The environmental impact categories of the Levkart

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A life cycle assessment

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Abstract

The start-up company LEVTEK is launching a new ultralight electric utility vehicle called the LEVKART. The Levkart uses a combination of robotics and AI-technology to offer semi-autonomous or autonomous riding and usage. The purpose of the vehicle is to serve as an alternative to cargo bikes and electric scooters designed for easy usage and as a more sustainable option to fossil-based transport. The purpose of this study is to evaluate the Levkart's environmental impact with the application of Life Cycle Assessment (LCA). This study analyzes the main environmental impact categories associated with the complete lifecycle of the Levkart using two different Life Cycle Impact Assessment (LCIA) methods: the *ReCiPe 2016 Endpoint* and *Ecological footprint 3.0* methods. The data used in the impact assessment was collected and analyzed in the Ecoinvent database and the SimaPro 9.5.0 software. Conducting a LCA for a company clarifies where the environmental impact is largest which in turn can contribute to the identification of possible improvements of a product. The results of the LCA proved that the main environmental impact categories of the Levkart were concerning resource use of minerals and metals, toxicity for human health and terrestrial global warming according to ReCiPe and EF methods. The extraction and production phase of the Levkart proved to have the largest environmental impact throughout its lifecycle, with gold as the primary contributor material. Gold is primarily found in the electronic components of the Levkart. A LCA conducted for gold production in China showed that the extraction and production phase of the lifecycle contributed to the most substantial overall environmental impact with the gold ore mining process being the most substantial. While gold has the highest impact score in all methods presented in the study, it only makes up for 0.06 % of the total mass of the Levkart.

Terminology

LCA, Life Cycle Assessment

LCI, Life Cycle Inventory

LCIA, Life Cycle Impact Assessment

ISO, International Organization for Standardization

Cradle-to-grave, a scope applied when conducting LCA. Cradle-to-grave scope includes all lifecycle phases of a product of service (Pagone, E. & Rashid, S., 2023).

Ecoinvent, global resource database for environmental data.

SimaPro, a life cycle assessment software (PRé Sustainability, 2024).

Endpoint, a method to derive characterization factors in the ReCiPe LCIA method. In endpoint, the environmental impact is visualized on three levels: human health, biodiversity and resource scarcity (RIVM, 2011).

Midpoint, a method to derive characterization factors in the ReCiPe LCIA method. In midpoint, the environmental impact is focused on single environmental issues (RIVM, 2011).

ReCiPe, a method for the impact assessment in life cycle assessments.

Ecological Footprint (EF), a method for the impact assessment in life cycle assessments.

DALY, disability life years, is a way of quantifying the effects on human health through accounting the years lost to death or reduce life quality due to illness (PRé Sustainability, 2016).

Pt, points.

Populärvetenskaplig sammanfattning

LEVTEK SWEDEN AB håller på att lansera en ny typ av elektriskt drivet fordon vid namn LEVKARTEN. Produkten ska med sina fyra hjul vara lätt och stabil att köra samtidigt som den erbjuder goda lastmöjligheter både inomhus och utomhus. Fordonet är utrustat med avancerade funktioner som möjliggör ökad säkerhet samt semi-autonom eller autonom körning. Innan Levtek lanserar deras nya produkt, vill de undersöka hur hållbar Levkarten är. Denna studie genomför detta genom att utföra en livscykelanalys (LCA) som täcker produktens hela livscykeln från utvinning av råmaterial till avfallshantering. Levkartens livscykel kan delas upp i fyra faser: utvinning & produktion, användning, transport och avfallshantering. Studien använder två olika metoder för att utvärdera vilken inverkan fordonet har på miljön, under dess livstid: *ReCiPe 2016 Endpoint* och *Ecological footprint 3.0*. Denna studie undersöker vilken typ av miljöpåverkan Levkarten orsakar under dess livscykel, genom att titta på olika kategorier. En stor mängd data samlas in över alla material och komponenter som ingår i produkten, tillsammans med massan för dessa. Insamlingen av data utförs av de två studenter som tillägnats uppgiften från Sustainalink, med stöd från Levtek, handledare och *Research Institutes of Sweden* (RISE). All insamlade data analyseras med hjälp av databaserna *Ecoinvent* och *SimaPro 0.5.0*. Resultaten från analysen visar att den största miljöpåverkan som Levkarten orsakar berör miljöaspekter såsom resursanvändning, specifikt av metaller och mineraler, människors hälsa och global uppvärmning. Vidare, är utvinning och produktionsfasen, den största orsaken till all miljöpåverkan associerad med Levkarten, med ädelmetallen guld som den stora boven. Allt guld som fordonet består av finns i de elektroniska komponenterna, där de ingår i moderkortet, batterikontakter och motorstyrkortet. Trots att guld är den största orsaken till Levkartens miljöpåverkan, så utgör det en oerhört liten del av den totala massan hos produkten, omkring 0.06 % av den totala vikten av fordonet på ca 20 kg.

Table of Contents

Introduction

LEVTEK is a start-up technology company developing software-defined ultralight vehicles and collaborative robots for sustainable transportation of both people and cargo (Levtek, 2024). Levtek is currently in the process of developing a new product known as the LEVKART (Sustainalink, 2024). The Levkart is a four-wheeled electric ultralight vehicle designed to be stable, easy to maneuver and to accommodate additional cargo space. The vehicle features multiple advanced functions through a combination of robotics and AI-technology, to offer semiautonomous or autonomous driving and usage (Levtek, 2024).

The Levkart serves a dual purpose; firstly, to serve as an alternative to electric scooters and cargo bikes, and secondly to replace and serve as a more sustainable alternative to fossil-based transport (Levtek, 2024 & Sustainalink, 2024). This is underscored by a survey conducted in 2019 where participants were asked what modes of transportation their use of the electric scooters replaced. The study found that electric scooters replaced mainly walked routes (39.8 %) and only 12 % of car trips. This indicates that the electric scooters that exist today have a limited ability to replace conventional vehicle rides, in contrast with the Levkart (Kazmaier et al., 2020).

As of today, Levtek are developing prototypes with an aim to launch the finished product onto the market within one and a half years (Sustainalink, 2024 & Levtek, 2024). Prior to the launching of the Levkart, Levtek aims to assess the environmental sustainability of the vehicle during its life cycle (Sustainalink, 2024). In this study, the assessment is conducted through the application of a Life Cycle Assessment (LCA) methodology. LCA is a system perspective model for evaluating the environmental impact associated with a product and service covering the complete life cycle, from the extraction of raw materials to the end-of-life (Manickam V. & Muralikrishna I.V. 2017). The application of LCA can help identify improvements of the environmental performance and support in decision making regarding the product (Manickam V. & Muralikrishna I.V. 2017).

Purpose and research questions

The purpose of this study is to assess the environmental impact associated with the ultralight vehicle the Levkart, which can help contribute to improving its environmental performance. The study aims to make this assessment through identifying the main environmental impact categories associated with the Levkart. This is done by conducting a cradle-to-grave Life Cycle Assessment (LCA). To clarify the purpose of the study, the following questions have been formulated to guide this study:

I. What are the main environmental impact categories associated with the life cycle of the Levkart?
II. Which life cycle phase has the greatest impact on the environment according to the ReCiPe 2016 Endpoint and Ecological footprint 3.0 methods?
III. What processes and materials have the highest impact on the environment in the extraction and production phase of the Levkart?

Environmental significance

Conducting a LCA for a company is of environmental significance for multiple reasons. The purpose of conducting LCAs is to evaluate the environmental impact of a product or a service by investigating all phases in its life cycle (Jolliet et al, 2016). Performing a LCA clarifies where the environmental impact is the largest which in turn can contribute to the identification of improvements for a product. Conducting a LCA for Levtek's vehicle the Levkart, will contribute to understanding the environmental impact associated with the entire lifecycle of the Levkart. This study highlights the main environmental impact categories of its life cycle, which in turn will give Levtek an opportunity to evaluate the sustainability and environmental performance of their product. This study helps Levtek identify areas where improvement and optimization are possible so that they can minimize their negative impact on the environment.

Methods

In this study the main environmental impact categories of the Levkart, were identified with the application of the LCA methodology. Conducting a LCA means evaluating the environmental impact of a product or service while taking all life cycle phases in consideration (Jolliet et al, 2016). This study is an attributional LCA, and the overall approach is quantitative since a LCA covers data from the extraction of raw materials to the disposal of the product. As stated by the International Organization for Standardization in ISO 14040, (ISO, 2006a), a LCA methodology is comprised of four steps:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

In the first stage, the scope and goal of the study is determined. This stage includes delineating and describing the system which will have a substantial impact on the results of the LCA (Jolliet et al, 2016). The first stage is where the purpose of the LCA is determined which sets the tone for how the results are going to be used and by whom. In the second stage the relevant data is collected and quantified, in the Life Cycle Inventory (LCI). All inputs and outputs included in the lifecycle of a product or service are quantified in this stage. In the third stage the environmental impact is assessed in what is referred to as a Life Cycle Impact Assessment (LCIA). There are different LCIA approaches with separate ways to determine how the inventory data is interpreted, how the information can be linked to environmental impacts and how the impacts can be compared. Lastly the results are interpreted and evaluated in the fourth stage. This last stage involves drawing conclusions about and evaluating the results, along with analyzing the limitations of the study as making recommendations based in the results from the LCI and LCIA (Jolliet et al, 2016).

Goal and scope definition

The goal for this study is, as stated in the purpose, to identify the main environmental impact categories associated with the Levkart and to investigate which lifecycle phase and material that contributes the most to the overall environmental impact. The functional unit used in this study is one Levkart with the mass of 20 kg. This functional unit is a quantification of all related inputs and outputs for the Levkart, which is equal to all components required to build the product (Chen, W. et al 2018). The LCA performed in this study covers all stages of the Levkart's life cycle, also known as a cradle-to-grave scope (Pagone, E. & Rashid, S., 2023). The system boundary of this study is distributed over four lifecycle phases: extraction of raw materials and production, usage, transport, and end-of-life. To visualize the limitations of this study in terms of the LCA and its scope, the following flowchart has been constructed.

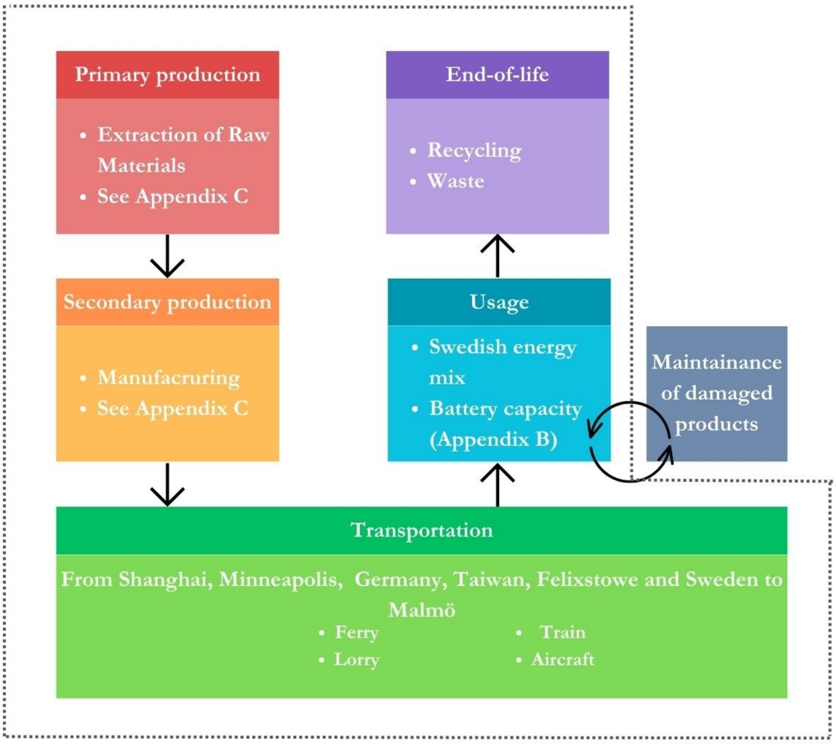


Figure 1.
Visualization of the system boundaries of this study's life cycle assessment. Figure made of Agnes Gulliksen, used with permission.

Inventory analysis

In the inventory analysis phase, the relevant primary data associated with the Levkart was collected through collaborative efforts from the two students that were assigned this project with support from both Levtek and the Research Institute of Sweden (RISE). In the data collection process, all necessary information for the conduction of a comprehensive LCA was gathered, including the information about the material composition of the components in the Levkart.

In terms of the extent of data collection associated with the different lifecycle phases of the Levkart, the most comprehensive phase was the extraction and production phase. Initially Levtek themselves provided a list of all included components along with details on all suppliers involved in the manufacturing of the Levkart. As a first approach, all suppliers were contacted, and their websites were thoroughly researched with the goal of obtaining information regarding the components they supply Levtek with. In response to incomplete data received from the suppliers and their websites, all components of the Levkart were comprehensively studied regarding their material composition and weight at Levtek's facility in Malmö, Sweden. The weighing of the components involved the use of two different scales, one for lighter components allowing a specificity of four decimals and another for the heavier components allowing a specificity of two decimals. The material composition including the share for each material for the components was estimated through the utilization of different sensory techniques. For complex components containing multiple materials, those with a share of less than 1 % to the total weight of the component were excluded. Due to limited experience with advanced materials, including some used in the Levkart, typical compositions were researched online in some cases to establish material references.

For the usage phase of the Levkart all necessary information was obtained from Levtek regarding details on the energy consumption, battery efficiency, cargo weight and years of service (tables 5 & 6, appendix). For the transport phase of the Levkart, estimations were made regarding the routes and modes of transportation with the help from the supplier information obtained from Levtek themselves (table 7 appendix). For the end-of-life phase of the Levkart, it was assumed that all included materials can be recycled and disposed of separately.

Impact assessment

According to ISO 14044, the third LCA step consists of an impact assessment that quantifies the environmental impact of a product or service. The impact assessment is based on inventory data and selected impact assessment methodologies (ISO, 2006b). This step was performed using the lifecycle assessment software SimaPro 9.5.0 (SimaPro, 2024). The data applied in the SimaPro software, is sourced from the Ecoinvent database version 3.8. Ecoinvent is a global resource that maintains a comprehensive life cycle inventory (LCI). The database provides data on the environmental impacts associated with a variety of products and services across their entire life cycles for more than 18 000 human activities. (Ecoinvent, a, n.d.). Ecoinvent provides background inventory data, which is derived from the integration of primary data sourced from Levtek, with processes in Ecoinvent. In this study the allocation, cut-off method by classification in Ecoinvent was chosen to allocate impact between co-products. Ecoinvent provides regionalized data on environmental impact, which is relevant because the Levtek relies on several international suppliers (Raül López I Losada, 2024). This study contains background data for activities performed in the following geographical locations according to Ecoinvent classification: China, Europe, Europe without Switzerland, Sweden, Global and Rest of the world. For the usage and end-of-life phase of the Levkart, Sweden was used as geographical location with the assumption that the product is used in Sweden and that every part of the vehicle will be disposed of in Sweden.

The LCIA method can be used to quantify the collected inventory data to ease the interpretation of the information (Janssen, A. 2024). In this study two different LCIA methods are used, to reduce the effect of systematic errors induced by the choice of methodology in the analysis. Firstly, the Environmental footprint method 3.0 (EF) combined with a normalization and weighting set, and secondly the ReCiPe 2016 Endpoint (ReCiPe).

The ReCiPe method aims to translate comprehensive impact assessment data into several indicator scores which express the relative extent of the environmental impact category. These indicators are derived in two ways: at midpoint or endpoint level (Pre-sustainability, 2016). In this study the ReCiPe method was applied which corresponds to three different protection areas: human health, ecosystem quality and resource scarcity (Huijbregts et al. 2016). Within these three protection areas there are multiple impact categories, summarized in appendix, table 4. The human health protection area is measured in the unit of "disability-adjusted life years" (DALY) which corresponds to the years of human life lost or disabled due to a specific disease (Rashedi & Khanam 2020). The ecosystem quality protection area calculates the damage from species density and potentially disappearing fraction of that species, and it is measured in the unit species.yr. The resource scarcity protection area corresponds to the damage from fossil fuels and metal source depletion, measured in the unit of USD2013 (Rashedi & Khanam, 2020).

EF is a LCIA method maintained by the European Commission. The method applied in this study is a midpoint method that assesses multiple environmental impact categories found in appendix table 3 (Ecoinvent. b, n.d.). Furthermore, a normalization and weighting set is applied to this impact assessment. The purpose of weighting according to ISO 14044 standard on LCA, is to convert and combine results from various environmental impact categories by using numbers based on value-choices (ISO, 2006). In SimaPro the impact categories are multiplied by specific factors and in turn results in a single score (SimaPro, 2020).

Ethical considerations

This study was performed in cooperation with a company; thus, an impartial and objective approach has been pursued throughout the progress of the paper. Given that the company's product the Levkart has not yet been launched, multiple ethical considerations have had an important role in the making of this study. To ensure confidentiality and the safety of information associated with the Levkart and Levtek themselves, a non-disclosure agreement (NDA) was signed among the parties. This ensures the mutual consensus of the relevant regulations and guidelines regarding what to include in the study. Another important ethical consideration is regarding the potential for "greenwashing" of Levtek and/or the Levkart. Greenwashing refers to the act of deceiving or misleading consumers regarding the environmental performance of a company or its product or service (Tinnie, 2013). To ensure the elimination of greenwashing in the study, the data and information has been presented using an objective and transparent approach.

In this study, suppliers from different countries have been contacted to obtain valuable data regarding material composition. Due to differences in geographical locations of these suppliers, it is expected that each country has a unique environmental development and sustainability priority. In turn, this influences the environmental impact associated with the different materials. Recognizing that all countries are different, a transparent and respectful communication have been prioritized and maintained throughout this study.

Delimitations

Conducting a LCA involves comprehensive collection and studying of data across a product's lifecycle, including everything from extraction of raw material to the end-of-life phase. Given the constraints of this bachelor thesis, the timeframe, and the limited available information about the Levkart, this study offers an estimation of the environmental impact associated with the product's lifecycle. The usage and end-of-life phases of the Levkart are completely unexplored given that the product is not yet launched. For the sake of delineating the scope of this study, usage of the product is not accounted for nor is the battery lifetime. This means that any deterioration of the components leading to replacements, is not accounted for. Furthermore, this study does not encompass the diversity in consumer types that may interact with the Levkart once it is launched. Therefore, a functional unit has been determined of an average cargo weight associated with the Levkart (table 5 appendix). This study is limited to the use of two LCIA methods, EF and ReCiPe. The purpose of this, is to identify the main impact categories for both methods separately. Hence, the LCIA methods will not be compared with each other since they are in fact different methods of quantifying environmental impacts.

Results

Impact categories

The main environmental impact categories associated with the life cycle of the Levkart according to the EF method are concerning resource use of minerals and metals and ecotoxicity. On the other hand, the main environmental impact categories according to the ReCiPe method are concerning toxicity for human health (non-carcinogenic) and global warming This is underscored by figures 2-4 presented below. The EF method data is aggregated into an overall impact assessment, whereas the ReCiPe method is distributed over three protection areas: "Human health", "Ecosystem quality" and "Resource scarcity" (table 4 appendix). The last protection area within ReCiPe, "Resource scarcity", only includes two impact categories. In this study it does not add any information of value for the results, although they can be found in appendix, tables 8 & 9. This is because ReCiPe does not compare impacts across the protection areas and therefor does not allow for an analysis on the extent of resource use in comparison with other impacts.

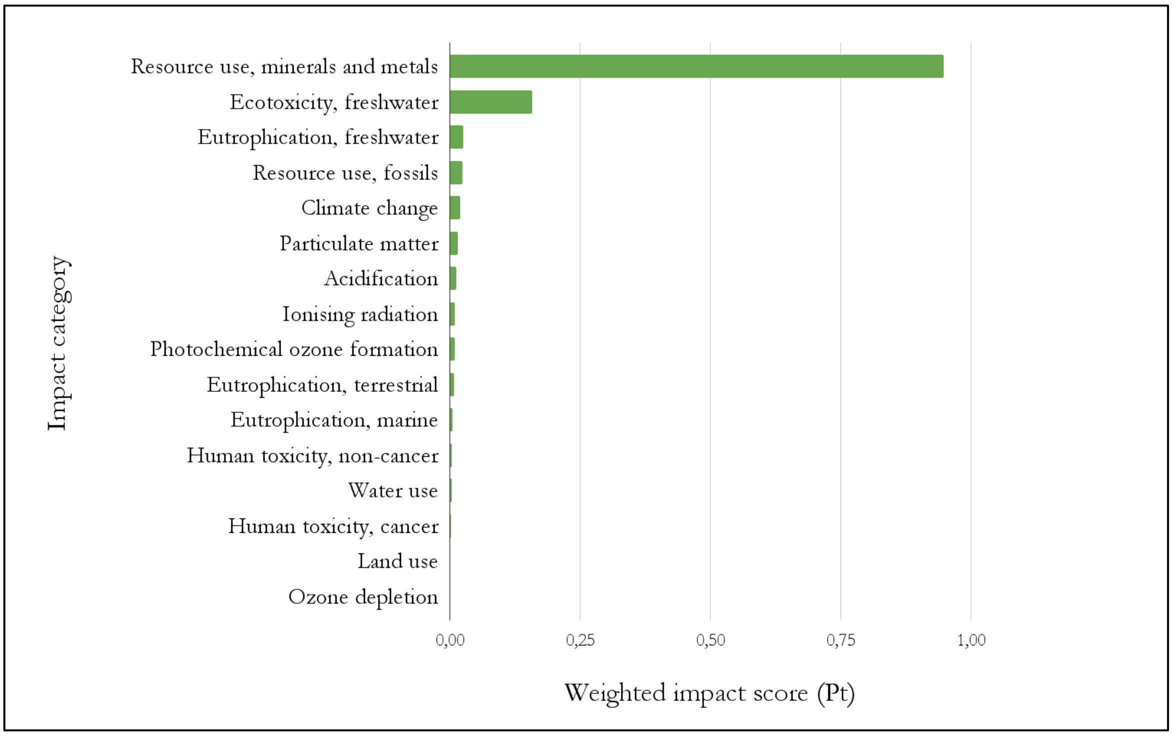


Figure 2.
Distribution of the impact scores across all impact categories in Ecological footprint method throughout the lifecycle of the Levkart with green as indicator.

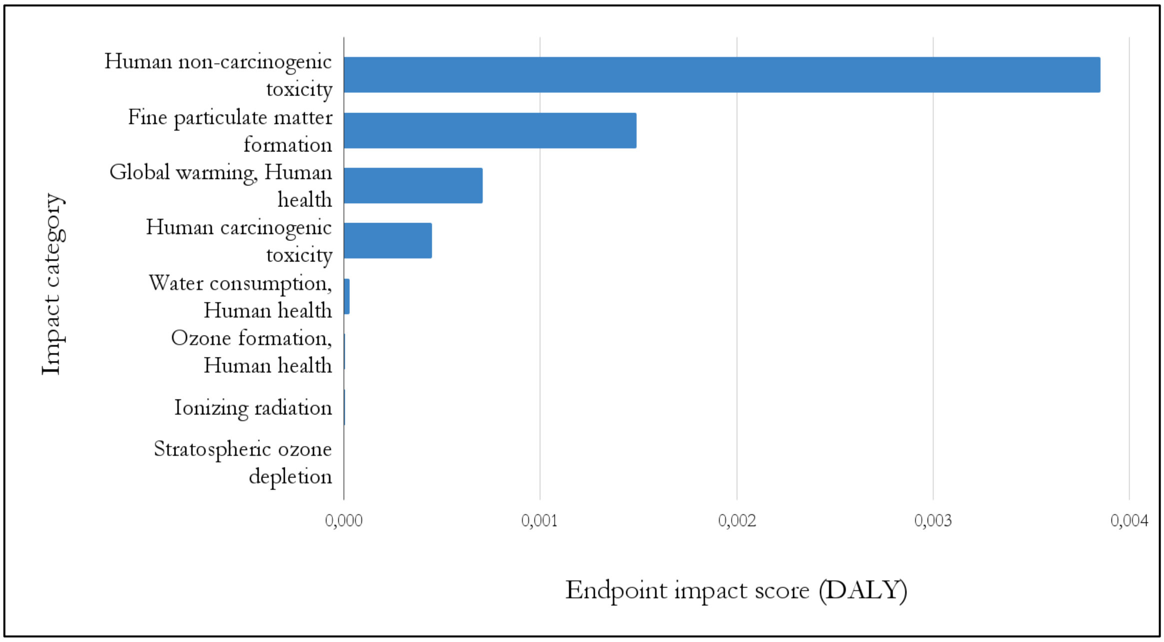


Figure 3.
Distribution of the impact scores across all impact categories in ReCiPe 2016 Endpoint method: Human health throughout the lifecycle of the Levkart with blue as indicator.

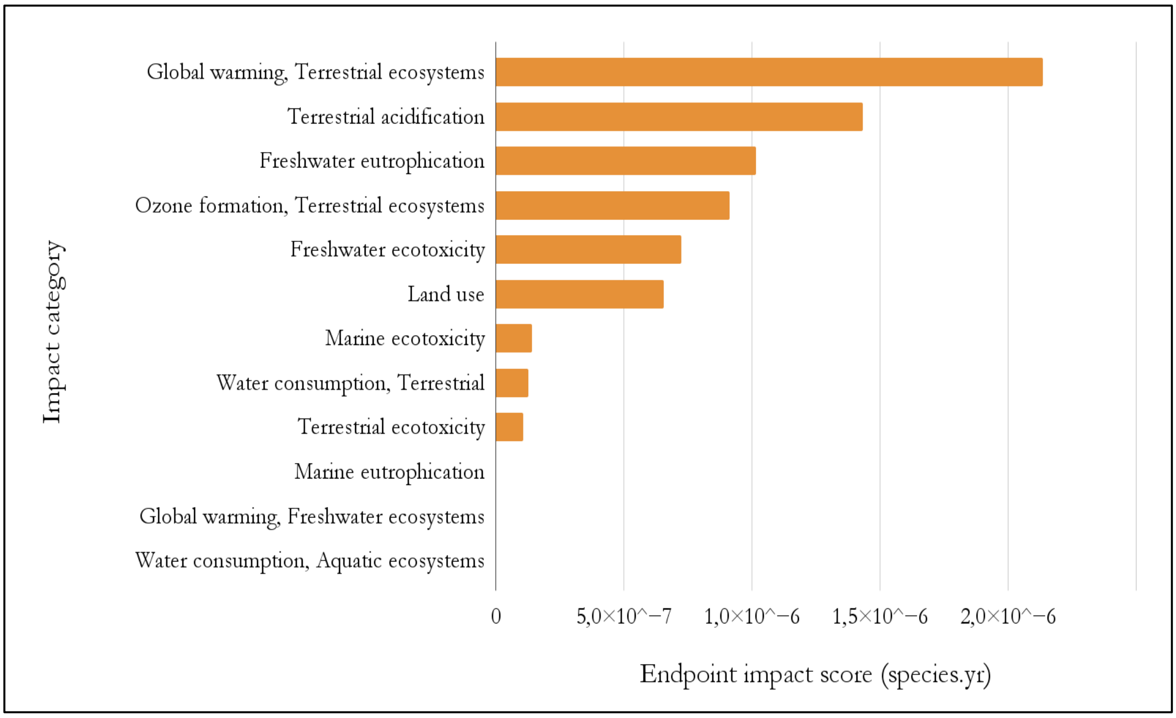


Figure 4.
Distribution of the impact scores across all impact categories in ReCiPe 2016 Endpoint method: Ecosystem quality throughout the lifecycle of the Levkart with orange as indicator.

Generally, when analyzing all results regarding the impact categories across both methods, toxicity has a high impact score, whether it is an ecotoxicity- or human toxicity impact category. Another environmental aspect that generally has a high impact score across all figures, is global warming and climate change. However, it is important to state that the scale of the impact score varies between the figures (2, 3 & 4). The weighted impact score (Pt) has a higher overall score reaching between 0-1 Pt (figure 2). In contrast, the endpoint impact score (DALY) has a lower overall score reaching between 0-0.004 DALY (figure 3) and the endpoint impact score (species.yr) the lowest score reaching between 0-2*10-6 species.yr (figure 4).

On the other hand, the ozone impact aspect varies in impact score across the figures (2, 3 & 4). In both the weighted impact score (Pt) as ozone depletion and the endpoint impact score (DALY) as ozone formation, the environmental impact score does not stand out (figure 2 & 3). However, the endpoint impact score (species.yr) ranked ozone formation as one of the main impact categories within the ecosystem quality protection area (figure 4). Although the methods are not directly comparable with each other, …

Life cycle phases

The extraction and production phase of the Levkart's life cycle accounts for the most part of the environmental impacts according to both ReCiPe and EF. This is underscored in figure 5, 6 and 7 where the extraction and production phase have the highest impact score across both methods and different endpoints considered. In numerical terms this means that the extraction and production phase accounts for around 96 % of the total impact according to the EF method. In the ReCiPe method, the extraction and production phase accounts for around 90 % for the endpoint impact (DALY) and around 47 % for the endpoint impact (species.yr) (tables 11, 12 & 13 in appendix).

The end-of-life phase also has a substantial impact score in figure 7, however this is not the case for figures 5 and 6. According to the ReCiPe method, the end-of-life phase contributes to approximately 36 % of the endpoint impact score (species.yr) (figure 7 and table 13 appendix). In contrast, the endpoint impact score (DALY) from the ReCiPe method and the weighted environmental impact score (Pt) from the EF method, show that the end-of-life phase accounts for less than 1 % of the total environmental impact.

When studying the overall impact score diversity in all three figures, it is clear that the weighted environmental impact in figure 5 is higher in comparison with the impact score in figures 6 and 7. The extraction and production phase reaches a weighted impact score of around 1,25 (Pt) in figure 5 whilst reaching an endpoint impact score of 0,006 (DALY) in figure 6 and 0,000003 (species.yr) in figure 7.

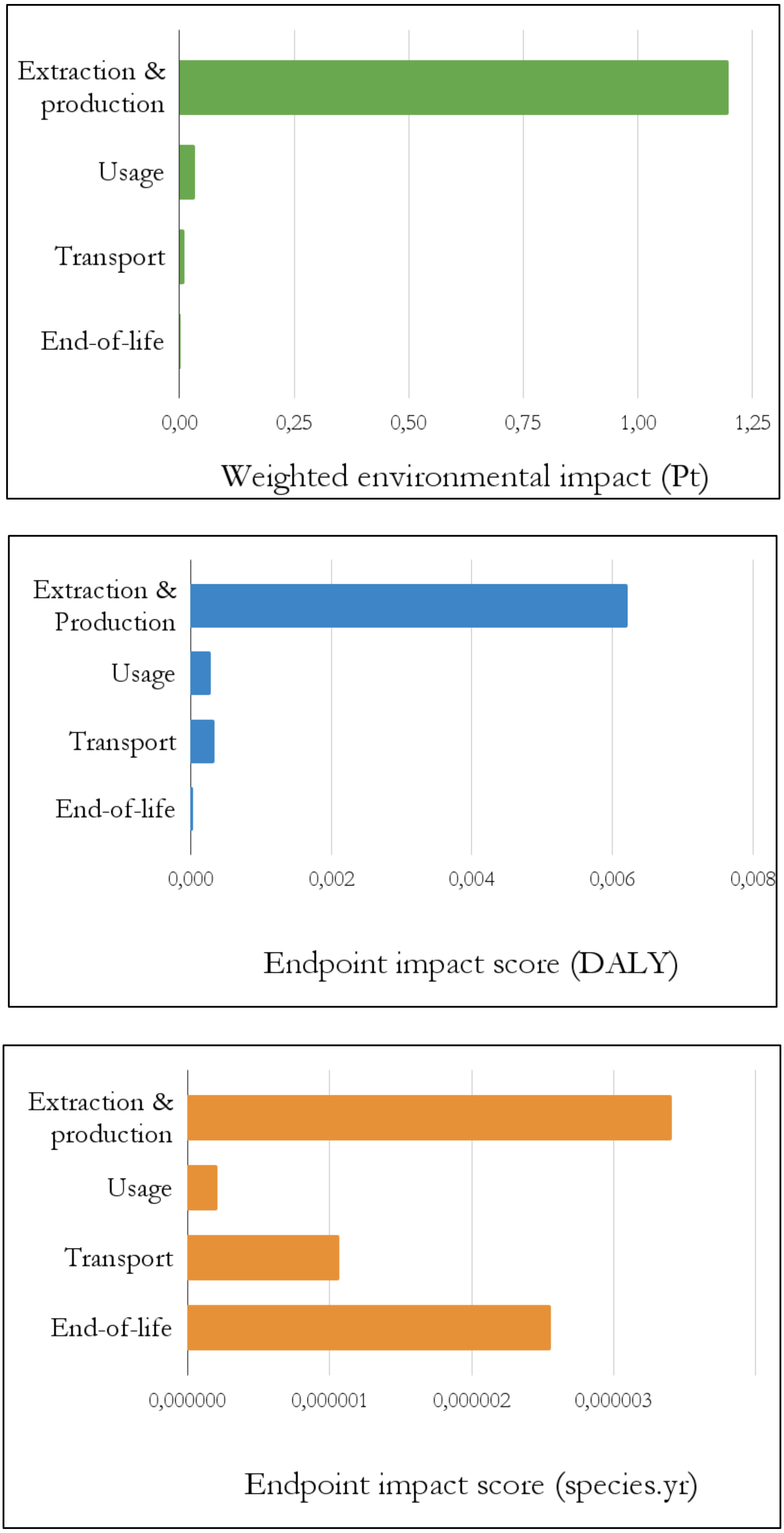
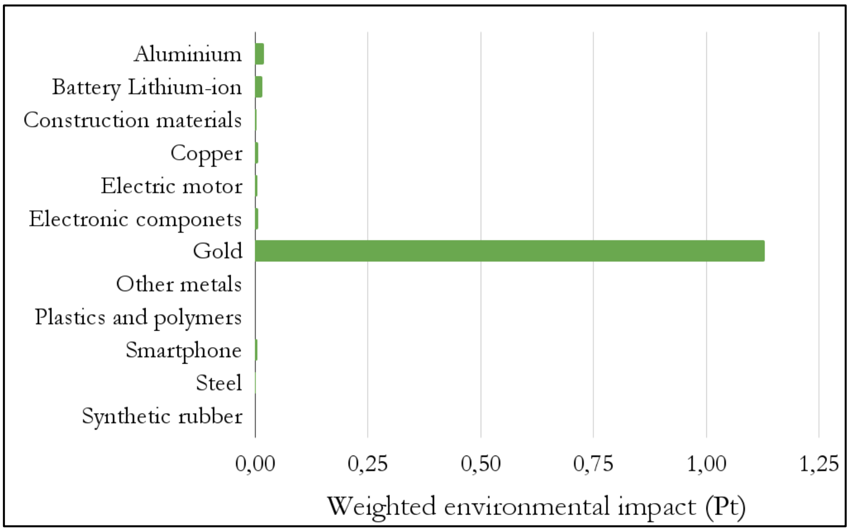


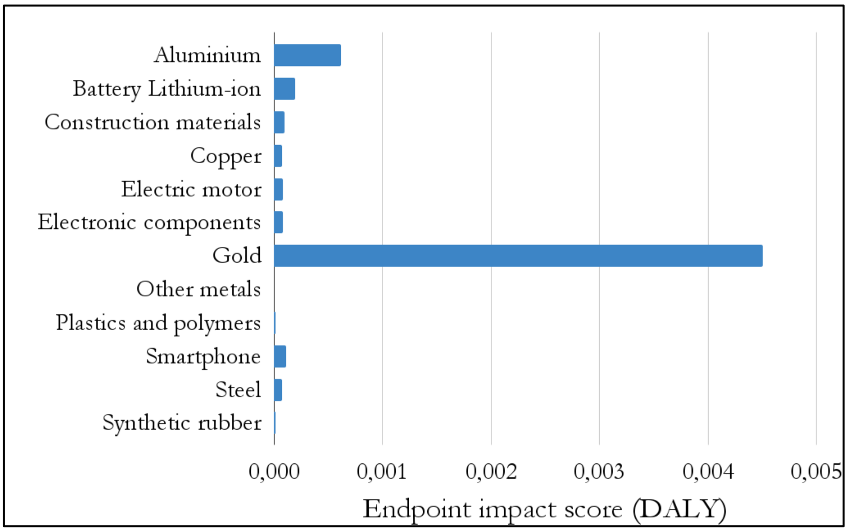
Figure 5, 6 & 7.

Distribution of the the weighted environment impact (Pt) with the Ecological footprint method (green), endpoint impact score (DALY) with the ReCiPe 2016:Human health method (blue) and the endpoint impact score (species.yr) with the ReCiPe 2016: Ecosystem quality method (orange) in the different life cycle phases of the Levkart.

Extraction & production

Out of all processes included in the extraction and production phase of the Levkart, (table 10 appendix), gold has had the most substantial environmental impact according to both LCIA methodologies (figures 8, 9 & 10). In numerical terms, gold accounts for around 94 % of the total weighted environmental impact (Pt) score (table 14 appendix) and around 77 % of the total endpoint impact score (DALY) (table 16 appendix). Another process with a high environmental impact is the extraction and production of aluminum, which is underscored mainly in the ReCiPe method (figures 9 & 10). For the endpoint impact score (species.yr) gold shares its high percentage with aluminum, as the gold accounts for around 54 % and aluminum for around 27 % (table 15 appendix).





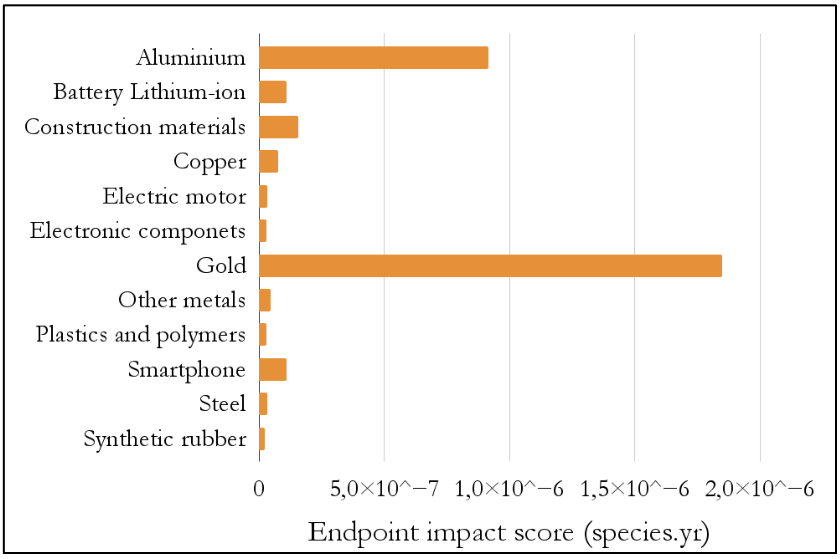


Figure 8, 9 & 10.
Weighted environmental impact (Pt), Endpoint impact score (species.yr) and Endpoint impact score (DALY) of the main processes from the extraction and production phase of the Levkart using the Ecological footprint method (green), the ReCiPe 2016 Endpoint methods: in the protection areas Human health (blue) and Ecosystem quality (orange).

Discussion

Main impact categories

According to the ReCiPe and EF LCIA methods used in this study the main impact categories concern resource use of minerals and metals, human toxicity, and global warming (figures 2, 3 & 4).

The specific impact category "Resource use, metals and minerals" in the EF method, problematizes the utilization of mineral- and metallic resources until the point of scarcity, which jeopardizes the availability of future usage (table 3 appendix). Given that the Levkart, consist of mainly metals of different kinds, it is reasonable that this is one of the main impact categories (table 1 & 2 appendix). The environmental problem lies mainly in mineral resources being at risk of depletion if not mined or managed sustainably (Xiong, et al. 2023). This has become a global challenge since the demand increases alongside with the growing population and industrialization. The exploitation of minerals and metals also affects the environment negatively (Xiong, et al. 2023). The resource use of minerals, specifically mining, affects both land, water, and air on a regional extent (Long et al. 2013, Schwarzenbach et al. 2010). Mining impacts the land through degradation, deforestation, and destruction of habitats. Furthermore, mining leads to the pollution of air and water due to toxic emissions (Xiong, et al. 2023). The impacts from mining on water is specifically due to acid mine drainage and through the water usage in processing associated with the mining. Acid mine drainage is the process when sulfide minerals are exposed to air and water, producing sulfuric acid in the process. Acidic water leads to toxic pollutions in different environments due to the travelling of waterways (Akcil & Koldas, 2006). This underscores the environmental impact associated with resource use, but also the connection between resource use of metals and minerals and ecotoxicity as environmental aspects. In this study, ecotoxicity specifically in freshwater is a key impact category, as it holds the second highest impact score (figure 2). Mining of minerals and metals can lead to habitat loss, pollution of water bodies and soil erosion which in turn can have severe effects on ecosystems and diversity (Xiong, et al. 2023).

The impact category "Human health, non-carcinogenic" from ReCiPe, highlights the role of non-carcinogenic toxicity in damage to human health (table 4 in appendix). This impact category is equivalent to increasing the risk of non-carcinogenic diseases (RIVM, 2024).

The impact category "Global warming, terrestrial ecosystems" from ReCiPe (figure 4) emphasizes the environmental impact on terrestrial ecosystems and its species through global warming. The terrestrial ecosystems have an important role in the global carbon cycle which in turn is highly affected by global warming (Ciais, P. et al., 2019 & Liu et al., 2022).

Extraction & production phase

When analyzing the complete lifecycle of the Levkart using ReCiPe and EF, the extraction and production phase has the most significant environmental impact (figures 5, 6 & 7). This means that most of the environmental impact associated with the Levkart is caused by the processes and materials included in the extraction and production phase. However, the usage and end-of-life phase of the Levkart, are completely unexplored since the product is not launched.

Gold has the highest impact score according to both the ReCiPe and EF method (figures 8, 9 & 10). In terms of the Levkart, gold is solely found in the electronic components (i.e. battery connectors, motor controller, motherboard).

A LCA using ReCiPe method was conducted for gold production in China (Chen, et al 2018). The study showed that the biggest environmental impact was metal depletion. Similarly in this study, the main impact category affected from gold extraction and production (ReCiPe method), was regarding resource use of metals and minerals (figure 13). Apart from metal depletion, impacts regarding other categories (i.e. climate change, terrestrial acidification, human toxicity, fossil depletion, particulate matter formation, and marine ecotoxicity) also made substantial contributions. Similarly, in this study the impact score proved to be substantial in similar impact categories (figure 11 & 12).

The LCA of gold production in China underscores that the gold ore mining has the most contribution to the metal depletion impact category (Chen, et al 2018). Similarly, this study showed that the extraction and production phase was the most substantial contributor to the overall environmental impact (figures 5, 6 & 7). Gold ore mining has multiple negative impacts on the environment, including directly degrading ecosystems due to the removal of vegetation and soil (Asner & Tupayachi 2017). Moreover, the extraction and production of gold damages biodiversity and human health because it sources chemicals such as cyanide and arsenic elements. The LCIA endpoint results of the gold production in China showed that the impact on human toxicity was 9.78*10-2 DALY (Chen, et al 2018). Similarly, in this study the human health categories, both non-carcinogenic and carcinogenic, have a substantial endpoint impact score between 3-4 *10^-3 DALY (figure 11).

While gold is responsible for the highest impact score in all methods presented in this study, this precious metal only makes up for a small part of the complete product. The total mass of gold is 1.2042 * 10^-2 kg which in relation to the complete 20 kg of the Levkart, is equivalent to approximately 0,06 % of the total vehicle (table 2 appendix). Another important note is the fact that all gold included in the Levkart is part of advanced electronic components such as the motherboard, motor controller and battery connectors.

Aluminum is the second most contributing material to the overall environmental impact of the Levkart (figure 8, 9 & 10). Aluminum is also the main material of the product, with a total mass of 18 kg, which is equal to 90 % of the total weight (table 1 appendix). In a LCA of electric scooters from 2022, alternatives for aluminum were researched because of its substantial environmental impact during its production phase (Ishaq, et al., 2022). The study underscored the intensive energy use both in the extraction processing phase, and the separating process requiring temperatures between 400-500 degrees Celsius. Given the extent of the environmental impact associated with aluminum, the study investigated multiple improvements and solutions. The study highlighted substitution to other materials and the usage of recycled aluminum as alternatives. The conclusion of the study was that in terms of carbon footprints, timber would be a potential substitute for aluminum because it had comparable mechanical properties with aluminum (Ishaq, et al., 2022).

Limitations of the study

This study has multiple limitations, including the limited data available associated with the Levkart's lifecycle. Firstly, the Levkart has not yet been launched which means there is no knowledge of the usage phase, nor the end-of-life phase as stated previously. This has led to the assumption that all waste produced from the Levkart, will be disposed of separately. It is important to state that there are some weaknesses to this assumption given that a comprehensive number of materials are included in multiple components that in turn are included in the Levkart. It is unlikely that all materials are disposed of separately, however as stated in the scope and delimitations of the study, this was necessary for the sake of completing the study. Secondly, there could be a presence of human error in this study, in terms of the estimations and assumptions made regarding the material composition of the Levkart. An example of this is through the utilization of the SUM tool in Google sheets to add masses together.

Future studies

For future studies, investigating the environmental performance of the Levkart post-launch would address existing gaps in this study. The data used to conduct this LCA is based on the current Levtek prototype, which may undergo changes before its anticipated launch. Apart from the material composition of the Levkart, examining the usage and end-of-life phases is imperative. An investigation of different disposal options for the product could fill a current knowledge gap of the end-of-life phase.

This LCA underscore gold as the material with most substantial environmental impact within the Levkart. Given the scope of this study, it is important to address the complexities involved in improving the environmental performance associated with gold. Gold is primarily found embedded into the electronic components of the Levkart. It would provide valuable insights to investigate whether the environmental impact varies depending on the geographical location of gold extraction and production.

As the second most impacting material, the use of aluminum in the Levkart could also be evaluated. Aluminum production is highly energy demanding and the environmental impact varies based on the energy mix of the producing country. Therefore, examining the effects of sourcing aluminum from different geographical locations is also important.

Furthermore, an evaluation of other alternatives for the components in the Levkart, specifically gold and aluminum, could be beneficial in future studies. By exploring substitutes for gold and aluminum, such as recycled options or less impacting, the overall environmental performance of the product could be improved.

During early discussion with Sustainalink and Levtek, an interest in comparisons with other ultralight electric vehicles, and vehicles in general, was stated. Hence, a comparative LCA with other vehicles would be of interest to see how changes in material types and the overall material composition would affect the environmental performance. This would be fulfilling in terms of understanding how different modes of transportation affect the environment in relation to the new and yet to be released Levkart.

Conclusion

In conclusion, this study analyzes the environmental impacts associated with the life cycle of the Levkart through the utilization of the ReCiPe Endpoint and Ecological footprint LCIA methods. The main environmental impact categories proved to be concerning resource use of minerals and metals and ecotoxicity for EF and human non-carcinogenic toxicity and global warming for terrestrial ecosystems for ReCiPe. This study shows that the extraction and production phase of the Levkart's life cycle has the greatest contribution to the overall environmental impact according to both LCIA methods. Additionally, gold has a specific role in the environmental impact even though it constitutes a small fraction of the total mass of the Levkart. Furthermore, aluminum constitutes a large fraction of the total mass of the Levkart and has the second largest environmental impact overall. Future studies could investigate the environmental performance of the Levkart after its launch to fill current data gaps, specifically examining the usage and end-of-life phases.

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Appendix

Table 1 Material input inventory
Macromaterials and their mass input for the manufacturing of the Levkart.

Material	Total input mass (kg)
Aluminium	18.008965
Steel	3.32045
Electric motor	1.27
Stainless steel	0.80466
Synthetic rubber	0.482231
Plastic	0.347467
Copper	0.3224834
Polyethylene	0.30901012
Polycarbonate	0.273814
Cables	0.273748
Cement	0.2706
Android phone	0.22
Battery	0.20976
Polyurethane	0.19652
Polyester	0.18649748
Chromium-molybden steel	0.17252
Brake lever	0.1501
ABS	0.11382

Table 2 Material input inventory
Micromaterials and their mass input for the manufacturing of the Levkart.

Material	Total input mass (10*-2 kg)
Charger	5.94
PCB	5.48562
Zinc coating	5.0155
TFE	3.6
FR4	2.592
Polypropylene	2.28
Glass	2.2
Polyamide	2.1864
Neodymium magnet	2.1566
Glassfibre	1.8132
Silicone	1.54
Gold	1.2042
Converter	1.08
Brass	0.8568
Silver	0.5412
Lead	0.0492
Nickel plating	0.0335

Table 3: Ecological Footprint method impact categories
All impact categories with unit and the definition according to European Commission, Joint Research Centre, Cerutti, A. et al. (2018).

Impact category	Unit	Definition
Climate change	Pt	Greenhouse gas emissions that change the climate for the worse impacting ecosystems, natural resources and indirectly impacting human health.
Ozone depletion	Pt	Increased ultraviolet radiation due to emissions that damage the ozone layer. Impacting human health by resulting in skin cancer and damage to vegetation.
Ionising radiation	Pt	All radiation that enhances the risk of cancer.
Photochemical ozone formation	Pt	Air pollution, "summer smog", and respiratory disease caused by emissions.
Particulate matter	Pt	Air pollution, "winter smog", and respiratory disease caused by emissions of tiny particles.
Human toxicity, non-cancer	Pt	Emissions of toxic matter impacting the health negatively, both through inhalation of air and indirectly through intake of food and water.
Human toxicity, cancer	Pt	Emissions of toxic matter enhancing the risk of cancer, both through inhalation of air and indirectly through intake of food and water
Acidification	Pt	Negative impact on water and soil through the presence of acid rain and low air quality due to emissions.
Eutrophication, freshwater	Pt	Abundance of nutrients in marine water as a result of over usage of fertilisers, e.g. farming and wastewater emissions. This can lead to lead to algal blooms and fish death.
Eutrophication, marine	Pt	Abundance of nutrients in freshwater as a result of over usage of fertilisers, e.g. farming.
Eutrophication, terrestrial	Pt	Abundance of nutrients in marine water as a result of over usage of fertilisers, e.g. farming and wastewater emissions. This can lead to lead to algal blooms in sea water.
Ecotoxicity, freshwater	Pt	Emissions of toxic matter leading to danger for freshwater organisms, e.g. fish and algae.
Land use	Pt	Utilization of land and soil that leads to endangerment in soil fertility and survival of animals and plants.
Water use	Pt	Utilization of freshwater leading to endangerment of availability for future usage.
Resource use, fossils	Pt	Utilization of fossil fuels affecting the availability for future usage.
Resource use, minerals and metals	Pt	Utilization of minerals and metals affecting the availability for future usage.

Table 4: ReCiPe 2016 Endpoint impact categories
All impact categories with protection area, unit and definition according to RIVM (2024).

Impact category	Protection area	Unit	Definition
Global warming, Human health	Human health	DALY	Increase in disease and malnutrition leading to damage for human health.
Stratospheric ozone depletion	Human health	DALY	Increase risk for cancer and other disease leading to damage for human health.
Ionizing radiation	Human health	DALY	Increase risk for cancer and other disease leading to damage for human health.
Ozone formation, Human health	Human health	DALY	Increase in respitory damage and disease leading to damage for human health.
Fine particulate matter formation	Human health	DALY	Increase in respitory damage and disease leading to damage for human health.
Human carcinogenic toxicity	Human health	DALY	Increase risk for cancer leading to damage for human health.
Human non-carcinogenic toxicity	Human health	DALY	Increase risk for other diseases leading to damage for human health.
Water consumption, Human health	Human health	DALY	Increase in malnutrition leading to damage for human health.
Global warming, Terrestrial ecosystems	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Global warming, Freshwater ecosystems	Ecosystem quality	species.yr	Increased endangerment for freshwater species leading to damage to ecosystems.
Ozone formation, Terrestrial ecosystems	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Terrestrial acidification	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Freshwater eutrophication	Ecosystem quality	species.yr	Increased endangerment for freshwater species leading to damage to ecosystems.
Marine eutrophication	Ecosystem quality	species.yr	Increased endangerment for marine species leading to damage to ecosystems.
Terrestrial ecotoxicity	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Freshwater ecotoxicity	Ecosystem quality	species.yr	Increased endangerment for freshwater species leading to damage to ecosystems.
Marine ecotoxicity	Resource scarcity	species.yr	Increased endangerment for marine species leading to damage to ecosystems.
Land use	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Water consumption, Terrestrial ecosystem	Ecosystem quality	species.yr	Increased endangerment for terrestrial species leading to damage to ecosystems.
Water consumption, Aquatic ecosystems	Ecosystem quality	species.yr	Increased endangerment for freshwater species leading to damage to ecosystems.
Mineral resource scarcity	Ecosystem quality	USD2013	Increased cost of extraction for mineral resources leading to damage in resource availability.
Fossil resource scarcity	Resource scarcity	USD2013	Increased cost of oil, gas and coal energy usage leading to damage in resource availability.

Table 5: Overview regarding the usage phase of the Levkart using the Swedish energy mix as proxy.

Product	Tot weight	Energy consumed to charge battery (Wh)	Range per battery charge (km)	Average cargo weight per battery charge (kg)	Kilometers travelled per year (km)	Years of service - lifetime
1 unit Levkart	20	500	30	100	6000	15yrs

Table 6: Overview regarding energy usage for the Levkart using the Swedish energy mix as proxy.

Charges per year	Energy used per year (Wh)	Energy used per year (kWh)	Energy used for a lifetime (kWh)
200	100000	100	500

Table 7: Transportation overview for the components included in the Levkart.
Details from all included transportations of components required in the Levkart, divided into four different modes of transportation.

Mode of transport	Total cargo weight (ton)	Distance (km)	Unit	Geographical location
Ferry	0.0127531	42485	1.0000E+0 metric ton*km	GLO
Lorry	0.0286759	3073.5	1.0000E+0 metric ton*km	RER
Train	0.0000832	800	1.0000E+0 metric ton*km	Europe w/o CH
Flight	0.0000011	6610	1.0000E+0 metric ton*km	GLO

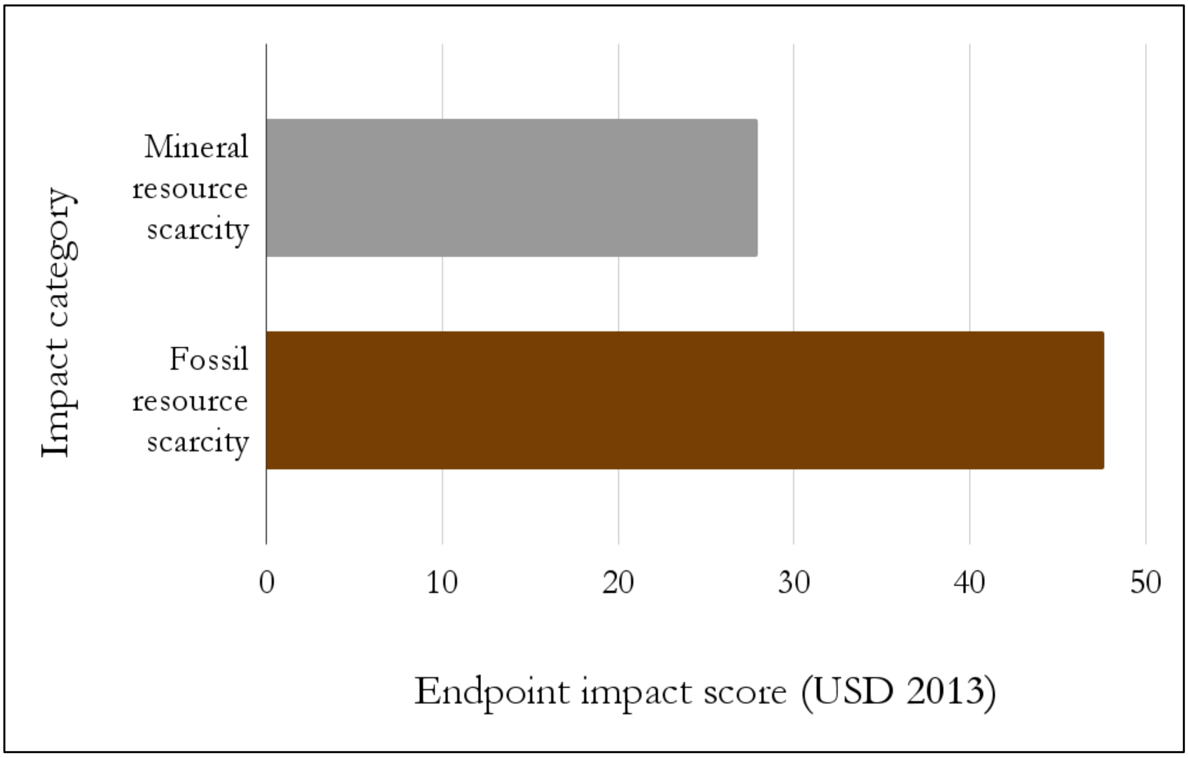

Figure 13.
Distribution of the impact scores across all impact categories in ReCiPe 2016 Endpoint method (Resource scarcity) throughout the lifecycle of the Levkart.

Table 8. Overview of the impact scores across all life cycle phases of the Levkart
All impact scores associated with the impact category Resource scarcity: mineral resource scarcity in ReCiPe 2016 Endpoint method.

Usage phase	Impact score (USD2013)	Share (USD2013)	Share (%)	Total impact score (USD2013)
Extraction & production	27,588	0,988	98,793	27,924
Usage	0,288	0,010	1,031	27,924
End-of-life	0,018	0,001	0,063	27,924
Transport	0,031	0,001	0,113	27,924

Table 9. Overview of the impact scores across all life cycle phases of the Levkart
All impact scores associated with the impact category Resource scarcity: fossil resource scarcity in ReCiPe 2016 Endpoint method in the usage phase.

Usage phase	Impact score (USD2013)	Share (USD2013)	Share (%)	Total impact score (USD2013)
Extraction & production	35,263	0,740	73,982	47,664
Usage	2,664	0,056	5,589	47,664
End-of-life	0,241	0,005	0,506	47,664
Transport	9,481	0,199	19,891	47,664

Table 10. Processes and materials in the extraction and production
All processes included in the extraction and production phase divided over 12 different themed groups.

Extraction & production processes	Included materials
Gold	Gold (SE & RoW)
Aluminium	Aluminium (CN & RER) & anodizing aluminium (DE)
Battery lithium-ion	Battery
Smartphone	Smartphone
Construction materials	Glassfibre & cement
Electronic components	Neodymium magnets, cables, brake lever (active electronic component), charger & converter
Electric motor	Electric motor
Copper	Copper oxide, sheet rolling, wire drawing (CN & RER)
Steel	Steel (RER & CN), chromium-molybden-steel, stainless steel
Plastics & polymers	Plastic (RER & RoW), polyurethane, polyester, polyamide, polyethylene, polycarbonate, polypropylene, TFE & ABS
Synthetic rubber	Synthetic rubber (RoW, RER & CN)
Other metals	Brass, nickel, zinc & lead

Table 11. Distribution of impact score among the lifecycle phases
Ecological footprint method distribution of weighted environmental impact (Pt) among all lifecycle phases.

Lifecycle phase	Weighted environmental impact (Pt)	Share (Pt)	Share (%)	Total weighted environmental impact (Pt)
Extraction & production	1,198459154	0,9625068062	96,25068062	1,245143563
Usage	0,03395004653	0,02726596959	2,726596959	1,245143563
Transport	0,00991263046	0,007961034177	0,7961034177	1,245143563
End-of-life	0,002818200223	0,002263353646	0,2263353646	1,245143563

Table 12. Distribution of impact score among the lifecycle phases
ReCiPe 2016 method distribution of endpoint impact score (DALY) among all lifecycle phases.

Lifecycle phase	Endpoint impact score (DALY)	Share (DALY)	Share (%)	Total endpoint impact score (DALY)
End-of-life	0,00003653672086	0,005313332049	0,5313332049	0,006876423404
Extraction & Production	0,006221643323	0,9047789756	90,47789756	0,006876423404
Usage	0,000282911493	0,0411422445	4,11422445	0,006876423404
Transport	0,0003353318669	0,04876544785	4,876544785	0,006876423404

Table 13. Distribution of impact score among the lifecycle phases
ReCiPe 2016 method distribution of endpoint impact score (species.yr) among all lifecycle phases.

Lifecycle phase	Endpoint impact score (species.yr)	Share (species.yr)	Share (%)	Total endpoint impact score (species.yr)
End-of-life	0,00000256134061	0,3535983554	35,35983554	0,000007243644013
Extraction & production	0,000003408200205	0,4705090696	47,05090696	0,000007243644013
Transport	0,000001064982375	0,147023014	14,7023014	0,000007243644013
Usage	0,0000002091208226	0,02886956098	2,886956098	0,000007243644013

Table 14. Distribution of impact scores among all extraction & production processes
Ecological footprint method distribution of weighted environmental impact (Pt) among all processes in extraction and production phase.

Extraction & production processes	Weighted environmental impact (Pt)	Total weighted environmental impact (Pt)	Share (Pt)	Share (%)
Precious metals	1,129315953	1,198424143	0,9423341137	94,23341137
Aluminium	0,02026715676	1,198424143	0,01691150573	1,691150573
Battery Lithium-ion	0,01593971018	1,198424143	0,01330055829	1,330055829
Electronic componets	0,007514965178	1,198424143	0,006270705759	0,6270705759
Copper	0,007022327602	1,198424143	0,005859634622	0,5859634622
Electric motor	0,005945779608	1,198424143	0,004961331629	0,4961331629
Smartphone	0,005511385986	1,198424143	0,004598860943	0,4598860943
Construction materials	0,003902851893	1,198424143	0,00325665326	0,325665326
Steel	0,00126410859	1,198424143	0,001054809015	0,1054809015
Plastics and polymers	0,0008088117378	1,198424143	0,0006748960644	0,06748960644
Synthetic rubber	0,0006880925379	1,198424143	0,0005741644489	0,05741644489
Other metals	0,0002430003205	1,198424143	0,0002027665429	0,02027665429

Table 14. Distribution of impact scores among all extraction & production processes
ReCiPe 2016 method distribution of endpoint impact score (species.yr) among all processes in extraction and production phase.

Extraction & production processes	Endpoint impact score (species.yr)	Total endpoint impact score (species.yr)	Share (species.yr)	Share (%)
Precious metals	0,000001850099383	0,000003408201641	0,5428374193	54,28374193
Aluminium	0,0000009150148328	0,000003408201641	0,268474383	26,8474383
Construction materials	0,000000155017916	0,000003408201641	0,04548378656	4,548378656
Smartphone	0,0000001094096292	0,000003408201641	0,03210186505	3,210186505
Battery Lithium-ion	0,0000001079558121	0,000003408201641	0,03167530079	3,167530079
Copper	0,00000007676233541	0,000003408201641	0,02252282684	2,252282684
Other metals	0,0000000460686923	0,000003408201641	0,01351700901	1,351700901
Electric motor	0,00000003262043392	0,000003408201641	0,00957115727	0,957115727
Steel	0,00000003236044478	0,000003408201641	0,00949487389	0,949487389
Plastics and polymers	0,00000003052345371	0,000003408201641	0,008955882579	0,8955882579
Electronic componets	0,00000002952625328	0,000003408201641	0,008663294132	0,8663294132
Synthetic rubber	0,00000002284245444	0,000003408201641	0,006702201584	0,6702201584

Table 14. Distribution of impact scores amon all extraction & production processes
ReCiPe 2016 method distribution of endpoint impact score (DALY) among all processes in extraction and production phase.

Extraction & production processes	Endpoint impact score (DALY)	Total endpoint impact score (DALY)	Share (DALY)	Share (%)
Precious metals	0,004507922283	0,005886311457	0,7658314236	76,58314236
Aluminium	0,000615883608	0,005886311457	0,104629803	10,4629803
Battery Lithium-ion	0,000199030586	0,005886311457	0,03381244561	3,381244561
Smartphone	0,0001139696645	0,005886311457	0,01936181347	1,936181347
Construction materials	0,00009467624542	0,005886311457	0,01608413794	1,608413794
Electronic componets	0,00008559606125	0,005886311457	0,01454154471	1,454154471
Electric motor	0,00008558014519	0,005886311457	0,0145388408	1,45388408
Copper	0,0000766170623	0,005886311457	0,01301614141	1,301614141
Steel	0,00007489039782	0,005886311457	0,01272280585	1,272280585
Plastics and polymers	0,00001521457877	0,005886311457	0,002584738998	0,2584738998
Synthetic rubber	0,00001347097239	0,005886311457	0,002288525249	0,2288525249
Other metals	0,000003459852178	0,005886311457	0,0005877793255	0,05877793255

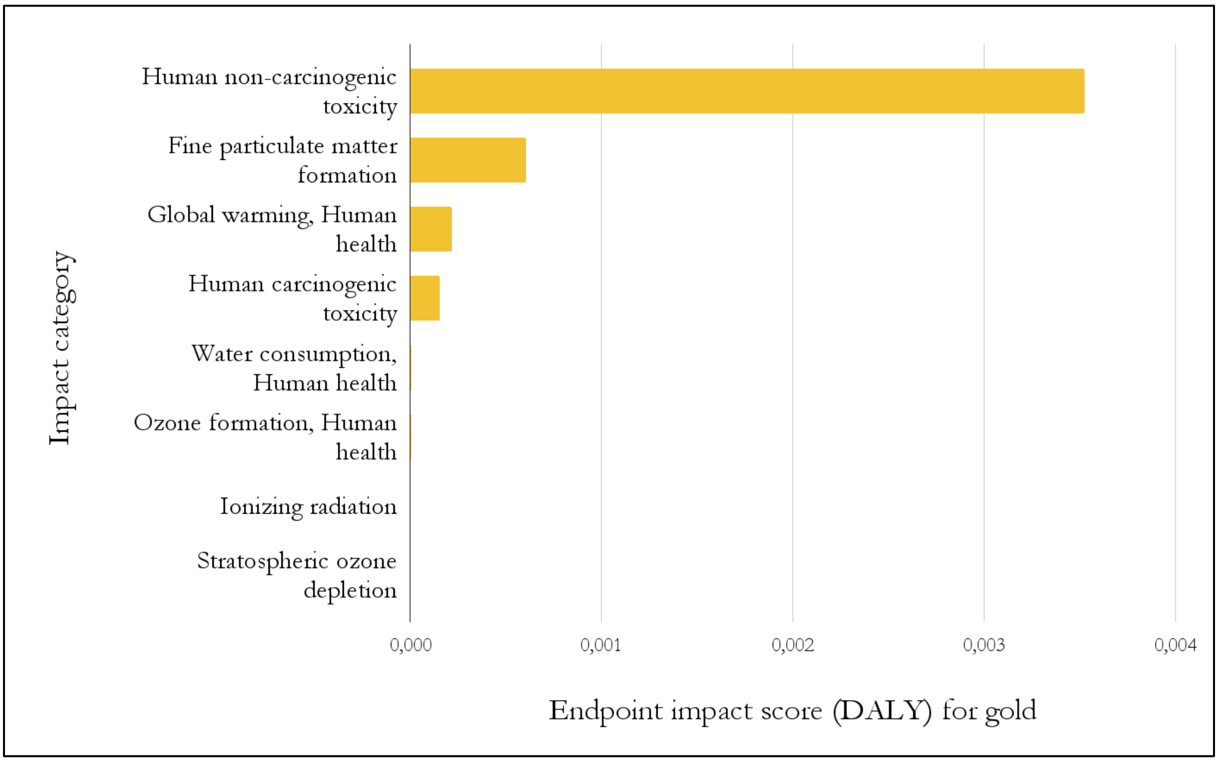

Figure 11.
Endpoint impact score (DALY) of gold during the extraction and production phase of the Levkart using the ReCiPe 2016 Endpoint methods (Human health) with the color gold as indicator.

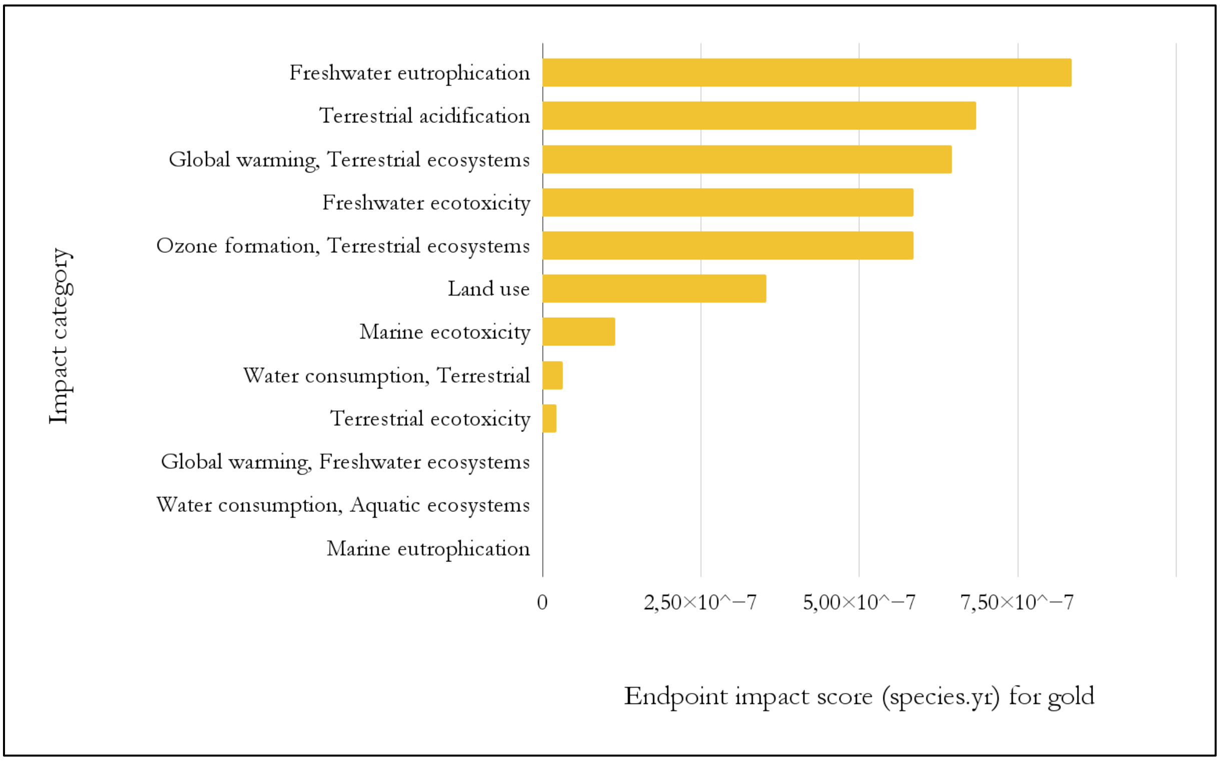

Figure 12.
Endpoint impact score (species.yr) of gold during the extraction and production phase of the Levkart using the ReCiPe 2016 Endpoint methods (Ecosystem quality) with the color gold as indicator.

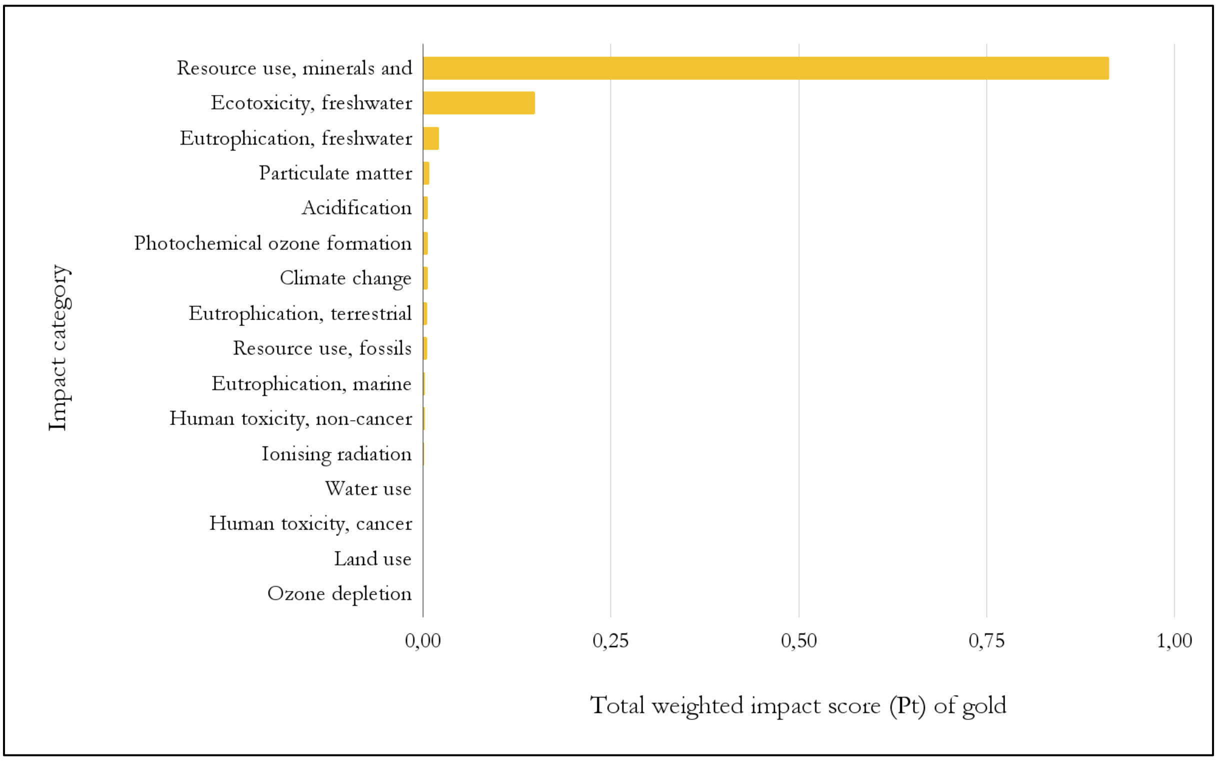

Figure 13.
Weighted impact score (Pt) of gold during the extraction and production phase of the Levkart using Ecological footprint method with the color gold as indicator.

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