VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

Heidi Perälä

ASSESSING THE CLIMATE IMPACT OF A COLLARING MACHINE THROUGH LIFE CYCLE ASSESSMENT

Case Study for T-DRILL

Technology

2025

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
Energiatekniikka

ABSTRACT

Author	Heidi Perälä
Title	Assessing the Climate Impact of a Collaring Machine through Life Cycle Assessment: Case Study for T-DRILL
Year	2025
Language	English
Pages	41
Name of Supervisor	Tiina Rinta-Rahko

The commissioner of the study is Finnish T-DRILL Oy that designs and manufactures machines intended for pipe branching, shaping and cutting. The underlying reason for the study was to evaluate the environmental impacts of the products and to enhance competence in performing life cycle assessment. The objective of the research was to examine the climate impact of the collaring machine TEC-220 in all life cycle stages and to study the implementation of life cycle assessment.

A quantitative research method was applied in the study. The research data included the commissioner's databases, customer interviews, instruction manuals, manufacturer specifications, public databases and literature reviews. No commercial software tools or databases were employed in the study. The theoretical foundation is based on literature review and standards ISO 14040 and 14044 that define the framework for life cycle assessment. The research followed the structure defined by the standards including the phases of goal and scope definition, inventory analysis, impact assessment and interpretation.

The carbon dioxide emissions of TEC-220 were calculated in all life cycle stages during the research. Findings indicated that the highest emissions result from the life cycle stages of raw material extraction and operation. Based on the results, the conclusion was drawn that to reduce emissions, it is advisable to favor low-emission methods and recycled materials in the raw material production, as well as to pay attention to electricity consumption during the operational phase. In addition, the results showed that the commissioner has several sustainable solutions and practices in place. The study concluded that it is advisable to use software tools and databases when conducting life cycle assessments in the future to reach a more reliable and accurate outcome.

Keywords life cycle assessment, climate impact, product life cycle, carbon dioxide emission

VAASAN AMMATTIKORKEAKOULU
Energiatekniikka

TIIVISTELMÄ

Tekijä	Heidi Perälä
Opinnäytetyön nimi	Elinkaariarviointi kaulustuskoneen ilmastovaikutuksista: tapaustutkimus yritykselle T-DRILL
Vuosi	2025
Kieli	Englanti
Sivumäärä	41
Ohjaaja	Tiina Rinta-Rahko

Tutkimuksen toimeksiantajana on suomalainen T-DRILL Oy, joka suunnittelee ja valmistaa putkien haaroitukseen, muotoiluun ja katkaisuun tarkoitettuja koneita. Lähtökohtana tutkimukselle oli tarve arvioida tuotteiden ympäristövaikutuksia sekä syventää osaamista elinkaarianalyysin toteuttamisesta. Tutkimuksen tavoitteena oli selvittää TEC-220 kaulustuskoneen ilmastovaikutukset elinkaaren kaikissa vaiheissa sekä perehtyä elinkaariarvioinnin sisältöön.

Tutkimuksessa sovellettiin kvantitatiivista tutkimusmenetelmää. Tutkimusaineistona käytettiin toimeksiantajan tietokantoja, asiakashaastatteluja, käyttöohjeita, valmistajien spesifikaatioita, julkisia tietokantoja, sekä kirjallisuuskatsausta. Tutkimuksessa ei käytetty kaupallisia ohjelmistoja tai tietokantoja. Tutkimuksen teoreettinen perusta pohjautuu kirjallisuuskatsaukseen ja standardeihin ISO 14040 ja 14044, joissa määritellään elinkaariarvioinnin viitekehys. Tutkimuksessa noudatettiin standardien määrittelemää rakennetta, johon sisältyvät vaiheet tavoitteiden ja soveltamisalan määrittely, inventaarioanalyysi, vaikutusarviointi ja tulkinta.

Tutkimuksessa laskettiin TEC-220:n hiilidioksidipäästöt kaikissa elinkaaren vaiheissa. Tuloksista havainnoitiin, että eniten päästöjä aiheutuu raaka-aineiden hankintavaiheessa ja koneen käyttövaiheessa. Tuloksista muodostettiin johtopäätös, että päästöjen vähentämiseksi kannattaa raaka-aineiden valmistusvaiheessa suosia vähäpäästöisiä menetelmiä ja kierrätettyjä materiaaleja sekä kiinnittää huomiota käyttövaiheen sähkönkulutukseen. Lisäksi tulokset osoittivat, että toimeksiantajalla on jo käytössä kestäviä ratkaisuja ja toimintatapoja. Tutkimuksen perusteella todettiin, että jatkossa elinkaariarvioinnit kannattaa toteuttaa ohjelmistoja ja tietokantoja hyödyntäen, mikä mahdollistaa luotettavamman ja tarkemman lopputuloksen.

Asiasanat elinkaariarviointi, ilmastovaikutus, tuotteen elinkaari, hiilidioksidipäästö

CONTENT

FIGURES

TABLES

ABBREVIATIONS

GWP	Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment

1 INTRODUCTION

Climate change, environmental impacts, and limited resources are key challenges in today's world. Various regulations guide nations and businesses in implementing the principles of sustainable development. The European Union's climate policy based on the United Nations Framework Convention on Climate Change, the complementary Kyoto Protocol, and the Paris Agreement, steers efforts to mitigate climate change (Ministry of the Environment, n.d.). The United Nations 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals together with the Paris Agreement on Climate Change provide direction for building a better world and co-operation on sustainable development in economic, social, environmental and governance dimensions (European Commission, 2019, p. 6). Furthermore, the European Commission and Parliament have adopted the Green Deal to make the EU climate-neutral by 2050, along with the Circular Economy Action Plan promoting sustainable waste management. (D’Adamo et al, 2024, p. 164).

Companies have recognized the importance of sustainability in their strategy. Regulations guide both sellers and buyers, making the sustainability of a product or service, as well as the company's environmental efforts, beneficial for business. (Spiliakos, 2018.) Stricter environmental regulations, changing consumer expectations, and the scarcity of resources are driving companies to replace traditional linear production with circular economy (Dröder & Vietor, 2025, p. 218).

Ellen MacArthur Foundation (n.d.) defines the circular economy as ”a system where materials never become waste and nature is regenerated”. Maintenance, reuse, refurbishment, remanufacture, recycling, and composting are the processes used to keep the products and materials in continuous circulation. In the circular economy, when products reach the end of their life, their material value is largely retained. Instead of becoming waste, these materials can be preserved by transforming them into new products. This will reduce waste and lessen the need for extracting new resources. (European Commission, 2019, p. 15.)

The transition to a circular economy offers a major opportunity to build sustainable competitive advantage. Continues efforts are needed to transform the consumption and production patterns. This can be achieved by increasing consumer awareness, and by improving product design and waste management. The focus on product design should be on durability, reparability, re-use and recyclability. Waste management efforts should prioritize prevention, recycling of materials, recovering energy, and reducing the use of landfills. (European Commission, 2019, p. 16.)

Companies are constantly seeking various ways to reduce the ecological footprint of their products and services while assessing their environmental impact. One key method is the life cycle assessment, which can help companies to understand sustainability and environmental impacts at different stages of a product's life cycle. (Dröder & Vietor, 2025, p. 223.) In circular economy, the life cycle assessment is seen as a standard practice (European Commission, 2019, p. 16).

1.1 Research Objective and Scope

The commissioner of this thesis, T-DRILL, has recognized the need to develop a better understanding of life cycle assessment (LCA) and to examine its applicability to the operations of the company. T-DRILL acknowledges the sustainability of its products and their position in the market but sees LCA as a way of improving sales and marketing. Although the company has already collected data on the energy consumption and emissions of its products, conducting a comprehensive study with detailed calculations is essential.

The objective of this thesis is to illustrate how LCA is carried out and what aspects should be considered in the process. A case product nominated by T-DRILL is used as an example in describing the process flow. The goal is to investigate the carbon dioxide emissions of the case product in all stages of its life cycle and to form conclusions based on the results. The theoretical framework will examine the different phases of LCA with a focus on international standards. To achieve the objective, the following research questions have been set:

- How to conduct a life cycle assessment?
- What are the carbon dioxide emissions of the case product during each stage of its life span?

This study is limited to the case product; hence its results may not be directly applicable to other products. Data collection and calculations will concentrate on carbon dioxide emissions, setting other environmental impacts out of scope. No commercial software tools or databases will be utilized in the research. Data used in the study is not intended for public release. If necessary, further details regarding this data can be obtained from the author of the thesis or from the commissioner of the study.

1.2 Case Company and Product

The case company, T-DRILL Oy, is a Finnish company established in 1978, specializing in the design, manufacturing, and marketing of machines and equipment used for tube branching, processing, cutting, and forming. Strong product development, customer focus, high quality, and decades of experience have made the company a leading player in its field. T-DRILL operates from three locations: the headquarters is in Laihia, a machining facility in Isokyrö, and a subsidiary, T-DRILL Industries Inc., in Atlanta, USA. T-DRILL has 95 employees in Finland. Since 2013, T-Drill has been part of the Leinolat Group. (T-DRILL, n.d.; T-DRILL, 2024.)

All T-DRILL products are manufactured in Finland, with approximately 98 percent of production exported to more than 70 countries worldwide. T-DRILL products enhance customers' production efficiency, quality, and cost-effectiveness in various sectors, including HVAC, automotive, shipbuilding, and process industries. The machines are durable and long-lasting, significantly reducing raw material consumption, welding needs, and waste generation. T-DRILL is committed to sustainable development and regularly monitors and evaluates the quality of its operations and the impact on the environment. (T-DRILL, n.d.; T-DRILL, 2024.)

The case product, TEC-220, is a collaring machine. TEC-220 weighs 1686 kilograms and the measurements of the machine in millimeters are 1850 x 980 x 1678. The machine is presented in Figure 1.

Figure 1. TEC-220 collaring machine (T-DRILL, n.d.).

TEC-220 is engineered to branch all forgeable materials (steel, stainless steel, aluminum, copper-nickel). With the machine, the entire collaring process from pilot hole milling to the finished branch outlet is performed on the same workstation in three automatic work cycles. This contributes to higher productivity and efficiency. Milling and collaring are controlled via the control panel and automatic lubrication. The estimated lifetime of TEC-220 is 15-20 years. (T-DRILL, n.d.)

1.3 Use of Artificial Intelligence

In this study, the AI application ChatGPT has been used for information retrieval, ideation, translation, and synonym exploration. The text has been edited with the help of AI to ensure the language is clear, understandable, and suitable for the study. The originality of the content and respect for copyrights have been maintained throughout the research. The information provided by AI has always been verified from the original source and sources have been cited in the text according to the guidelines. All references listed in the thesis have been used by the writer and are not created by AI. During the writing process, AI has been used responsibly and in compliance with data protection regulations.

2 THEORETICAL FRAMEWORK

This chapter presents the theoretical framework for life cycle assessment (LCA). It begins with the definition of LCA followed by the different phases and the reporting of LCA study. Limitations and challenges of LCA are detailed in the final chapter.

2.1 Definition of Life Cycle Assessment

LCA is a systematic method for analyzing the environmental impacts of products or processes throughout their entire life cycle, covering stages from raw material extraction to production, use, and ultimately disposal. LCA enables the identification and comparison of ecological and economic critical points throughout a product's life cycle, the identification of environmental impacts, and the development of measures to reduce ecological footprint and resource consumption. (Dröder & Vietor, 2025, p. 223.)

The International Organization for Standardization has outlined the principles and guidelines of LCA; ISO 14040 defines the principles and framework, and ISO 14044 depicts the requirements and guidelines. These standards together create the LCA framework. According to ISO 14040, LCA is divided into four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. Figure 2 illustrates the phases of LCA and the direct applications in which the LCA results can be utilized. (SFS, 2006a; SFS, 2006b.)

In some cases, the goal of an LCA can be fulfilled by conducting only the phases of inventory analysis and interpretation. This is typically called life cycle inventory study (LCI study). The goal and scope must also be defined in the LCI study, while the life cycle impact assessment phase is left out. An LCI study on its own must not be used for making comparisons that are meant to be publicly communicated as comparative claims. (SFS, 2006b.)

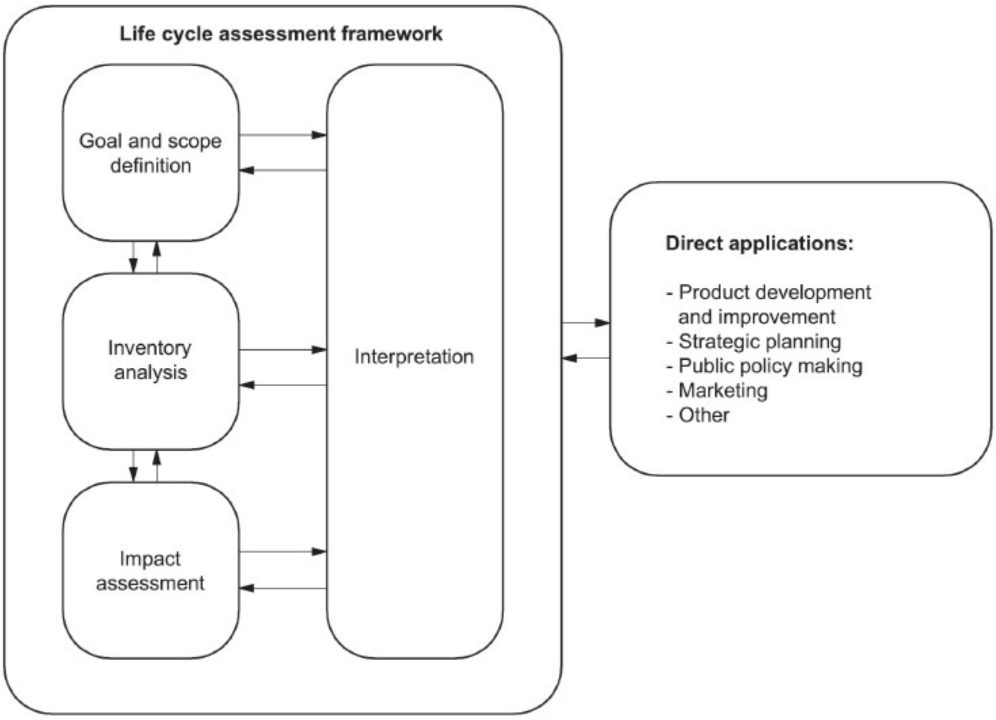

Figure 2. LCA phases and applications (SFS, 2006a).

LCA primarily examines the environmental aspects and impacts of a product system. Generally, economic and social impacts are not considered. Each phase of LCA relies on the outcomes of the other phases, making the LCA an iterative study. The iterative approach enhances the thoroughness and consistency of the study and its reported findings. Due to the fundamental complexity of LCA study, transparency is a core guiding principle in achieving a correct interpretation of the results. (SFS, 2006a.)

2.2 Phase 1: Goal and Scope Definition

The first phase of LCA is the goal and scope definition. This is a crucial phase, and the results of the LCA are often significantly influenced by the decisions made during this phase. The goal is set to guide the whole process; it outlines the purpose of the process. The scope specifies what will be measured and how, outlining the course of action for the process. (Jolliet et al, 2015, p. 23.; Ecochain, n.d.)

It is essential to define the goal before setting the scope. The goal consists of the following:

- Intended application: what is the purpose of the study?
- Basis for undertaking the study: what are the reasons for conducting the study?
- Target audience: for whom is the research aimed at?
- Publication: are the results intended to be used in public comparative assertion?

The goal serves as a guide in setting the scope and boundaries of the study. The intensity and precision of the study should be acknowledged during the goal definition. (Curran, 2012, p. 61; Klöpffer & Grahl, 2014, p. 44.)

Following the goal definition, the scope of the study is clearly stated. The scope includes the definition of the following elements: the product system, function of the product system, the functional unit and the system boundary. In addition, allocation procedures, life cycle impact assessment methodology and types of impacts, data requirements, assumptions, value choices, limitations and data quality requirements are part of the scope. Critical review, if there is any, should also be outlined as well as the type and format of the report required for the study. (SFS, 2006b.)

The functions, that is the performance characteristics, of the product system should be identified before determining the functional unit and system boundaries. Since a single product may have multiple functions, it might be challenging to select one exact function of a system. In these cases, it is relevant to identify the primary and secondary functions of a system. The primary function is similar between different alternatives, but the secondary function is explicit to each scenario. If the secondary functions vary significantly between alternatives, they may reveal a comparative bias. When examining part of a larger system, the assigned function generally corresponds to the function of the full system. (SFS, 2006b; Jolliet et al, 2015, p. 26.)

The main objective of a functional unit is to present a reference to which the input and output data are scaled in a mathematical sense (SFS, 2006b). The impact of two functional units is double that of one meaning that the functional unit needs to be measurable and additive. Inventory flows and impacts for each scenario are calculated in accordance with the functional unit. The functional unit is the same for all scenarios. The amounts of goods and services purchased per functional unit are represented as reference flows. These constitute the basis for creating the environmental inventory. (Jolliet et al, 2015, p. 27-28.)

The system boundary outlines which unit processes will be included within the LCA (SFS, 2006b). In most cases, the system boundary is structured around the life cycle stages that the study incorporates (Horne et al, 2009, p. 44). There are four system boundaries that define the scope of LCA: cradle-to-gate, cradle-to-grave, gate-to-gate and gate-to-grave. (Mahmud, 2023, p. 13.) Cradle-to-gate evaluates the phases of raw material extraction, manufacturing and processing of a product until it leaves the factory. Cradle-to-grave assesses all stages throughout the product's life cycle, from raw material extraction to final disposal. Gate-to-gate studies only one phase, for example the transportation or usage. Cradle-to-cradle is like cradle-to-grave, but the waste stage is exchanged to recycling or upcycling process making it reusable for another product. (Ecochain, 2015.) Using a process flow diagram to illustrate the system, including the unit processes and their connections, can be beneficial (SFS, 2006b).

2.3 Phase 2: Inventory Analysis

Second phase, life cycle inventory analysis (LCI), consists of data collection, data calculation and allocation. In this phase, relevant input and output materials, energies and emissions of a product system are estimated. The result is a list of all interactions with the environment during any life cycle stage of the product system. Since the process of implementing an inventory analysis is iterative, new requirements or limitations may be recognized, or the goal or scope may need adjustments along the way. (SFS, 2006a; Ecochain, n.d.)

ISO 14044 (SFS, 2006b) illustrates the operational steps to follow when carrying out the LCI (Figure 3.).

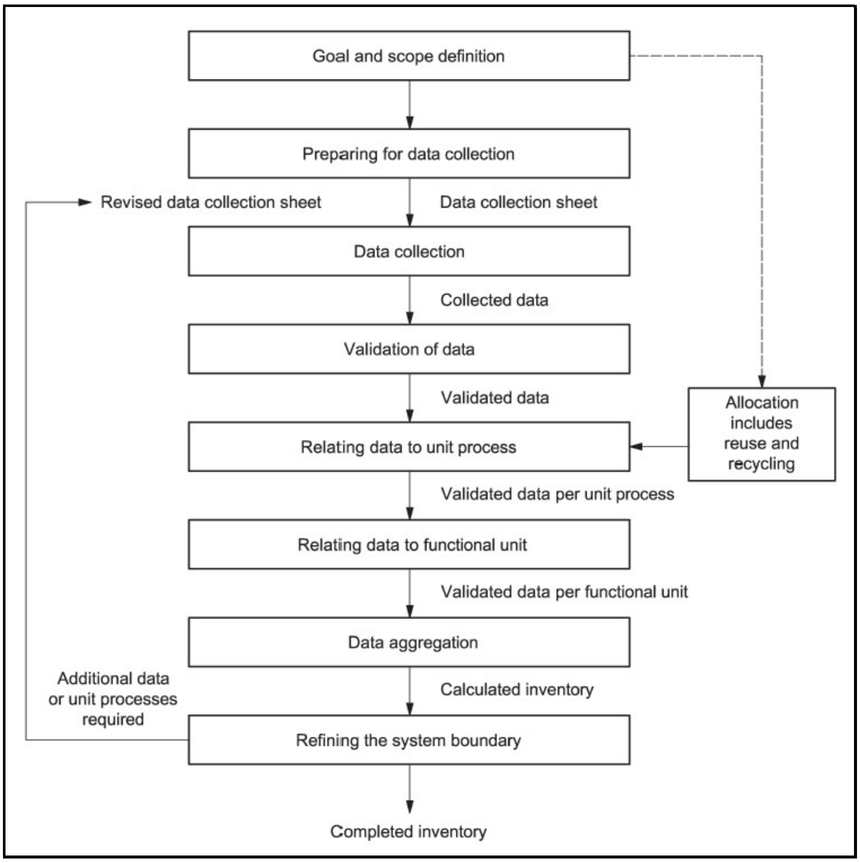

Figure 3. Simplified steps for LCI (SFS, 2006b).

The goal and scope definition serves as the foundational framework for LCI. All data included in the inventory, whether qualitative or quantitative, should be collected for each unit process that has been defined as part of the system boundary. Data collection requires an abundance of resources. Practical limitations on data collection should be considered and reported in the study. According to ISO 14044, data for each unit process within the systems boundary may be sorted under the following categories:

- inputs of energy, raw material, ancillary and other physical inputs
- products, co-products and waste
- releases to air, water and soil, and
- other environmental aspects. (SFS, 2006b.)

Calculation procedures are required after data collection to generate the results of the inventory. The procedures include the validation of collected data and the linking of data to unit processes and to the reference flow of the functional unit. All calculation procedures and assumptions made must be clearly recorded, and the same procedures should be used consistently throughout the study. The validity of data should be verified during the data collection process. Mass balances, energy balances and comparative analyses of release factors are examples of procedures involved in data validation. (SFS, 2006a; SFS, 2006b.)

The quantitative inputs and outputs of a unit process are calculated in relation to the flow defined for each unit process. The flows of all unit processes are scaled relative to the reference flow, based on the flow diagram and the flows between unit processes. This calculation should result in linking all input and output data of the system to the functional unit. Inputs and outputs of the product system should be aggregated only if they relate to substances of the same kind and have similar environmental impacts. Due to the iterative nature of LCA, decisions regarding data inclusion shall be based on a sensitivity analysis which helps to limit subsequent data processing to only those inputs and outputs that have been identified as significant in relation to the goal of the study. (SFS, 2006b.)

ISO 14040 (SFS, 2006a) defines allocation as "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems". An allocation procedure should be considered when conducting an LCI for a system involving multiple products and recycling schemes. Few industrial processes produce only a single output or follow a linear flow of raw material inputs and outputs; instead, they typically yield multiple products and recycle intermediates or discarded products as raw materials. Inputs and outputs must be allocated to different products according to established procedures. The sum of the allocated inputs and outputs of a unit process must equal the total inputs and outputs of the unit process prior to allocation. The procedures must be documented and explained together with the allocation method. (SFS, 2006a; SFS, 2006b.)

2.4 Phase 3: Impact Assessment

The third phase of LCA is the life cycle impact assessment (LCIA) phase. The LCIA phase addresses the questions of how to interpret the data gathered in LCI phase, how to connect the results to their environmental impacts and how to compare the different impacts (Jolliet et al, 2015, p. 105). According to ISO 14040 and 14044, the LCIA phase includes mandatory and optional elements. The mandatory elements consist of three parts based on which LCIA profile is obtained. Utilizing the LCIA profile, optional elements can then be performed. Elements of the LCIA phase are illustrated in Figure 4. (SFS, 2006a; SFS, 2006b.)

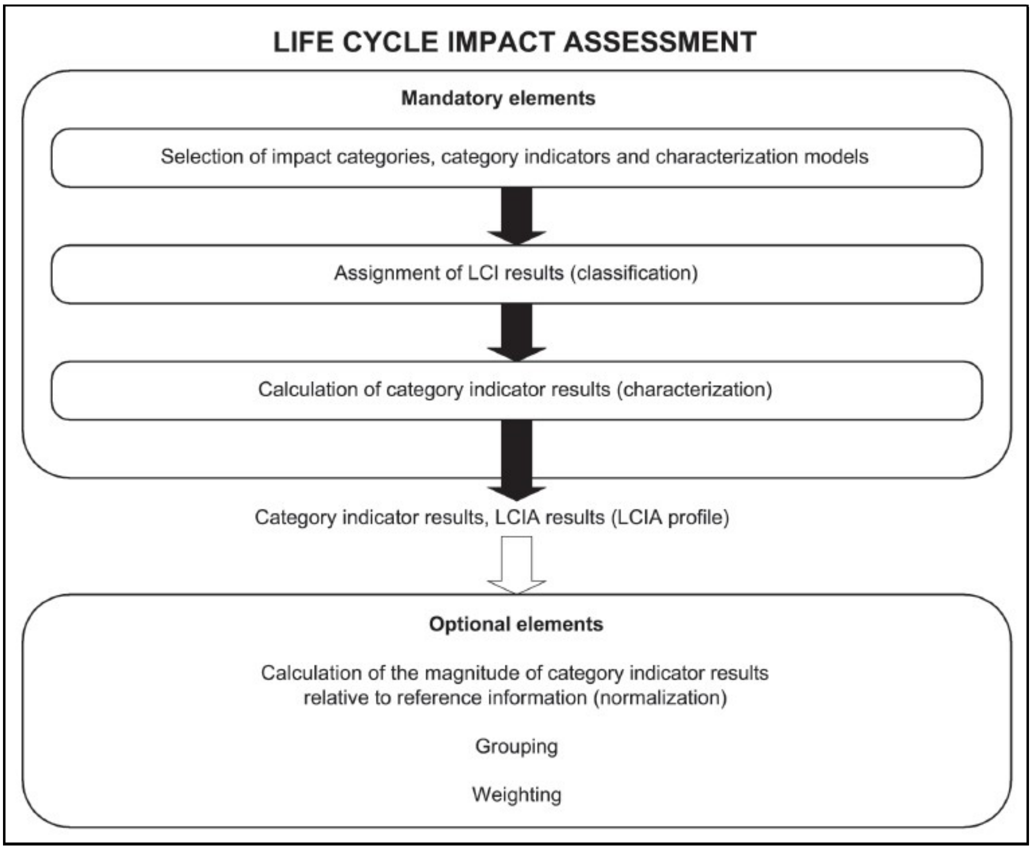

Figure 4. Elements of the LCIA phase (SFS, 2006a).

The first part of mandatory elements is the selection of impact categories, category indicators and characterization models. Since ISO 14044 does not define them, the selection of impact categories is left to the discretion of the LCA practitioner. ISO 14044 does recommend that the chosen impact categories, category indicators and characterization models are internationally accepted, are based on international agreement or are acknowledged by an authorized international board. Selection of categories should be made in the first phase of LCA because they must align with the goal and scope of the study. Due to the iterative nature of the LCA study, completion of the goal and scope is however possible. (Klöpffer & Grahl, 2014, p. 187-190.) The most common impact categories are listed in Table 1 (Hillege, 2019).

Table 1. Common impact categories (Hillege, 2019).

Impact category	**Description**
Climate change	Potential global warming caused by emissions of greenhouse gases.
Ozone depletion	Measure of air pollutants that harm the stratospheric ozone layer.
Acidification	Potential acidification of water and soils caused by the discharge of gases such as sulfur dioxide and nitrogen oxides.
Eutrophication	Increase of nutritional elements in freshwater/marine/terrestrial ecosystem because of the emission of nitrogen or phosphor-containing compounds.
Photochemical ozone formation	Potential of ground-level ozone (smog) formation through reactions activated by sunlight due to gas emissions.
Depletion of resources	Divided into the depletion of natural non-fossil resources and natural fossil fuel resources.
Human toxicity	Repercussions on humans of toxic, divided into non-cancer and cancer-related, substances released to the environment.
Water use	The amount of water consumed based on regionalized freshwater availability constraints.
Land use	Assessment of soil quality changes.
Eco-toxicity	Effects of environmental toxins on freshwater organisms.
Ionizing radiation	Harm to human health and the environment from radionuclide emissions.

Classification is the second part of mandatory elements and means that the LCI results are assigned to the selected impact categories. Klöpffer and Grahl (2014, p. 190) state, that classification includes a distinction between LCI results that can be assigned to only one impact category. Additionally, LCI results that refer to more than one impact category should be identified and assigned considering the distinction between parallel mechanisms and serial impact mechanisms. (Klöpffer & Grahl, 2015, p. 190-191.)

Characterization, that is the calculation of category indicator results, is the third part of mandatory elements. Klöpffer & Grahl (2014, p. 191) identify characterization as the core of LCIA. The definition in ISO 14044 (SFS, 2006b) reads:

> The calculation of indicator results (characterization) involves the conversion of LCI results to common units and the aggregation of the converted results within the same impact category. This conversion uses characterization factors. The outcome of the calculation is the numerical indicator result.

The LCIA method used for calculating the indicator results must be identified and documented as well as the value choices and assumptions selected (SFS, 2006b).

LCIA methods provide collections of impact categories and the ways the categories are calculated. The methods differ by the number and choice of impact categories, how the LCI results are classified into impact categories and how the impact indicators are characterized. Usually, the chosen LCA software produces the outcome of LCIA by allowing the selection of the LCIA method and by calculating the impact category results. (Ecochain, n.d.)

The optional elements of LCIA phase are normalization, grouping and weighting. When the category indicator results are divided by selected reference values, the optional element of normalization is used. The category result indicators are more important if they are larger than the compared reference values. Grouping is a formation of classes, which means that the impact categories can be ranked under a certain hierarchy or sorted on a nominal basis. Weighting is based on value choices and might include aggregation of the weighted results. Weighting is strictly for internal purposes and should not be used when LCA is intended for comparative assertion. (Klöpffer & Grahl, 2014, p. 192-200.)

2.5 Phase 4: Interpretation

The life cycle impact interpretation is the fourth and final phase of LCA. ISO 14040 and 14044 state that the interpretation phase should provide results that are coherent with the goal and scope of the LCA study and reach conclusions, explain limitations and provide recommendations. The interpretation should acknowledge that the LCIA findings stem from relative approach, that they represent potential environmental effects, and that they do not predict actual impacts. The elements of interpretation and its relationship with previous phases of LCA are presented in Figure 5. (SFS, 2006a; SFS, 2006b.)

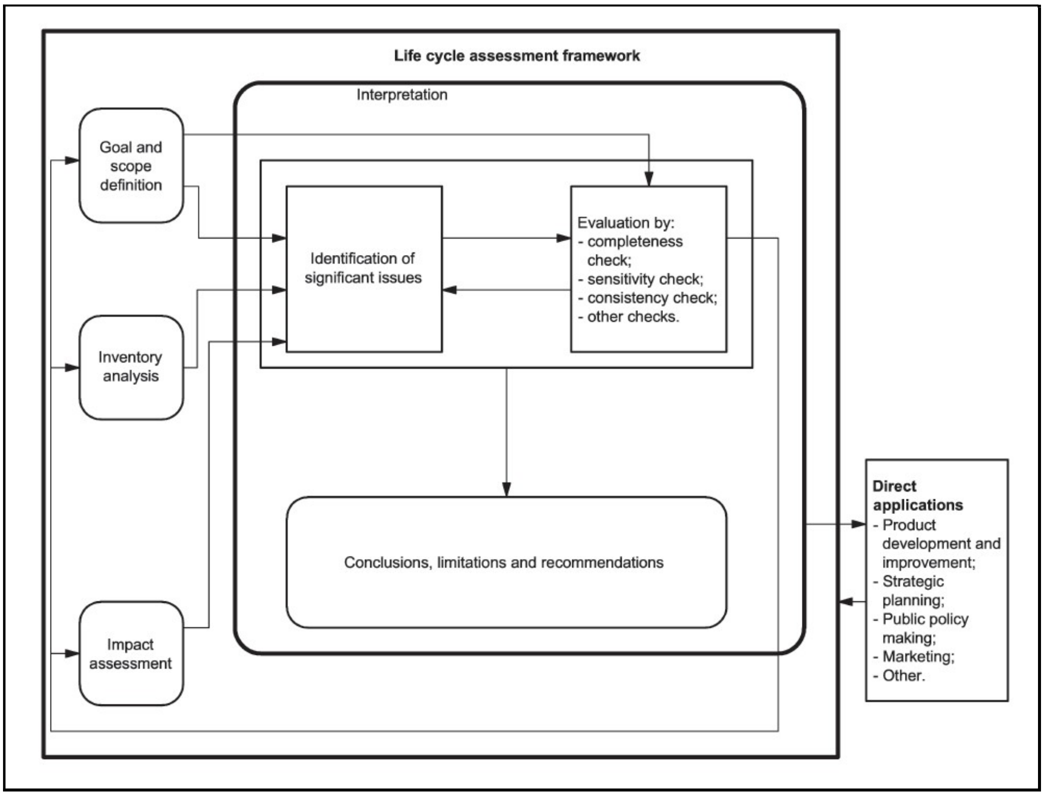

Figure 5. Elements of the interpretation phase (SFS, 2006b).

Interpretation requires careful attention and sufficient time allocation but is often done superficially. Thorough interpretation should be performed during all LCA phases; after the goal and scope definition, after the LCI phase, after characterization and after the evaluation of overall impact. The input of each life cycle stage should be compared and analyzed as well as the input of each system component. Finally, the contributions of each pollutant and extracted substance should be evaluated to recognize which of them create the most impact for each impact category. (Jolliet et al, 2015, p. 149-150.)

It is reasonable to begin the interpretation on a high level, for example the life cycle stages, and then move towards more detailed results (Ecochain, n.d.). Identifying the life cycle stages where intervention can significantly reduce the environmental impacts of the studied product is the main purpose of this phase. In addition, the goal is to analyze the potential sources of uncertainty. The focus should be on the life cycle stages and groups of processes that create the most significant impact as well as in the life cycle stages in which there is the highest potential to decrease impacts with limited contribution. Sometimes it is even possible to reduce both the environmental impacts and costs at the same time. (Jolliet et al, 2015, p. 149-150.)

Jolliet et al (2015, p. 156) suggest, in case of slightest unforeseen or surprising result, never to dismiss it but to explain the discrepancy and understand and learn from it. According to Ecochain (n.d.), LCA may uncover trade-offs between different environmental impact categories; for example, reducing impact in most categories will result in greater depletion of raw materials. Decision-making is more complex due to the requirement to consider results of multiple impact categories, but it is vital in preventing the environmental trade-offs. Evaluation intends to build trust into the reliability of the LCA results and into essential parameters as well as deliver a clear and comprehensible overview of the LCA study (Klöpffer & Grahl, 2014, p. 333).

ISO 14044 defines, that techniques of completeness check, sensitivity check and consistency check, shall be taken into consideration during the evaluation. The purpose of completeness check is to verify the availability and completeness of the relevant information and data needed for the interpretation and to consider the necessity of any missing or incomplete information. The sensitivity check determines how uncertainties related to input data, allocation methods, or the calculation of category indicator results affect them. The aim is to assess the reliability of the results and conclusions. The intention of consistency check is to define if the assumptions, methods and data correspond to the goal and scope of the LCA. (SFS, 2006b.)

A logical sequence for processing conclusions is identifying issues, evaluating completeness, sensitivity and consistency, and outlining preliminary conclusions and comparing them with the goal and scope. Recommendations are formed based on final conclusions and they should depict a reasonable consequence of the conclusions. (SFS, 2006b.) The results of interpretation phase should deliver clear and usable information for decision-making (Jolliet et al, 2015, p. 149).

2.6 Reporting

A fundamental part of LCA is the reporting strategy. A successful report should cover the various phases of the LCA study and present the results and conclusions in an adequate form. ISO 14044 states that ”the results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail”. The type and format of the report should be outlined during the definition of the scope. (SFS, 2006b.)

In case the LCA results are intended to be disclosed to the public or to any third party other than the commissioner or the practitioner of the study, a separate third-party report should be compiled.

Confidential information may be excluded from the third-party report, but it should consist of the following structure:

- general aspects
- goal of the study
- scope of the study
- life cycle inventory analysis
- life cycle impact assessment (where applicable)
- life cycle interpretation
- critical review (where applicable).

ISO 14044 provides a full list of aspects under the main headings that should be covered in the third-party report. (SFS, 2006b.)

2.7 Limitations and Challenges

LCA has limitations and it can give misleading and contradictory results if not applied properly. According to Ellen MacArthur Foundation (2022), LCA favors short term gain over systemic change and often ignores impacts that are harder to measure. In addition, it relies on assumptions and measures only the metrics that are given to it. The possible subjectivity could weaken the credibility of the compiled data and thus raise concerns about the results. Additionally, LCA analysis generally deals with environmental issues leaving the social and economic effects out of scope. When interpreting the results of LCA, reliability and availability of the data as well as the authors of the LCA and other contributing factors should always be considered. Adopting a critical approach is essential, and special attention should be given to the interpretation and communication of the conclusions. (Ellen MacArthur Foundation, 2022; Jolliet et al, 2015, p. 203-204.)

Key challenges in LCA include data gaps and data heterogeneity. Information must be collected throughout the entire life cycle, but significant data interruptions often occur in the analysis, increasing the risk of distortions and making it difficult to form a comprehensive view. Data from different sources may come in various forms and formats, requiring standardization into a consistent structure. To ensure that the results of different analyses are comparable, the analysis must be based on a uniform and coherent foundation. Therefore, the data needs to be converted into the specific formats required by LCA models. (Dröder & Vietor, 2025, p. 224.)

Certain measures can improve data quality and the analysis process. The exchange of information between production, procurement, logistics, and other relevant functions enables comprehensive data collection, helps prevent data gaps, and supports a broader and more accurate analysis of environmental impacts. The digitalization of data collection and processing creates the conditions for real-time data gathering and updates, as well as faster responses to changes in the production process, making it possible to carry out LCA more efficiently and cost-effectively. (Dröder & Vietor, 2025, p. 225.)

Jolliet and others (2015, p. 203-204) question what the real consequences of the improvements and changes suggested by LCA are. LCA overlooks numerous possible consequences, including the following risks:

- risks to human health and natural environment due to behavior changes brought on by the alternative,
- risks to health stemming from fluctuations in available income,
- risks to health and environment caused by structural changes or innovations.

The ability to predict actual impacts is limited, because measures taken to reduce one impact may cause other effects, which can be either positive or negative. (Jolliet et al, 2015, p. 203-204.)

3 RESEARCH METHODS

This quantitative research applies a case study approach focusing on the life cycle carbon dioxide emissions of a single collaring machine, using a process-based LCA methodology. The collaring machine in question, TEC-220, is presented in subsection 1.2. The study produces an Excel spreadsheet with calculations of the company's carbon dioxide emissions. The data in the Excel spreadsheet contains classified information and is not intended for public release.

The study follows the guidelines of ISO 14040 and 14044 consisting of the following phases: definition of the goal and scope, inventory analysis, impact assessment and interpretation. After performing all the calculations, the overall results are analyzed, and conclusions are drawn accordingly. Certain limitations should be considered when interpreting the results and these are acknowledged in the analysis.

The Excel spreadsheet is divided into worksheets according to the different life cycle stages. These include raw materials, transportation from suppliers, manufacturing, transportation to customer, operational phase and end of life. Final worksheet, overall results, combines all the calculations together. In addition, the spreadsheet contains input data that outlines information about the product and study including the definition of the goal and scope.

The goal of the study is to calculate carbon dioxide emissions from all the life cycle stages of the machine. Results of the study are seen to support the marketing and sales of the company, this being the reason behind the study. The intended audience of the study are the relevant parties in the organization. The study is not intended for comparative assertions or as such to be disclosed to the public.

The scope of the study outlines the product system, one complete TEC-220 machine with the most common additional tools included, and the system boundary, cradle-to-grave. The chosen impact category is global warming potential (GWP). Interpretation aims to identify significant issues and evaluate possible uncertainties.

For the data collection of the study both primary and secondary data is utilized. The primary data includes the company’s own database and internal materials, tests and measurements performed by the staff, customer interviews conducted by the sales and service departments, the enterprise resource planning (ERP) system, user manuals and manufacturer specifications. The secondary data consists of public databases, online sources and literature reviews. In addition, a local client company is interviewed via email to gather their experiences of using the machine.

The Excel spreadsheet outlines the sources of information and whether the data is estimated or not available. Assumptions are made in the absence of accurate data, but this is clearly documented. No commercial LCA software or database is applied in the study, which limits the access to reliable data. This study focuses solely on GWP excluding other environmental impacts; this is a value choice outlined in the scope of the study.

4 ANALYSIS

This chapter presents the results of the LCA study for the collaring machine TEC-220, with a specific focus on GWP. Results are expressed in kilograms of carbon dioxide equivalent (kg CO_2-eq). All results and values were calculated using Excel spreadsheet. The chapter begins with the review of the different life cycle stages and their results. The structure of analysis follows the style of the Excel spreadsheet. After the life cycle stages, the overall results of the study are examined. The limitations of the study are considered in the final chapter.

4.1 Raw Materials

TEC-220 is a collaring machine that weighs 1686 kilograms. T-DRILL manufactures some of the parts in their machining facility, but most components are ordered from a variety of suppliers. All the machine components, totaling 548, are listed in excel. In addition, the list includes the most common tools delivered with the machine, amounting to 184 components. These numbers do not reflect the actual amount of a specific component, and the list may include the same component in several rows in case it is used in different parts of the machine.

Calculations for carbon dioxide emissions have been completed for some of the products by T-DRILL. Missing data has been obtained through direct inquiries with the suppliers. The worksheet distinguishes between products for which emission data has been obtained from the supplier and those for which the supplier has confirmed that data is not yet available. The remaining have been marked as data not available. The missing emissions have been calculated using either the emission factors used by T-DRILL and the Company Group or the emission factors obtained from free databases or online sources. The chosen method is recorded next to the calculation.

The total emissions of raw materials, value that includes both the raw materials and their manufacturing, were estimated to be 18,921 kg CO_2-equivalent. The machine contributes 86% of the total emissions: components of the machine total in 16,186 kg CO_2-equivalent and the additional tools in 2,735 kg CO_2-equivalent. The results indicate that raw materials generate a significant number of emissions. The high figure is due to this stage covering the extraction and processing of steel, aluminum, and various electronic components. The machine contains many high-emission materials such as steel. Additionally, the gear motor and electrical components contribute significantly to the overall impact. A major factor is also the large size of the machine and the extensive number of components.

4.2 Manufacturing

The manufacturing phase includes the assembly of the machine and the general operations of the factory, such as electricity, heating and business travel. T-DRILL manufactures approximately 15 complete TEC-220 collaring machines annually. The calculations of the manufacturing phase consider the carbon dioxide emissions from the following activities: electricity consumption and district heating, waste management, employee commuting, business travel and company vans. These values have been allocated from the total emissions of the factory based on the weight of one complete machine. Business travel includes all the trips made by sales and maintenance. Company vans are utilized for the transportation between the factory and the machining facility and for the visits to the nearby subcontractors. An estimate of the powder coating work from two different suppliers has also been added to the manufacturing phase, as it was not included in the material calculations.

The total emissions were estimated to be 2,521 kg CO_2-equivalent. Figure 6 illustrates the percentual distribution of emissions in the manufacturing phase. The biggest share of emissions, 65%, results from business travel. Travel by the maintenance and sales departments is usually carried out via air travel, which contributes more significantly to emissions. Employee commuting accounts for the second largest share of emissions, 29%. The share of electricity and district heating is 4%. The electricity used by the factory is emission-free, produced by wind power (24%) and nuclear power (76%).

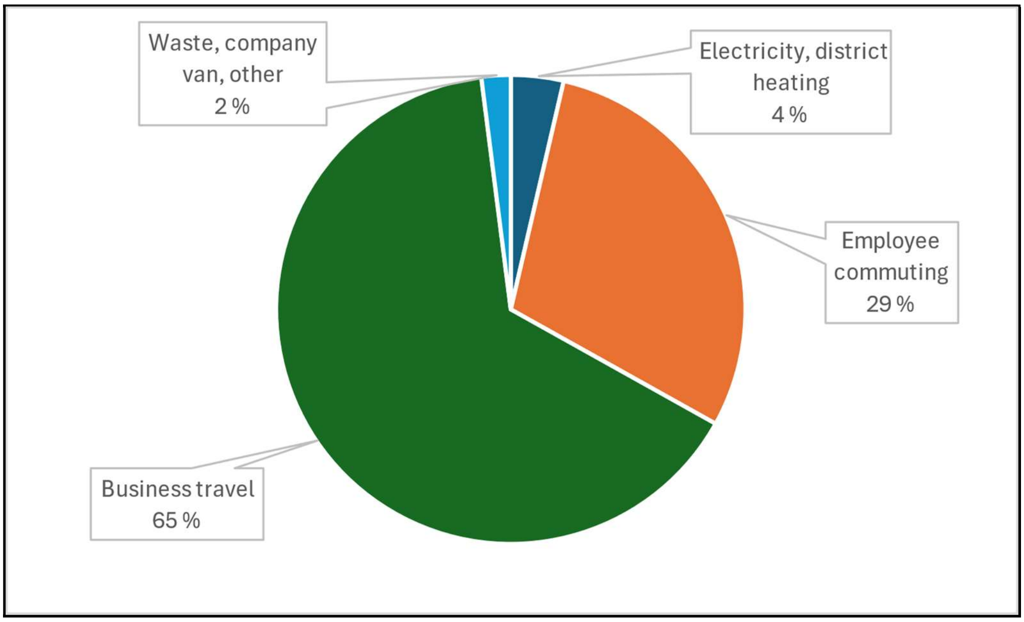

Figure 6. Distribution of CO_2-eq in the manufacturing phase (%).

4.3 Transportation

The emission data for transportation from suppliers is obtained from T-DRILL's ERP system. The calculation is based on the emissions of the mode of transport and the transport distance from the supplier within Finland. The manufactured machine is delivered to the customer via truck transportation by a logistics company. The transportation emissions are based on the 2024 emissions report of the logistics company. The average emission has been calculated considering the transport route and the weight of the product including the shipping platform. The study assumes that the customer's site is in Central Europe. The emissions of the shipping platform and package materials are also calculated under transportation.

The emissions from all transportation of one complete machine amount to 338 kg of CO_2-equivalent. This figure includes the emissions from components supplied by external vendors (11% of total CO_2-eq), as well as the transportation of the finished product to the customer (89% of total CO_2-eq). The transportation represents a relatively small portion of the overall GWP impact.

4.4 Operational Phase

The operational phase of the machine includes emissions from electricity consumption, spare parts and their shipment, lubricant, maintenance, and waste. The lifespan of the machine is estimated to be 20 years. The electricity consumption of the machine is based on power consumption and collaring speed measured by T-DRILL and to the annual production volume of the collars. The production volume is an average obtained from 15 customer companies. Utilizing these values and the average emission factor for electricity use in Europe, the annual electricity consumption has been calculated. Additionally, the emission calculations consider electricity consumption when the machine is in standby mode. According to the experiences of maintenance department, most customers do not turn off the machine entirely. The standby mode has been calculated using the estimation of 250 working days in a year.

The emissions for the shipment of spare parts are based on the estimation from the shipping service. The emissions of the spare parts have been calculated as a percentage of the machine’s total weight and total emissions, based on the weight of the shipped spare parts. The emissions of business travel by the maintenance department have already been calculated in the manufacturing phase. Scheduled maintenance is generally carried out by customer companies' own maintenance team. The emissions of chemical products used in the maintenance process are calculated as well, using estimated values.

Lubricant is used during the collaring process; therefore, its associated emissions are included in the operational phase. The amount of lubricant used has been calculated according to the milling and collaring speed, the amount of mist lubricant devices and their spraying velocity. It is recommended to change the oil of the machine every 2–3 years. The oil change has been included in the waste emission calculations.

The total emissions attributed to the operational phase are 13,116 kg of CO_2-equivalent. With the lifespan expected to be 20 years, the annual emissions for the operational phase are 659 kg of CO_2-equivalent. The percentual distribution of emissions in the operational phase is presented in Figure 7.

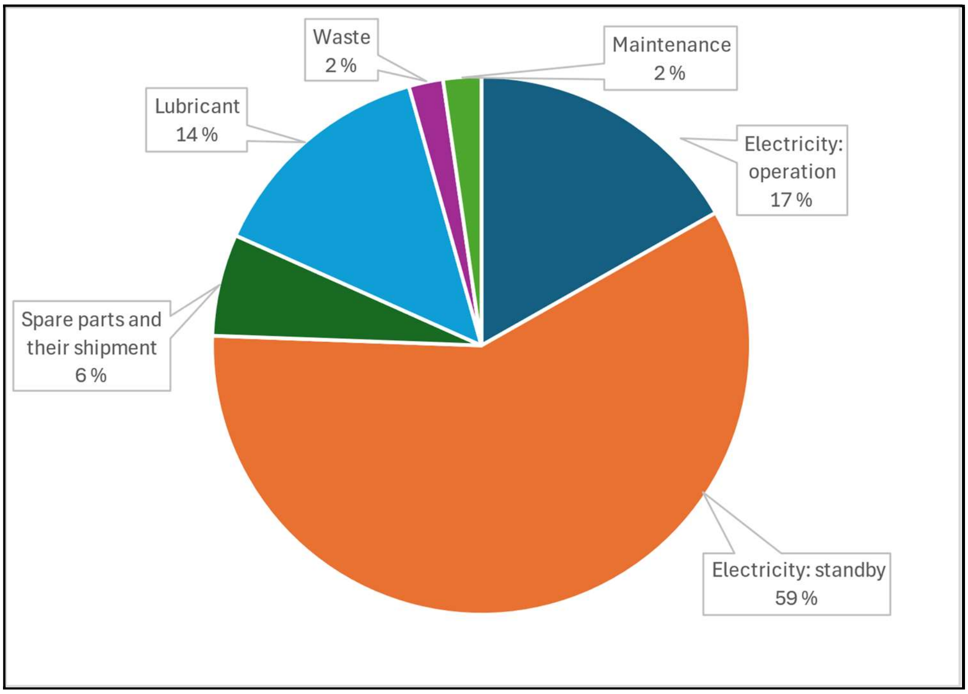

Figure 7. Distribution of CO_2-eq in the operational phase (%).

The highest emissions during the entire lifespan resulted from the standby electricity, 59%. Electricity consumption, when the machine is being used, generated 17% of the emissions. Lubricant use contributes notably, 14%, to the total emissions of the operational phase. The share of maintenance is only 2% but this is because the travel conducted by the service department is recorded under manufacturing.

4.5 End of Life

Proper management of the end-of-life phase is essential to minimize environmental impacts and maximize resource efficiency. Customers can return the machine to T-DRILL or dismantle and recycle in accordance with regional recycling guidelines. In the calculations, it was assumed that the machine is dismantled by the customer. The machine contains approximately 1,475 kilograms of steel and aluminum components and the remaining 211 kilograms consist of electrical components, plastics, gear motor, and other materials. Recycling steel and aluminum decreases emissions. Plastics and electrical components may be partly recycled, incinerated or landfilled. The total emissions of the end-of-life phase resulted in 1,221 kg of CO_2-equivalent.

4.6 Overall Results

Based on the research, the total carbon dioxide emissions of one TEC-220 over its entire lifecycle, 20 years of operation, are 36,117 kg CO_2-equivalent. This total impact encompasses all life cycle stages: raw material extraction, manufacturing, transportation, operational phase and end-of-life phase. Detailed breakdown of the total emissions is shown in Table 2 and in Figure 8.

Table 2. Carbon dioxide emissions of TEC-220.

Life Cycle Stage	**kg CO_2-eq**	**%**
Raw materials	18,921	52
Manufacturing	2,521	7
Transportation	338	1
Operational Phase	13,116	36
End of life	1,221	3

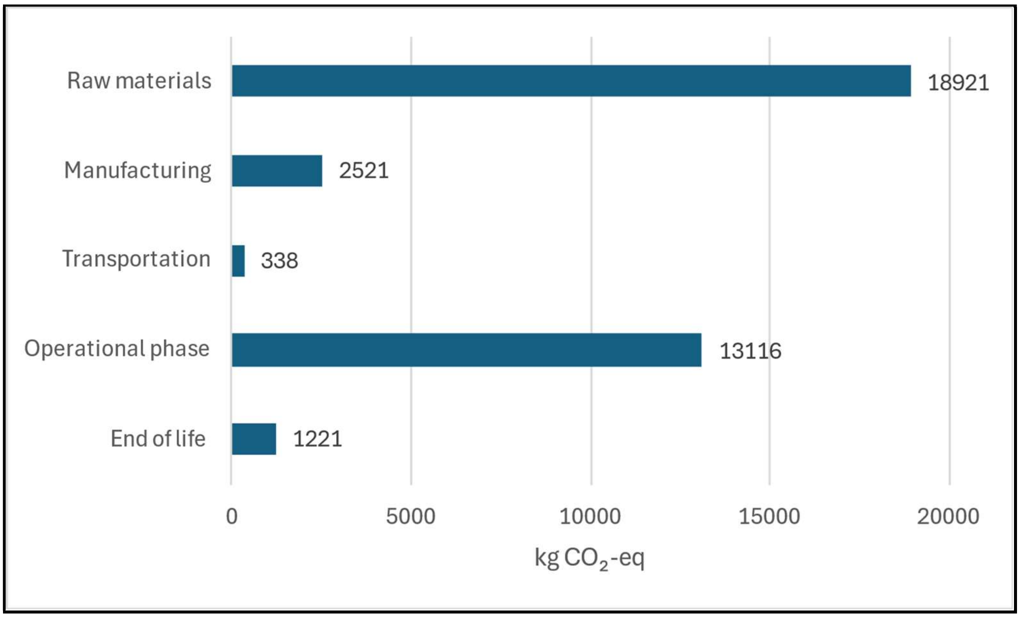

Figure 8. Emissions in the different life cycle stages.

According to the results, raw materials contribute the most to the total emissions (52%), followed by the operational phase (36%). The manufacturing phase accounts for only 7% of the total emissions. The research suggests that the lifecycle stages causing the least emissions are transportation (1%) and the end-of-life phase (3%). The percentual share of the overall results are presented in Figure 9.

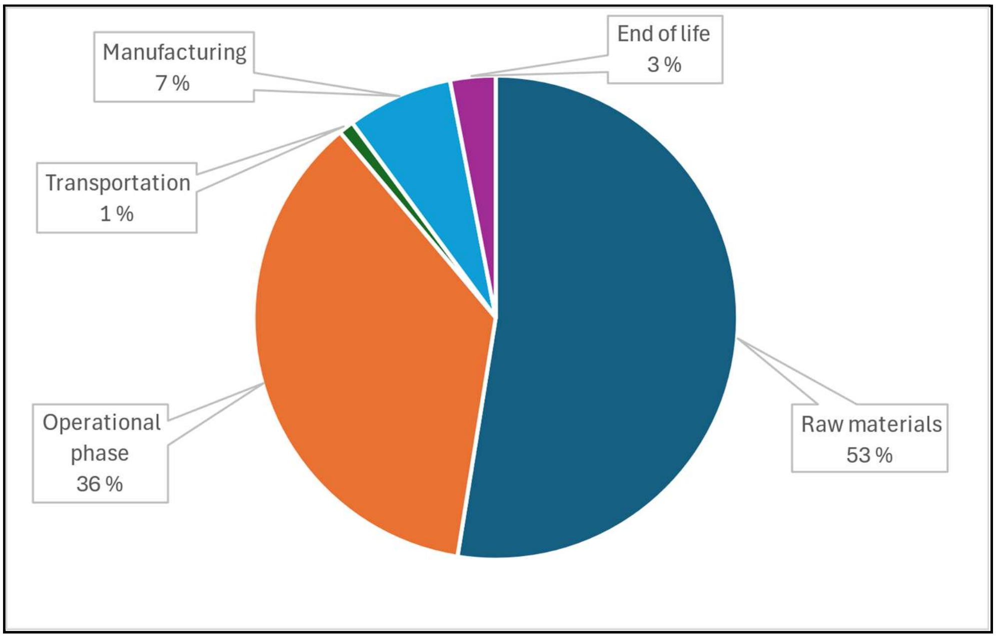

Figure 9. Emissions in the different life cycle stages.

The findings show that raw materials, along with their manufacturing, make a significant contribution to total emissions. This may be explained through the high carbon intensity of raw material production. Approximately 85% of the components used in TEC-220 are made of steel, steel-based products or steel alloy. Utilizing steel products produced by low-emission methods would be a more sustainable choice from an environmental perspective. In addition, utilizing recycled materials and reducing energy consumption during the raw material extraction can have a significant role in the overall emissions.

The operational phase contributes to 36% of total emissions. As presented in subsection 4.4, this results from the machine operating in standby mode, leading to higher overall electricity use. Turning off the machine when it is not in use can significantly reduce the overall emissions as illustrated in Figure 10. In the study, it was calculated that the machine is in standby mode 24 hours per day, 250 working days in a year. From these values, the actual collaring time was deducted. When changing the scenario, standby mode being only five hours per day, the total emissions decreased 6,783 kg CO_2-equivalent. This results in the operational phase contributing only to 22% of total emissions. Additionally, it is possible to optimize the emissions from the electricity consumption, both during the operation of the machine and during the standby of the machine, by using renewable energy sources.

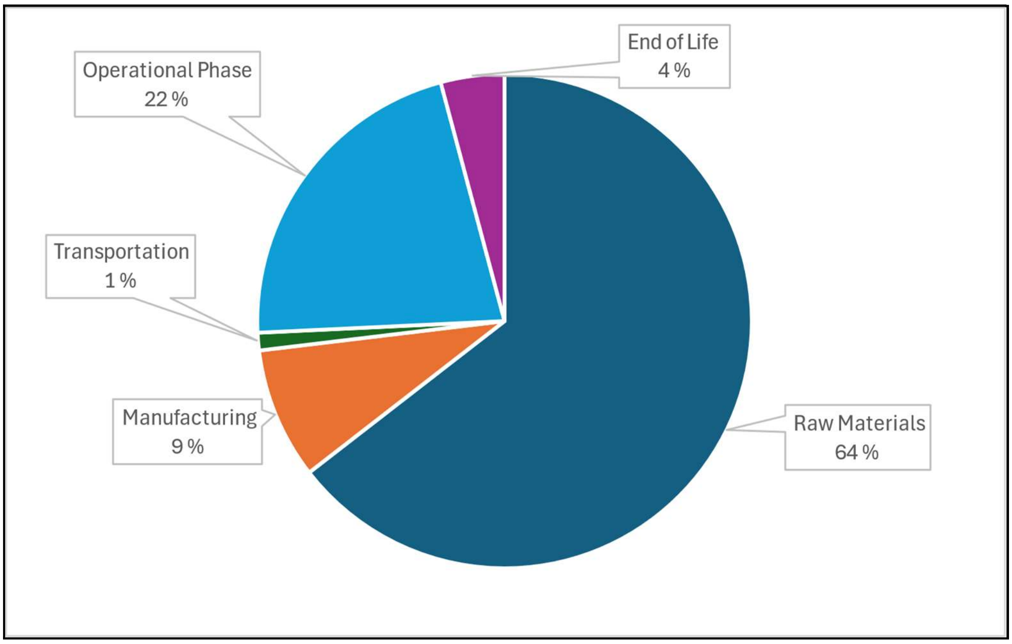

Figure 10. Scenario featuring reduced standby power consumption.

The manufacturing phase produces relatively low emissions, but energy-efficient solutions and low-emission technologies can be employed to improve the overall impact. Emissions from transportation and the end-of-life phase are minimal, yet their assessment and improvement are also important for overall sustainability. Reducing emissions requires measures especially in the raw material production and in the operational phase of the machine, but the development of manufacturing and logistics processes as well as the end-of-life recycling also support the environmental goals.

4.7 Limitations

Although efforts were made to ensure data accuracy, the study and the results have limitations that should be acknowledged. Due to the lack of access to relevant databases, the results are based on limited data sources, estimations and assumptions, which may reduce their reliability. Calculations, as performed manually, may involve errors. Regional variations in emission factors are not considered due to the lack of reliable data. Some assumptions are simplified which may affect the accuracy of the results.

The emissions of raw materials are calculated using different emission factors, some are based on monetary value, some on the material. Some data is received from the suppliers, but the calculation method may vary between suppliers and products. Transportation from suppliers is calculated from their Finnish location although some products may arrive directly by flight from their manufacturer in another country. Transportation to customers is based on an average route to Europe, values may differ significantly if customer is located further.

The values for electricity consumption are strictly based on input data and scenario defined in the scope. The emission factor used does not consider how electricity is generated, and it is assumed to remain constant over the lifespan of 20 years, which may not reflect the plans for global decarbonization. Spare parts are calculated only based on shipment; the study does not consider other replaceable components. The end-of-life emissions are assessed at a general level. The recycling processes during the dismantling phase may vary significantly depending on the location.

5 CONCLUSIONS

This study highlights the importance of choices made during all stages of a product’s life cycle. To decrease the emissions caused by different processes and to ensure environmentally friendly procedures, it is vital to analyze the different stages and highlight the factors that have the greatest contribution to the total emissions. This research revealed, or possibly confirmed, the life cycle stages of TEC-220 that produce the most emissions.

The results show that the strategies to reduce the operational electricity consumption and the use of renewable energy sources, low-emission production methods and components made of recycled materials will enhance the sustainability of the machine. The findings can support the manufacturers and customers in making more sustainable decisions. At the same time, the results also indicated that the case company has already made environmental efforts and sustainable choices.

The biggest limitation of the research is the lack of accurate data for emission factors and regional factors. This may have a huge impact on the results even though the percentual share of life cycle stages and their emissions would remain the same. Consequently, generalization and comparison of the results is difficult. The other factor is that the study excludes all other environmental impacts and focuses solely on the global warming potential. This may give a misleading impression of the results, as the impacts could be greater and more significant in other categories. In addition, critical review of the study is advisable, and necessary, in case of using the results for public comparative purposes.

In future research, emphasis should be placed on the quality of data. It is recommended that the next LCA study is performed using proper software tools and databases. This is crucial for ensuring the accuracy and efficiency of the study. In addition to the most common LCA tools like SimaPro, GaBi and OpenLCA, there are many alternatives to choose from. Some of the next-generation tools require even less manual input because they utilize AI and real-time data processing.

In summary, the study was able to accomplish the objective and managed to answer the research questions. The study provides an indicative result regarding the environmental friendliness of the machine and its impact on the climate. The results should be interpreted in their context and not used as absolute truths. The theoretical framework highlights the importance of conducting all the phases of LCA study as guided by ISO 14040 and 14044.

REFERENCES

Curran, M. (2012). *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products.* Wiley-Scrivener. https://ebookcentral-proquest-com.ezproxy.puv.fi/lib/vamklibrary-ebooks/detail.action?docID=1047617

D'Adamo, I., Gastaldi, M. & Nallapaneni, M. (2024). *Sustainable Development Goals.* MDPI - Multidisciplinary Digital Publishing Institute. https://directory.doabooks.org/handle/20.500.12854/152977

Dröder, K. & Vietor, T. (2025). *Circularity Days 2024*. Springer Fachmedien Wiesbaden GmbH. DOI: 10.1007/978-3-658-45889-8

Ecochain. (n.d.) *LCA Beginner course.* Retrieved April 9, 2025, from https://academy.ecochain.com/course/lca-beginner-course [Limited availability]

Ecochain. (2025). *The Data You Need for a Life Cycle Assessment (LCA).* Retrieved April 9, 2025, from https://ecochain.com/blog/input-data-for-lca/

Ellen MacArthur Foundation. (2022). *Life Cycle Assessment for the circular economy*. Retrieved March 25, 2025, from https://www.ellenmacarthurfoundation.org/life-cycle-assessment-for-the-circular-economy

Ellen MacArthur Foundation. (n.d.). *What is a circular economy?* Retrieved March 25, 2025, from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

European Commission. (2019). *Reflection Paper: Towards a Sustainable Europe by 2030.* Retrieved March 19, 2025, from https://commission.europa.eu/document/download/3dab8f75-8c9d-4cf2-b215-d9098e69b654_en?filename=rp_sustainable_europe_30-01_en_web.pdf

Hillege, L. (2019). *Impact Categories (LCA): The Complete Overview*. Retrieved April 21, 2025, from https://ecochain.com/blog/impact-categories-lca/

Horne, R., Grant, T. & Verghese, K. (2009). Life Cycle Assessment: Principles, Practice, and Prospects. CSIRO Publishing. https://ebookcentral-proquest-com.ezproxy.puv.fi/lib/vamklibrary-ebooks/detail.action?docID=474357

Jolliet, O., Crettaz, P., Jolliet, A., Saade-Sbeih, M. & Shaked, S. (2015). *Environmental Life Cycle Assessment*. CRC Press. https://doi.org/10.1201/b19138

Klöpffer, W. & Grahl, B. (2014). *Life Cycle Assessment (LCA): A Guide to Best Practice*. Wiley-VHC. https://ebookcentral-proquest-com.ezproxy.puv.fi/lib/vamklibrary-ebooks/detail.action?docID=1658826

Mahmud, M. A. P., Farjana, S. H., Lang, C. & Huda, N. (2023). *Green Energy: A Sustainable Future.* Elsevier.

Ministry of the Environment. (n.d.) *Euroopan unionin ilmasto-politiikka*. Retrieved March 31, 2025, from https://ym.fi/euroopan-unionin-ilmastopolitiikkaunionin ilmastopolitiikka - Ympäristöministeriö

Spiliakos, A. (2018). *What Does "Sustainability" Mean in Business?* Harward Business School. Retrieved March 31, 2025, from https://online.hbs.edu/blog/post/what-is-sustainability-in-business

Suomen Standardisoimisliitto SFS ry. (2006a). Environmental management. Life cycle assessment. Principles and framework (ISO 14040:2006 + A1:2020).

Suomen Standardisoimisliitto SFS ry. (2006b). Environmental management. Life cycle assessment. Requirements and guidelines (ISO 14044:2006 + A1:2018 + A2:2020).

T-DRILL. (n.d.) *Company profile.* Retrieved March 25, 2025, from https://t-drill.com/fi/yritysinfo/

T-DRILL. (2024). *T-DRILL yritysesitys.* [Limited availability]