The environmental impact of the Levkart

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A life cycle perspective

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Abstract

Carbon emissions from the transport sector are one of the main drivers of climate change, and electrified transportation is one attempt to reduce the sector's climate impact. Levtek Sweden AB is a start-up company developing the Levkart, a lightweight and autonomous four wheeled vehicle. To aid Levtek in developing a sustainable vehicle, this thesis aims to investigate the environmental impact of the Levkart during its lifecycle in comparison with other means of transportation. Furthermore, this study suggests areas of improvement, to aid Levtek before introducing the vehicle to the market. The study was conducted using a cradle-to-grave life cycle assessment. The LCIA method IPCC 2021 was used for the impact categories GWP100 and GWP20. The impact assessment was performed with software Ecoinvent 3.8 and Sima Pro 9.5.0. The environmental impact of the Levkart during its lifetime is 9 gCO2-eq/km or 797 kgCO2-eq, with its main contributors being the production and extraction phase (80%). The main materials driving the climate impact are precious metals, aluminum and cement. In comparison with other vehicles, the Levkart has a greater environmental impact than bicycles, but less impact than other means of electrified transportation, regardless the use of different energy mixes. To improve the environmental impact of the Levkart, recommendations are to change to replace or reduce the amount of the main impacting materials, to use swappable batteries, charge the battery with solar power and to substitute aluminum with timber.

Keywords: Life cycle assessment. Global warming potential, Micro mobility vehicles, environmental impact

List of acronyms

ALLEA, All-European Academics

E-scooter, Electric scooter

GHG, Greenhouse gasses

GWP20, Global Warming potential over a 20-year time horizon

GWP100, Global Warming potential over a 100-year time horizon

LCA, Life Cycle Assessment

LCIA, Life Cycle Impact Assessment

NDA, Non-Disclosure Agreement

POES, Personally Owned Electric Scooters

Populärvetenskaplig sammanfattning

Fossilbaserad transport är en av de största källorna till dagens globala uppvärmning och därmed är eldriven transport en viktig del till en grön omställning av samhället. Levtek Sweden AB är ett start-up bolag som vill följa med i denna omställning genom att lansera det nya eldrivna och fyrhjuliga mikromobilitetsfordonet – Levkarten. Levkarten kommer erbjuda en autonom och lätthanterlig produkt på marknaden inom 1,5 år med syftet att kunna transportera tyngre last. Med en livscykelanalys undersöker denna studie Levkartens miljöpåverkan och de huvudsakliga bidragande faktorerna. Syftet är att jämföra hur hållbar Levkarten är i relation till andra fordon, samt att bidra med rekommendationer för Levkarten som kan minska dess växthusgas-avtryck. Studien är en så kallad cradle-to-grave analys och undersöker Levkartens påverkan under hela dess livscykel, från utvinning av råmaterial, till sluthanteringen av produkterna. Resultatet genererade en total miljöpåverkan av Levkarten på 797 kgCO2-eq, varav 80% av denna härstammade från produktionsfasen. Vidare indikerade resultatet att påverkan från guld och silver, aluminium och cement var störst för produkten. I relation till andra fordon har Levkarten endast högre miljöpåverkan än cyklar, men presterar bättre än övriga fordon, oavsett vilken energimix som använts för jämförelsen. Studien diskuterar olika förbättringsåtgärder för att minska Levkartens miljöpåverkan och föreslår i samband med det områden för vidare studier. Rekommendationerna för Levkarten är att utesluta eller minska mängden material med hög påverkan, att använda utbytbara batterier, att laddas med solenergi, samt att byta ut aluminium mot trä.

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Introduction

Carbon emissions from transportation are one of the main causes of climate change and electrified transport is one adaptation proposed to reach the Paris Agreement (International Renewable Energy Agency, 2019). One common type of electrified vehicles are electric scooters (e-scooters), which are micro mobility vehicles either shared or personally owned (POES). Studies show large variations in climate change impacts of e-scooters due to different production processes, given that the production phase is the main driver of emissions trough their lifecycle (Kazmaier et al., 2020). Even though e-scooters often are presented as sustainable, many LCA studies show that shared e-scooters are not a more sustainable choice than other means of transportation (Sun & Ertz, 2022; Felipe-Falgas et al., 2021; Kazmaier et al., 2020).

Levtek Sweden AB is a startup company developing the four wheeled software-defined, ultralight vehicle, the Levkart, with collaborative robots for transportation of people and cargo. The Levkart, aims to bridge a gap between manual and autonomous riding. The vehicle uses a combination of robotics and AI-technology for collaborative, semi-autonomous or autonomous riding. The purpose of the vehicle is to provide a practical and safe alternative to today's vehicles for transportation indoors and outdoors. It aims to be an alternative to cargo bikes and e-scooters, as well as a more sustainable option to fossil-based transport. Levtek is currently in the prototyping phase of development and aims to launch the Levkart onto the market within one and a half years (J. Snowdon, personal communication, May 23, 2024)

To aid Levtek with developing a sustainable vehicle, this study aims to investigate how environmentally friendly the Levkart is in relation to other micro mobility vehicles. To investigate this, the study aims to perform a life cycle assessment (LCA) of the Levkart looking at its hotspots of greenhouse gasses (GHG). Hotspots are defined in this study as the main contributors to GHG emissions. This will be investigated along with a comparison analysis of GHG for other micro mobility vehicles. In addition, this study aims to identify areas of improvement for the GHG of the Levkart. Therefore, this study will contribute to mapping the environmental impact of the Levkart.

Background

Life cycle assessment

A life cycle assessment is a method for mapping the environmental impact of a product during its life cycle to be able to identify areas of improvement (Jolliet et al., 2016). The life cycle of a product consists of several phases, namely extraction of raw materials, production, transport, usage and end-of-life treatment (European commission, 2010). The method is structured in four phases: defining goals and scopes of the study, inventory analysis, impact assessment, and interpreting the results (Jolliet et al., 2016). The environmental impact of a product assessed with an LCA is the impact on the natural environment, human health and reduction of natural resources (European commission, 2010).

Global Warming Potential

According to article 3 paragraph 1 in the European Union regulation on fluorinated greenhouse gasses, global warming potential (GWP) is the "climatic warming potential of a greenhouse gas relative to that of carbon dioxide (CO2)" (Regulation 2024/573). GWP is a measure of greenhouse gas quantities that considers their relative strength to cause climate change, expressed in tons of carbon dioxide equivalents (Regulation 2024/573).

GWP can be measured with different timeframes to be able to compare GHG with different lifetimes. The GWP100 measures the energy absorbed by a gas over a hundred years whereas GWP20 measures over twenty years. GHG with shorter lifetimes will have a comparatively higher GWP evaluated over short time horizons, than GHG with longer lifetimes (Environmental Protection Agency, 2024).

Previous research

According to an LCA study of electrical scooters in Germany, using the IPCC 2013 life cycle inventory analysis (LCIA) method, the GWP of an e-scooter is 165 gCO2-eq/km. The material and production phase are the most impacting and accounts for 73% of the total emissions. The aluminum and battery production causes the most emissions within the production category. Additionally, the study presents that by swapping the battery of the scooter, instead of disposing of the scooter, its GWP can be reduced by 12%. Furthermore, the study stated that by using recycled materials, the GWP is improved. However, the most efficient way to improve the GWP of the e-scooter's life cycle was increasing the lifetime of the vehicle. By increasing the life by

15 months, the GWP is reduced by 68 gCO2-eq/km. Increasing its lifetime by using swappable batteries and using electricity with low GWP is shown to have the biggest impact on the GWP of the e-scooters (Kazmaier et al., 2020).

Another LCA analysis, which used the ReCiPe Midpoint LCIA method, of POES in Italy showed that the GWP was 21 gCO2-eq/km. The major impact to the GWP for the product was from the processing of materials with the battery production contributing the most. The study showed that e-scooters have higher GWP than bicycles (8 gCO2-eq/km) but lower GWP than electric bicycles (40 gCO2-eq/km), battery electric vehicles (80 gCO2-eq/km), e-mopeds (95 gCO2-eq/km) and e-motorcycles (119 gCO2-eq/km). The study also evaluated substitute materials to decrease the GWP of e-scooters. By replacing aluminum with timber and steel, the GWP of e-scooters can be decreased by 50%. Timber is a good substitute for aluminum because of its comparable mechanical properties. Furthermore, by charging the e-scooters with solar power the GWP decreases 44% in overall carbon emissions (Ishaq et al., 2022).

An attributional LCA of e-scooters in Brussels, using the ReCiPe 2016 LCIA method at midpoint and endpoint level, showed that shared scooters have a GWP of 131 gCO2-eq/km. A POES on the other hand has an impact of 67 gCO2-eq/km. They argue that the short lifetime of e-scooters causes high GWP-values. The study states that the material phase has the most impact with aluminum having the largest impact, followed by the battery, wiring boards and the electric motor respectively. By increasing the lifespan of the scooter, the GWP impact decreases, and to call e-scooters a sustainable mobility solution, their lifespans must be at least 9.5 months (Moreau et al., 2020).

Aim and research questions

Since Levtek is a startup company there is limited information and data about the environmental impact of the Levkart. The climate impact of the Levkart is unknown and this study aims to fill that knowledge gap by performing an early-stage LCA, enabling to influence the development of the product. There is previous research about the climate impact of other micro mobility vehicles which can contribute to a comparison between the Levkart and other micro mobility vehicles (Ishaq et al., 2022; Kazmaier et al., 2020; Moreau et al., 2020). This study aims to gather information regarding the environmental impact of the Levkart's life cycle to identify areas of improvement before introducing the product to the market. Furthermore, this study aims to compare the Levkart's climate impact with similar micro mobility vehicles. To analyze GWP emissions of the Levkart a LCA method will be used. Thus, the following research questions have been developed:

I. What is the global warming impact of the Levkart during its life cycle?

II. What is the global warming impact hotspots of the Levkart during its life cycle?

III. What global warming impact does the Levkart have in comparison with other micro mobility vehicles?

Relevance for environmental science

Carbon emissions from transportation are one of the main impacts of global warming and therefore fossil-free means of transportation are essential to reduce the GHG emissions (International Renewable Energy Agency, 2019). The transport sector contributes to 15.5% of the total GWP globally, with 53.7 GtCO2-eq in 2017 (Moreau, 2020). Electrified transportation such as e-scooters is one attempt to reduce the sectors climate impact. Though, e-scooters are today used for leisure rides, 44% of the trips taken are replacing walking and only 12% replaces other means of transportation (Kazmaier et al., 2020). The aim of the Levkart is, due to its ability to transport heavy goods, to replace transportation vehicles rather than replacing walking. By studying the environmental performance of the Levkart, this study is of great relevance for future constructions of environmentally friendly vehicles.

Furthermore, this study is of relevance for environmental science since the purpose of a LCA is to map environmental impacts, such as GHG (Jolliet et al., 2016). Besides these environmental impacts this study also covers three of the global sustainable development goals: goal 9 - Industry, innovations and infrastructure; goal 12 - Responsible consumption and production; and goal 13 - Climate action (United nations, n.d).

Method

This study consists of an attributional LCA of the Levkart and a non-systematic literature review for a comparison analysis with other micro mobility vehicles. The LCA method was chosen since it is the most common method for quantifying environmental impacts for transportation (Moreau, 2020). By using a combination of LCA data and an analysis of previous literature, this study will use a combination of a qualitative and quantitative method. To collect the results for this study the guidelines for ISO 14044 have been used (European commission, 2010).

An LCA has four phases of performing an assessment including: goal and scope definition, inventory analysis, impact assessment and interpretation of the products life cycle (Jolliet et al., 2016). The method for three of the phases is presented below, whereas the interpretation of the Levkart's life cycle is presented in the results and discussion section of this study.

Goal and scope definition

The scope is represented by the aim of this study: to evaluate the global warming potential and its hotspots of the Levkart during its lifecycle. The impact category used is GWP which will be based on two different time horizons: a 20-year time horizon (GWP20) and a 100-year time horizon (GWP100). The different time horizons have been chosen to include GHG with different atmospheric lifetimes (Skytt et al., 2020). The characterization factor for the GWP emissions will be measured in kilograms of carbon dioxide equivalents (kg CO2-eq). The functional unit analyzed in this study is one unit of a 20 kg Levkart and includes the quantity of the components needed to build one Levkart. The system boundary is cradle to grave and is visualized through four phases: extraction of raw materials and production, transport, usage, and end-of-life treatment. Service during the usage phase is not included in the system boundaries (Figure 1).

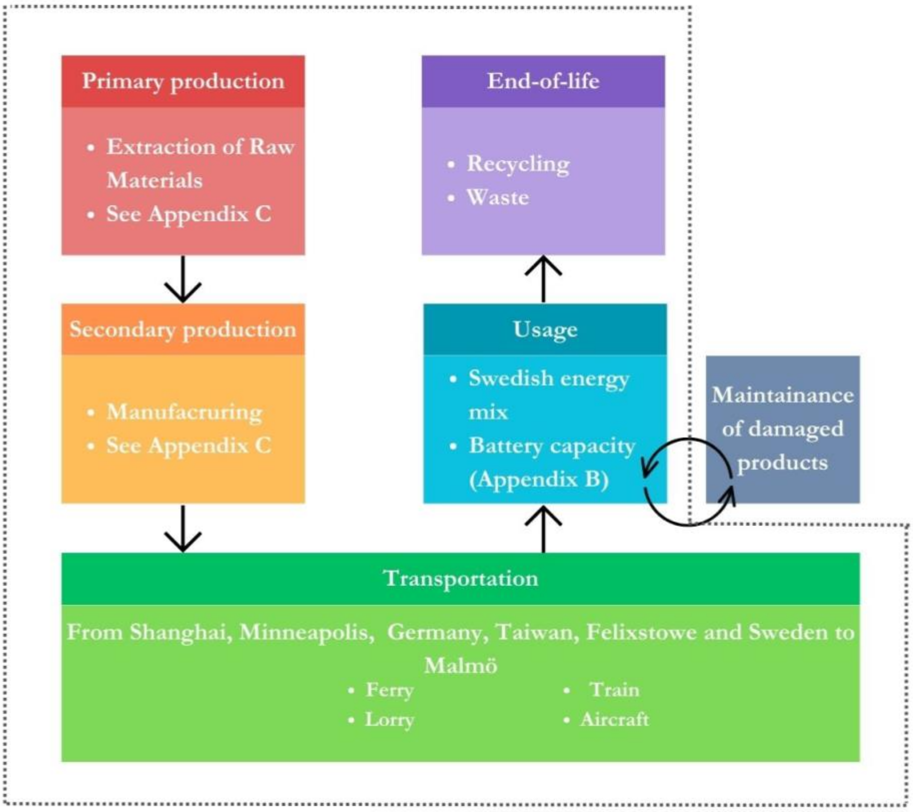

Figure 1
The system boundaries of the study, with excluded processes outside the dotted line.

The goal of this study is to evaluate the GWP impacts of the Levkart in relation to other means of transportation, as well as investigate key parameters that influence the environmental performance of the Levkart. To evaluate this goal, several subcategories have been defined: estimate the GWP impact of the Levkart and identify its most impacting life cycle phases; what including elements causes the most impact in GWP; to compare the environmental efficiency of the Levkart in relationship to other vehicles; how the environmental impact of the Levkart can be improved.

The goal definition of an LCA consists of six aspects that should be documented (European commission, 2010). The intended application, limitations, reasons for carrying out the study and influential actors are presented in the delimitations, ethical reflection and relevance for environmental science sections of this study. The targeted audience for this study is teachers and students at Lund University and the employees at Levtek. This study will also be disclosed to the public by its publication at Lund University.

Inventory analysis

The inventory analysis is combined of two methods: a primary and secondary inventory. The primary inventory was collected from four different sources: by students, suppliers, Levtek and by the Research Institutes of Sweden (RISE). The suppliers varied in how much information they could contribute with regarding the materials' composites and weights. Therefore, most of the primary inventory was collected manually. All the materials were weighed with two different scales, one allowing two decimals for heavier materials, and one allowing four decimals for lighter materials. The material compositions were determined by touch and sight and are therefore rough estimations. For each material two assumptions have been made: firstly, what materials the vehicle parts are composed of, and secondly the share of raw material for each composite. A delimitation was made for complex components, that includes several different materials, to only include materials that contribute to more than 1% of the product's weight. For complex electronic components, normal compositions were researched for a reference value.

The transportation phase was estimated based on the supplier countries. All transports from China were calculated to be transported by ferry from Shanghai's port to Gothenburg, and by lorry from Gothenburg to Malmö. The transportation from the USA was calculated from the Minneapolis-Saint Paul International airport to Amsterdam airport by aircraft, from Amsterdam to Gothenburg by ferry, and from Gothenburg to Malmö by lorry. From Taiwan the transportation was calculated by ferry to Rotterdam, by train from Rotterdam to Copenhagen, and by lorry from Copenhagen to Malmö. For Great Britain the transportation route was calculated by ferry from Felixstowe to Gothenburg, and then by lorry. The rest of the transportation routes were estimated to be by lorry. The same transportation routes have been used for all materials being shipped from the same supplier country.

To model the environmental impacts of the usage phase the electricity amount used was calculated based on a 15 Ah and 43 V battery. The battery has a lifetime of 15 years and is estimated to use 1500 kWh of electricity during its lifetime. The calculations in this study are based on an average cargo weight of 100 kg per battery charge (Table 1 & 2, Appendix B).

The secondary inventory was collected from the inventory database Ecoinvent 3.8 with the allocation, cut-off by classification method. Ecoinvent is a life cycle inventory database consisting of more than 20 000 datasets containing information about materials environmental impacts (Ecoinvent, n.d.a). The geographies used were based on the location of the supplier country. For end-of-life processes Sweden has been used, when possible, regardless of supplier country, since the products will be disposed of in Sweden. The full inventory analysis is represented in Table 1, Appendix C.

Impact assessment

The environmental impact data gathered from Ecoinvent was given as a reference product and had to be recalculated with the unique values of the Levkart. The recalculations were made using the software SimaPro 9.5.0 (PRé Sustainability, 2024). The functional unit of a 20 kg Levkart was used as a reference product for all the calculations. The functional unit for the total climate impact of the Levkart was measured in gCO2-eq/km, since it's the standardized functional unit used in the research field. To calculate the functional unit, the formula below has been used. The kilometers traveled during the 15-year lifetime is calculated based on the information given from Levtek regarding the battery capacity and is estimated to 90 000 km (Table 1 & 2, Appendix B).

$$\frac{gCO_2 - eq}{km} = \frac{kgCO_2 - eq}{90\,000} \times 1000$$

For the remaining calculations, the functional unit kgCO2-eq has been used. The impact assessment was of a general structure and scope (GSS) type, and the indicator was damage assessment. To access the GWP20 and GWP100 scores for material impact the IPCC 2021 LCIA method was used. For the assessment we assume that all materials are being disposed of during the end-of-life phase, and that all materials are derived from raw materials. The estimated lifetime of the Levkart for this study is 15 years.

Comparison with other vehicles

To make a comparative analysis between the GWP emissions of the Levkart and other micro mobility vehicles, a non-systematic literature review has been used. This enables a comparison with important findings from previous research without being an all-encompassing review of the topic (Huelin et al., 2015). To find previous research the search engine LUBsearch was used. Due to the knowledge gap in the field, a convenience selection of vehicles was used. There were few studies found using a similar or comparable LCA method to this study and therefore, only three studies are used for the comparison. The inclusion criteria were studies using GWP as a unit, studies analyzing electric vehicles, and studies performed in Europe. The inclusion criteria enable comparisons with the Levkart and vehicles using other energy mixes. The included electric vehicles are personally owned e-scooters (POES) from both Italy and Belgium; e-bicycle; battery electric vehicle; e-moped; e-motorcycle; and shared e-scooters, from Belgium and Germany. As a point of reference, a standard bicycle was included in the comparison. A summary of the previous research is demonstrated below (table 1).

Table 1
Summary of non-systematic literature review, presenting type of vehicle, GWP, methods used to perform LCA and source.

Vehicle	GWP / gCO2-eq/km	Methods	Source
Bicycle	8	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
POES (Italy)	21	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
POES (Belgium)	67	Attributional LCA, Ecoinvent 3.4, SimaPro 8.5	Moreau et al., 2020
E-bicycle	40	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
Battery electric vehicle	80	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
E-moped	95	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
E-motorcycle	119	Ecoinvent-36, Open LCA, ReCiPe Midpoint V1.11	Ishaq et al., 2022
Shared e-scooter (Belgium)	131	Attributional LCA, Ecoinvent 3.4, SimaPro 8.5	Moreau et al., 2020
Shared e-scooter (Germany)	165	Ecoinvent 3.5, IPCC 2013	Kazmaier et al., 2020

Delimitations

A LCA is a comprehensive analysis and due to time limitations only GWP emissions will be analyzed. This delimitation was determined in consultation with Levtek, since GWP emissions are the environmental impact mostly discussed on the micro mobility vehicle market. This limitation also makes it possible to compare Levkart's GWP emissions with other vehicles.

Since Levtek is a startup company, there is limited data for analysis from the various life cycle stages, particularly regarding end-of-life treatment, battery capacity and energy usage. As the Levkart has not yet been launched, this study represents an early-stage LCA, and relies on data collected from environmental inventory databases and assumptions. The early-stage LCA contains more estimated data but allows Levtek to do early adaptations to enhance the environmental performance of the Levkart. Consequently, the results from this study cannot be used for marketing purposes of the Levkart without being at risk for greenwashing. Due to lack of data, a limitation of this study is the exclusion of the processes regarding maintenance of the Levkart during its usage phase. Due to the difficulty of estimating the maintenance needed, and in what extent, the service needs for the Levkart throughout its lifetime are not included in the scope of this study.

The limitations of this study are in line with the limitations of an LCA-method. These include impact coverage-limitations, method-related limitations and assumption-related limitations (European commission, 2010). One delimitation of this study is the assumptions made of the material compositions, since incorrect assumptions can significantly impact the results. These assumptions however were necessary due to the extent of this bachelor thesis. A more far-reaching thesis would have a greater amount of time for collecting correct compositions from suppliers.

Ethical reflection

For guidance with the ethical concerns of this study the All-European Academics (ALLEA) fundamental principles of research integrity was applied (ALLEA, 2023). The ethical concern of this study includes the confidentiality of Levtek's product, which is eliminated with a signed non-disclosure agreement (NDA) with the company. The NDA might compromise the published material for patent and trademark protection reasons. Furthermore, the risk for selection bias, in the comparison with other micro mobility vehicles, will be minimized by choosing reviewed scientific papers for the analysis and not company data itself (Haneuse, 2016).

Another ethical concern regarding this study is the risk of greenwashing. Lyon and Montgomery (2015) argue that the term greenwash is complex and therefore should have a broad definition. They conclude that the term greenwashing refers to when an organization's product, service or practice is communicated in a way that results in people perceiving the organization as more environmentally conscious than it is (Lyon & Montgomery, 2015). The results of this study could be used for marketing the Levkart and could therefore be used for greenwashing. To minimize the risk for greenwashing, all relevant LCA data will be presented in this study, regardless of their positive or negative impact on the environment. This will be done for both the Levkart and other micro mobility vehicles.

Parts of the data material for the LCA will be collected from Levtek's suppliers. Data comes from Sweden and several other countries, mainly China. This risks a biased result making Sweden look more prominent regarding their environmental work. This calls for transparency as an author and for openness as a reader for countries presenting their environmental data differently.

Regardless of these ethical concerns this study is of importance because it will elaborate the knowledge of Levkart's environmental impact. The results of this study may be affected by the company secrecy and therefore some results could be excluded in the study.

Results

When analyzing the results, minor differences are found between the GWP100 and GWP20 scores. Therefore, only the GWP100 values are analyzed in the result section of this study. The scores from the GWP20 analysis are found in Appendix A.

Global warming potential of the Levkart

The total GWP100 of the Levkart is calculated to be 9 gCO2-eq/km, or 797 kgCO2-eq, with its main impact in the extraction and production phase, representing 80% of the total GWP100 impact. This is followed by the usage phase (9% of total GWP100), for which the maintenance of the product is not accounted for. The transport of components comes third (9% of total GWP100) and lastly the end-of-life treatment (2% of total GWP100). The total GWP100 of the Levkart for the different life cycle stages is presented in kgCO2-eq (figure 2).

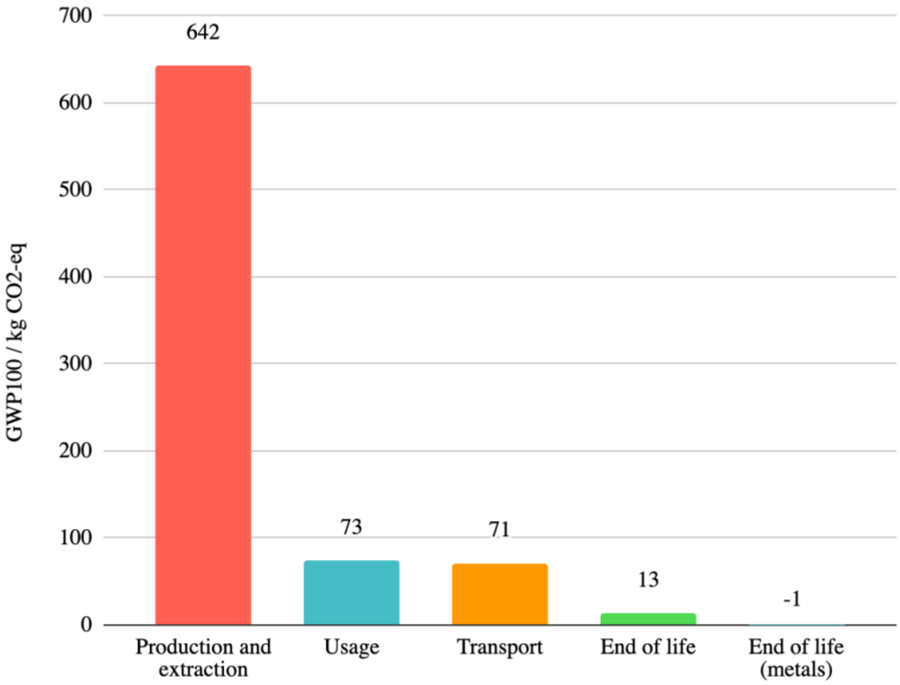

Figure 2
GWP100 in kgCO2-eq for the Levkart's life cycle phases, presenting end of life for metals separately.

The end-of-life phase is divided into two sections: end-of-life for metals and end-of-life for the remaining components. This is since the metals have a negative GWP100 impact during end-of-life. This can be explained by the metals being recycled instead of disposed due to it being more cost-efficient than raw material extraction.

Material hotspots of the Levkart

Due to the extraction and production phase being the main impact of the Levkart, the following results are analyzed in more detail for this phase. When dividing the production phase into ten categories, based on materials sharing similar attributes, precious metals show the main impact (figure 3).

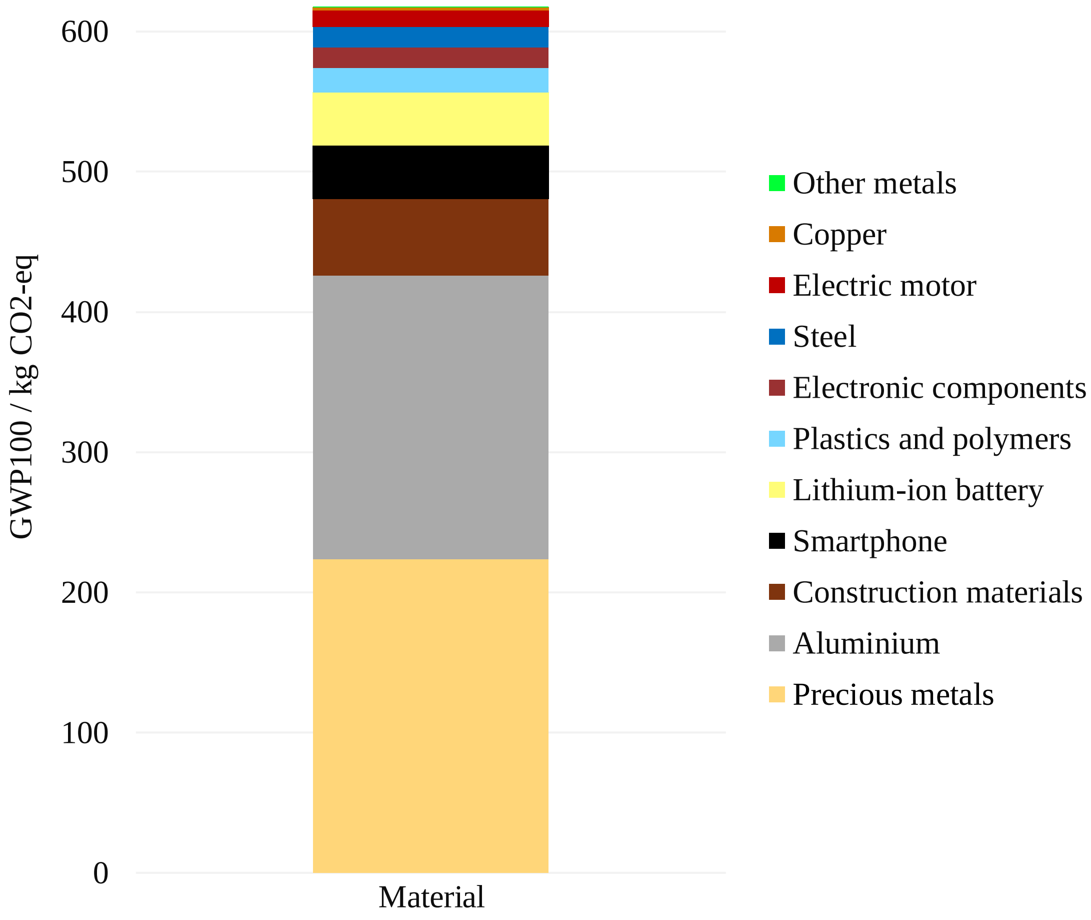

Figure 3
GWP100 values in kg CO2-equivalents for all production and extraction processes.

The GWP100 for precious metals are 224 kgCO2-eq, which is equal to 28% of the total impact of the Levkart's life cycle. Precious metals are followed by the aluminum (202 kgCO2-eq), construction materials (55 kgCO2-eq) and the smartphone (38 kgCO2-eq).

When calculating the GWP values of the extraction and production phase for the unique materials used in the Levkart, gold and silver are the largest contributors (figure 4a).

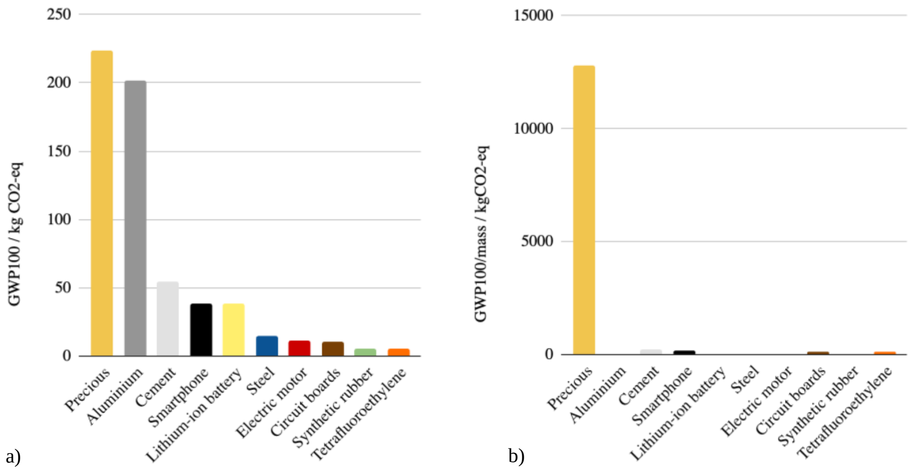

Figure 4
GWP100 (a) and GWP100/mass (b) for top 10 materials with the most environmental impact for all production and extraction processes.

Following gold and silver are aluminum, cement (binding material used in drum brake pads; 55 kgCO2-eq), the smartphone and the lithium-ion battery (38 kgCO2-eq). When dividing the GWP100 by the material mass, gold and silver have the foremost impact equal to 12796 kgCO2-eq, followed by: cement (202 kgCO2-eq); the smartphone (174 kgCO2-eq); circuit boards (108 kgCO2-eq); and tetrafluoroethylene (Teflon, 139 kgCO2-eq; figure 4b).

When calculating the GWP100 per component instead of materials the top five components with the most impact are the battery connectors (112 kgCO2-eq), the motherboard PCB (68 kgCO2-eq), the complete drum brake assembly (59 kgCO2-eq), the motor controller PCB (55 kgCO2-eq) and the battery (43 kgCO2-eq; figure 5).

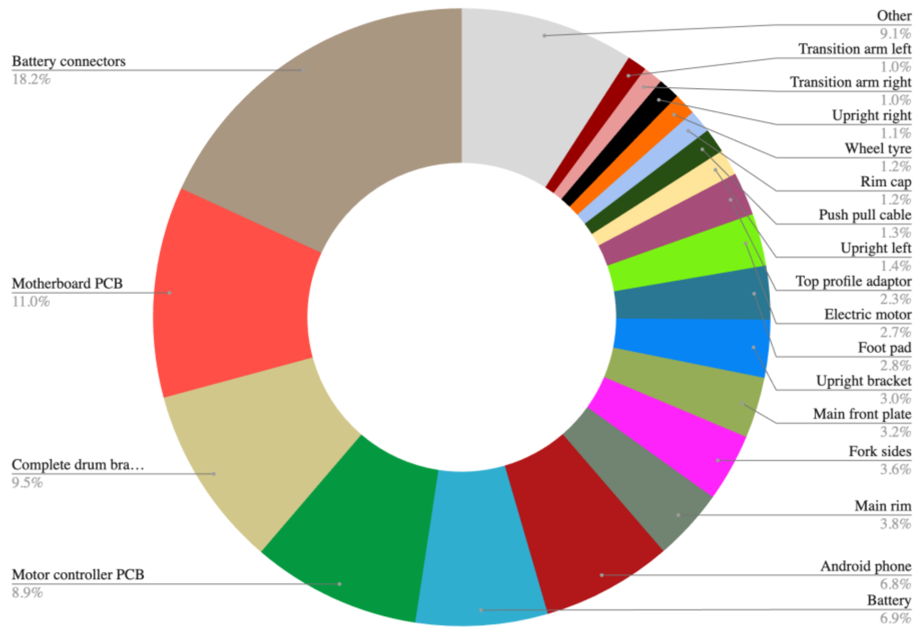

Figure 5
Share of GWP100 per component for all production and extraction processes, only including composite names for components greater than 1%. Remaining materials are represented as "other".

Comparison with other vehicles

When comparing the environmental impact of the Levkart with other means of electrified transportations the total GWP100 of 9 gCO2-eq/km is used. The GWP for the other means of transportations are accessed from previous research (table 1). The Levkart has a greater GWP impact than a regular bicycle (8 gCO2-eq/km), but a smaller impact than POES (21 and 67 gCO2-eq/km), e-bicycles (40 gCO2-eq/km), battery e-vehicles (80 gCO2-eq/km), e-mopeds (95 gCO2-eq/km), e-motorcycles (119 gCO2-eq/km) and shared e-scooters (131 and 165 gCO2-eq/km; Ishaq et al., 2022; Kazmaier et al., 2020; Moreau et al., 2020). The results of the comparison are presented in figure 7 with the values for the Levkart visualized in orange.

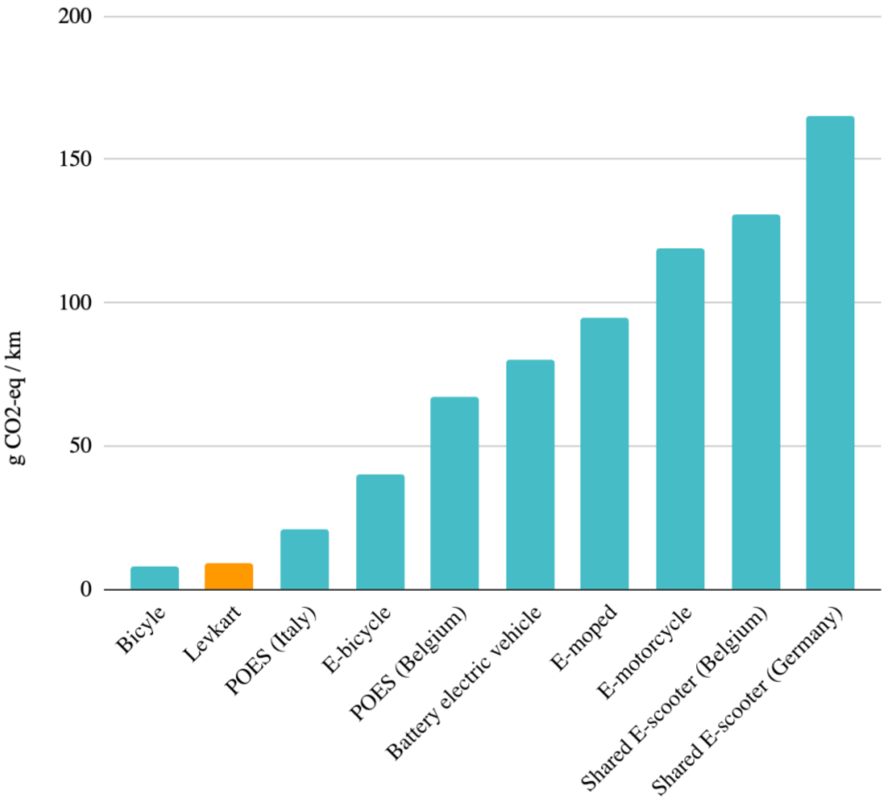

Figure 6
Grams of CO2-eq per kilometer for different means of transportation, with the Levkart visualized in orange.

Discussion

The life cycle assessment of the Levkart makes it possible to identify its environmental impact, regarding GWP, and its hotspots. The assessment of the life cycle is used for a comparison between several vehicles. The results from this study map areas of improvement for the Levkart regarding its GWP impacts.

Environmental impact

The total global warming impact of the Levkart during its life cycle is 9 gCO2-eq/km, or 797 kgCO2-eq, with the production and extraction phase having the greatest impact, corresponding to 80% of the total life cycle. This aligns with previous LCA's of e-scooters, where the main impact lies within the production phase (Ishaq et al., 2022; Kazmaier et al., 2020; Moreau et al., 2020). For the Levkart, both when dividing materials into 10 categories (figure 3) and when identifying the top ten unique materials (figure 4a), the main impacting materials are gold and silver (224 kgCO2-eq), aluminum (202 kgCO2-eq) and construction materials (55 kgCO2-eq; figure 3). The precious metals represent 28% of the environmental impact of the Levkart's life cycle.

According to Kazamaier et al. (2020) and Moreau et al. (2020), the main impact categories of an e-scooter is aluminum followed by battery production, whereas Ishaq et al. (2022) identifies the battery production as the main environmental impact. Aluminum being one of the main impact categories of the Levkart corresponds with previous research and is likely due to the large amount of aluminum used to produce the frame. To produce the Levkart, 18 kg of aluminum is used out of a 20 kg final product (Appendix C). Precious metals, which are the main impact category of the Levkart, are not mentioned as a main impact in any of the previous studies. This might be due to no use of precious metals to produce an e-scooter, or due to the small mass of precious metals, and therefore, the metals might not have met the inclusion criteria for their studies. The weight of the precious metals in the Levkart is approximately 15 grams (Appendix C).

The third main impact material for the Levkart is construction materials (cement and glass fiber), with cement being a binding material in the drum brake pads. Cement is not mentioned in previous studies of e-scooters, which could be since the presence of cement, in the complete drum brake assembly, are an estimation and not information given by the suppliers. To be able to draw conclusions regarding the impact of cement on the Levkart's life cycle, a more detailed follow-up on the material composites of the brake assembly should be made.

According to previous life cycle assessments of e-scooters, one of the largest environmental impacts is battery production (Ishaq et al., 2022; Kazmaier et al., 2020; Moreau et al., 2020). However, the assessment of the Levkart's life cycle shows that the battery production has the fifth greatest environmental impact within the production phase. To calculate the impact of the lithium-ion battery, data was collected from Ecoinvent, which may have affected the reliability of the result. A cradle to gate life cycle assessment of the production phase of lithium-ion batteries produced in China shows an impact of 2222 kgCO2-eq (Mera et al., 2021). By using the same battery weight (22.2 kg; Mera et al., 2021) as in the study but for the Ecoinvent data, the lithium-ion battery acquires a GWP of 404 kgCO2-eq (Ecoinvent, n.d.b). This calls for using the impact assessment of the battery with prudence, since differences occur regarding the impact of a lithium-ion battery.

Recommendations for improvement

The recommendations below are based on the results of this study (figure 4b & figure 5), and therefore, some of the materials and components discussed may not be included in the Levkart or may be included in different amounts. Therefore, they should be followed with caution. Though, due to this study being an early-stage LCA, implementations of the recommendations can help improve the performance of the Levkart before introducing it to the market.

When dividing the impact from materials by their mass, the general impact regardless of weight is identified. Gold and silver have the main impact of 12796 kgCO2-eq, followed by cement (202 kgCO2-eq), the smartphone (174 kgCO2-eq), circuit boards (108 kgCO2-eq) and Teflon (139 kgCO2-eq). All categories, except the smartphone, are estimated to correspond to 1% of the total weight of the materials. Therefore, the most impacting materials of the Levkart are only present in very small amounts. By substituting these materials with alternatives composed of different materials, the estimated total GWP of the Levkart could decrease by a maximum of 284 kgCO2-eq. The smartphone, as it is a composite of several materials, might be harder to substitute, and therefore the recommendation is to evaluate the necessity of the smartphone in the Levkart.

When calculating the impact of the production phase based on components, a total of 5 out of 73 components account for more than 50% of the total environmental impact (figure 6). The most impacting components are the battery connectors (112 kgCO2-eq), the Motherboard PCB (68 kgCO2-eq), the complete drum brake assembly (59 kgCO2-eq), the motor controller PCB (55 kgCO2-eq), and the battery (43 kgCO2-

eq). Among the main impacting components, all except the battery contain either gold, silver or cement, which are the main materials driving the GHG emissions. Therefore, it is of interest to evaluate substitute components, to improve the environmental impact. If substituting the materials are not possible, it could be of interest to reduce the amount of the impacting materials.

According to Kazmaier et al. (2020), e-scooters with swappable batteries reduce their global warming potential by up to 12%. Therefore, an evaluation of the potential to change the batteries in the Levkart to swappable batteries could be of interest to improve the environmental impact. Swappable batteries are a future goal for Levtek but are not included in today's prototypes (J. Snowdon, personal communication, May 23, 2024). Furthermore, by charging the battery with solar power, the GWP impact can improve by 44% of the overall carbon emissions (Ishaq et al., 2022). An assessment of the possibilities of implementing these changes to the battery could therefore improve the impact of the Levkart.

Lastly, aluminum is one of the main impact materials of the Levkart due to its large weight. Ishaq et al. (2022) have evaluated the possibility of exchanging aluminum with other materials and showed that by substituting aluminum with timber and steel the overall GWP could decrease by up to 50%. By substituting aluminum with 50% recycled aluminum, the total carbon emissions could decrease by up to 27% (Ishaq et al., 2022). Though, it is important to note that this only improves the GWP of the Levkart, but not the overall global warming, since a use of recycled aluminum in the Levkart results in other products having to extract aluminum from raw materials. Therefore, the recommendation is to replace aluminum with other materials rather than recycled aluminum, for improvement of the environmental impact.

Comparison with other vehicles

In the comparison with other vehicles the Levkart performs worse than bicycles, but performs better than POES, e-bicycles, battery e-vehicles, e-mopeds, e-motorcycles and shared e-scooters (figure 6). Due to few studies being compared, the results may be deviant from reality.

The comparison with other vehicles uses energy mixes from different countries, whereby the Levkart is calculated based on a Swedish energy mix, which could affect the results of this study. Alessio et al. (2024) argues that primary data of energy mixes should be used for a more correct assessment, since data from inventory databases can be unreliable or outdated. Furthermore Algieri et al. (2024) argues that the energy mix used affects the resulting emission factor, and that a larger number of renewable sources lowers the carbon emissions. However, a study of the energy mixes of batteries in electric vehicles, concludes that different energy mixes does not affect the environmental impact in a substantial way (Bhosale et al., 2023). Thus, the impact of different energy mixes is unclear and should be used with caution for comparisons. The countries used for comparison in this study, has different energy mixes and when calculating the GWP for the different countries, based on the battery capacity of the Levkart (Appendix B), the Swedish energy mix gains a GWP of 73 kgCO2-eq. This is substantially smaller than the GWP for Belgium of 386 kgCO2-eq; for Italy, 567 kgCO2-eq; and for Germany, 774 kgCO2-eq (Ecoinvent, n.d.c; Ecoinvent, n.d.d; Ecoinvent n.d.e). Therefore, the Levkart's performance, in comparison with other means of transportation, is influenced by using a Swedish energy mix. Though, when recalculating the Levkart with the aforementioned energy mixes, the Levkart still performs better than other means of transportation, although not as substantially; Belgium, 12 gCO2-eq/km; Italy, 14 gCO2-eq/km; and Germany, 17 gCO2-eq/km.

According to previous research one of the most influential parameters on the environmental impact of e-scooters is their lifetime and battery (Kazmaier et al., 2020; Moreau et al., 2020). By increasing the lifetime of an e-scooter by 15 months the GWP is reduced with 68 gCO2-eq/km (Kazmaier et al., 2020). A shared e-scooter is estimated to have a lifetime of 6 months (Kazmaier et al., 2020), while Levkart's impact is calculated with a lifetime of 15 years. Therefore, the long lifetime of the Levkart may influence its estimated impact since a prolonged lifetime leads to a decrease in GWP.

Lastly, the comparison with other vehicles might be flawed due to the complexity of comparing different LCA methods. In a study performed on the recycling of Lithium-ion batteries, testing 7 different allocation methods, they concluded that comparisons of different LCA's must be implemented with carefulness, since the choice of method affects the outcome (Du, et al., 2022). Furthermore, a cradle-to-grave study on lithium-ion batteries showed that comparisons between LCA's are methodologically problematic regarding different definitions of functional units, choice of allocation methods, system boundaries and end-of-life treatments (Hermansson et al., 2023). In this study, the same functional unit (gCO2-eq/km) has been used for the comparisons, GWP has been used as a as an impact category, and Ecoinvent have been used as an inventory database. Therefore, the comparison is still relevant, but should be used with caution.

Limitations

In LCA, assumptions regarding the product cause uncertainties regarding the results. For this study there is limited data available regarding material composition, transportation routes and amount of recycled material used. The secrecy regarding material information from the suppliers lead to several assumptions, such as material composites, manufacturing and end-of-life treatment. Furthermore, there is limited to no data available regarding the usage and end-of-life phases of the Levkart since the product has yet to be launched. For the usage phase, this may lead to discrepancies regarding the capacity of the battery. Regarding the end-of-life phase, the limited data leads to the assumption that all materials are recycled separately. This assumption is deficient due to many materials being complex and composed of several sub-materials. Therefore, it is unlikely that all materials will be recycled separately. During the data collection several human errors may occur due to the extensive amount of data. The human errors regard the calculations made as well as the determination of mass. Lastly there is a limited amount of environmental impact data in the Ecoinvent software. Therefore, the results may not be comprehensive enough due to missing impact data regarding materials, material processes or geographies.

Future studies

The result in this study assesses the environmental impact of the Levkart based on its current state. For future studies, it would be of interest to assess a new LCA after the launch of the Levkart, especially regarding the usage and end-of-life phases. A more comprehensive study could also conduct a more extensive data collection of the material composites. The recommendations for improved environmental impact in this study are based on previous research but not modified to Levkart's needs. Therefore, it would be of interest for future studies to evaluate the proposed recommendations in relation to the capabilities of the Levkart.

Conclusion

The life cycle assessment concludes that the total impact of the Levkart during its lifetime is 9 gCO2-eq/km, or 797 kgCO2-eq, with its main impact in the production and extraction phase (80%). The main materials driving impacts are precious metals, aluminum and cement. The identified hotspots correspond somewhat with previous research, with the impact from the battery being the major difference. A reduction of the main impact materials could improve the environmental impact of the Levkart with a maximum of 284 kgCO2-eq. The main impact materials are included in the components causing the largest impact and are therefore of interest to substitute. Further recommendations are to overlook the possibilities to change the batteries to swappable batteries, charging with solar power and exchange aluminum with timber. The Levkart has a greater environmental impact than bicycles, but smaller impact than other means of electrified transportation, regardless of energy mix used. The findings of this study are based on estimations of material composites, battery capacity, transportation routes and disposal.

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Appendix

Appendix A

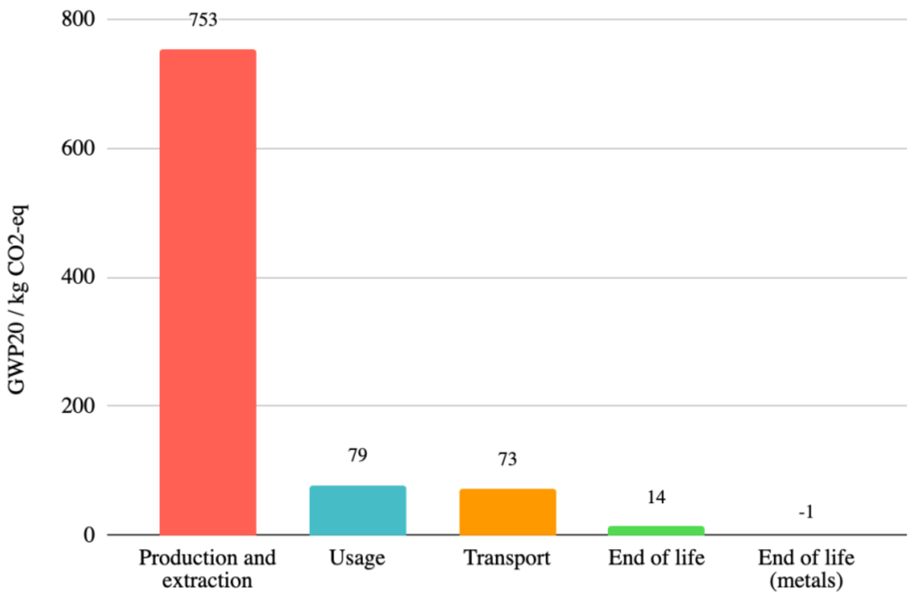


Figure 1
GWP20 for the Levkart’s life cycle phases, with end of life for metals presented separately.

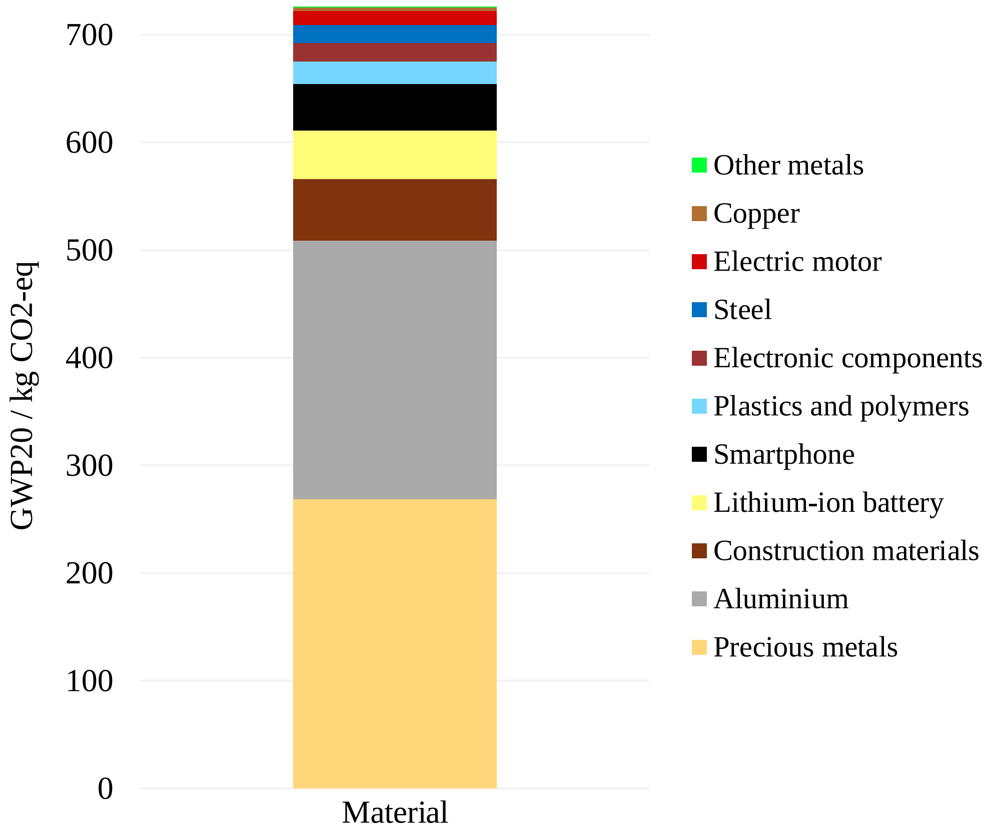


Figure 2
GWP20 values in kg CO2-equivalents for all production and extraction processes.

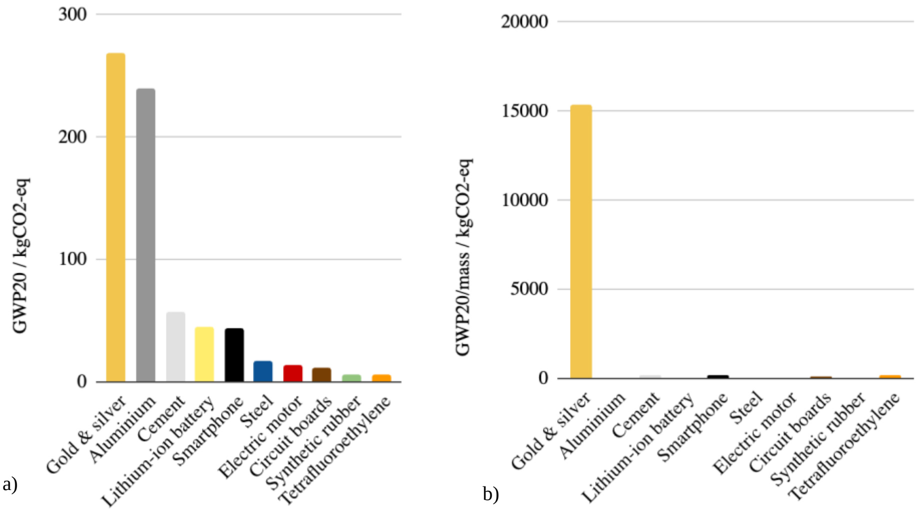


Figure 3
GWP20 (a) and GWP20/mass (b) for top 10 materials with the most environmental impact for all production and extraction processes.

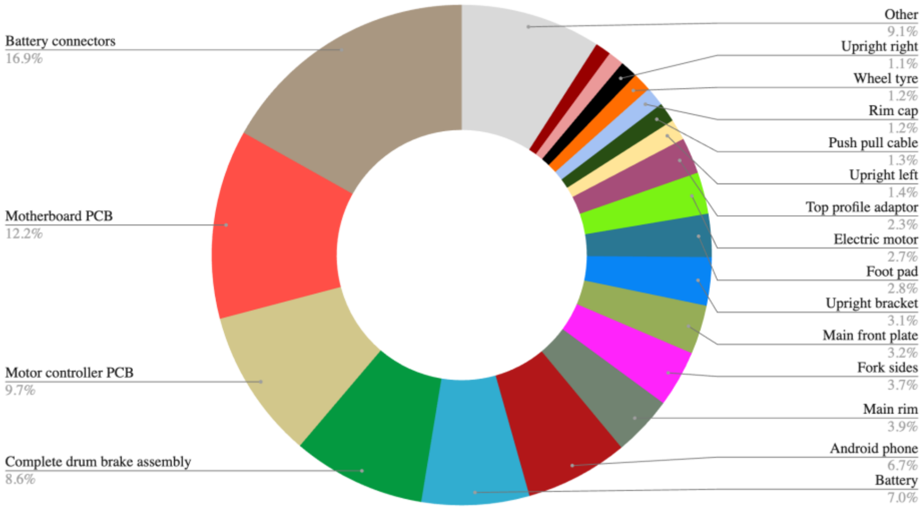


Figure 4
Share of GWP20 per component for all production and extraction processes, only including values for components greater than 1%.

Appendix B

Table 1
Overview of lithium-ion battery used in the Levkart.

Product /unit	Tot weight /kg	Battery type	Battery capacity /Ah	Battery capacity /V	Traveling per year /km	Lifetime /Years
1 Levkart	20	Lithium-ion	15	43	6000	15

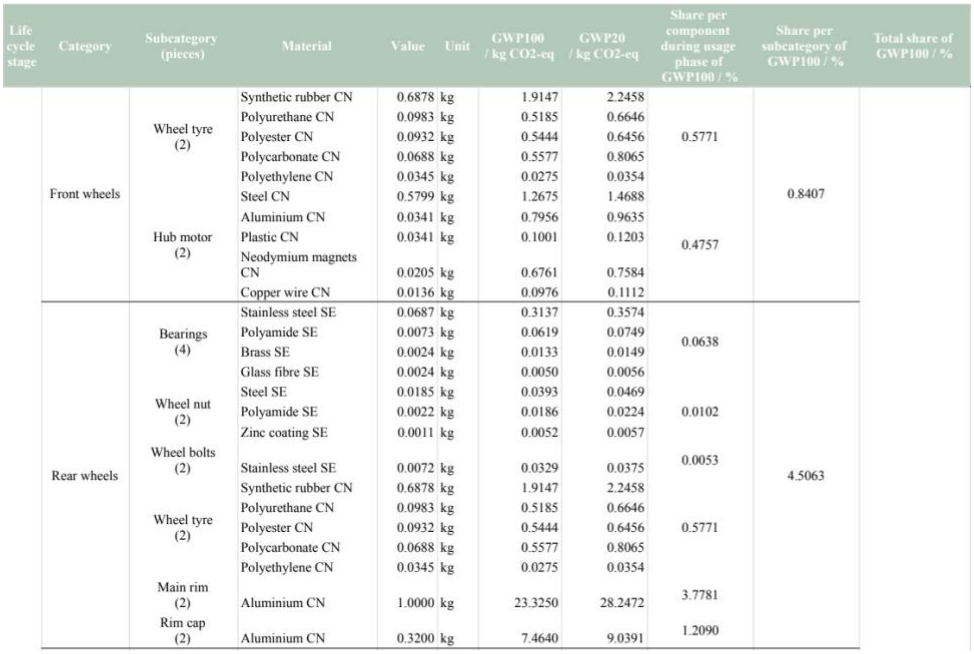
Table 2
Overview of energy consumption of the Levkart.

Charges per year /amount	Range per battery charge /km	Average cargo weight per battery charge /kg	Wh consumed to charge battery /Wh	Energy usage per year /kWh	Energy usage per lifetime /kWh
200	30	100	500	100	1500

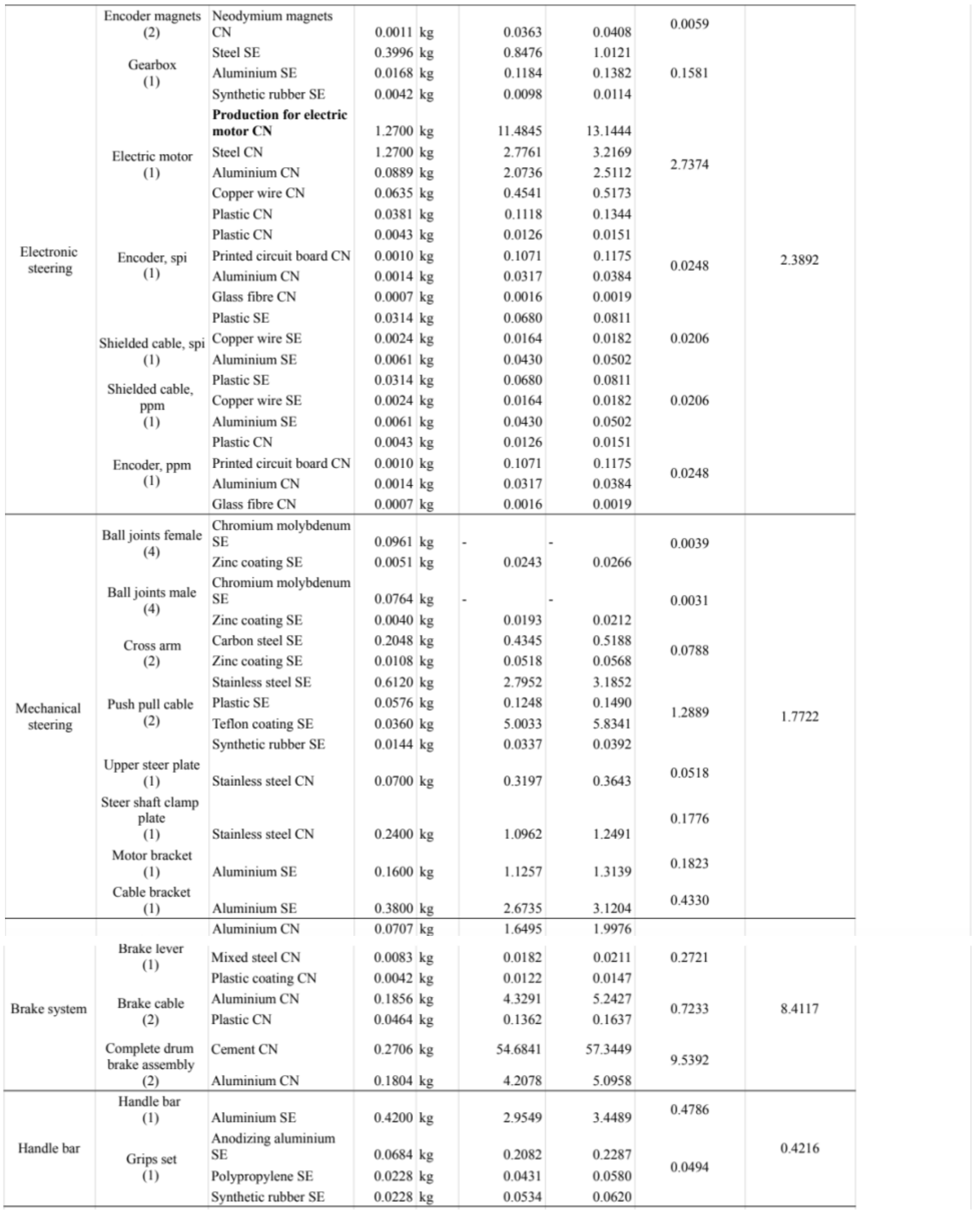
Appendix C

Table 1

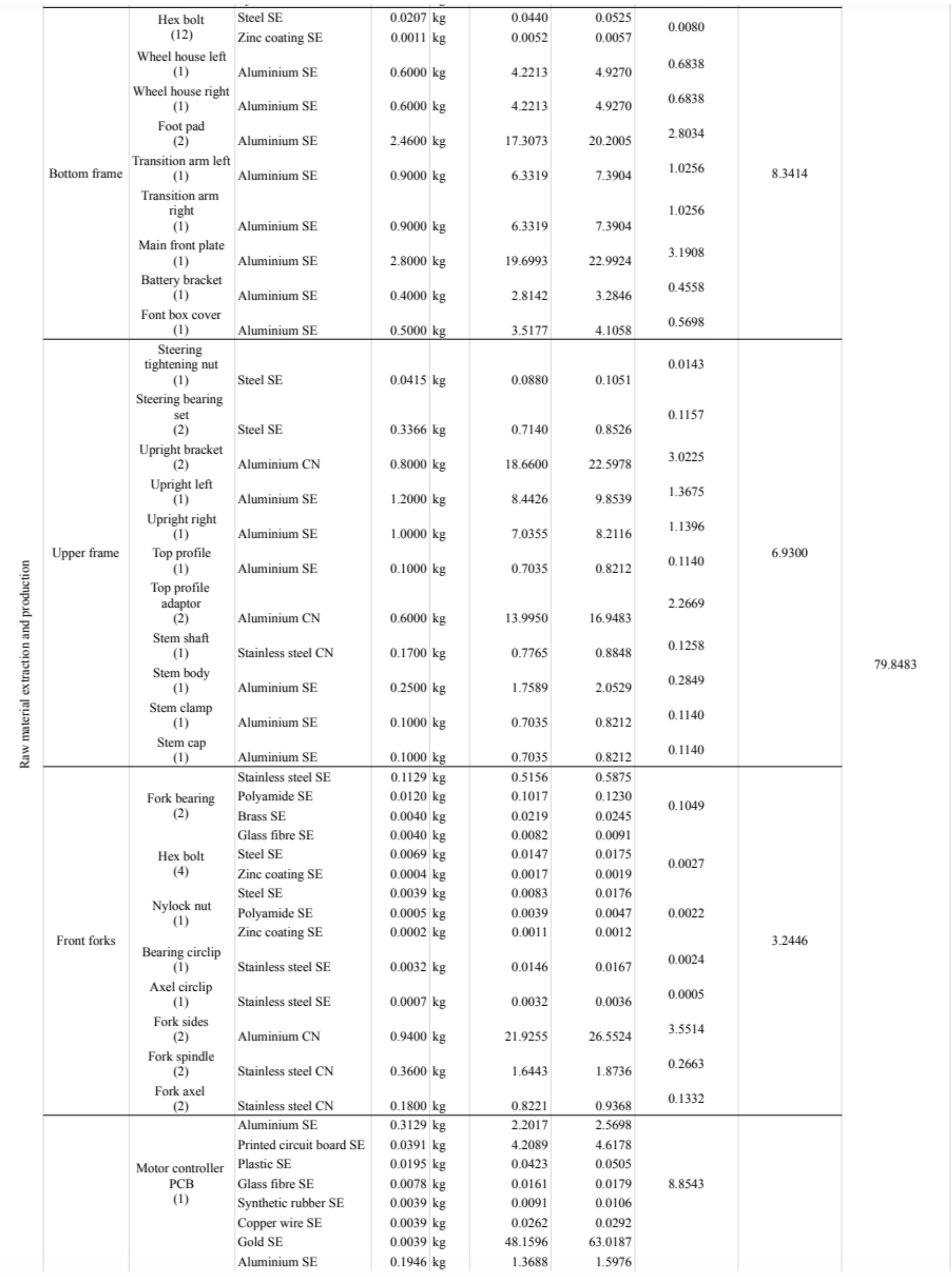
Summary of Life Cycle Assessment of the Levkart listing life cycle stage, categories, subcategories, materials, value, unit, GWP100, GWP20 and share per component, subcategory and total share of the Levkart based on GWP100 scores.



Life cycle stage	Category	Subcategory (pieces)	Material	Value	Unit	GWP100 / kg CO2-eq	GWP20 / kg CO2-eq	Share per component during usage phase of GWP100 / %	Share per subcategory of GWP100 / %	Total share of GWP100 / %
	Front wheels	Wheel tyre (2)	Synthetic rubber CN	0.6878	kg	1.9147	2.2458	0.5771	0.8407	
			Polyurethane CN	0.0983	kg	0.5185	0.6646			
			Polyester CN	0.0932	kg	0.5444	0.6456			
			Polycarbonate CN	0.0688	kg	0.5577	0.8065			
			Polyethylene CN	0.0345	kg	0.0275	0.0354			
		Hub motor (2)	Steel CN	0.5799	kg	1.2675	1.4688	0.4757		
			Aluminium CN	0.0341	kg	0.7956	0.9635			
			Plastic CN	0.0341	kg	0.1001	0.1203			
			Neodymium magnets CN	0.0205	kg	0.6761	0.7584			
			Copper wire CN	0.0136	kg	0.0976	0.1112			
	Rear wheels	Bearings (4)	Stainless steel SE	0.0687	kg	0.3137	0.3574	0.0638	4.5063	
			Polyamide SE	0.0073	kg	0.0619	0.0749			
			Brass SE	0.0024	kg	0.0133	0.0149			
			Glass fibre SE	0.0024	kg	0.0050	0.0056			
		Wheel nut (2)	Steel SE	0.0185	kg	0.0393	0.0469	0.0102		
			Polyamide SE	0.0022	kg	0.0186	0.0224			
			Zinc coating SE	0.0011	kg	0.0052	0.0057			
		Wheel bolts (2)	Stainless steel SE	0.0072	kg	0.0329	0.0375	0.0053		
		Wheel tyre (2)	Synthetic rubber CN	0.6878	kg	1.9147	2.2458	0.5771		
			Polyurethane CN	0.0983	kg	0.5185	0.6646			
			Polyester CN	0.0932	kg	0.5444	0.6456			
			Polycarbonate CN	0.0688	kg	0.5577	0.8065			
			Polyethylene CN	0.0345	kg	0.0275	0.0354			
		Main rim (2)	Aluminium CN	1.0000	kg	23.3250	28.2472	3.7781		
		Rim cap (2)	Aluminium CN	0.3200	kg	7.4640	9.0391	1.2090		

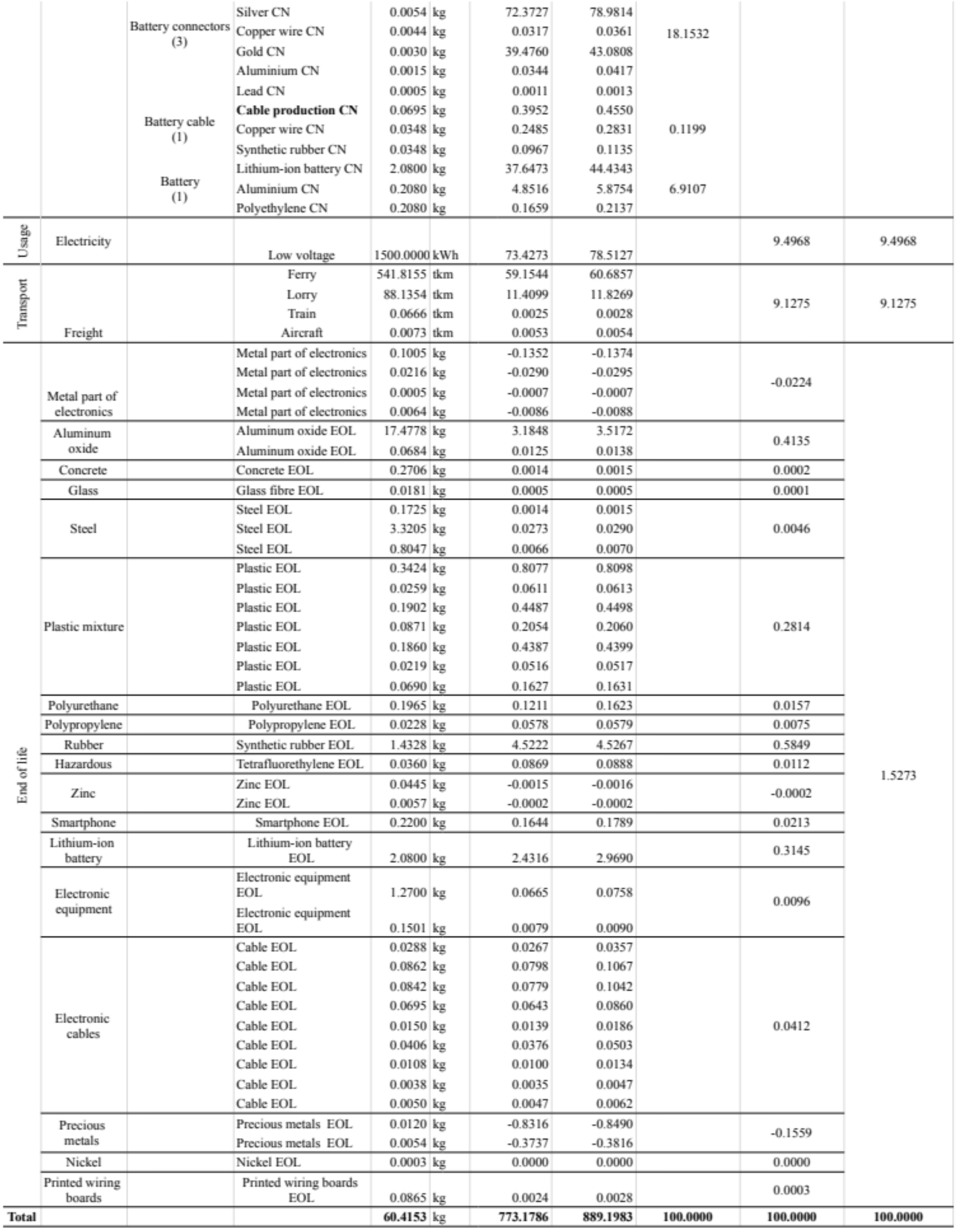


Electronic steering	Encoder magnets (2)	Neodymium magnets CN	0.0011	kg	0.0363	0.0408	0.0059	2.3892
	Gearbox (1)	Steel SE	0.3996	kg	0.8476	1.0121	0.1581	
		Aluminium SE	0.0168	kg	0.1184	0.1382		
		Synthetic rubber SE	0.0042	kg	0.0098	0.0114		
	Electric motor (1)	**Production for electric motor CN**	1.2700	kg	11.4845	13.1444	2.7374	
		Steel CN	1.2700	kg	2.7761	3.2169		
		Aluminium CN	0.0889	kg	2.0736	2.5112		
		Copper wire CN	0.0635	kg	0.4541	0.5173		
		Plastic CN	0.0381	kg	0.1118	0.1344		
	Encoder, spi (1)	Plastic CN	0.0043	kg	0.0126	0.0151	0.0248	
		Printed circuit board CN	0.0010	kg	0.1071	0.1175		
		Aluminium CN	0.0014	kg	0.0317	0.0384		
		Glass fibre CN	0.0007	kg	0.0016	0.0019		
	Shielded cable, spi (1)	Plastic SE	0.0314	kg	0.0680	0.0811	0.0206	
		Copper wire SE	0.0024	kg	0.0164	0.0182		
		Aluminium SE	0.0061	kg	0.0430	0.0502		
	Shielded cable, ppm (1)	Plastic SE	0.0314	kg	0.0680	0.0811	0.0206	
		Copper wire SE	0.0024	kg	0.0164	0.0182		
		Aluminium SE	0.0061	kg	0.0430	0.0502		
	Encoder, ppm (1)	Plastic CN	0.0043	kg	0.0126	0.0151	0.0248	
		Printed circuit board CN	0.0010	kg	0.1071	0.1175		
		Aluminium CN	0.0014	kg	0.0317	0.0384		
		Glass fibre CN	0.0007	kg	0.0016	0.0019		
Mechanical steering	Ball joints female (4)	Chromium molybdenum SE	0.0961	kg	-	-	0.0039	1.7722
		Zinc coating SE	0.0051	kg	0.0243	0.0266		
	Ball joints male (4)	Chromium molybdenum SE	0.0764	kg	-	-	0.0031	
		Zinc coating SE	0.0040	kg	0.0193	0.0212		
	Cross arm (2)	Carbon steel SE	0.2048	kg	0.4345	0.5188	0.0788	
		Zinc coating SE	0.0108	kg	0.0518	0.0568		
	Push pull cable (2)	Stainless steel SE	0.6120	kg	2.7952	3.1852	1.2889	
		Plastic SE	0.0576	kg	0.1248	0.1490		
		Teflon coating SE	0.0360	kg	5.0033	5.8341		
		Synthetic rubber SE	0.0144	kg	0.0337	0.0392		
	Upper steer plate (1)	Stainless steel CN	0.0700	kg	0.3197	0.3643	0.0518	
	Steer shaft clamp plate (1)	Stainless steel CN	0.2400	kg	1.0962	1.2491	0.1776	
	Motor bracket (1)	Aluminium SE	0.1600	kg	1.1257	1.3139	0.1823	
	Cable bracket (1)	Aluminium SE	0.3800	kg	2.6735	3.1204	0.4330	
		Aluminium CN	0.0707	kg	1.6495	1.9976		
Brake system	Brake lever (1)	Mixed steel CN	0.0083	kg	0.0182	0.0211	0.2721	8.4117
		Plastic coating CN	0.0042	kg	0.0122	0.0147		
	Brake cable (2)	Aluminium CN	0.1856	kg	4.3291	5.2427	0.7233	
		Plastic CN	0.0464	kg	0.1362	0.1637		
	Complete drum brake assembly (2)	Cement CN	0.2706	kg	54.6841	57.3449	9.5392	
		Aluminium CN	0.1804	kg	4.2078	5.0958		
Handle bar	Handle bar (1)	Aluminium SE	0.4200	kg	2.9549	3.4489	0.4786	0.4216
	Grips set (1)	Anodizing aluminium SE	0.0684	kg	0.2082	0.2287	0.0494	
		Polypropylene SE	0.0228	kg	0.0431	0.0580		
		Synthetic rubber SE	0.0228	kg	0.0534	0.0620		



Raw material extraction and production	Bottom frame	Hex bolt (12)	Steel SE	0.0207	kg	0.0440	0.0525	0.0080	8.3414	79.8483
			Zinc coating SE	0.0011	kg	0.0052	0.0057			
		Wheel house left (1)	Aluminium SE	0.6000	kg	4.2213	4.9270	0.6838		
		Wheel house right (1)	Aluminium SE	0.6000	kg	4.2213	4.9270	0.6838		
		Foot pad (2)	Aluminium SE	2.4600	kg	17.3073	20.2005	2.8034		
		Transition arm left (1)	Aluminium SE	0.9000	kg	6.3319	7.3904	1.0256		
		Transition arm right (1)	Aluminium SE	0.9000	kg	6.3319	7.3904	1.0256		
		Main front plate (1)	Aluminium SE	2.8000	kg	19.6993	22.9924	3.1908		
		Battery bracket (1)	Aluminium SE	0.4000	kg	2.8142	3.2846	0.4558		
		Font box cover (1)	Aluminium SE	0.5000	kg	3.5177	4.1058	0.5698		
	Upper frame	Steering tightening nut (1)	Steel SE	0.0415	kg	0.0880	0.1051	0.0143	6.9300	
		Steering bearing set (2)	Steel SE	0.3366	kg	0.7140	0.8526	0.1157		
		Upright bracket (2)	Aluminium CN	0.8000	kg	18.6600	22.5978	3.0225		
		Upright left (1)	Aluminium SE	1.2000	kg	8.4426	9.8539	1.3675		
		Upright right (1)	Aluminium SE	1.0000	kg	7.0355	8.2116	1.1396		
		Top profile (1)	Aluminium SE	0.1000	kg	0.7035	0.8212	0.1140		
		Top profile adaptor (2)	Aluminium CN	0.6000	kg	13.9950	16.9483	2.2669		
		Stem shaft (1)	Stainless steel CN	0.1700	kg	0.7765	0.8848	0.1258		
		Stem body (1)	Aluminium SE	0.2500	kg	1.7589	2.0529	0.2849		
		Stem clamp (1)	Aluminium SE	0.1000	kg	0.7035	0.8212	0.1140		
		Stem cap (1)	Aluminium SE	0.1000	kg	0.7035	0.8212	0.1140		
	Front forks	Fork bearing (2)	Stainless steel SE	0.1129	kg	0.5156	0.5875	0.1049	3.2446	
			Polyamide SE	0.0120	kg	0.1017	0.1230			
			Brass SE	0.0040	kg	0.0219	0.0245			
			Glass fibre SE	0.0040	kg	0.0082	0.0091			
		Hex bolt (4)	Steel SE	0.0069	kg	0.0147	0.0175	0.0027		
			Zinc coating SE	0.0004	kg	0.0017	0.0019			
		Nylock nut (1)	Steel SE	0.0039	kg	0.0083	0.0176	0.0022		
			Polyamide SE	0.0005	kg	0.0039	0.0047			
			Zinc coating SE	0.0002	kg	0.0011	0.0012			
		Bearing circlip (1)	Stainless steel SE	0.0032	kg	0.0146	0.0167	0.0024		
		Axel circlip (1)	Stainless steel SE	0.0007	kg	0.0032	0.0036	0.0005		
		Fork sides (2)	Aluminium CN	0.9400	kg	21.9255	26.5524	3.5514		
		Fork spindle (2)	Stainless steel CN	0.3600	kg	1.6443	1.8736	0.2663		
		Fork axel (2)	Stainless steel CN	0.1800	kg	0.8221	0.9368	0.1332		
		Motor controller PCB (1)	Aluminium SE	0.3129	kg	2.2017	2.5698	8.8543		
			Printed circuit board SE	0.0391	kg	4.2089	4.6178			
			Plastic SE	0.0195	kg	0.0423	0.0505			
			Glass fibre SE	0.0078	kg	0.0161	0.0179			
			Synthetic rubber SE	0.0039	kg	0.0091	0.0106			
			Copper wire SE	0.0039	kg	0.0262	0.0292			
			Gold SE	0.0039	kg	48.1596	63.0187			
			Aluminium SE	0.1946	kg	1.3688	1.5976			

Vehicle electronics	Motherboard PCB (1)	Printed circuit board SE	0.0259	kg	2.7930	3.0643	11.0417	42.9907	
		FR4 SE	0.0181	kg	0.0670	0.3934			
		Gold SE	0.0052	kg	63.9169	83.6377			
		Glass fibre SE	0.0026	kg	0.0053	0.0059			
		Copper wire SE	0.0026	kg	0.0174	0.0194			
	Android phone (1)	**Smartphone production CN**	0.2200	kg	38.3778	43.5190	6.8365		
		Polycarbonate CN	0.0836	kg	0.6778	0.9802			
		Aluminium CN	0.1165	kg	2.7182	3.2918			
		Glass CN	0.0220	kg	-	-			
		Lithium-ion battery CN	0.0176	kg	0.3186	0.3760			
		Polyethylene CN	0.0194	kg	0.0154	0.0199			
		Silicone CN	0.0154	kg	-				
		Copper CN	0.0154	kg	0.0985	0.1116			
	Cable harness lower (1)	**Cable production CN**	0.0288	kg	0.1638	0.1885	0.0540		
		Copper wire CN	0.0230	kg	0.1648	0.1877			
		Polyethylene CN	0.0058	kg	0.0046	0.0059			
	Cable harness upper (1)	**Cable production CN**	0.0862	kg	0.4901	0.5643	0.1615		
		Copper wire CN	0.0690	kg	0.4931	0.5618			
		Polyethylene CN	0.0172	kg	0.0138	0.0177			
	Brake lever, electronic (1)	**Production active electronic component CN**	0.1501	kg	0.7598	0.8926	0.6292		
		Plastic CN	0.0705	kg	0.2070	0.2489			
		Aluminium CN	0.0300	kg	0.7002	0.8480			
		Printed circuit board CN	0.0195	kg	2.1101	2.3163			
		Steel CN	0.0150	kg	0.0328	0.0380			
		Copper wire CN	0.0075	kg	0.0537	0.0611			
		Synthetic rubber CN	0.0075	kg	0.0209	0.0245			
	Motor cables (2)	**Cable production CN**	0.0842	kg	0.4788	0.5512	0.1577		
		Copper wire CN	0.0674	kg	0.4817	0.5488			
		Polyethylene CN	0.0168	kg	0.0134	0.0173			
	Switch block (1)	Polycarbonate CN	0.0284	kg	0.2302	0.3329	0.0676		
		Acrylonitrile Butadiene Styrene CN	0.0284	kg	0.1292	0.1752			
		Cable production CN	0.0050	kg	0.0287	0.0330			
		Polyethylene CN	0.0010	kg		0.0010			
		Aluminium CN	0.0013	kg	0.0294	0.0356			
	Throttle (1)	Polycarbonate CN	0.0243	kg	0.1967	0.2844	0.0557		
		Acrylonitrile Butadiene Styrene CN	0.0243	kg	0.1104	0.1496			
		Aluminium CN	0.0011	kg	0.0251	0.0305			
		Synthetic rubber CN	0.0043	kg	0.0120	0.0141			
	USBc adapter (1)	**Charger production CN**	0.0038	kg	0.0998	0.1162	0.2252		
		Acrylonitrile Butadiene Styrene CN	0.0017	kg	0.0078	0.0105			
		Aluminium CN	0.0011	kg	0.0266	0.0322			
		Integrated circuits CN	0.0004	kg	0.0402	0.0441			
		Copper wire CN	0.0002	kg	0.0016	0.0019			
		Printed circuit board CN	0.0002	kg	0.0247	0.0271			
		Synthetic rubber CN	0.4273	kg	1.1896	1.3953			
	USBc to TTL adapter (1)	**Converter production CN**	0.0108	kg	0.4309	0.4986	0.0916		
		Copper wire CN	0.0049	kg	0.0348	0.0396			
		Aluminium CN	0.0038	kg	0.0882	0.1068			
		Brass CN	0.0022	kg	0.0119	0.0133			
	USBc charger (1)	**Charger production CN**	0.0406	kg	1.0659	1.2415	0.3477		
		Acrylonitrile Butadiene Styrene CN	0.0183	kg	0.0831	0.1127			
		Aluminium CN	0.0122	kg	0.2841	0.3441			
		Integrated circuits CN	0.0041	kg	0.4293	0.4711			
		Copper wire CN	0.0024	kg	0.0174	0.0198			
		Printed circuit board CN	0.0024	kg	0.2634	0.2892			
		Synthetic rubber CN	0.0012	kg	0.0034	0.0040			
	USBc splitter (1)	**Charger production CN**	0.0150	kg	0.3938	0.4587	0.1285		
		Acrylonitrile Butadiene Styrene CN	0.0068	kg	0.0307	0.0416			
		Aluminium CN	0.0045	kg	0.1050	0.1271			
		Integrated circuits CN	0.0015	kg	0.1586	0.1740			
		Copper wire CN	0.0009	kg	0.0064	0.0073			
		Printed circuit board CN	0.0009	kg	0.0973	0.1068			
		Synthetic rubber CN	0.0005	kg	0.0013	0.0015			
	Charging port (1)	Zinc SE	0.0057	kg	0.0274	0.0300	0.0052		
		Plastic SE	0.0007	kg	0.0015	0.0017			
		Nickel coating SE	0.0003	kg	0.0034	0.0038			
		Acrylonitrile Butadiene Styrene CN	0.0344	kg	0.1567	0.2124			



		Battery connectors (3)	Silver CN	0.0054	kg	72.3727	78.9814	18.1532		
			Copper wire CN	0.0044	kg	0.0317	0.0361			
			Gold CN	0.0030	kg	39.4760	43.0808			
			Aluminium CN	0.0015	kg	0.0344	0.0417			
		Battery cable (1)	Lead CN	0.0005	kg	0.0011	0.0013	0.1199		
			Cable production CN	0.0695	kg	0.3952	0.4550			
			Copper wire CN	0.0348	kg	0.2485	0.2831			
			Synthetic rubber CN	0.0348	kg	0.0967	0.1135			
		Battery (1)	Lithium-ion battery CN	2.0800	kg	37.6473	44.4343	6.9107		
			Aluminium CN	0.2080	kg	4.8516	5.8754			
			Polyethylene CN	0.2080	kg	0.1659	0.2137			
Usage	Electricity		Low voltage	1500.0000	kWh	73.4273	78.5127		9.4968	9.4968
Transport	Freight		Ferry	541.8155	tkm	59.1544	60.6857		9.1275	9.1275
			Lorry	88.1354	tkm	11.4099	11.8269			
			Train	0.0666	tkm	0.0025	0.0028			
			Aircraft	0.0073	tkm	0.0053	0.0054			
End of life	Metal part of electronics		Metal part of electronics	0.1005	kg	-0.1352	-0.1374		-0.0224	1.5273
			Metal part of electronics	0.0216	kg	-0.0290	-0.0295			
			Metal part of electronics	0.0005	kg	-0.0007	-0.0007			
			Metal part of electronics	0.0064	kg	-0.0086	-0.0088			
	Aluminum oxide		Aluminum oxide EOL	17.4778	kg	3.1848	3.5172		0.4135	
			Aluminum oxide EOL	0.0684	kg	0.0125	0.0138			
	Concrete		Concrete EOL	0.2706	kg	0.0014	0.0015		0.0002	
	Glass		Glass fibre EOL	0.0181	kg	0.0005	0.0005		0.0001	
	Steel		Steel EOL	0.1725	kg	0.0014	0.0015		0.0046	
			Steel EOL	3.3205	kg	0.0273	0.0290			
			Steel EOL	0.8047	kg	0.0066	0.0070			
	Plastic mixture		Plastic EOL	0.3424	kg	0.8077	0.8098		0.2814	
			Plastic EOL	0.0259	kg	0.0611	0.0613			
			Plastic EOL	0.1902	kg	0.4487	0.4498			
			Plastic EOL	0.0871	kg	0.2054	0.2060			
			Plastic EOL	0.1860	kg	0.4387	0.4399			
			Plastic EOL	0.0219	kg	0.0516	0.0517			
			Plastic EOL	0.0690	kg	0.1627	0.1631			
	Polyurethane		Polyurethane EOL	0.1965	kg	0.1211	0.1623		0.0157	
	Polypropylene		Polypropylene EOL	0.0228	kg	0.0578	0.0579		0.0075	
	Rubber		Synthetic rubber EOL	1.4328	kg	4.5222	4.5267		0.5849	
	Hazardous		Tetrafluorethylene EOL	0.0360	kg	0.0869	0.0888		0.0112	
	Zinc		Zinc EOL	0.0445	kg	-0.0015	-0.0016		-0.0002	
			Zinc EOL	0.0057	kg	-0.0002	-0.0002			
	Smartphone		Smartphone EOL	0.2200	kg	0.1644	0.1789		0.0213	
	Lithium-ion battery		Lithium-ion battery EOL	2.0800	kg	2.4316	2.9690		0.3145	
	Electronic equipment		Electronic equipment EOL	1.2700	kg	0.0665	0.0758		0.0096	
			Electronic equipment EOL	0.1501	kg	0.0079	0.0090			
	Electronic cables		Cable EOL	0.0288	kg	0.0267	0.0357		0.0412	
			Cable EOL	0.0862	kg	0.0798	0.1067			
			Cable EOL	0.0842	kg	0.0779	0.1042			
			Cable EOL	0.0695	kg	0.0643	0.0860			
			Cable EOL	0.0150	kg	0.0139	0.0186			
			Cable EOL	0.0406	kg	0.0376	0.0503			
			Cable EOL	0.0108	kg	0.0100	0.0134			
			Cable EOL	0.0038	kg	0.0035	0.0047			
			Cable EOL	0.0050	kg	0.0047	0.0062			
	Precious metals		Precious metals EOL	0.0120	kg	-0.8316	-0.8490		-0.1559	
			Precious metals EOL	0.0054	kg	-0.3737	-0.3816			
	Nickel		Nickel EOL	0.0003	kg	0.0000	0.0000		0.0000	
	Printed wiring boards		Printed wiring boards EOL	0.0865	kg	0.0024	0.0028		0.0003	
Total				**60.4153**	kg	**773.1786**	**889.1983**	**100.0000**	**100.0000**	**100.0000**

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