D1.3. Ecodesign guideline covering environmental, material criticality and circularity considerations

Reinventing High-performance pOwer converters for heavy-Duty electric trAnSport

Grant Agreement Number 101056896

Deliverable name:	Ecodesign guideline covering environmental, material criticality and circularity considerations
Deliverable number:	1.3
Deliverable type:	R
Work Package:	WP1: System specifications; components and materials. Ecodesign considerations
Lead beneficiary:	VALEO EMBRAYAGES/ VALEO EAUTOMOTIVE
Contact person:	Rainer Pamminger; rainer.pamminger@tuwien.ac.at
Dissemination Level:	PU
Due date for deliverable:	January 31, 2023

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

DOCUMENT CONTROL PAGE

Author(s):	Rainer Pamminger, Sebastian Glaser, Philipp Feuchter
Contributor(s):	TUW, VAL, VS, UPC, AIT, AU
Reviewer(s):	UPC
Version number:	v.4 M9
Contractual delivery date:	31 – 01 – 2023
Actual delivery date:	31 – 01 – 2023
Status:	Submitted

REVISION HISTORY

Version	Date	Author/Reviewer	Notes
v.1	14 – 12 – 2022	Pamminger (TUW)	Creation, First Draft
v.1.1	10 – 01 – 2023	Barbu (AU)	Input from AU
v.1.2	19 – 01 – 2023	Lumbreras (UPC)	Input from UPC
v.1.3	23 – 01 – 2023	Thibault (VAL)	Input from VAL
v.1.4	23 – 01 – 2023	Waider (VS)	Input from VS
v.1.5	23 – 01 – 2023	Jaber (AIT)	Input from AIT
v.2 M9	25 – 01 – 2023	Pamminger (TUW)	Final, Ready for review
v.3 M9	30 – 01 – 2023	Alvarez (UPC) / Lumbreras (UPC)	Reviewed
v.4 M9	31 – 01 – 2023	Romeral (UPC)	Final version submitted

ACKNOWLEDGEMENTS

The work described in this publication was subsidised by Horizon Europe (HORIZON) framework through the Grant Agreement Number 101056896.

DISCLAIMER

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

EXECUTIVE SUMMARY

The deliverable describes the methodology of the Ecodesign process with a focus on environmental-, criticality- and circularity considerations concerning the integrated motor drive (IMD). A Life cycle assessment (LCA) screening according to the ISO 14040/44 standard is performed for the environmental consideration.

Within the project 30 % of the total IMD's Global Warming Potential (GWP) should be reduced. The methodology for circularity and criticality is roughly presented and still under development. Reference products and intended improved solutions, needed for later assessments, are described as far as possible. Furthermore, conceptual material/product selection matrixes, as part of the Ecodesign Guideline are presented.

As detailed in the description of the action, the updated version of this deliverable will be presented by month 15.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 DESCRIPTION OF THE DOCUMENT AND PURSUE

This report describes the RHODAS Ecodesign considerations. Within the RHODaS project the integrated motor drive (IMD) powertrain will be analysed on an environmental basis. The Technical University of Vienna (TUW) will guide the project in this direction and will perform several assessments on the environmental burdens, the material criticality and on the material circularity. This document is a first draft for deliverable 1.3 (D1.3) for M9. The tasks, a timetable, the guiding questions, the planned results, and the methodology are roughly presented.

Table 1 shows the preliminary timeline for the Task 1.6 and Task 1.7 and both deliverables in D1.3 M9 and D1.3 M15.

Table 1.1: Primary timeline for Task 1.6 and 1.7 (own illustration).

Task	Timeline
Definition of reference product	Dec 2022
Data acquisition, LCA Screening	Dec 2022 – Jan 2023
Deliverable D1.3 in M9	Jan 2023
LCA Screening	Jan – Feb 2023
Circularity and Criticality Screening	Feb – Mar 2023
Ecodesign Guideline	Mar – May 2023
Deliverable D1.3 in M15	Jul 2023

In Figure 1.1 the Ecodesign methodology in the RHODaS project is illustrated.

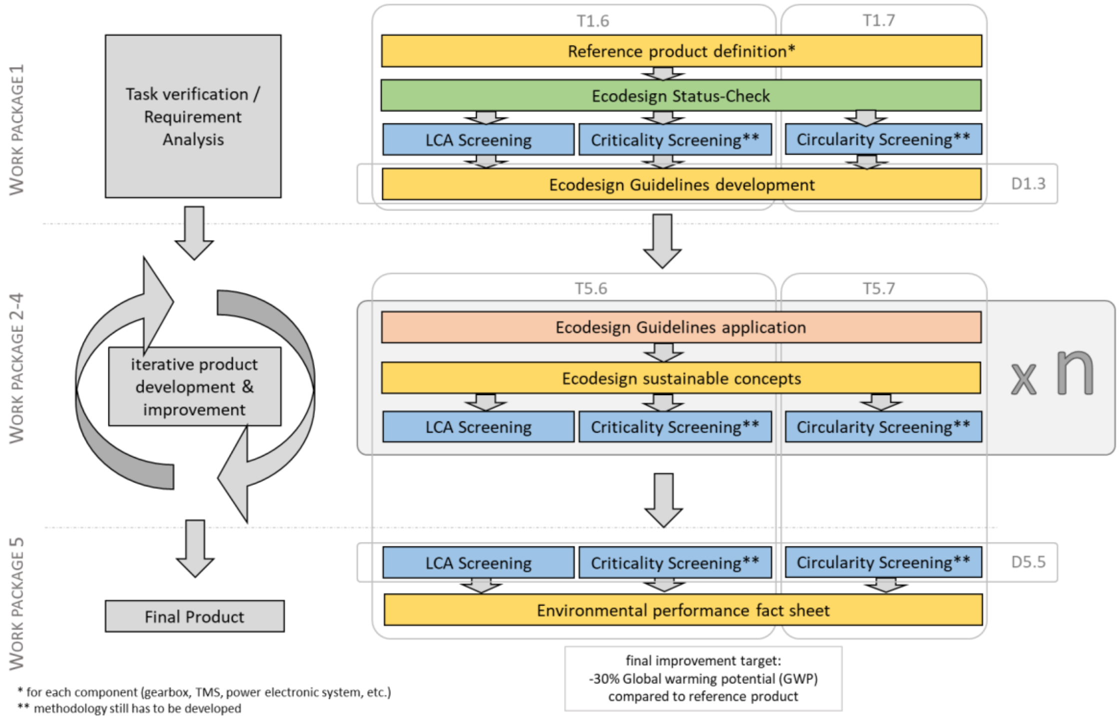


Figure 1.1: Ecodesign Methodology of RHODaS project (own illustration).

1.2 WPS AND TASKS RELATED WITH THE DELIVERABLE

This deliverable refers to Task 1.6 and Task 1.7 included in WP1: System specifications; components and materials. Ecodesign considerations.

2 Detailed description of work package 1

The methodology for work package 1 is described in chapter 2.1. In work package 1 the TUW has two tasks (T1.6 & T1.7) and one deliverable (D1.3). The first task, T1.6, and the deliverable, D1.3, as defined in the proposal, are described in chapter 2.2.

2.1 METHODOLOGY FOR WORK PACKAGE 1

The methodology for D1.3 is shown in Figure 2.1 for work package 1. Following the definition of the reference product a Ecodesign Status Check will be performed to evaluate the current status of reference product data availability. After data collection a first LCA screening, a criticality screening (T1.6) and a circularity screening (T1.7) will be performed. Moreover, within a workshop together with the producer information about the production process of the component is collected and first product design ideas are generated. Additionally, literature research is used to collect further data and information. The assessment results are translated into the Ecodesign Guideline (D1.3) in the next step. The Ecodesign Guideline is meant as a supporting method for product development to make decisions towards a more environmentally friendly product. This Ecodesign Guideline also includes elements like material selection matrixes / property charts.

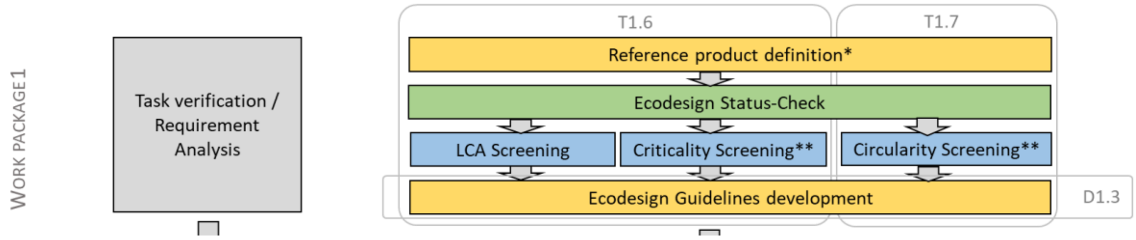


Figure 2.1: Ecodesign Methodology of RHODaS project – Work package 1 (own illustration).

2.2 DESCRIPTIONS OF TASKS T1.6 AND T1.7

T1.6 Specifications from environment and material criticality (M6-M15) (Lead: TUW; Participants: VAL, VS)

"In this task, specifications for the powertrain development covering environmental and material criticality considerations are deeply evaluated by TUW, who will gather data provided by material manufacturers (VisIC, GaN Technologies) for assessing the environmental performance and material criticality of new WBG dies and components, where generic datasets are currently not available at all. Beside the semiconductor parts, the environmental performance of the whole powertrain is assessed using streamlined LCA in T5.6. Weak spots and improvement potentials from an environmental and material criticality (rare earth metals) point of view are identified with the support from VAL and VS. Recommendations are included in an Ecodesign guideline report, including material selection matrixes and property charts covering environmental indicators, costs, technical parameters etc. are developed. This Ecodesign guideline report is used as a decision support tool in the design process (WP4) of the elements of the powertrain."

T1.7 Circularity considerations (M6-M15) (Lead: TUW; Participants: UPC, AIT, AU, BOS, VAL, VS)

"Considering End-of-life and circular strategies for the powertrain's components, e.g., to influence design for separating and recovering the powertrain parts that can be more easily treated, recycled, repaired etc. Realisation of circular designs of powertrains is also carried out by TUW, with the support from project partners UPC, AIT, AU, BOS and

especially VAL and VS. Circular design requirements along different circular design strategies are detailed in the Ecodesign guideline report included in D1.3."

2.3 DESCRIPTION OF DELIVERABLE 1.3 (D1.3)

D1.3 Ecodesign guideline covering environmental, material criticality and circularity considerations (T1.6, T1.7) (R) (M9, M15) (Responsible: TUW)
The deliverable 1.3 (D1.3) is divided into 2 parts, with the respective deadlines in M9 and M15.

M9: concept Ecodesign guideline: definition of reference elements of powertrain, scope, boundaries, scenarios for streamlined LCA. First results and learnings from LCA screening. Description of Method: -for supporting the product development / design process regarding LCA, Circularity and Criticality. Definition of the material selection matrixes.

M15: final Ecodesign guideline: including elaborated content by the means of recommendations for environmental assessment of SiC / GaN devices, material selection matrixes, final Ecodesign guideline. Results of initial assessment (LCA-, Circularity- and Criticality Screening) covering the powertrain, identified weak spots.

3 Reference Product definition

For environmental assessments it is necessary to have a reference product to be able to compare the results with and to know where to focus on. The reference product is mostly the product that should be improved or a product with a comparable performance. The powertrain comprises the elements required to provide power to the wheel. The power output of the powertrain targeted in the project is 150 kW. The powertrain can be divided into an electro-mechanical-, the electronic- and a thermal system. Figure 3.1 shows the elements and systems of the power train.

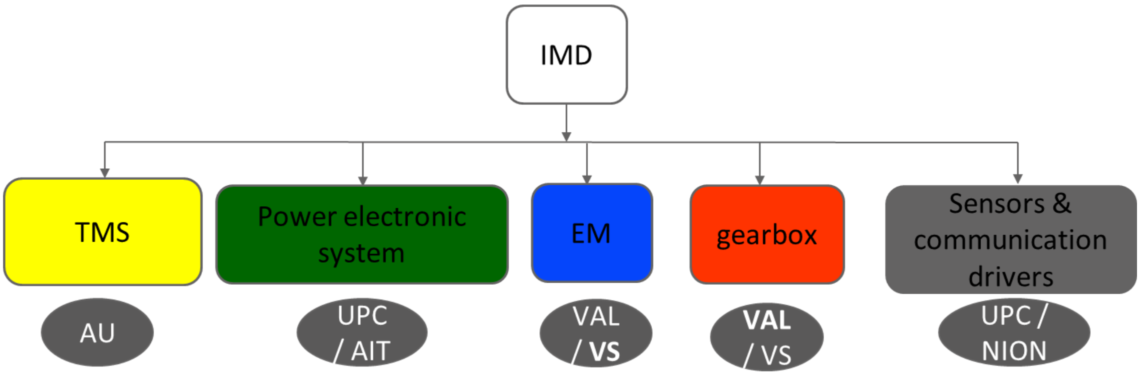


Figure 3.1: Powertrain subcomponents and partners (own illustration in accordance with RHODaS consortium).

The electro-mechanic system includes the electric motor (EM) and the gearbox. The electronic system includes the power converter and systems for control and monitoring (Power electronic system + Sensors and communication drivers). The thermal system (TMS) includes the system for cooling the inverter and the electric motor.

3.1 THERMAL MANAGEMENT SYSTEM

The thermal management system (TMS) may, among others, have the following main tasks:

- Ensure the junction temperature of power semiconductors is kept below the maximum allowed limit by the manufacturer
- Detect and possibly handle overload situations

The description below regarding the TMS will be limited to the discussion related to the environmental impact of design choices of another existing similar project.

A reference product of the TMS is still missing but will be added here later. Instead, a reference project is presented.

3.1.1 DESCRIPTION OF THE TMS REFERENCE PROJECT

A recent EU project, DriveMode, is used as a reference (EU horizon 2020 grant Nr. 769989), for being approximately of a similar size and already optimized product. The following description is based on the DriveMode documentation of the basic concept of the cooling circuit [1]. It will not only describe relevant major components of the DriveMode system but also the minor subsystems, such as liquid pressure control systems, air removal, filtration and so on.

The motor and inverter were designed specifically for the DriveMode project. (The motor in RHODAS is an existing motor design that cannot be changed). The final design was then to cool the motor and inverter with Glycol as seen in Figure 3.2. The gearbox was cooled with oil, but that was not part of the cooling system in the project. It used one coolant pump per propulsion of the motor and inverter. As coolant, 1.1 litres of a 50% water + 50% glycol mixture were used. The integrated power module used for the inverter was directly designed for the project, such that the power module had a direct interface to the glycol. This avoided the need for a cold plate and thermal paste and thus decreased the thermal resistance from semiconductor junction to glycol.

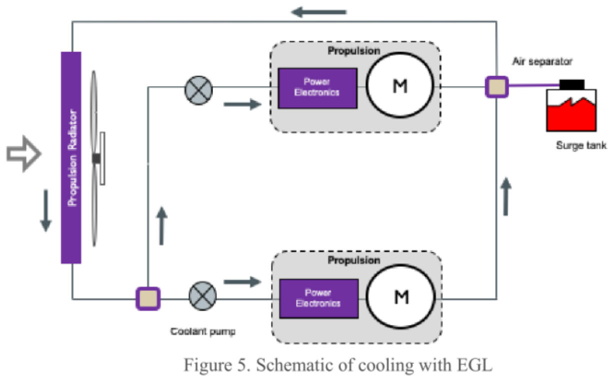


Figure 3.2: Cooling system used in the DriveMode project (shared by AU).

3.1.2 DESCRIPTION OF INTENDED TMS (IMPROVED SOLUTION)

3.1.2.1 GRAPHIC OF THE PROPOSED TMS

Including all main components/functions and all inputs (energy, fluids, etc.) and outputs (emissions, heat, etc). The proposed system is limited by design choices. The motor is designed for oil cooling, and the expected test setup requires some coolant for the inverter cooling.

The TMS key components are shown in Figure 3.3. Note that coolants and pumps are outside the scope of the project, but may be implemented to test the IMD and the proposed cooling systems (heatsinks, heat pipes...).

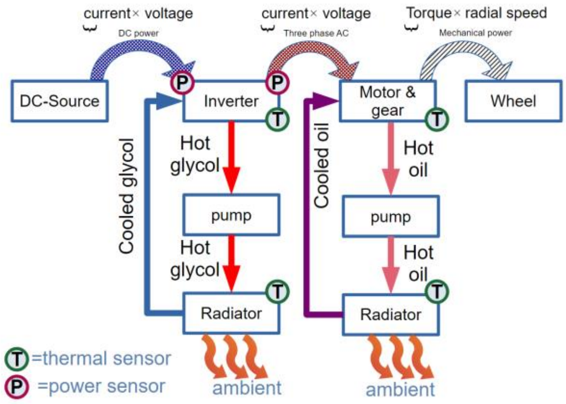


Figure 3.3: Proposed cooling circuit (shared by AU).

The inverter is sourced from a DC-source, and it directly powers an existing three-phase Permanent Magnet Synchronous Motor (PMSM). The gearbox may not be used in the project, so it is set as a part of the motor.

The key features of the TMS are:

- Monitor and measure temperatures to send warning/alarms to the main system control unit.
- Evaluate the thermal loading of the system components regarding the lifetime, using the thermal sensors T and the power sensors P.
- Calculate the maximum power/current under overload conditions for the motor control.
- Ensure the junction temperature of semiconductor devices not to exceed the limit.

3.1.2.2 INTERFACES TO OTHER COMPONENTS OF THE IMD

The detailed list of the required electrical interfaces is specified in the electrical requirements section.

For the 150 kW test setup:

- The inverter is connected to a cold plate by the glycol coolant. The exact type of glycol used will be determined at a later stage.
- Motor is connected to the oil cooling system through the bearings. The exact type of oil used will be determined at a later stage.
- The TMS communicates to the control system state machine and the inverter.

This was also described in D1.1 but is repeated here due to its relevance.

The proposed TMS intends to reduce the negative effect of high thermal loading by ensuring sufficient cooling. The cooling is ensured by monitoring the system conditions and using active prediction to limit the thermal loading of the IMD and the aging. This is considered to be a potential improvement relative to the reference project.

The active prediction is based on detailed thermal models of the main components and is evaluated on the fly in the drive. This quasi-real-time detailed thermal model is also used to estimate the remaining useful lifetime of the converter. The needed detail level of the thermal model will be determined based on the test and the CFD/FEM simulations, which is again considered to be an improvement compared to the reference project.

A small-scale two-phase cooling system may also be tested. The two-phase cooling can potentially reduce the size and weight of the cooling system. This is also considered as a potential improvement. Different dual-phase materials may be considered, and different pumping/valve setups may also be considered.

The environmental impact of the cooling system is reduced, since the amount of coolant is reduced, and the amount of material used for the radiator may also be reduced/optimized. It is also expected in the small-scale trial to remove the pump for glycol and use the evaporation – condensation cycle to move the liquid. The design will consider two major topologies for the two-phase system: heat pipe and thermal syphon.

Due to the high thermal loading of the inverter, the connection to the cold plate becomes critical. This requires a detailed investigation into the required smoothness of the power components and the cold plate. Furthermore, an optimised pattern of the thermal paste also needs to be investigated, together with an investigation of the thermal behaviour of involved materials (thermal expansion/thermal conduction/mechanical contact for power connections).

3.2 POWER ELECTRONIC SYSTEM

The main components consist of the power stage and the control unit, responsible of delivering power to the motor and performing advanced control and modulation techniques, respectively. The proposed design will be compared to a previous inverter that has been developed within the scope of the HORIZON 2020 Project FITGEN, which is of similar size and power range.

3.2.1 DESCRIPTION OF THE REFERENCE POWER ELECTRONIC SYSTEM (STATUS QUO)

The electronic system consists mainly of the power converter with its control and sensors. The power converter is connected to a battery, which supplies direct current, and to the motor. The converter transforms the direct current received from the battery into alternating current which controls the motor.

Currently, power converters used in the automotive industry are very large, use several materials and are located far away from the motor. The power converter developed at RHODAS will be integrated with the motor to form a compact IMD. In addition, most commercial converters are based on silicon.

A 6-phase 2-level SiC-based inverter, which was developed during the EU project FITGEN (GA #824335) was chosen as a reference system. The maximum output power of the reference inverter is 180 kW which corresponds to the power range of the proposed RHODAS design (150 – 250 kW).

The reference power electronic system consists of the 6-phase power inverter stage and an additional DC/DC converter with a maximum output voltage of 750V. In the scope of the project, its main use case was the control of a 6-phase Buried Permanent Magnet-Synchronous machine (BPM-SM) with a continuous output power of 70 kW. Like RHODAS, the tight integration of the motor and power-electronics within one case was one major concern.

3.2.1.1 GRAPHIC OF THE POWER ELECTRONIC SYSTEM

A detailed explosion view of the inverter is shown in Figure 3.4.

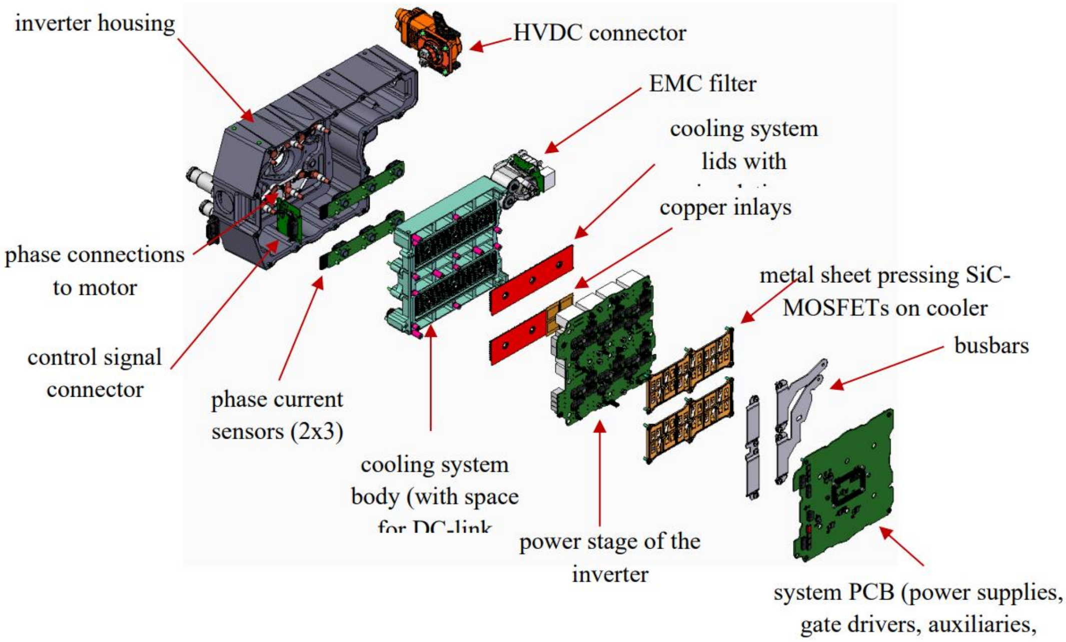


Figure 3.4 Explosion view of the FITGEN reference inverter with all the main components [2].

3.2.1.2 LIST OF MAIN-COMPONENTS OF THE POWER ELECTRONIC SYSTEM

The main components of the power electronic system are: System PCB, Power stage, cooling system body, busbar, inverter housing.

3.2.1.3 INTERFACES OF THE POWER ELECTRONIC SYSTEM TO OTHER COMPONENTS OF THE IMD

The electronic system is connected to the battery of the electric vehicle and the engine. The thermal management system is also connected to the inverter, as it must dissipate the heat produced in the inverter. The inverter communicates via CAN bus interface with the vehicle control unit (VCU). The interfaces of the power electronic system are shown in Figure 3.5.

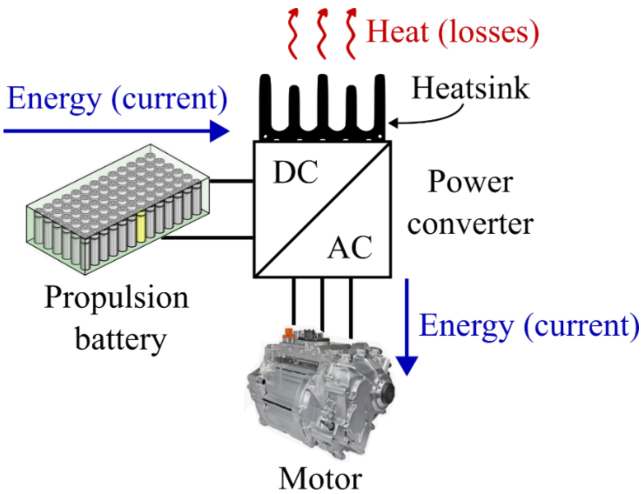


Figure 3.5: Power electronic system (shared by UPC).

3.2.2 DESCRIPTION OF INTENDED POWER ELECTRONIC SYSTEM (IMPROVED SOLUTION)

The developed inverter that will be implemented within RHODAS, has to handle a maximum DC-link voltage of up to 1000 V. The three-level T-type inverter design increases the efficiency of the drive, in certain load points. This is an advantage especially under partial load conditions. Due to the hybrid design (combination of GaN and SiC semiconductors) the inverter losses should be reduced in comparison to state-of-the-art inverters.

3.2.2.1 DESIGN CHANGES COMPARED TO THE REFERENCE PRODUCT (WHICH COMPONENTS ARE DIFFERENT? WHAT HAS TO BE CHANGED? MATERIAL, DESIGN, ETC.)

The proposed power stage of the inverter consists of different types of semiconductors. For the common source branch, GaN semiconductors will be used instead of SiC semiconductors. The developed inverter within RHODAS will not include a DC/DC converter, which will further simplify the overall design.

The proposed inverter will be a 3-phase 3-level inverter. Fewer phases also drop the need for additional sensors (e.g., current sensors), whereas the offered additional voltage level (provided by the common-source branch) leads to an increase of the efficiency in partial load points.

3.2.2.2 WHICH DIFFERENT MATERIAL/DESIGN OPTIONS OF THE POWER ELECTRONIC SYSTEM WILL BE LOOKED AT DURING THE PROJECT?

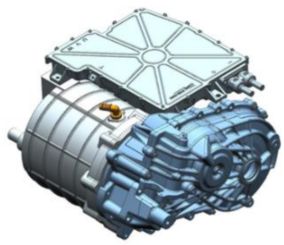
Different busbar designs will be simulated and compared during the developing phase. The power stage design depends on the availability of power modules for the GaN branch of the RHODAS T-type inverter. If there is no available GaN module, discrete semiconductors must be combined with SiC power modules. If such a combination is necessary, the design must be adjusted accordingly to keep commutation loops small.

3.3 ELECTRIC MOTOR (EM)

3.3.1 DESCRIPTION OF THE REFERENCE EM (STATUS QUO)

Depicted in Table 3.1 are current products in series production as status quo of usual applications in electric powertrains.

Table 3.1: Current EMs in series production (shared by VS).

Standalone P2,5 hybrid eDrive	Standalone BEV eMotor	Partly integrated drivetrain system
50kw	150kw	250kw
		

3.3.1.1 FUNCTION OVERVIEW OF THE EM

In Table 3.2 the main functions of the electric motor are presented.

Table 3.2: Function overview of the EM (shared by VS).

Primary function	• Transferring electrical power to mechanical power to provide required torque at a specific speed
Secondary functions	• Provide speed information sensor signal • Provide temperature sensor signal • Provide mechanical structures to transfer torque and force load
As part of the high voltage subsystem further functions	• durable insulation HV parts against ground and phase to phase • Protection against contact of HV parts • Thermal safety (overheat protection)

3.3.1.2 IN- OUTPUT VISUALISATION OF THE EM

In Figure 3.6 the Input and Output material and energy flows of the EM are shown.

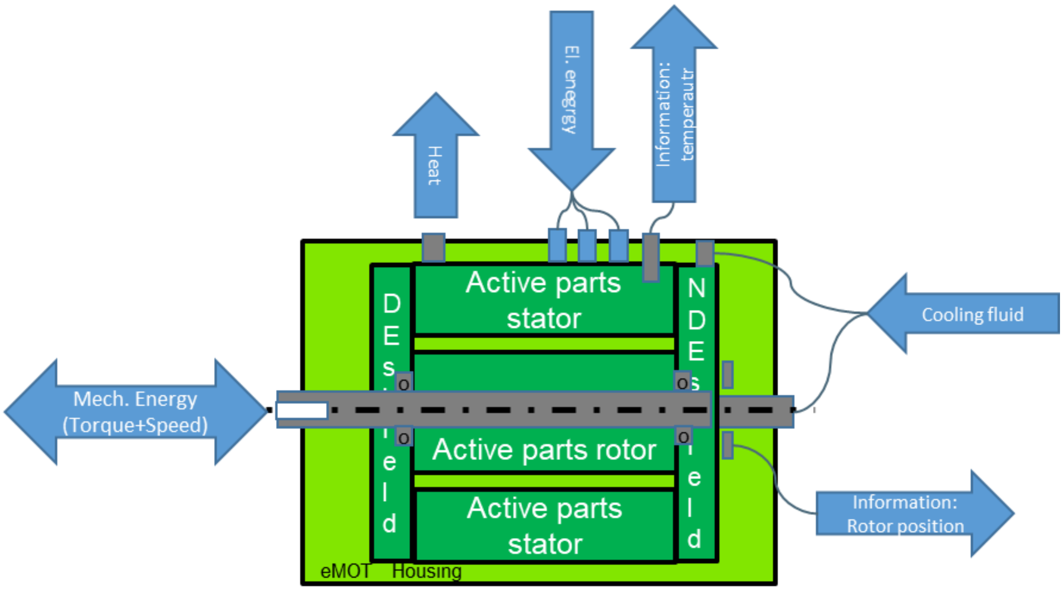


Figure 3.6: Input- / Output flows of the EM (shared by VS).

3.3.1.3 INTERFACES OF THE EM TO OTHER COMPONENTS OF THE IMD

In Figure 3.7 a general overview of the IMD is shown. In Figure 3.8 an interface overview of the EM is presented.

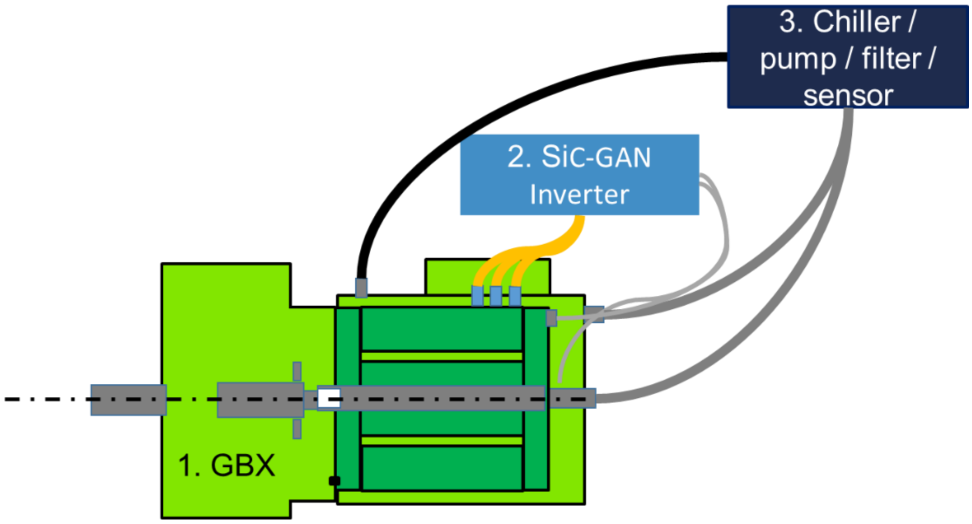


Figure 3.7: General interface overview of the IMD (shared by VS).

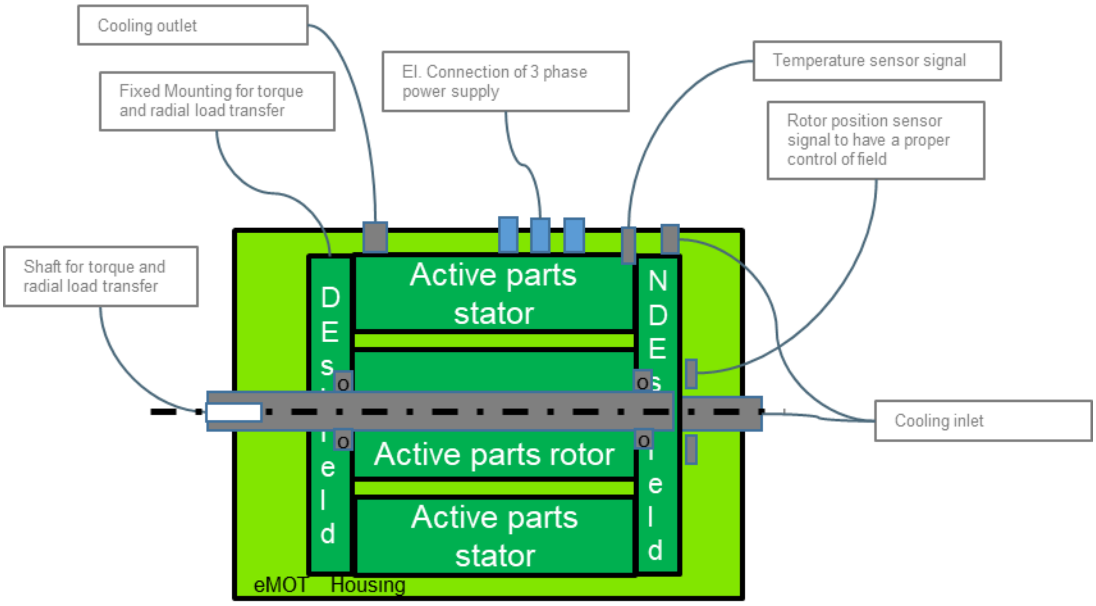


Figure 3.8: Interface overview of the EM (shared by VS).

3.3.1.4 MAIN COMPONENTS OF THE EM

The main components of the EM are: Cooling fluid guidance system, Rotor with magnets and eSteel package, Stator with Cu-winding and eSteel package + isosystem, Shaft for transfer of mechanical Power, Rotor position sensor, Temperature sensor, Connection device for HV system, Shields and housing.

3.3.2 DESCRIPTION OF INTENDED EM (IMPROVED SOLUTION)

Targeted product improvements on the EM during the project are shown in Table 3.3.

Table 3.3: Description of targeted product improvements (shared by VS).

Sustainability	Adaption on use case
1. Reduction of material due to function integration Future Steps: 2. New motor topology to be investigated (EESM) 3. Repair + Recyclability investigation	1. Power-speed characteristics to be investigated and adapted if needed 2. Insulation and winding design rework due to 1000V level of high voltage system

3.4 GEARBOX

3.4.1 DESCRIPTION OF THE REFERENCE GEARBOX (STATUS QUO)

The following schema in Figure 3.9 is based on internal External Functional Analysis (EFA) for the Gearbox overall application. It is not focused on the RHODaS scope and need to be adjusted depending on agreed needs. The Main Functions are specified in purple colour. The standard Constraint Functions are specified in green colour. In Table 3.4 the main functions of the gearbox are described.

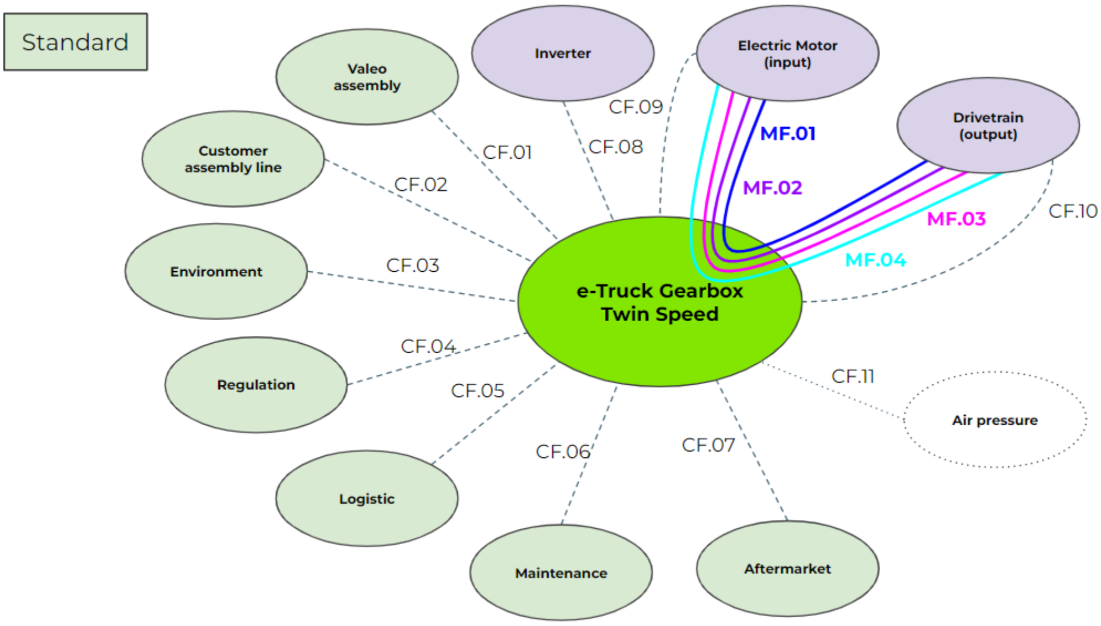


Figure 3.9: External Function Analysis (shared by VAL).

Table 3.4: Main functions of the gearbox (shared by VAL).

FUNCTION	DESCRIPTION	ENVIRONMENT 1	ENVIRONMENT 2
MF.01	Transmit torque between	Electric Motor	Drivetrain
MF.02	Transmit speed between	Electric Motor	Drivetrain
MF.03	Transmit torque between	Drivetrain	Electric Motor
MF.04	Transmit speed between	Drivetrain	Electric Motor

3.4.1.1 GRAPHIC OF THE GEARBOX

In Figure 3.10 a 3D model of the gearbox is shown. Figure 3.11 presents a schematic illustration of the gearbox.

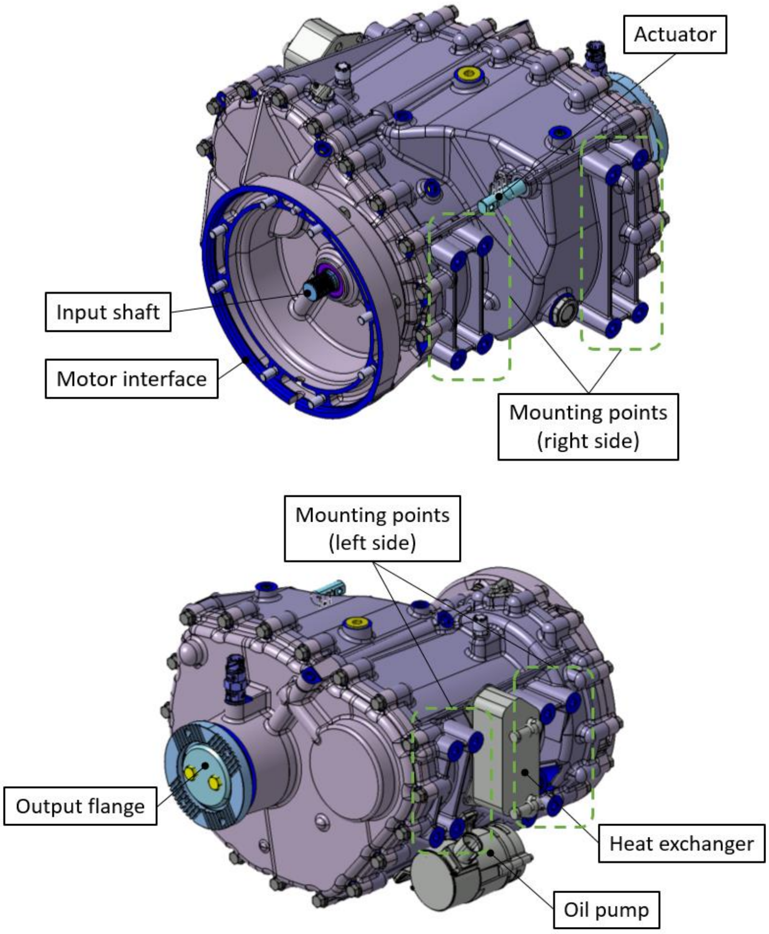
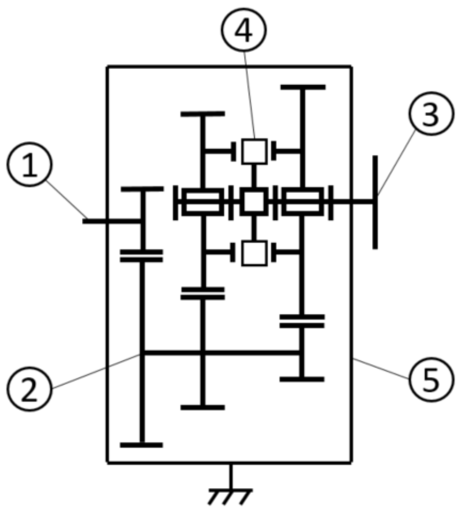


Figure 3.10: 3D Modelling of the gearbox (shared by VAL).



① Input shaft connected to the Electric Motor shaft.

② Layshaft

③ Output shaft with 2 free wheels & output flange.

④ Dog Clutch to operate the speed shifting.

⑤ Casing assembly split in 3 parts.

(Bearings are not represented)

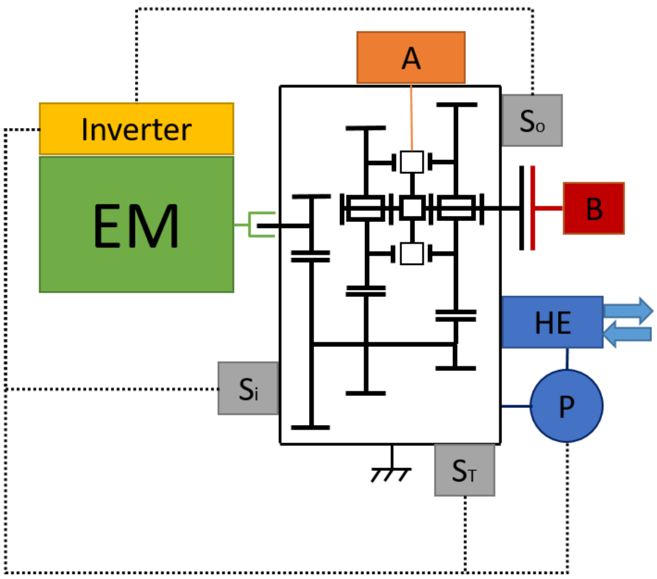
Figure 3.11: Schematic illustration of the gearbox (shared by VAL).

3.4.1.2 MAIN COMPONENTS OF THE GEARBOX

The main components of the gearbox are: taper roller bearing, needle roller bearing, gear, shaft, dog clutch shifting system, output flange, lip seal.

3.4.1.3 INTERFACES TO OTHER COMPONENTS OF THE IMD

In Figure 3.12 a general overview of the IMD is shown. Additionally, all the interfaces that connect the gearbox with all the other components are presented.



EM = Electric Motor
S_i = Input speed Sensor
S_o = Output speed Sensor
S_T = Oil Temperature Sensor
P = Oil Pump
HE = Water Heat Exchanger
A = Manual Actuator
B = Test Bench
………… Communication link with the Inverter
→ Water exchange with the test bench

Figure 3.12: General overview of the IMD and interfaces of the gearbox (shared by VAL).

DESCRIPTION OF INTENDED GEARBOX (IMPROVED SOLUTION)

This information is not yet available.

3.5 SENSORS & COMMUNICATION

Not relevant for the Ecodesign process.

4 Ecodesign Status Check

The so called Ecodesign Status Check is a questionnaire that consists of nine questions, mentioned in chapter 2.4.3. The background is explained for each question to help the reader understanding what the intention of the question is. The Ecodesign Status Check is sent to all partners of the project. The aim of the questionnaire is to evaluate the current status of reference product data availability and to get an idea of the current environmental awareness of all the project partners on their reference product. The Ecodesign Status Check is performed for each subcomponent of the integrated motor drive (IMD), shown in Figure 3.1.

4.1.1 QUESTIONS ADDRESSED IN THE ECODESIGN STATUS CHECK

In the Ecodesign Status Check the following questions are asked:

1) Are you familiar with the concept of Life Cycle Assessment (LCA)?
2) What is your reference product for the RHODaS project?
3) Do you know the greenhouse gas emissions of the reference product or its components?
4) Are you familiar with the EU's list of 30 critical raw materials?
5) Do you have a detailed Bill of material of your reference product? It should list at least the type of materials and their mass (e.g., Copper – 1 kg, Polypropylene – 0.5 kg, …)?
6) Do you know the most valuable components in your reference product, from an economic perspective?
7) What is the intended lifetime of your improved reference product?
8) Are you familiar with circular business models?
9) Can modularity be applied at your improved reference product?

4.2 FIRST RESULTS

The Ecodesign Status Check has been sent to all partners after the 2nd general assembly meeting in Vienna at the Austrian Institute of Technology (AIT). These received results for the most relevant parts (inverter, gearbox, and electric machine) are presented below.

4.2.1 STATUS CHECK VALEO - GEARBOX

Results showed that VAL has basic knowledge on LCA and already provided a BOM for a TWIN SPEED E-Truck GBX gearbox defined as reference product. The gearbox TWIN SPEED E-Truck is under development and should last for 1.2 Mio km. Concerning the questions on critical raw material no data is available so far, so support from TUW will be necessary. From a legal point of view remanufacture of gearboxes is mandatory, therefore these aspects are already taken into account in the design process.

4.2.2 STATUS CHECK AIT & UPC – INVERTER

AIT and UPC are familiar with LCA studies, but no data on greenhouse gas emission of their reference product is available. The reference product is a generic IGBT based inverter, data will be provided together by AIT and UPC. An alternative option is gathering data by teardown of an existing IGBT based inverter. Defining the BOM of the generic reference inverter is currently in progress. In addition, a BOM and a LCA study from a similar project on a SiC inverter has been shared. Information on criticality and circularity is missing and support from TUW will be necessary.

4.2.3 STATUS CHECK AARHUS UNIVERSITY – THERMAL MANAGEMENT SYSTEM

Aarhus University did not share any information about their knowledge on LCA, Circularity and Criticality. Most probably help from TUW is necessary. They shared a reference project with a similar set up as planned for the RHODaS project, and as a reference product an Infineon HybridPACK Drive Module (IGBT Module) was chosen to define the thermal management system requirements.

4.2.4 STATUS CHECK VALEO SIEMENS – ELECTRIC MACHINE

VALEO Siemens has knowledge on LCA and also have performed an LCA on their reference product and are therefore aware of the product’s greenhouse gas emissions. The reference product in focus will be a permanent magnet synchronous motor that is in serial production, called Daimler EQS. The motor that is under development and will be probably used for the project is also a permanent magnet synchronous motor, called GHP 250 and is an improvement of the previous one. VALEO Siemens shared a BOM to perform an LCA Screening, LCA results will be compared with VALEO Siemens internal ones. Concerning the questions on critical raw material and circularity, no information was shared with TUW. Probably support from the TUW is necessary.

5 Life cycle considerations

To develop a powertrain that corresponds to an Ecodesign approach, the whole powertrain development process is going to be supported through environmental assessment and eco-design considerations. In this way, the right decisions can be made at any point in time.

Modern electric powertrains, in particular converters and motor controllers require semiconductor materials and rare earth metals. It will be investigated if those parts show a significant environmental impact.

To improve dimensions like efficiency, power density e.g., new wide band gab (WBG) semiconductors will be used. In relation to this rather new technology open and therefore interesting issues are:

- Identifying particularly relevant life cycle stages in terms of the environmental impacts of WBG dies / components using Life Cycle Assessment (LCA). Definition of methodological approach is part of D1.3 M9.
- Calculating the environmental impacts of materials and the process steps used to produce (SiC, GaN) components using LCA. Final results are part of D1.3 M15.

But not only the semiconductor parts are relevant, other parts have environmental impacts too and may have room for improvements. It is important to analyse which of the possible measures have an impact and where, and how big is it? Furthermore, it has to be clarified if there any contradicting effects.

- Screening LCA of / analysing typical powertrains to reveal general weak spots and improvement potentials from an environmental point of view. Therefore, the approach for the screening LCA is defined in D1.3 M9 (scope, boundaries, etc.)

The findings will be reported as figures similar to material selection matrixes or material property charts. Those figures will not only cover materials, but also include typical parts, components, modules, technical / electrical design, technologies, etc. that are related to powertrains.

- Defining properties for charts/matrixes: environmental indicators, costs, technical parameters etc. (D1.3 M9)
- Processing the analysis results for further use in the development of the powertrain: selection matrixes / property charts. (D1.3 M15)

5.1 GUIDING QUESTIONS WITH FOCUS ON THE LIFE CYCLE PERSPECTIVE

- What is environmental assessment using Life Cycle Assessment (LCA) and what do the results stay for?
- How is the LCA performed and what are the uncertainties?
- What is the GWP of the reference integrated motor drive (IMD) powertrain?
- **Which design aspects can be considered to reduce the environmental (e.g., kgCO_2-eq) burden of IMD powertrains?** (-> direct impact on the Ecodesign guideline)

5.2 METHODOLOGY OF THE LIFE CYCLE PERSPECTIVE

Following the definition of the reference product the Ecodesign Status Check will be performed to evaluate the current status of reference product data availability. Within a workshop together with the producer information about the component is collected. From the collected information the product's life cycle according to the ISO 14040 standard is assessed, performing a LCA screening. In case no primary data from the industry is available, generic data from the ecoinvent 3.8 database will be used if available. Additionally, literature research is used to find best case studies and to collect further data and information.

5.2.1 LIFE CYCLE ASSESSMENT PROCESS

In Figure 5.1 the LCA Process is shown. First, the goal and the scope of the assessment is defined. In this step the functional unit, observed life cycle stages, products, processes, boundaries, cut-off rules, assessment method and the intended target group of the product system are specified. In the second step the life cycle inventory is analysed. This means all input and output energy and material flows within the chosen system are considered. All this energy and material flows are then environmentally assessed in the life cycle impact assessment through impact categories, e.g., Global Warming Potential, Land Use, Acidification Potential, etc, which are depending on the assessment method that has been chosen. At the end the results are interpreted, summarized and clearly communicated. Each step is of iterative nature and can always be adapted if needed [3].

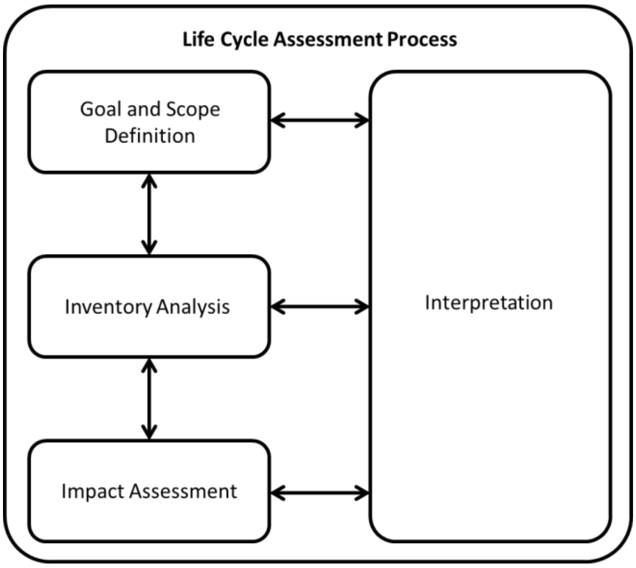


Figure 5.1: Life Cycle Assessment Framework according to ISO14040 [3].

5.2.2 PRODUCT Category Rules

For a more standardized and comparable approach, there exist so called product category rules (PCRs). PCRs, mainly designed for developing an environmental product declaration (EPD), are voluntary and give guidance how to assess specific product categories, e.g. buses, windows, packaging, etc. **Unfortunately, there is no PCR available for freight transport vehicles like trucks**, therefore two similar PCRs for passenger buses (PCR 2016:04) and for electric motors (PCR 2022:06) are used to get an idea on which cut-off rules to set, which boundaries to choose, etc.

The following definitions are among others suggested by the PCRs, and their suitability for e-trucks in general and the RHODaS Project in particular has yet to be evaluated [4, 5]:

- The functional unit is to provide 1kW of mechanical power during the reference service life (RSL)
- The reference service life (RSL) is set to 25 years
- The scope is “cradle to grave”, including material extraction, material production, assembly, transportation, use and waste management
- The boundaries towards nature are where the flows enter the technical system (e.g., product system) and where emissions are emitted to air, water, soil
- Polluter pays principle is used: for recycling material used in the manufacturing phase the transportation from the scrapyard to the recycling plant, the recycling process, and the transportation from the recycling process to the manufacturer is considered. For material that is going to recyling, only the transportation to the scrapyard is considered
- The temporal boundary for emissions is set to 100 years
- A cut-off rule of 1% is applied to the mass, environmental impacts, and energy use
- Environmental performance indicators? https://www.environdec.com/indicators
- the use of the energy mix in the region/country where the vehicle is operated will be used, or is approximated with EU27 electricity mix
- ISO 22628:2002 for end of life

5.3 EXPECTED OVERALL RESULTS – LCA

The results will contain a definition of all reference components of the powertrain as well as a definition of scope, boundaries, and scenarios for the LCA screening. The results of the first LCA screenings are presented via the environmental impact indicator Global Warming Potential (GWP). These results will be used to derive specific Ecodesign Guideline for the IMD and its components.

5.3.1 EXPLANATORY RESULTS OF THE POWERTRAIN

For two selected elements of the powertrain, the electric motor and the gearbox, the models first iteration is shown in Figure 5.2 and Figure 5.3. The LCA software SimaPro 9.3.0.3. and the database Ecoinvent 3.7.1 is used for modelling. Th impact category GWP is calculated via IPCC 2021 GWP 100 V1.0.

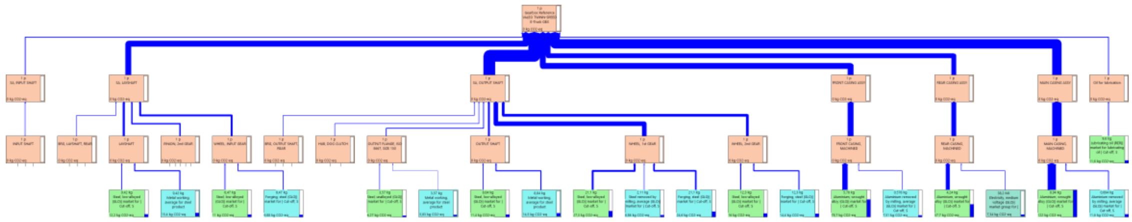


Figure 5.2: Draft model of reference gearbox, status check (own illustration).

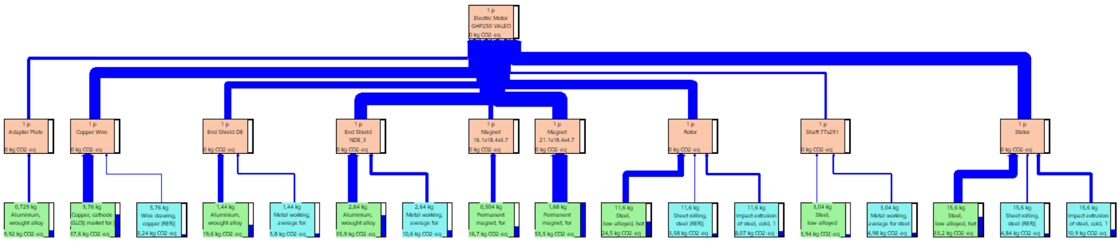


Figure 5.3: Draft model of electric motor, RHODaS product development (own illustration).

6 Criticality considerations

The criticality consideration is essential, especially when it comes to long life products that are used for several years or decades. The criticality of a material is defined by the EU as the relation between the economic importance and the supply risk of that material [6]. If this ratio reaches a certain threshold, it is seen as critical raw material. Moreover, rare earth elements are a group of elements in the periodic table of elements, that are part of the critical raw materials. The production of critical raw materials lies mainly in countries that may be geopolitically problematic now or in the future or/and the amount of these materials in the earth's crust is depleting, which leads to a supply risk of the material. If the material is also largely used, is barely substitutable and plays a key role in future technologies, it is seen as economic important. For the environmental product design, it is important to understand which materials are used, if there is an option to reduce the amount of these materials and if there is an option for a better reusability and recyclability of these materials in the product.

6.1 GUIDING QUESTIONS WITH FOCUS ON THE **CRITICALITY PERSPECTIVE**

- How can criticality of materials be assessed and what are the uncertainties?
- Which critical materials are found in reference IMD powertrains?
- **Which design aspects can be considered to reduce the criticality of IMD powertrains?**
  (-> direct impact on the Ecodesign guideline)

6.2 METHODOLOGY TO ASSESS CRITICALITY

The methodology to assess criticality will be developed during the project. A first draft will be presented in M9, and the final methodology will be part of D1.3 M15. Studies like the EU report on critical raw material will be used to develop the methodology. Following the definition of the reference product the Ecodesign Status Check will be performed to evaluate the current status of reference product data availability. Within a workshop together with the producer information about the component is collected. Additionally, literature research is used to find best case studies and to collect further data and information. From the collected information a criticality assessment as defined before is performed to be used as a basis for the Ecodesign guideline definition.

Current criticality methods can be divided in three general approaches to criticality assessment. With the help of a criticality matrix as an abstraction of the classic risk assessment, with a risk index as a multi-indicator approach and with time series analyses, statistical trends, and scenarios [7].

The criticality matrix plots the parameters on the two axes. The EU method for critical raw materials is based on such a matrix and it compares the Economy Importance (EI) and Supply Risk (SR) of the raw materials. The material is considered critical if the defined threshold is exceeded. In the 2020 report on critical raw materials, the EU classifies 30 raw materials as critical [6].

Some studies use a hierarchical risk index for criticality assessment. Several indicators can be used for the assessment and their weighting can influence the final result. A report from 2008 to ensure the material safety of the UK is based on this methodology. The assessment of 69 materials was composed of 8 different sub-indicators. The sub-indicators were each quantified by a scale from 1 (low) to 3 (high) [8].

As an alternative to the static screening methods described above, the approach of investigating potential supply shortages by analysing future developments on the supply and demand side was also pursued. As an example, the Federal Institute for Geosciences and Natural Resources (BGR) in cooperation with Volkswagen Group Research (area "Environmental Product") can be mentioned here. The aim was to assess medium-term supply risks of metallic raw materials [9].

The aim of the assessment method during the RHODaS project will provide supporting statements in the product development process. Therefore, the assessment method should provide feedback statements about the planned components regarding their raw material criticality. This already differs from the methods described above because the evaluation is product-based and not material-based. Insufficiently detailed statements about which indicators of raw materials are critical as in the EU method is also a problem. This information is relevant for suggestions for improvement.

A difficulty for all evaluation methods of raw material criticality is to get consistent and qualitative data. The developed method should use already existing data from other assessment methods. Again, the EU method offers a solid database structure. The hierarchy of data prioritises official EU data and member data over those from trade/industry associations and other special interest groups. Where possible, it also prioritises the use of data for Europe over datasets that relate to the whole world e.g., global data.

The preliminary method for assessing the criticality of raw materials for the components of the electric drive train is shown in Figure 6.1. Four blocks can be identified. The **System Boundary** determines the level of detail for the assessment. The **Assessment** step uses relevant parameters within the system boundary to identify critical raw materials. The **Evaluation** step summarise the results. The evaluated results are formulated into guidelines for the end user in the **Feedback** step.

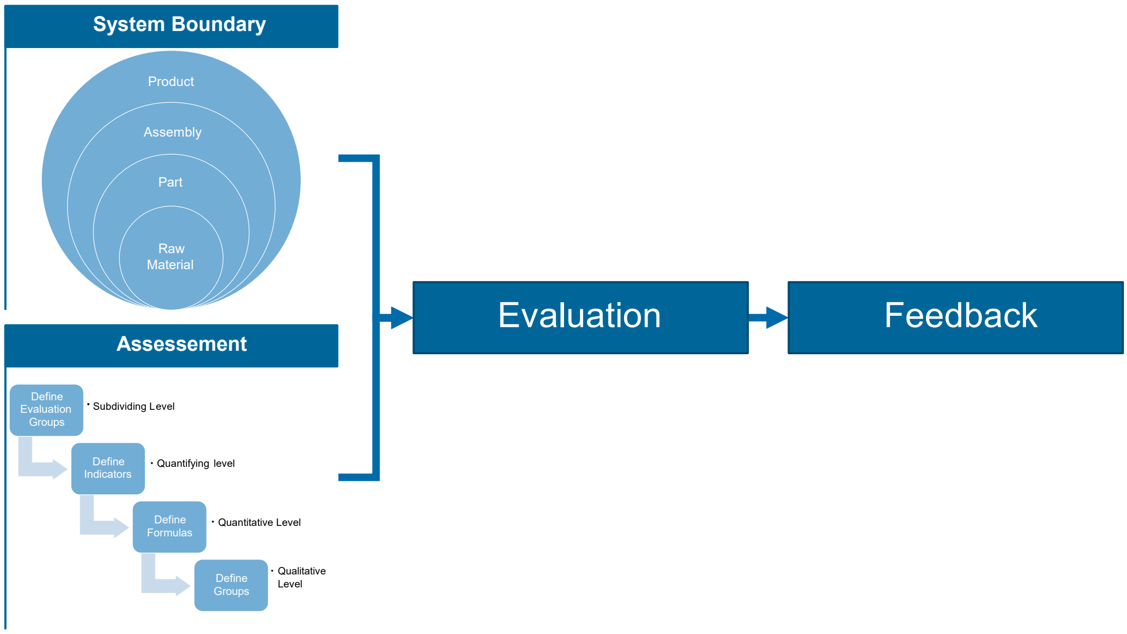


Figure 6.1: (Preliminary) Methodology of the criticality assessment model (own illustration).

6.3 EXPECTED OVERALL RESULTS – CRITICALITY CONSIDERATIONS

The final result from the criticality screening will contain an overview of different assessment approaches for criticality. The results should contain a definition of all reference components of the powertrain as well as a definition of scope, boundaries, and scenarios for the criticality screening. The results from the assessments will contain a list of relevant critical raw materials. These results will be used to derive specific Ecodesign Guideline for the component. The Ecodesign Guideline could contain for example material selection matrixes.

7 Circularity considerations

Circularity considerations play a key role to utilize the full environmental potential of the design of future powertrains. For the powertrains design, aspects like technical lifetime, use time, upgradability, durability etc. must be considered. Realising circular strategies like repair, reuse, remanufacturing, and recycling (recover critical materials or components/modules containing critical materials) requires appropriate scenarios. Those ideas and scenarios have to be considered and defined in advance, as they influence the powertrains design. The outcomes will be collected in a circular design guideline with circular design requirements along different circular design strategies, with focus on electrical powertrains.

- End-of-life and circular strategies for the modules using GaN components, e.g., to influence design for separating and recovering the powertrain parts that can be more easily treated, recycled, repaired etc. Definition of relevant CE-strategies for E-vehicles in general and specifically for the powertrain and its individual components (drive, converter, control unit, switches, sensors, etc.). (D1.3 M9)
- Derive circular design requirements for each strategy and each (group of) components. (D1.3 M15)
- Develop a design guideline including an assessment scheme on the fulfilment of the design requirements. (D1.3 M15)

7.1 GUIDING QUESTIONS WITH FOCUS ON THE CIRCULARITY PERSPECTIVE

- What is the idea behind the circular economy?
- How can circularity be assessed and what are the uncertainties?
- What is the current state of the art of circularity for reference IMD powertrains and what are the main problems?
- **Which design aspects can be considered to improve the circularity of IMD powertrains?**
  (-> direct impact on the Ecodesign guideline)

7.2 METHODOLOGY TO ASSESS CIRCULARITY

The methodology to assess circularity will be developed during the project, first draft will be presented in M9, and final methodology will be part of D1.3 M15. Studies like the circularity gap report [10] and defined use scenarios will be used to develop the methodology. Following the definition of the reference product the Ecodesign Status Check will be performed to evaluate the current status of reference product data availability. Within a workshop together with the producer information about the component is collected and ideas for circular design with powertrains are generated. Additionally, literature research is used to find best case studies and to collect further data and information. From the collected information a circularity assessment as defined before is performed to be used as a basis for the Ecodesign guideline definition.

7.3 EXPECTED OVERALL RESULTS – CIRCULARITY CONSIDERATIONS

The final result from the circularity screening will contain an overview of different assessment approaches for circularity. The results should contain a definition of all reference components of the powertrain as well as a definition of scope, boundaries, and scenarios for the circularity screening. The results from the assessments will describe the current circularity of the product. These results will be used to derive a specific Ecodesign Guideline for the component. The Ecodesign Guideline could contain for example strategies for circular economy.

8 Ecodesign Guideline

The assessment results are translated into the Ecodesign Guideline. The Ecodesign Guideline is meant as a supporting method for product development to make decisions towards a more environmentally friendly product. This Ecodesign Guideline also includes elements like material selection matrixes / property charts.

These matrixes or charts are first on a basic material level, but can also be considered on a higher level, e.g., on the component level, a powertrain's element level or even on a scenario level.

8.1 MATRIXES ON A MATERIAL LEVEL

Materials relevant for RHODaS product development process (e.g., occurring design decisions) will be selected. Environmental impact categories are selected in line with relevant PCR's (see chapter 5). Materials are compared with:

- environmental impacts,
- criticality considerations and
- suitability for recycling.

In Table 8.1 a conceptual material selection matrix based on environmental impacts is shown. For calculating the environmental impacts, the LCA software SimaPro 9.3.0.3. and the database Ecoinvent 3.7.1 or higher will be used. Calculation methods like EN 15804 V1.02 focusing on a broad range of impact categories or IPCC 2021 GWP 100 V1.0 as an example for single issue method can be applied. Quantitative results are targeted.

Table 8.1: Selection matrix based on environmental impacts (concept; own illustration)

Environmental Impacts	**…**	**…**	**…**	**…**	**…**
	A*biotic* ***D****epletion* ***P****otential, Elements*	xx kg SB-eq	yy kg SB-eq	yy kg SB-eq	…
	G*lobal* ***W****arming* ***P****otential*	x kg CO_2-eq	y kg CO_2-eq	z kg CO_2-eq	…
		Material A	*Material B*	*Material C*	…
		Materials relevant for RHODaS			

In Table 8.2 a conceptual material selection matrix based on material criticality is shown. Here the criticality method explained in chapter 2 is used. Qualitative indication is aimed for.

Table 8.2: Selection matrix based on material criticality (concept; own illustration).

Material Criticality	**high ☹**	**Low ☺**	**Medium 😐**	**…**
	Material A	*Material B*	*Material C*	…
	Materials relevant for RHODaS			

In Table 8.3 a conceptual material selection matrix based on recyclability is presented. Here the recyclability method that will be later explained in chapter 2 is used. Qualitative indication is aimed for.

Table 8.3: Selection matrix based on recyclability (concept; own illustration).

Recyclability	**high ☺**	**medium 😐**	**low ☹**	**…**
	Material A	*Material B*	*Material C*	…
	Materials relevant for RHODaS			

Note: At the material level, only the recyclability part of the circularity strategies seems to matter. Other circularity strategies like repair, reuse or remanufacturing show a major design level influence, and can therefore only be compared at a higher level (component-, element-, concept of powertrains level).

8.2 MATRIXES ON A COMPONENT-, ELEMENT-, OR CONCEPT OF POWERTRAIN-LEVEL

At a higher level than the material level, further comparisons are conceivable regarding different properties. These questions must arise during the project, or more precisely during design decisions, and can then be answered in this way by the environmental side. In Figure 8.1 higher levels other than material level are shown and explained in Table 8.4.

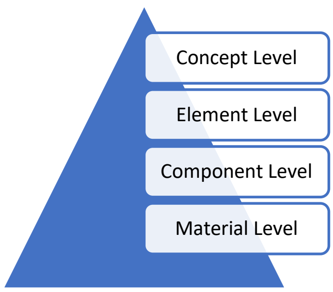


Figure 8.1: Levels of matrixes (own illustration).

Table 8.4: Explanation of matrix levels (own illustration).

Level of matrixes	Examples
materials	gearbox housing steel / aluminium / sec. aluminium / …
components	IGBT/ SiC MOSFET / GaN HEMT / use of modules / use of discrete power semiconductors
elements	Electric motors PMM / PMSM / PMSynRM / … Full SiC T-Type Inverter / Hybrid T-Type Inverter / IGBT Inverter
concepts	Inverter is integrated into common housing / external housing

On the highest level (concepts), different concepts or even scenarios can be compared, E.g., suitability with respect to different CE scenarios and the associated environmental impacts. In Table 8.5 a conceptual selection matrix based on product level is presented.

Evaluation in terms of:

- relevant properties in terms of environmental impacts / criticality / circularity
- efficiency
- energy consumption
- required energy in production
- content of specific materials or material compositions
- …

Table 8.5: Selection matrix based on product level (concept; own illustration).

Relevant properties	…	…	…	…	…
	***G**lobal **W**arming **P**otential*	x kg CO_2-eq	y kg CO_2-eq	z kg CO_2-eq	…
	Efficiency	x %	y %	z %	…
		PMM	*PMSM*	*PMSynRM*	…
		electric motor – applied technology			

Example: Different types of electric motors respectively the applied technology. Hints can be given based on own project internal assessments or literature studies. However, it is not yet possible to assess the data situation, as the questions that arise will only become clear during the project.

9 CONCLUSION

The deliverable 1.3 M9 mainly describes the methodology of the Ecodesign process in the RHODaS Project by the TUW with a focus on three main considerations: environmental-, criticality- and circularity considerations concerning the integrated motor drive (IMD). The main goal of the project is to achieve a reduction of at least 30 % of the IMD's total global warming potential within the project.

The environmental consideration will be done through a life cycle assessment screening (LCA-Screening) according to the ISO 14040/44 standard. Additionally, product category rules (PCRs) for motors and passenger buses are used to define goal and scope of the assessment. The criticality and circularity considerations will be done through methodologies that are still under development by the TUW. A rough methodology concept for the criticality assessment is presented.

The deliverable also describes the results derived from the status check questionnaire that has been sent to all project partners. For the majority of the project partners knowledge on LCA exist, for criticality and circularity considerations help from the TUW is needed.

All project partners have been additionally involved in a detailed definition of the reference product and the description of the intended improved product. For the reference product, a product that is well known and is comparable to the intended improved product of the project should be chosen. A clear definition of all reference products in detail still is under discussion and will be complemented later. However, the late input contribution of the project partners led to a deviation from the deliverable's due date.

A first concept of the *Ecodesign Guideline* is presented, including conceptual material selection matrixes based on environmental impacts, criticality considerations and suitability for recycling. Also, a conceptual product-based selection matrix based is presented.

REFERENCES

[1] Tribioli, L., "D5.1 Documentation of the basic concept of the cooling circuit," 2019.

[2] FITGEN, "Final technical report Part B, p. 51," 2022.

[3] International Organization for Standardization (ISO), Environmental management — Life cycle assessment — Principles and framework. ISO14040:2006, 2006.

[4] EPD International, "Public and private buses and coaches. PCR 2016:04 " 2016.

[5] EPD International, "Electrical motors and generators and parts thereof (for industrial applications). PCR 2022:06," 2022.

[6] European Commission, "Study on the EU's list of Critical Raw Materials (2020)," 2020.

[7] Glöser-Chahoud, S., "Quantitative Analyse der Kritikalität mineralischer und metallischer Rohstoffe unter Verwendung eines systemdynamischen Modell-Ansatzes " 2017.

[8] Morley, N. & Eatherley, D., "Material Security - Ensuring resource availability for the UK economy," 2008.

[9] Rosenau-Tornow, D.; Buchholz, P., et al., "Assessing the long-term supply risks for mineral raw materials-a combined evaluation of past and future trends," Resources Policy, 2009. **34**(4): p. 161-175.

[10] Circle Economy, "Circularity Gap Report 2022," 2022.

Appendix A.

A.I. ECODESIGN STATUS-CHECK

The Ecodesign-Status Check, that has been sent to all partners is presented below.

Ecodesign - Status Check

Within the RHODaS project the integrated motor drive (IMD) powertrain will be analyzed on an environmental basis. We, the Technical University of Vienna, will guide the project in this direction and will perform several assessments on the environmental burdens, the material criticality and on the material circularity. The key point here is that we cannot manage what we can't measure, therefore your contribution is essential to get reliable results. You on the other hand will benefit from useful insights about your products/ components from an environmental perspective, which will become more and more relevant in the future, especially from a legal point of view (see for example "Ecodesign for Sustainable Products Regulation" (ESPR)).
Below we have prepared three chapters covering the environmental burdens, criticality, and circularity with three leading questions each to get a first idea which information already exists, and where to focus on.

Project-Partner	
responsible Person	

Environmental burdens

ad 1: *Life Cycle Assessment (LCA) is a method to calculate the environmental impacts of a product or process on soil, water and air. The results are expressed for example as kg-CO_2-equivalents.*

1) Are you familiar with the concept of Life Cycle Assessment (LCA)?

- Yes, I had to do with it already.
- I have just heard about it and know what it is for
- No, I don't know it

ad 2: *For LCA analysis it is necessary to have a reference product to be able to compare the results with and to know where to focus on. The reference product is mostly the product that should be improved or a product with a comparable performance. For example, you could take the iPhone 13 as a reference product for the iPhone 14 and* *express through an LCA where it has been improved from an environmental perspective.*

2) What is your reference product for the RHODaS project?

ad 3: *The most common value of a LCA calculation is the global warming potential (GWP). It is expressed as kg-CO_2-equivalents and is known for the potential of something to increase global warming. The CO_2-equivalents stand for all the greenhouse gases (Carbon dioxide - CO_2, Methane - CH_4, Nitrogen Dioxide - NO_2, etc.) that are emitted during the lifecycle of the calculated product and summarizes them.*

3) Do you know the greenhouse gas emissions of the reference product or its components?

- Yes (LCA study, Environmental Product Declaration (EPD), or other type of LCA data exists). Can you provide them to us? (☐ Yes | ☐ No)
- No, we need help!

Criticality

ad 4: *Materials that surpass a specific relation between economic importance and supply risk for a given region or country are rated as critical for this region/ country. The EU report on critical raw materials is updated every 3 years and consists right now 30 critical elements. According to the EU CRM Report 2020 the following 30 materials are classified as critical: Antimony, Fluorspar, Magnesium, Silicon Metal, Baryte, Gallium, Natural Graphite, Tantalum, Bauxite, Germanium, Natural Rubber, Titanium, Beryllium, Hafnium, Niobium, Vanadium, Bismuth, Heavy REEs, PGMs, Tungsten, Borates, Indium, Phosphate rock, Strontium, Cobalt, Lithium, Phosphorus, Coking Coal, Light REEs, Scandium*

4) Are you familiar with the EU's list of 30 critical raw materials (see *ad 4*)?

- Yes. Are some of them used in parts or components of your reference product?
  - Yes. Can you provide them to us? (☐ Yes | ☐ No)
  - No!
- No, we need help!

ad 5: *To quantify the criticality and the environmental burden, the composition of products is needed at least on material level. If the product*

	mainly consists of standard electronics, try to break down into basic types of electronic components and add the most relevant technical facts, to be able to identify the electronic component and its size and mass.
	5) Do you have a detailed Bill of material of your reference product? It should list at least the type of materials and their mass (e.g., Copper – 1 kg, Polypropylene – 0.5 kg, …) ○ Yes! Can you provide that to us? (☐ Yes | ☐ No) ○ No, we need help!
	ad 6: *Very cost intensive components should be used as long as possible from an economic point of view. If a component has beyond that even a huge environmental burden, it makes even more sense to stronger focus on it.*
	6) Do you know the most valuable components in your reference product, from an economic perspective? ○ Yes. Can you provide the info to us? (☐ Yes | ☐ No) ○ No!
Circularity	***Info:*** *These questions focus on the material circularity of the product/component. It is a factor how much of the materials or components that are used in the product will be used in a second use, either as secondary resource, or as a whole product. The circularity can be crucial to reduce emissions, material depletion and material criticality.* ***ad 7:*** *The product's lifetime is important to estimate when it will be available as a secondary resource and what is planned to happen at the end of life, namely the end of use phase.*
	7) What is the intended lifetime of your improved reference product?
	ad 8: *A circular business model can be for example "Product as a Service (PaaS)", where the producer keeps ownership of the product, and the customer is only paying for the service (e.g. km of driving, hours of light, etc.).*

8) Are you familiar with circular business models?

- Yes. Is it possible to implement a circular business model for your improved reference product and what's the idea behind it?
- No, we need help!

ad 9: *Modular products are easier to disassemble, and their parts may be used in different applications. This could for example extend the spent lifetime of components or makes it easier to repair broken parts and avoid waste.*

9) Can modularity be applied at your improved reference product?

- Yes. How would it look like?
- No, we need help!