well as the EQFD (where it was deemed as the KPI with highest priority), but not necessarily to the RiT Checklist, where the poor GHG emission performance of the benchmark product was not mentioned.

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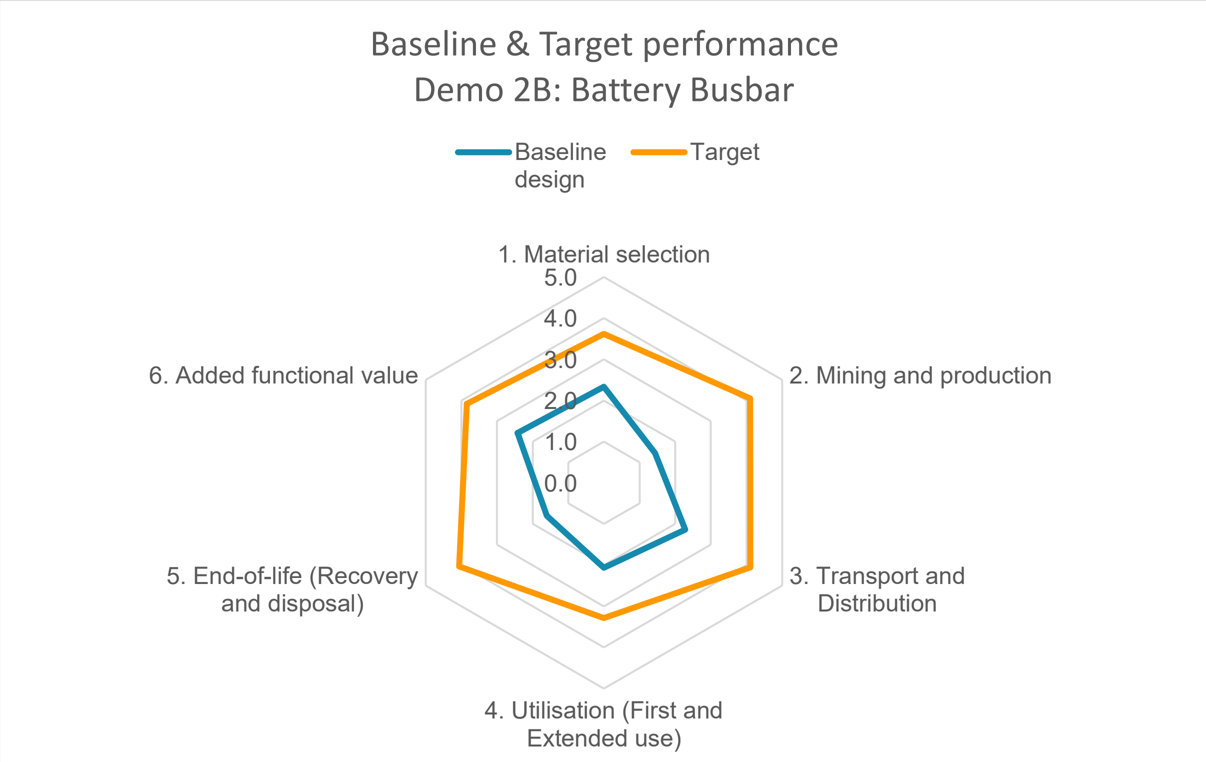

Figure 33: Baseline & target performance DEMO 2B: Battery Busbar

4.3.3. IMPROVEMENTS & FEASIBILITY

The "Mining and Production", "End-of-Life", "Added functional value" and "Material Selection" category were chosen as focus life cycle strategies. All the improvement options of the inventory were deemed desirable and feasible, which begs the question whether no other options were considered but were (subconsciously) filtered out and therefore not documented. Most of the improvement options were feasible short term, two of them were feasible long term. Only one options was not chosen for the new design. This improvement option (selection of bio-sourced or recycled materials for casing) was only feasible for the long term. Yet, the other option deemed feasible in the long-term (add sensors in the casing), is selected for the new design. A clarification for these different decisions was not provided.

Interestingly, the KPI "Reduction of GHG emissions" was not listed amongst the 'Intended KPI effects' for any of the improvement options, even though this was the most important KPI for the product and it is a key organisational objective. While "Total Electricity consumption" is listed for "Mining and Production", the link is less direct (which is also reflected in the relationship scoring of the EQFD).

4.3.4. RESULTS

The final results of the demonstrator 2B: Battery Busbar are shown in Figure 34. It is clear that the improvement options selected for the new design are expected to achieve an improvement in almost all life cycle strategies except for the "Transport and Distribution" category. Interestingly, only two categories meet the target performance, one of which was not a chosen focus life cycle strategy, the "Utilisation" category. This could be an indication that the iEDGE toolkit stimulated the user to think of possible impacts of the improvement options beyond the intended KPI effect.

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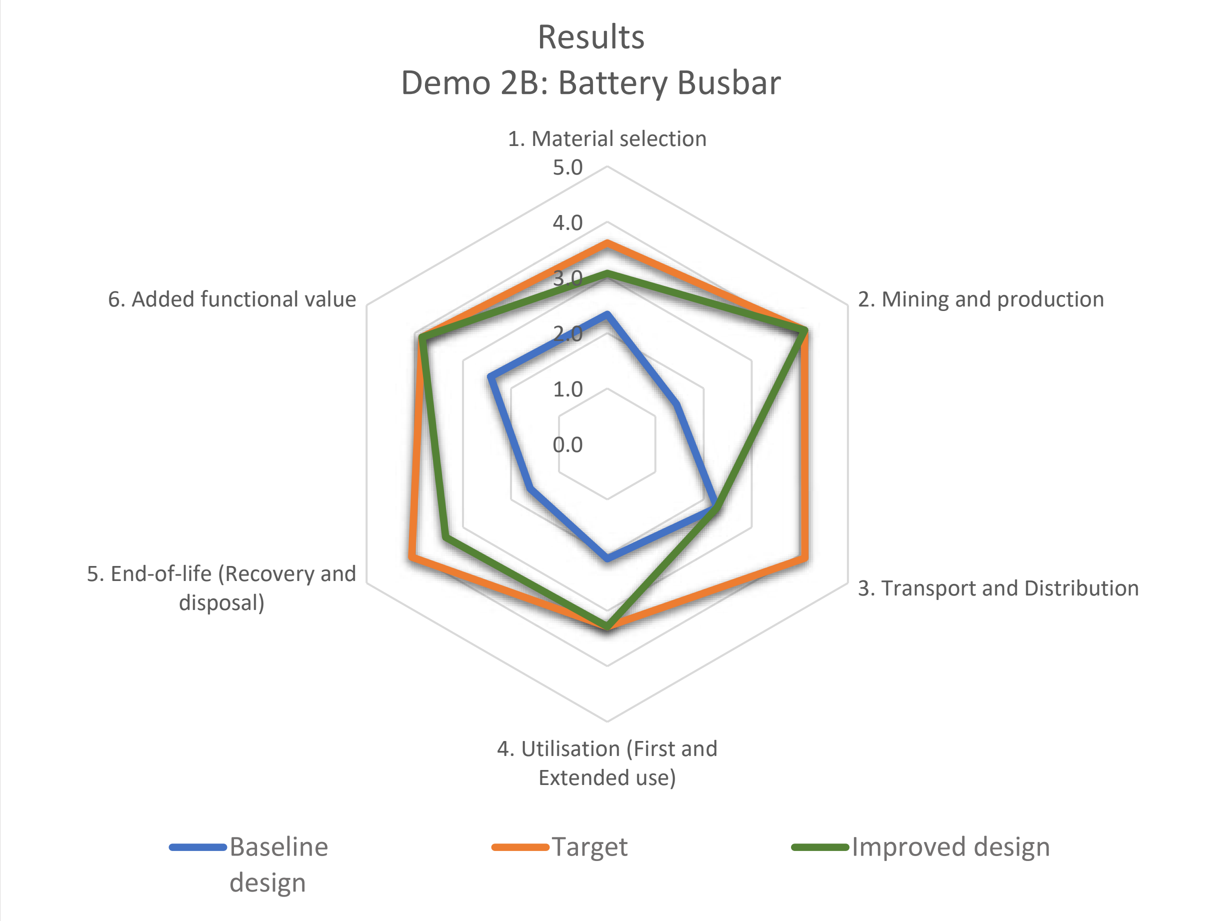

Figure 34: Final results iEDGE tool DEMO 2B: Battery Busbar

4.3.5. KEY MESSAGES

- Some KPIs were not specific to the objectives, suggesting that the guided brainstorm assessment of the RiT Checklist provided additional insights regarding the identification of the Requirements and KPIs.
- An obvious correlation between RiT Checklist results with the EQFD relationship scoring and performance evaluation could not be identified, while there was a strong correlation with the objectives. This suggests that the organisational objectives of the "Framing the Context" sheet were used more as background information for these assessments rather than the RiT Checklist.
- The KPI that could have benefited most from any improvement was not addressed in inventory of possible improvement options. It is unclear whether this was a conscious decision or not.
- The Improvements inventory showed no unfeasible improvement options. This suggests part of the thought process to identify improvement options was not documented.
- The toolkits performance evaluation possibly allowed for spotting additional effects of the improvement options, resulting in improvements that were not the focus design life cycle categories.

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4.4. DEMO 3 RESULTS: CROSS CAR BEAM

The assessment of the demonstrator 3 (Cross Car Beam), was performed by TOFAS. The objectives of TOFAS are shown in Table 9. When comparing the objectives to the other demonstrator partners, it is remarkable that TOFAS's objectives do not emphasize the environmental objectives but focus on the quality of the product itself.

Table 9: Objectives TOFAS

Organisational objectives (Internal)	
A	Deliver first class quality products to our customers
B	To improve people's quality of life by providing them with the products
Trends and societal objectives	
D	Increase the quality of production
Compliance objectives	
G	Increase the WCM level to World Class
H	ISO 14000

4.4.1. RIT CHECKLIST & EQFD – REQUIREMENTS AND KPIS

Both the 'impact landscape' input in the RiT Checklist and the Requirements and KPIs, documented in the "RiT Checklist" sheet, do correspond with each other. When looking at the provided answers in the checklist, it is clear that the bottlenecks of the benchmark product are used to formulate requirements. Interestingly, this resulted in a relatively great number of environmental requirements and only one or a few economic, technical, or social requirements. Considering the objectives of TOFAS, this suggests that the use of the RiT checklist may have led to additional insight into the impact landscape of the product.

Based on the RiT Checklist, TOFAS formulated the following requirements and KPIs for the EQFD:

Design (life-cycle) strategies ↓	High-level requirements - (What) ↓
1. Material selection	Lighter Steering Column Strength Crash Safety
2. Mining and Production	Less impact on climate change Less emissions damaging human health
3. Transport and Distribution	
4. Utilisation (First and Extended use)	Less Energy NVH Performance
5. End-of-life (Recovery and disposal)	
6. Added functional value	

Figure 35: Formulated requirements by TOFAS

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For these requirements TOFAS defined the following KPIs across multiple subcategories:

Environmental			Economic
Ecological		Human health	Mining & production
CO2 eq.	kw/km	PMF emissions	Euro
Technical			
Mechanical		Protection	
Weight (gr)	Hz	Displacement	

Figure 36: Defined KPIs by TOFAS

The formulated requirements focus only on three of the six different Life Cycle Strategies, even though the RiT Checklist has covered impacts in all the different strategies. This suggests that only the bottlenecks that are perceived to be of high importance or have the largest impact have been shortlisted and converted into requirements. This is also shown by the importance rating of the requirements in the EQFD, which all scored “5” (very important) except for one requirement (“Less impact on climate change”). The tool does provide room to include requirements that are of lower importance (by using the importance rating) in the EQFD. Which indicates that in this case, the full potential of the RiT Checklist and EQFD is not used by documenting requirements that are currently of low(er) importance.

4.4.2. BASELINE & TARGET PERFORMANCE

Since only three design life-cycle strategies had received formulated requirements, you would expect that these three life cycle categories would be also the suggested design strategies. However, looking at Figure 37 and Figure 38 it seems that the “End-of-Life” category is one of the most prioritised design life cycle strategies. There seems to be no other reason for this than the scoring which was given to the benchmark and target for this design strategy even though there were no dedicated “End-of-Life” requirements formulated. The delta between benchmark and target implies that there are significant impact concerns and potential for improvement. One would expect to see these mentioned in the RiT Checklist, which doesn’t seem to be the case.

The individual scoring performance shows that every KPI is scored for all life cycle categories. It is of course possible that some KPIs have an effect in other life cycle category, but it is not expected that this is the case for all of them when half of the life cycle categories did not have a specific requirement. It appears that the effort to score each cell was a misinterpretation of what is intended for the tool. It is possible that the designer missed the explanation in the guideline which explains that when is not possible to score a KPI, you are meant to score it a “0” to not affect the total scoring of the design life cycle strategy.

Nevertheless, it may very well be that the designer realised there was indeed significant gains to be achieved for this category while he was undertaking the performance scoring. This is emphasized by the fact that the designer did indeed list the improvement option under the “End-of-Life” category as well during the Improvements exploration, although not all of the KPIs scored high in target in the performance evaluation are mentioned here.

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DECISION: Chosen focus	
No. 1	1. Material selection
No. 2	5. End-of-life (Recovery and disposal)
No. 3	4. Utilisation (First and Extended use)
Comments: Output of the suggested focus is pretty satisfying thats why I dont want to add another focus	

Figure 37: Chosen focus strategy DEMO 3 Cross Car Beam

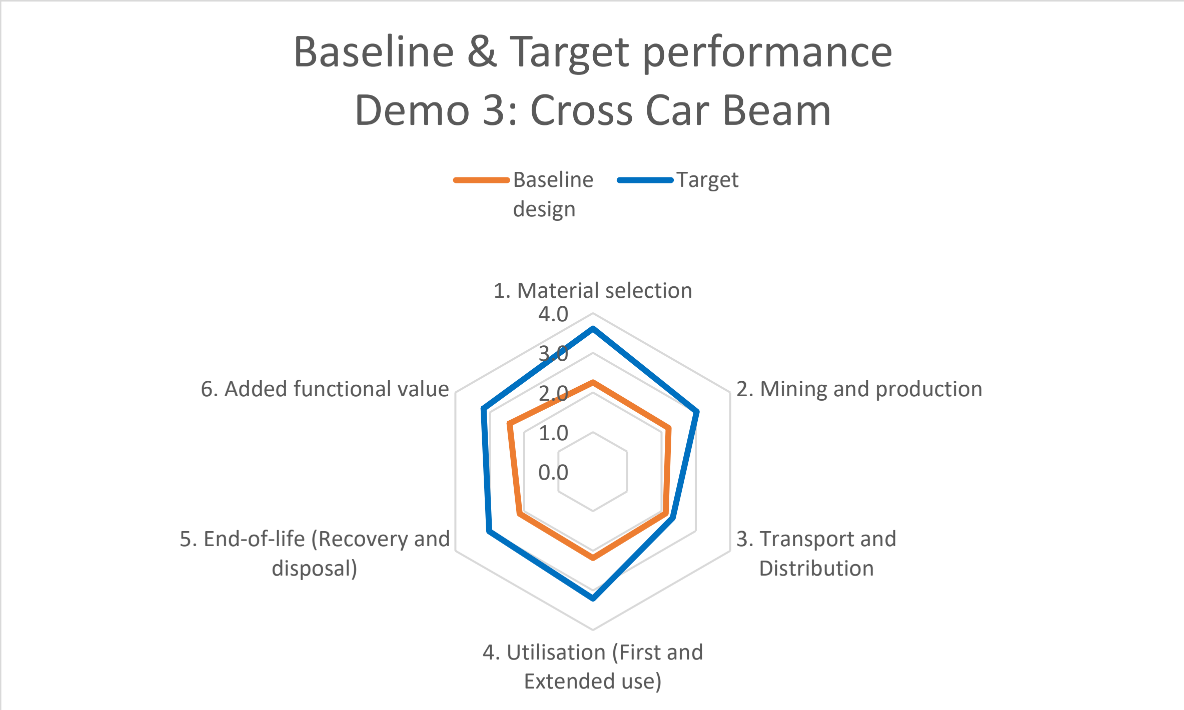

Figure 38: Baseline & Target performance Demo 3 Cross Car Beam

4.4.3. IMPROVEMENTS & FEASIBILITY

Comparing the outcome of the Improvements & Feasibility assessment of Demo 3 to the other demonstrators, it is clear that some parts of the assessment has been interpretated differently (as described under 4.2.2).

The designer effectively identified one key improvement option, which affects the three chosen design life cycle strategies. This could very well be a conscious decision; to have one main improvement to focus on for your new design, which can also have a positive effect in multiple categories of a product's life cycle and for different KPIs. What is noticed however, is that no other possible improvement options were mentioned in the inventory, while the intention is to use this as a means to brainstorm. Does this mean that no others were explored?

Demo 3 focused on the composite material which is also one of the main goals for the LEVIS Project. This is clearly reflected by the Improvements & Feasibility section of the iEDGE toolkit where the partner solely evaluated the improvement of using composite material on the three chosen design life cycle categories. As a result, composite cross car beam was determined to indeed be desirable. This design improvement will be new in the market. The Effects analysis over the improvement option ("Use of composite material") was performed for the three suggested life cycle categories. The effects were in general positive or unknown, except for the economic focus area, which had a negative impact.

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This seems to be in line with the targets that were set for the economic KPI, which were set similar or even lower than the benchmark. This indicates that it is acceptable that the improvement results in additional costs. However, the designer pointed out there were still some uncertainties regarding the effect on the price of the product. This has been pointed out in the Effects analysis of the "Improvement and Feasibility" section.

4.4.4. RESULTS

The results of Demo 3 are shown in Figure 39. It is clear that the new design is expected to achieve significant improvements especially on the three chosen design life cycle categories. The individual performance scoring corresponds in most parts with the Effects analysis performed in the Improvement & Feasibility assessment.

The economic performance scoring for the new design related to the "End-of-life" category was different than what is suggested in the "Improvements & Feasibility" sheet. In the latter it was expected to have a negative impact in the "End-of-Life" category while in the performance scoring the new design scores better in the economic KPI than the benchmark product. However, after evaluation with TOFAS this apparently was a small mistake, which needed to be updated.

This does highlight the need for regular sanity checks on any inconsistencies in the different steps of the iEDGE toolkit, since a wrong input number may have unintentional consequences. Regardless, there are significant number of indications that the selected improvement will have a positive effect in multiple key design categories.

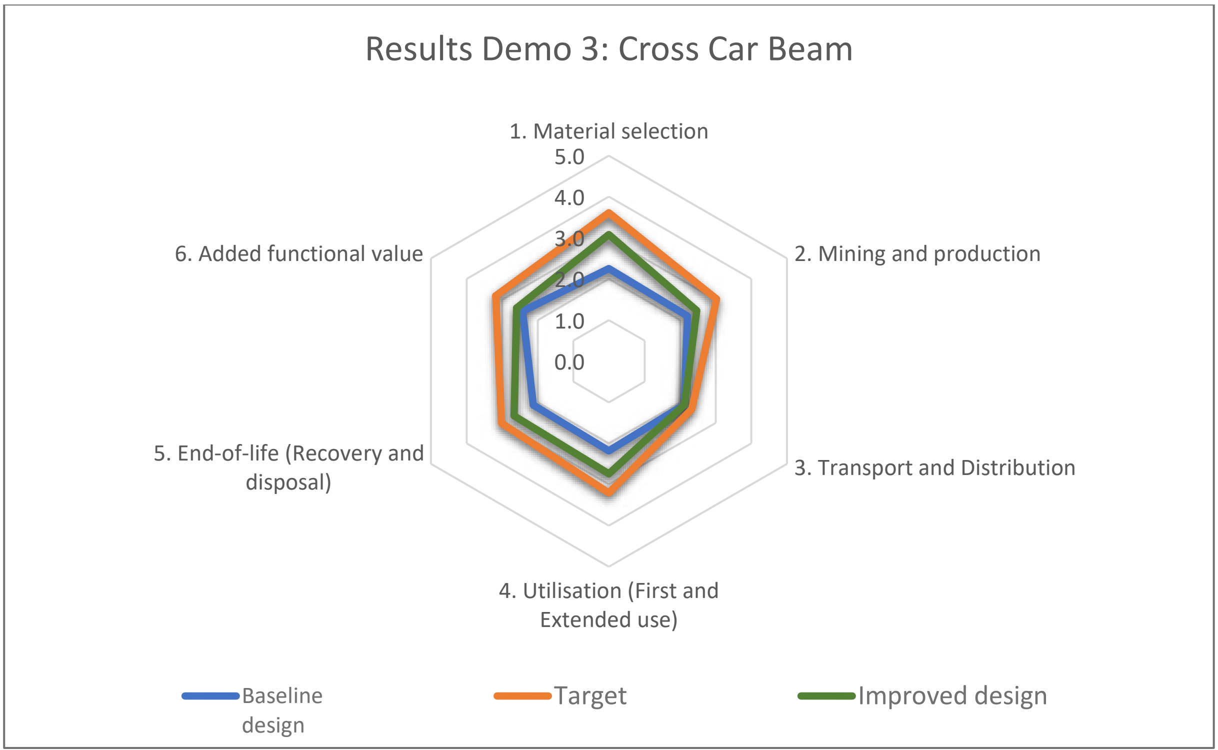

Figure 39: Results Demo 3 Cross Car Beam

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4.4.5. KEY MESSAGES

- The strong link between the requirements and the RiT Checklist, along with the small number of requirements related to the company's objectives, suggests the RiT Checklist did provide additional insight into the impact landscape of the benchmark product.
- The Improvements inventory showed only one improvement option (and therefore also no improvement assessed as being unfeasible at this stage. This suggests any brainstorming about possible (other) improvement options was not documented.
- To ensure logic and proportionality in the different scoring exercises, it can be highly beneficial for the toolkit user(s) to do a 'sense-check' after each section.

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4.5. EVALUATION

During and after completion of the entire assessment process using the iEDGE toolkit, the partners were asked for feedback and evaluate the proposed methodology, tool, guideline and support. This paragraph discusses the feedback and remarks that were provided by the partners.

4.5.1. CONTEXT OF PARTICIPANTS

The participants indicated having varying background knowledge and experience regarding eco-design, circular economy and Life Cycle Assessment, ranging from 'no experience or knowledge' to already 'sufficient knowledge to integrate it into their work'. Also, not all participants already had improvement options in mind before starting using the toolkit. The differences in background knowledge and experience makes the feedback more valuable. Now it can be analysed what the effect is of having this already available knowledge to the effectiveness of the iEDGE toolkit.

4.5.2. RESULTS FROM THE TOOLKIT ASSESSMENT

From the responses of the partners, it seems that the results of the toolkit were mostly in line with the expectations they had beforehand. Only one partner (which had the least prior experience and knowledge with eco-design) expected a bit different result/output from the toolkit. However, this partner also reported that the toolkit provided some unexpected insights. In all, all the partners thought the results were of value for the design process and all the partners plan to (partially) use the eco-design principles to base the new design (choices) on.

4.5.3. USE OF THE IEDGE TOOLKIT AND GUIDELINE

The initial usage of the toolkit seemed difficult for all the partners. Even though they mentioned that the guidelines (chapter 3) helped a lot to understand the steps of the iEDGE toolkit, personal assistance was required by all the partners to finish the toolkit properly, all having different questions. Both the toolkit and the Guideline has been updated since to address those problems. The partners did however mention that they would have confidence that the next time they would use the toolkit they would spend less time on it and no additional guidance would be necessary. In addition to helping the partners to complete the toolkit assessment, and based on feedback from the partners, a use case has been created to serve as an example. This can be used to get some additional insight on the general intention behind the steps of the methodology. It was also requested by the partners to have a list of possible requirements and KPIs to serve as an inspiration or example. However, we decided not to do this. The use case already serves as an example on how to assess the steps of the toolkit and ways of formulation. Although we recognize such a list could be considered very useful for users of the tool, we also considered that such a list would never be 'complete' and also creates the risk of (unintentionally or subconsciously) steering the thought process, instead of guiding it. The requirements and KPIs have to be defined based on the product specific objectives and impact landscape, not based on frequently used requirements or KPIs. Providing an extensive list of examples could mean the process is influenced too much, resulting in a set of eco-design principles which is not as case-specific as it should be.

In this case, all partners thought the iEDGE toolkit would be worth the time they needed to spend compared to the value it provided. However, not all steps of the toolkit were seen as equally valuable. Figure 40 shows the rating of the value of each step of the iEDGE toolkit by the partners, scoring from 1 (very low) to 5 (very high). It is interesting to see that the steps that needed the most personal support (RiT Checklist and requirements selection) were deemed least valuable (on average). It is possible that the time needed to perform these steps is considered too much. To improve this, the

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Checklist questions have been updated and rephrased to better guide the user in this 'brainstorm' thought process to reduce the time and effort to do this assessment.

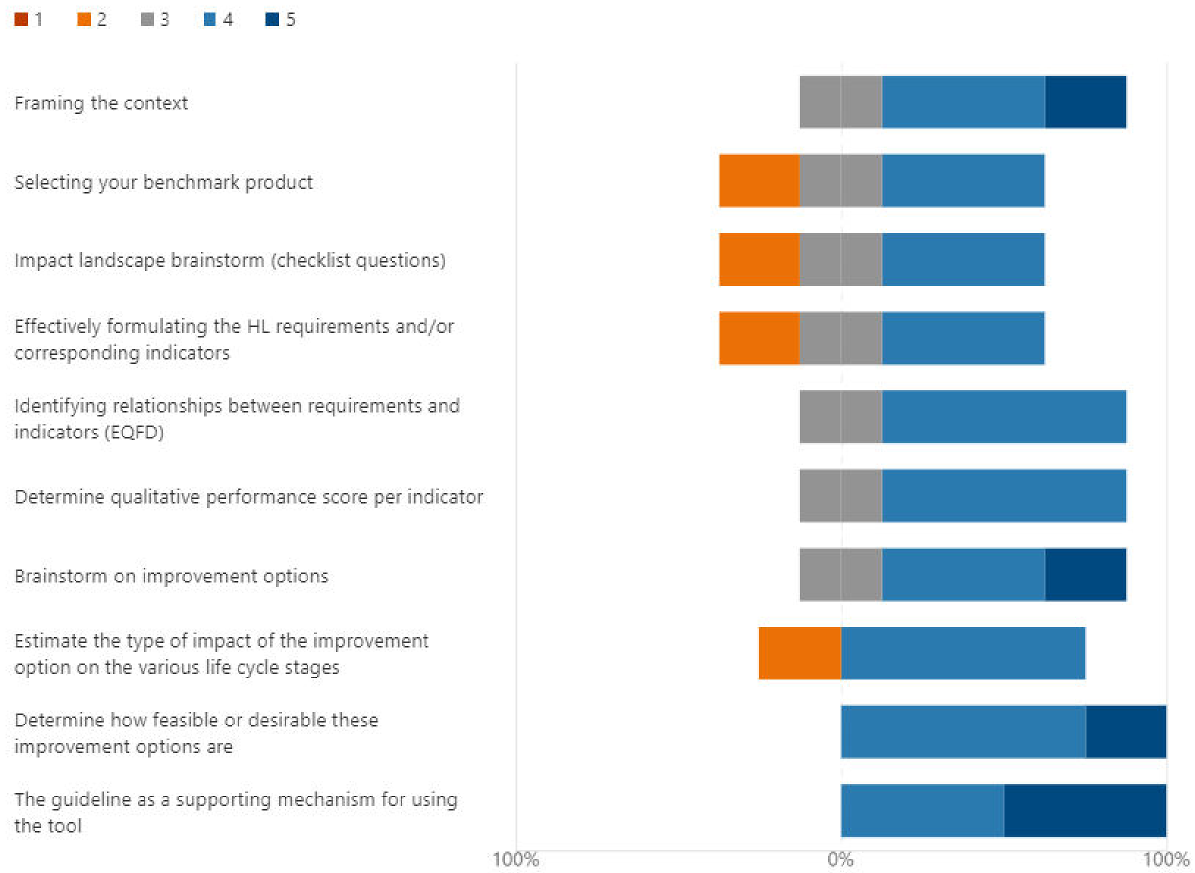

Figure 40: Perceived value of the steps by the demonstrator partners

It is interesting to see that the sections which are considered to be most important from an eco-design perspective (the brainstorm on the product's impact landscape, formulation of requirements and KPIs and estimating the impact of the possible improvements) are the steps that do require the most time and effort. Of course, this is not entirely unexpected as they are asked to explore and consider aspects that is not (yet) an area of expertise and requires them to think outside-the-(normal)box.

4.5.4. IMPROVEMENTS AND POTENTIAL FOR FUTURE USE

From the results of the demonstrators, the feedback sessions and the evaluation from the partners some key improvements could be formulated:

- A use case (example) iEDGE toolkit would help the partners get a quick view on what the general thought is behind the steps of the methodology by looking at possible results.
- List of suggested requirements and KPIs as inspiration and means to see how they need to be formulated. However, it was chosen not to provide this, in order to keep the requirements and KPIs case specific and not being steered in direction that doesn't fit their objectives and impact landscape.
- More freedom to change the worksheets. This has been solved by providing the partners with unprotected excel files.

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- More guidance from the RiT Checklist questions. A solution has been found by changing the questions itself and the providing detailed explanation in the guideline.
- Automatically suggest the “desirability” of the product based on the Effects-analysis in the “Improvements and Feasibility” step. This been improved in the new version. Additionally, “Desirability” has been changed to “Impact risk level”. This means that, instead of manually choosing whether the improvement options are desirable or not, the toolkit automatically provides the impact risk level of the improvement options (see chapter 3.4.3)
- The toolkit should provide automated suggestions for focus KPIs. This has been addressed in the new version of the tool (see Annex 7.3.6).
- The toolkit should provide additional information on the strategy dashboard that helps with the decision to choose which strategy to pick for the improvement options. For example, the amount of KPIs the life cycle category has effect on, the top 5 most prioritised KPIs, etc.

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5. CONCLUSIONS AND RECOMMENDATIONS

5.1. ACROSS ALL DEMONSTRATORS

Apart from the results and key message highlighter in the Results chapters for each respective demonstrator there are also some key conclusions and ensuing recommendations that can be drawn from evaluating the process and results across all demonstrators. Looking at these results from the demonstrator assessments, there are some similarities and commonalities which provides the basis for the conclusions below.

Outlook of the results: For all demonstrators the selected improvement options, based integration of case-specific eco-design principles, are expected to achieve significant improvements in comparison to their respective baselines. These improvements are shown across multiple life cycle categories and are therefore indicative for effective chosen eco-design strategies. The design improvements did not always meet their targets. This indicates there is either more room for improvement or the targets were set quite ambitious. It will be interesting to see what the results will be once the LCA (and LCC) is performed (as part of Workpackage 6) for each demonstrator product (both for the benchmark product and detailed new design). This will undoubtedly provide new insights into the early design decision and possible further improvements.

Value of the results: The results of the demonstrators and also the feedback provided by the partners indicate that the iEDGE toolkit (and its Guideline) did provide valuable information and insights for the new design. All the demonstrators identified improvement options, focussing on particular KPIs that were of high importance (which often related to the strategic objects of the company), while getting a better overview of its relation to the different life cycles categories as well as finding a balance between the four main focus areas (Environmental, Economic, Technical and Social). Additionally, the partners reported value in all of the steps of the eco-design methodology and showed interest in using this method for future projects. Of course, improvements can and have to be made both in usage of the methodology and the usage of the toolkit itself.

Results relevant to Circular Economy: Three of the four demonstrators showed requirements and KPIs that are strongly linked to the repairability and recyclability of the product. These KPIs were even (amongst) the most important for the whole product (regarding the Strategic Importance Score). However, only one demonstrator had an improvement option dedicated to this KPI (which surprisingly was the demonstrator where the recyclability was relatively least important for the product). These results are strong indications that the partner organisations are looking beyond the “Utilisation” stage and recognize the importance of designing their products to better fit with the circular economy concept and are preparing for this upcoming trend. The dedication to this in the improvement options could still improve.

5.2. ADOPTION OF ECO-DESIGN AND IEDGE TOOLKIT

Time and effort: Adopting and integrating eco-design into the ‘normal’ design process takes time and effort, especially when first embarking on this route. Designers (and others involved) are asked to explore and consider aspects that is not (yet) an area of expertise and requires them to think outside-the-(normal)box. These steps are often considered to be most difficult.

Recommendation: Companies aiming to adopt eco-design to improve their product’s sustainability (and circularity) should realise this will take additional time and effort particularly in relation to

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brainstorms on the wider impact (and ways to improve this) across the product's life cycle, especially at first. The same timeframe as your 'business-as-usual' design process decreases the success. Include eco-design as part of their job description or responsibilities and allow people to invest some additional time and effort (including the possibility to involve other colleagues who are not designers).

Visibility of KPIs with largest improvement opportunity: KPIs that could have benefited most from improvement were not addressed by several partners.

Recommendation: Although the choice not to address these can be because of legitimate reasons, it did suggest that the tool needed to highlight this better. Therefore, this function was added in the latest version of the toolkit.

Documenting the thought process behind the decisions: This feature of the toolkit seems to be underused by all the partners. Especially decisions or options which are deemed of low importance or unfeasible were not shown in any of the demonstrators. There may be several possible reasons for this. For example, partners may not be used to brainstorm from an eco-design perspective, there may have been no or little opportunity to involve colleagues who could bring a different expertise (and perspective) to the table or there may have been time constraints.

Recommendation: It is important for future reflection and learning experience that the thought process is captured as much as possible. Ensure sufficient time is reserved for the process to properly document the reasoning behind the decisions.

There were several indications which suggests that the tool was not yet used to its full potential as a brainstorm and decision-making documentation tool. For example:

- In the RiT Checklist the inventoried impacts often seemed to focus on the area with the most logical connection, for example cost related impact tended to concentrate in the Economic category, whereas the reason for high costs may originate from environmental causes or, alternatively, costs could be low because environmental impacts are not accounted for.
- Several partners had listed no unfeasible improvement options in the "Improvements & Feasibility" section. Although the tendency to automatically think in 'feasible' options only is an understandable tendency, it does suggest users don't seem to document their full thought process and possible "out of the box" solutions.

It must be said that the fact that these aspects were not documented in the different sections does not mean that the partners have not considered these. Input regularly suggest they do consider these. However, by not documenting this thought process it will be difficult to consult and retrace the considerations and decisions at a later stage. The new version of the toolkit provides the user with even more possibilities to add information in different sections to document thought processes (reasonings and justifications).

*Recommendation***:** To further improve the brainstorm and documentation purpose of the tool, it can be recommended to do the assessment as a joint effort between colleagues (perhaps even organise dedicated workshops and appoint a brainstorm moderator)

Extended version in combination with LCA: *There can also be added value found in considering an extended version of the iEDGE toolkit, one where LCA and LCC output is integrated into the process of*

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eco-design (as shown in

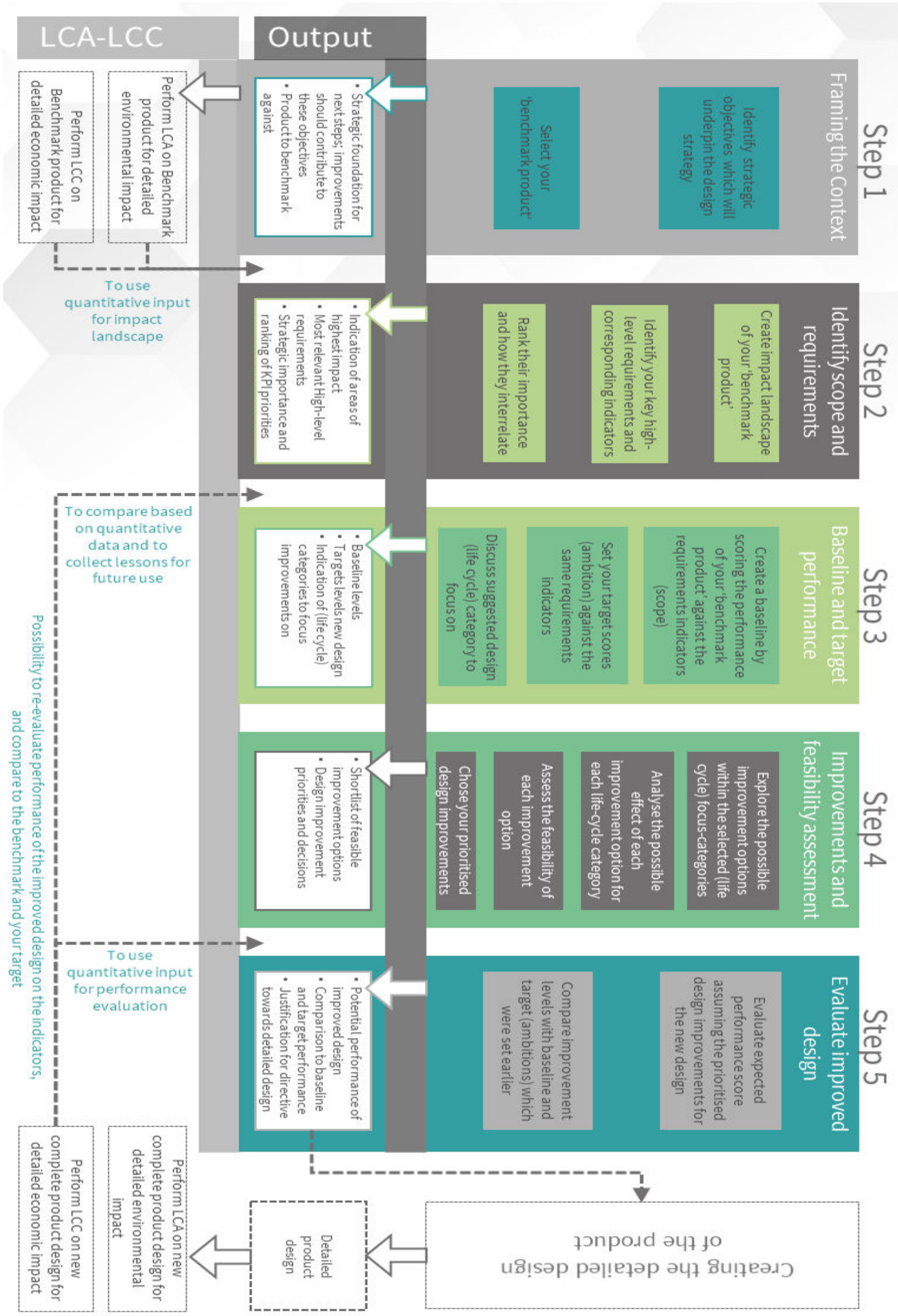

Figure 41). LCA and LCC results of the benchmark product can be used to increase the effectiveness of the RiT checklist brainstorm session and assess a better impact landscape. While LCA and LCC data of

the new design can be used to reflect on the eco-design process. Using this, future eco-design processes will become easier, better and produce stronger results and designs.

Better with more experience: The difficulties that the partners experienced during the RiT checklist brainstorm session and improvement options step of the toolkit resulted in some missed opportunities to get the full potential of the iEDGE toolkit. Possibly because of (a combination of) time constraints or a lack of previous eco-design experience and knowledge. More experience with the toolkit, along with proper reflection of the design process and the design afterwards (with the help of quantified LCA and LCC data), should increase the knowledge of the designers about the impact of the product and their design decisions on the full life cycle of the product. Using this information, the iEDGE could be completed faster while identifying desirable improvement options. The feedback from the partners confirms using the toolkit for the first time was experienced with some difficulty, particularly in combination with the relatively new knowledge areas of eco-design and circular economy (particularly the application of it). The partners also largely indicated that having done this once, they expect it will be quicker, easier to understand and to assess the next time they use the tool.

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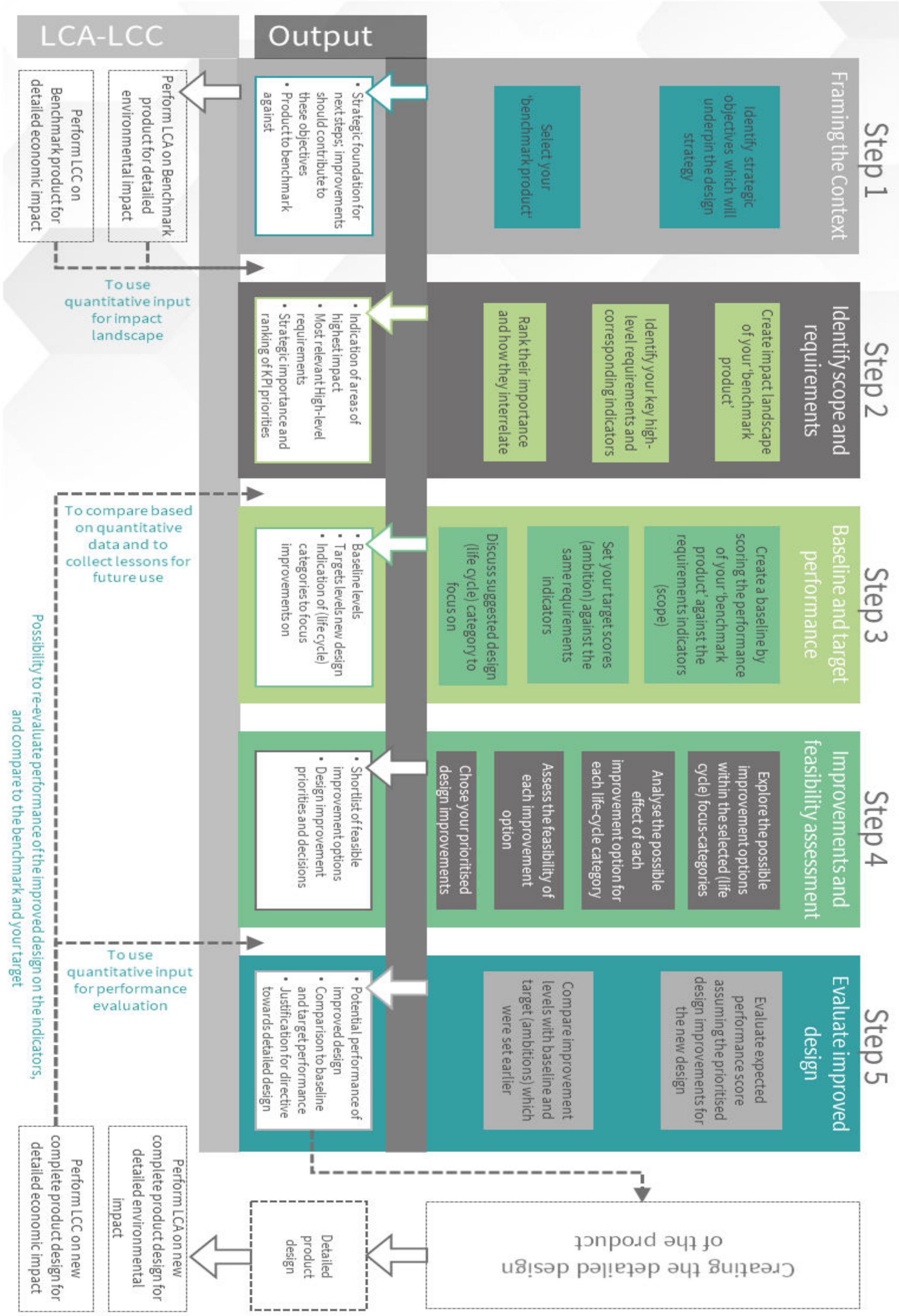

Figure 41: iEDGE Roadmap overview - Extended Quantitative option (incl. LCA-LCC)

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7. ANNEX

7.1. IEDGE TOOLKIT

This annex refers to the toolkit itself and is provided as a separate file.

7.2. IEDGE TOOLKIT ROADMAP SUMMARY BROCHURE

For the purpose of the LEVIS project and its partners, a separate brochure has been created as possible dissemination material. This “LEVIS_iEDGE Roadmap in a nutshell” provides a summary overview of the purpose, goals and visual structure of the toolkit.

7.3. THE COMPLETE ‘IEDGE’ TOOLKIT’ USE CASE

To clarify the usage of the iEDGE toolkit for the designers, a use case is produced to act as an example. The use case is shown in this chapter.

7.3.1. HOME PAGE

LEDGER	
Company name	Demo4Wheels
Project Title	P215/65R15 Wheel rim passenger vehicle design with eco-design principles
Project Leader	A. Demo
Product ID	TESTCASE1
Start Date	07/07/2021
Sign-off Date	
Sign-off signature	

7.3.2. FRAMING THE CONTEXT

Listing of overarching key ambitions, goals and obligations underpinning the design decisions		
Organisational objectives (Internal)		Comments
A	Deliver high quality products to our customers	Link company website, mission statement
B	Achieve net-zero emission production in 2040	Link company website, objectives
C	Be a job provider for local community	Have good relations with our surroundings
Trends and societal objectives		Comments
D	Transition to renewable energy	In line with Paris Agreement
E	Change to circular economy	Less waste and material security
F	<insert here>	
Compliance objectives		Comments
G	Compliance ISO 90001, 14001	Wish to maintain certification
H	Compliance EU Regulation No 124	Legal requirement
I	<insert here>	

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Description and specifications of the benchmark product	
Benchmark product	
Product name	Wheel4Bench
Model	X1
Manufacturer	Bench2Wheel
Serial no./product ID	W4BXX001
General description	Aluminium rim for high end passenger electric vehicles.
Justification (why this product as benchmark)	Bench2Wheel shares the same organisational and societal objectives as Demo4Wheels. The benchmark product (W4BXX001) has the same target audience as the TESTCASE1.
Picture(s)	

7.3.3. RIT - CHECKLIST

	Environmental	Economic	Technical	Social
1. Material selection				
What types of materials are used, and what impacts may be related to them:	Aluminium	Alumnium, relatively cheap	Aluminium, maintains strength and durability	
Where is the biggest cost impact associated to used materials (why)?		Aluminium, Only materials used.		
Consider the (relative) energy intensity of mining the(se) material(s)				
What is the likelihood that the mining of these material(s) generally require (potentially) dangerous procedures?				
Are there potential indications of ethical supply chain risks?				
Where is the material coming from? (consider transport of the material)	Bauxit mine Australia, Transport by ship	Bauxit mine Australia, high tranport costs		Bauxit mine Australia, relatively good working conditions
Does the material require specific type of transportation (procedure)?			Solid state, every transportation option is possible.	
Relative distances to transport				
What are considerations of critical properties of the materials?				
Known for certain necessary properties				
Any specific (such as surface) treatment needs			Paint, to decrease corrosion and look esthetically pleasing	
What are the current (other) considerations for the material choices?		Low costs	Lightweight, strong and durable	
What would potential dematerialization mean?	Re-use/recycle old rims	Less material potentially lowers purchase costs?	Structural optimization for efficienty purposes	
How well does the material lend itself to reduce without losing properties?				
Does the product use virgin (raw) materials or recovered (raw) materials?	Exclusively virgin materials, no recycling facility at place.			

Provisional Selection for EQFD	High-level Requirement	Indicator
1. Material selection	Use of recycled aluminium	% virgin material
2. Mining and Production	Use less energy during production	Energy consumption (kWh)
	Produce less greenhouse gas emissions during production	GHG emissions (kg CO2 eq.)
3. Transport and Distribution	Less plastic use for packaging	Kg plastic
4. Utilisation (First and Extended use)	Lightweigth product	kg product
5. End-of-life (Recovery and disposal)	Energy use during melting proces	Energy consumption (kWh)
6. Added functional value		

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High-level Requirement	Indicator	High-level Requirement	Indicator	High-level Requirement	Indicator
Possibility to re-sell-re-buy	Lifetime rim (years)	Long life-time	lifetime rim (years)		
Low material costs	costs in euros				
				Amount of incidents uring production	# incidents
				Good labour right standards in supply chain	percentage of suppliers in the chain certified with 'X'
Less product waste due to scratching	Waste /1000 rims produced				
		Lifetime/durability	Corrosion		
		Strong product	N/m2		
		Heat dispersion optimization	W/(m2K)		

7.3.4. EQFD

Design (life-cycle) strategies ↓	Importance rating	Justificication	High-level requirements - (What) ↓
1. Material selection	3	User requirement	Low material costs
	5	High-end product	Long life-time
	4	Social objectives	Use of recycled aluminium
2. Mining and Production	2	Social objectives	Use less energy during production
	5	CSR (corporate social responsibility)	Amount of incidents during production
	4	CSR (corporate social responsibility)	Good labour right standards in supply chain
	5	Organisational objectives	Produce less greenhouse gas emissions during production
3. Transport and Distribution	4	Social objectives	Less plastic use for packaging
	2	Social objectives & cost reduction	Less product waste due to damaged goods
4. Utilisation (First and Extended use)	5	User requirement & social objective	Lightweigth product
	5	User requirement	Strong product
	1	User requirement	Possibility to re-sell or re-buy
	4	User requirement	Durability
5. End-of-life (Recovery and disposal)	4	Social objectives	Energy use during melting proces
6. Added functional value	2	Tyre lifespan for user	Optimization of heat dispersion

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Subcategories	Ecological				Mining & production	Use & disposal	
Key Performance indicator (How) → **High-level requirements - (What) ↓**	% virgin material	Energy consumpion (kWh)	Amount of wrapping material (Kg plastic)	GHG emissions (kg CO2 eq.)	Investment costs (euros)	Wasted products /1000 rims produced	Add optional requirement
Low material costs	0	0	0	0	9	0	
Long life-time	1	3	1	9	1	0	
Use of recycled aluminium	9	1	0	3	3	0	
Use less energy during production	0	9	0	3	1	0	
Amount of incidents during production	0	0	0	0	0	0	
Good labour right standards in supply chain	0	0	0	0	1	0	
Produce less greenhouse gas emissions during production	3	3	1	9	1	1	
Less plastic use for packaging	1	0	9	1	1	9	
Less product waste due to damaged goods	0	1	9	3	1	9	
Lightweigth product	0	3	0	1	1	0	
Strong product	0	0	0	0	3	1	
Possibility to re-sell or re-buy	0	0	0	0	3	0	
Durability	0	0	0	1	0	0	
Energy use during melting proces	1	9	0	3	1	0	
Optimization of heat dispersion	0	1	0	1	1	0	
Strategic importance score	64	107	64	141	90	64	0
Importance %	6%	11%	6%	14%	9%	6%	0%
Priorities rank	**7**	**4**	**7**	**1**	**5**	**7**	**14**

Subcategories	Mechanical			Thermal			Protection		
Key Performance indicator (How) → **High-level requirements - (What) ↓**	Strength (N/m2)	Lifetime of rims (years)	Lightweight product (kg)	W/(m2K)	Add optional requirement	Add optional requirement	Corrosion	Add optional requirement	Add optional requirement
Low material costs	0	0	0	1			0		
Long life-time	3	9	0	0			9		
Use of recycled aluminium	1	1	0	3			0		
Use less energy during production	0	0	0	0			0		
Amount of incidents during production	0	0	0	0			0		
Good labour right standards in supply chain	0	0	0	0			0		
Produce less greenhouse gas emissions during production	0	0	0	0			0		
Less plastic use for packaging	0	1	0	0			1		
Less product waste due to damaged goods	1	0	0	0			0		
Lightweigth product	1	0	9	0			0		
Strong product	9	3	0	0			1		
Possibility to re-sell or re-buy	3	9	0	3			3		
Durability	9	9	0	0			3		
Energy use during melting proces	0	0	0	0			0		
Optimization of heat dispersion	0	0	0	9			3		
Strategic importance score	110	113	45	36	0	0	75	0	0
Importance %	11%	11%	5%	4%	0%	0%	8%	0%	0%
Priorities rank	**3**	**2**	**11**	**13**	**14**	**14**	**6**	**14**	**14**

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Subcategories	Employee health & safety		
Key Performance indicator (How) → **High-level requirements - (What) ↓**	# incidents	Percentage of suppliers certified with 'X'	Add optional requirement
Low material costs	0	0	
Long life-time	0	0	
Use of recycled aluminium	0	0	
Use less energy during production	0	0	
Amount of incidents during production	9	1	
Good labour right standards in supply chain	1	9	
Produce less greenhouse gas emissions during production	0	0	
Less plastic use for packaging	0	0	
Less product waste due to damaged goods	0	0	
Lightweigth product	0	0	
Strong product	0	0	
Possibility to re-sell or re-buy	0	0	
Durability	0	0	
Energy use during melting proces	0	0	
Optimization of heat dispersion	0	0	
Strategic importance score	49	41	0
Importance %	5%	4%	0%
Priorities rank	**10**	**12**	**14**

7.3.5. PERFORMANCE EVALUATION

	Key Performance indicator (How) →	% virgin material	Energy consumpion (kWh)	Amount of wrapping material (Kg plastic)	GHG emissions (kg CO2 eq.)	Investment costs (euros)	Wasted products /1000 rims produced	Add optional requirement
Design (life-cycle) strategies ↓	**Product - (Which) ↓**							
1. Material selection	Benchmark performance	1	2	0	2	5	0	
	Target	3	4	0	5	4	0	
	Improved design	1	2	0	3	3	0	
2. Mining and production	Benchmark performance	1	1	0	1	3	5	
	Target	4	4	0	5	3	5	
	Improved design	1	1	0	1	3	5	
3. Transport and Distribution	Benchmark performance	0	3	1	2	4	3	
	Target	0	3	4	3	4	4	
	Improved design	0	4	4	4	2	5	
4. Utilisation (First and Extended use)	Benchmark performance	0	0	0	0	3	0	
	Target	0	0	0	0	4	0	
	Improved design	0	0	0	0	3	0	
5. End-of-life (Recovery and disposal)	Benchmark performance	1	2	0	1	4	0	
	Target	4	5	0	4	4	0	
	Improved design	1	2	0	1	4	0	
6. Added functional value	Benchmark performance	0	0	0	0	0	0	
	Target	0	0	0	0	0	0	
	Improved design	0	0	0	0	0	0	

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Design (life-cycle) strategies ↓	Key Performance indicator (How) → Product - (Which) ↓	Strength (N/m2)	Lifetime of rims (years)	Lightweight product (kg)	W/(m2K)	Add optional requirement	Add optional requirement	Corrosion
1. Material selection	Benchmark performance	3	3	4	3			2
	Target	3	4	5	4			4
	Improved design	3	4	4	3			4
2. Mining and production	Benchmark performance	4	4	2	3			4
	Target	4	4	3	3			4
	Improved design	4	4	2	3			4
3. Transport and Distribution	Benchmark performance	0	0	0	0			0
	Target	0	0	0	0			0
	Improved design	0	0	0	0			0
4. Utilisation (First and Extended use)	Benchmark performance	0	3	0	0			2
	Target	0	4	0	0			4
	Improved design	0	3	0	0			5
5. End-of-life (Recovery and disposal)	Benchmark performance	0	0	0	0			0
	Target	0	0	0	0			0
	Improved design	0	0	0	0			0
6. Added functional value	Benchmark performance	0	0	0	3			0
	Target	0	0	0	4			0
	Improved design	0	0	0	3			0

Design (life-cycle) strategies ↓	Key Performance indicator (How) → Product - (Which) ↓	# incidents	Percentage of suppliers certified with 'X'	Add optional requirement	Total
1. Material selection	Benchmark performance	2	0		2,7
	Target	4	0		4,0
	Improved design	4	0		3,1
2. Mining and production	Benchmark performance	3	1		2,7
	Target	5	5		4,1
	Improved design	5	5		2,9
3. Transport and Distribution	Benchmark performance	4	4		2,8
	Target	4	4		3,6
	Improved design	4	5		3,9
4. Utilisation (First and Extended use)	Benchmark performance	5	0		3,1
	Target	5	0		4,1
	Improved design	5	0		3,8
5. End-of-life (Recovery and disposal)	Benchmark performance	4	4		2,3
	Target	4	4		4,2
	Improved design	4	5		2,4
6. Added functional value	Benchmark performance	0	0		3,0
	Target	0	0		4,0
	Improved design	0	0		3,0

7.3.6. STRATEGY DASHBOARD

Design (life-cycle) strategies ↓	Performance scoring		
	Baseline design	Target	Improved design
1. Material selection	2,7	4,0	3,1
2. Mining and production	2,7	4,1	2,9
3. Transport and Distribution	2,8	3,6	3,9
4. Utilisation (First and Extended use)	3,1	4,1	3,8
5. End-of-life (Recovery and disposal)	2,3	4,2	2,4
6. Added functional value	3,0	4,0	3,0

OUTPUT: Suggested focus	
No. 1	5. End-of-life (Recovery and disposal)
No. 2	2. Mining and production
No. 3	1. Material selection

DECISION: Chosen focus	
No. 1	5. End-of-life (Recovery and disposal)
No. 2	2. Mining and production
No. 3	3. Transport and Distribution

Comments: Material selection in this case not a real possibility since the available options are scares and not feasible.

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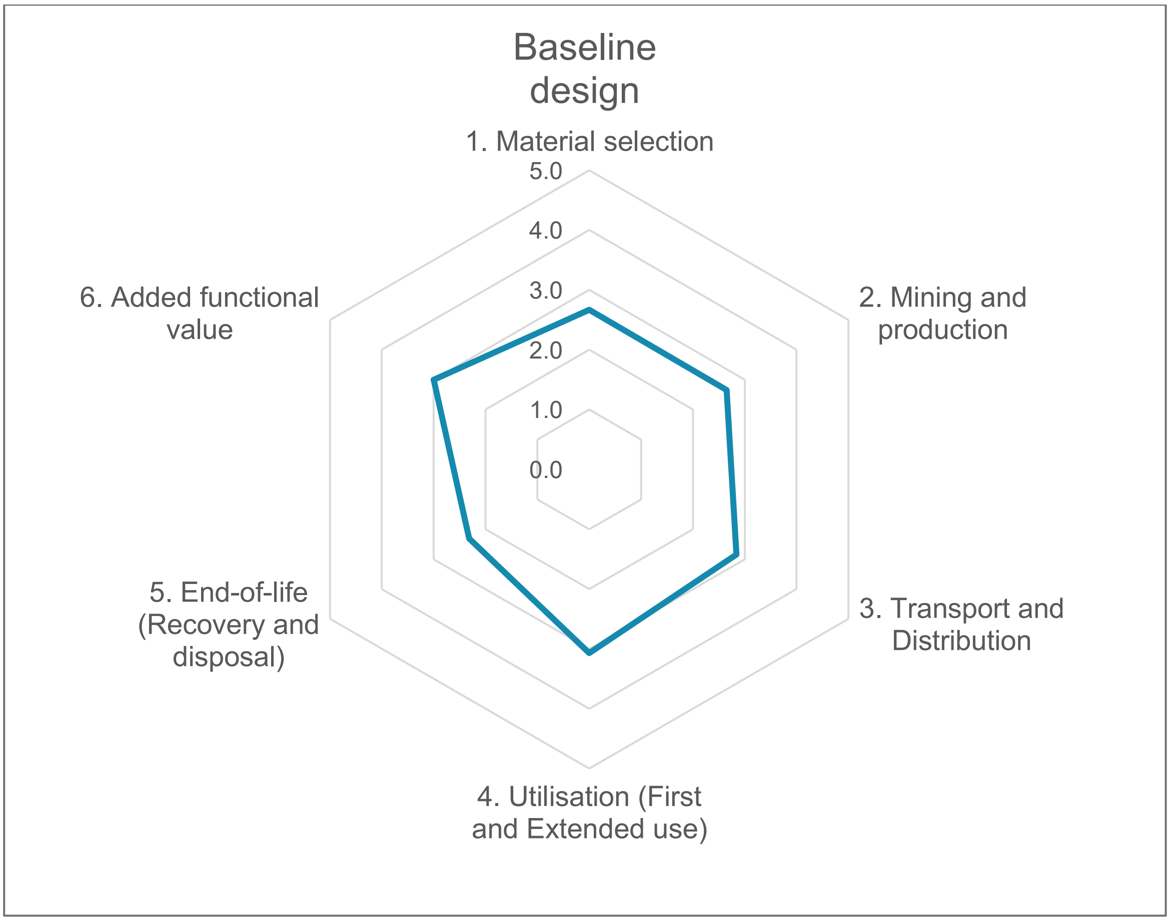
OUTPUT: Suggested top 5 focus KPIs					
5. End-of-life (Recovery and disposal)		2. Mining and production		3. Transport and Distribution	
No. 1	GHG emissions (kg CO2 eq.)	No. 1	GHG emissions (kg CO2 eq.)	No. 1	Amount of wrapping material (Kg plastic)
No. 2	Energy consumpion (kWh)	No. 2	Energy consumpion (kWh)	No. 2	GHG emissions (kg CO2 eq.)
No. 3	% virgin material	No. 3	% virgin material	No. 3	Wasted products /1000 rims produced
No. 4		No. 4	Percentage of suppliers certified	No. 4	
No. 5		No. 5	# incidents	No. 5	



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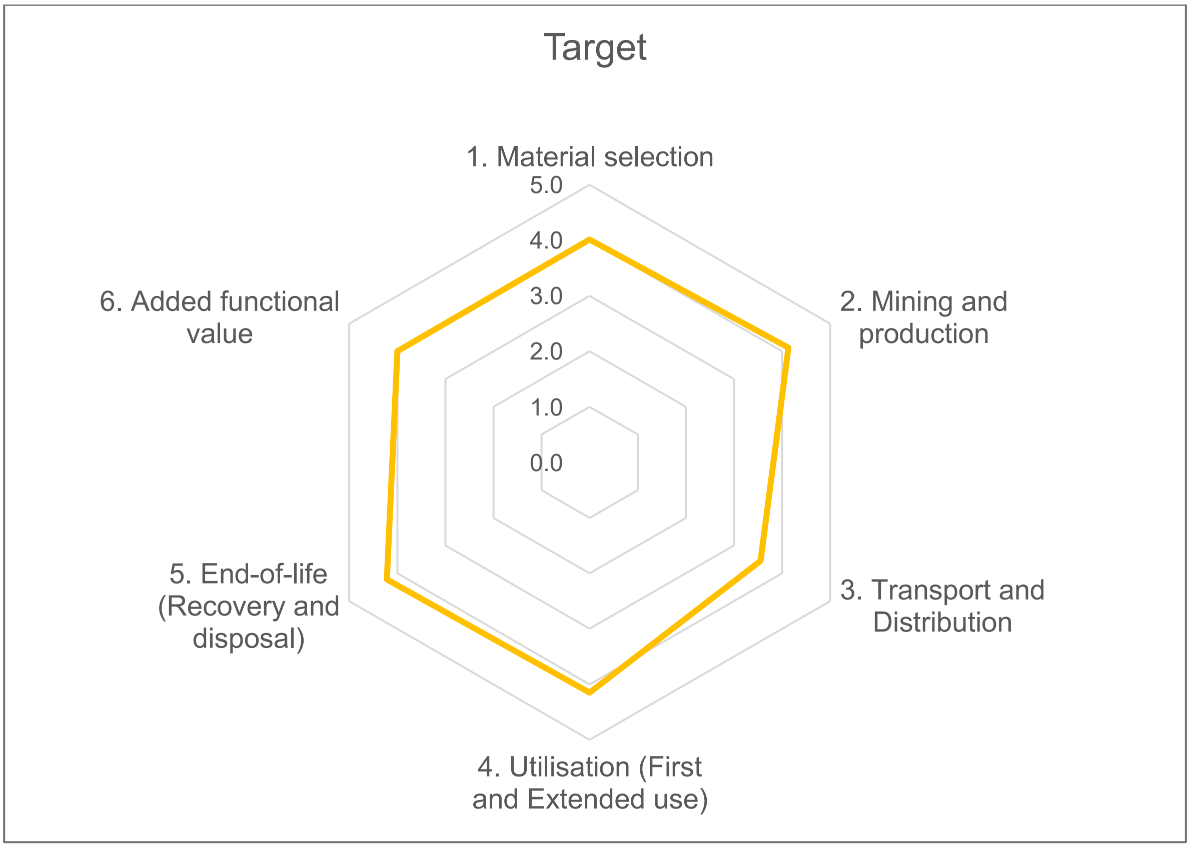

7.3.7. IMPROVEMENTS & FEASIBILITY

Design (life-cycle) strategies	Top 5 KPIs	No.	Improvement option	Application Description	Intended KPI effect
2. Mining and production	**GHG emissions (kg CO2 eq.)** **Energy consumpion (kWh)** **% virgin material** **Percentage of suppliers certified with 'X'** **# incidents**	2.0	Use recycled aluminium	Instead of using only virgin material, mix it with a "X" percentage of recycled material when folding and casting the aluminium	% virgin material, GHG emissions (kg CO2 eq.)
		2.1	Change brand surface treatment	Use a brand of surface treatment that ensures certifications of good labour rights across the supply chain.	Percentage of suppliers certified with 'X'
		2.2			

Effect on design (life-cycle) categories					
Design categories	**Environmental**	**Economic**	**Technical**	**Social**	**Reasoning**
1. Material selection	Positive	Negative	Negative	Positive	Positive environmentlale effect cause less virgin material is needed. However, decreases over time the purity of the aluminium rims which decreases the technical spects. Also costs increases.
2. Mining and production	Positive	Negative	Negative	Positive	
3. Transport and Distribution	Neutral	Neutral	Neutral	Neutral	
4. Utilisation (First and Extended use)	Neutral	Neutral	Neutral	Neutral	
5. End-of-life (Recovery and disposal)	Neutral	Neutral	Neutral	Neutral	
6. Added functional value	Unknown	Unknown	Unknown	Unknown	
1. Material selection	Positive	Negative	Positive	Positive	A new brand is more expensive, but it does provide certainty on that the requirement for good labour conditions are met. Brand also protects the rim better against corrosion.
2. Mining and production	Neutral	Neutral	Positive	Positive	
3. Transport and Distribution	Neutral	Neutral	Neutral	Neutral	
4. Utilisation (First and Extended use)	Positive	Neutral	Neutral	Neutral	
5. End-of-life (Recovery and disposal)	Neutral	Neutral	Neutral	Neutral	
6. Added functional value	Unknown	Unknown	Unknown	Unknown	

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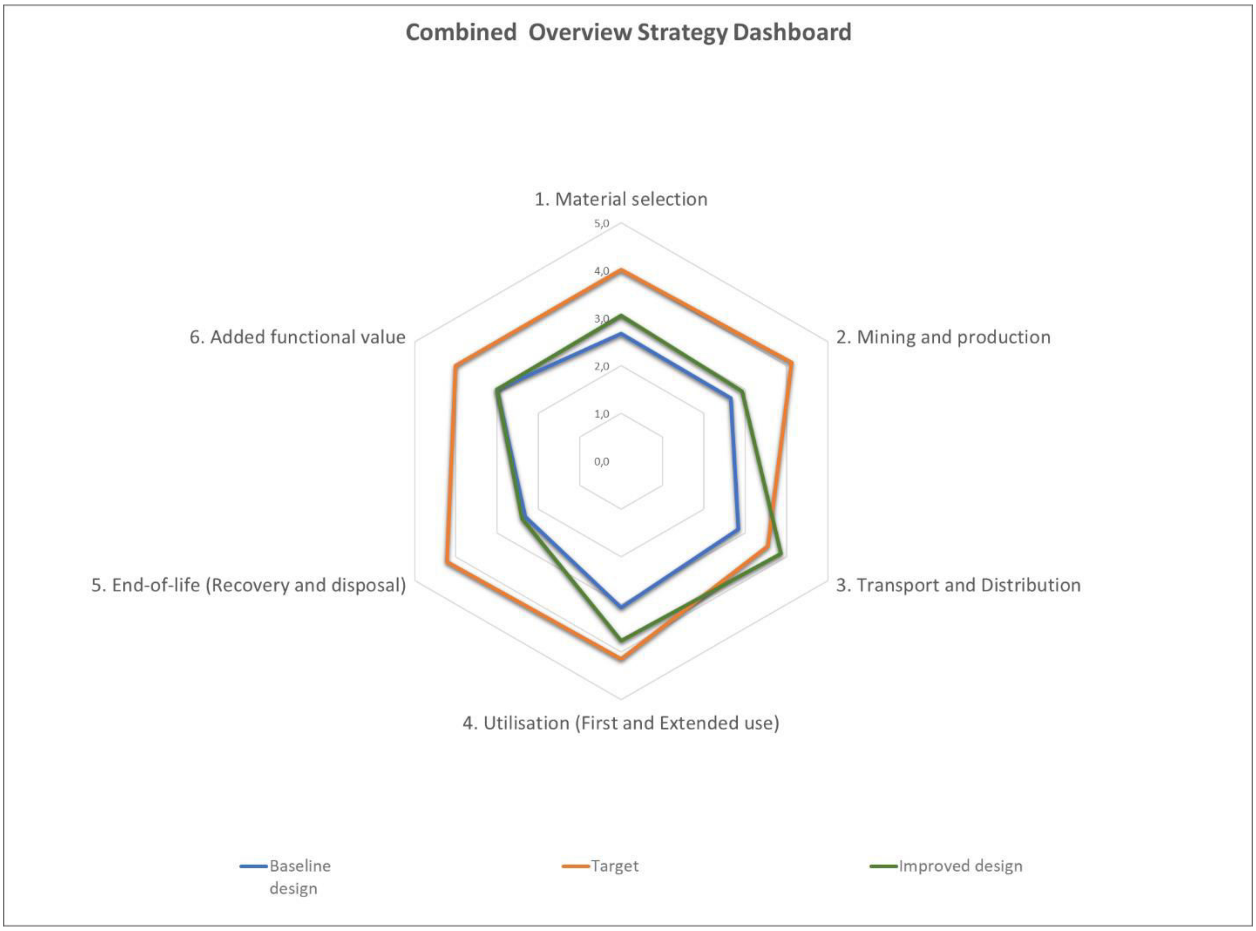
Design priorities: Selecting your case-specific eco-design principles				
Feasibility	Desirability	Priotity	New design choice	Justification notes
Feasible-short term	Desirable	**High Priority**	**No**	Desirable and feasible, but not enough investment money available when combined with other design improvement options.
Feasible-short term	Desirable	**High Priority**	**Yes**	

7.3.8. RESULT



Product specific (eco-)design principles			
Id.	**Life cycle strategy**	**Improvement option**	**Requirements related KPIs**
2.1	**2. Mining and production**	Change brand surface treatment	Percentage of suppliers certified with 'X'
3.0	**3. Transport and Distribution**	Use strong wooden boxes with foam on the inside walls for packaging	Amount of wrapping material (Kg plastic), Wasted products /1000 rims produced

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