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SCIENTIFIC REPORT

Life Cycle Assessment of Residential Electric Vehicle Charging Units

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Contents

Acronyms and Abbreviations

A	Ampere
CSI	Crustal Scarcity Indicator
EoL	End-of-Life
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GLO	Global (LCA market data representation)
IC	Integrated Circuit
LCI	Life Cycle Inventory
OCCB	Overcurrent Circuit Breaker
PCB	Printed Circuit Board
RCD	Residual Current Detector
RER	Europa (LCA market data representation)
RoW	Rest of World (LCA market data representation)
SOP	Surplus Ore Potential
V	Volt
W	Watt

1. Introduction

In the last decades, there has been a shift in society towards greater electrification, as can be noticed in the rising numbers of Electric Vehicles (EVs). As this new infrastructure expands, it is crucial to study its environmental impacts. While numerous studies have examined the environmental consequences of EVs, there is a noticeable shortage of research concerning the environmental impacts of EV charging stations and charging points.

The overall aim of the study is to provide guidance on the charging units' contribution to environmental impact as the number of EVs increases. As the majority of all EV charging – around 80% – is residential slow AC charging, according to Blonsky et al. (2021), this study focuses on that type.

2. Goal and scope

2.1 Goal definition

The goal of this study is to assess the life cycle environmental impacts of residential and workplace charging equipment for EVs in Europe.

Specifically, the study aims to answer the following research questions:
Research question 1 (RQ 1):
What is the impact of emissions and resource use caused by a typical wall-mounted EV charging unit, and additional equipment required for metering and electric protection, for residential or workplace charging *at factory gate?*
Research question 2 (RQ 2):
What is the impact of emissions and resource use caused by a typical wall-mounted EV charging unit, and additional equipment required for metering and electric protection, for residential or workplace charging, *over its complete lifetime?*

The study is intended to be used as a knowledge base for industry and policy makers, as well as the public, about the environmental impacts of EV charging equipment.

2.2 Objects of study and functional unit

The study covers two types of wall-mounted EV charging units:
- Ensto one home 7.4 kW EVH321B-HC000 (Ensto, n.d.-a), hereafter referred to as *Ensto*.
- EVlink ProAC 7.4 kW EVB3S07N4EAM (Schneider Electric, 2023), hereafter referred to as *EVlink*.

These two units are not fully equivalent in terms of safety components and auxiliaries needed for the charging installation to function properly and abide by European and Swedish standards (International Electrotechnical Commission [IEC], 2017; Svensk Elstandard, 2023). The standard by IEC covers multiple countries and therefore refers to local standards and regulations for some specifics. The Swedish standard was chosen as representative for the local regulations. Examples of complementary components needed are Residual Current Detectors (RCDs), overcurrent circuit breakers (OCCBs), and charging cables including connectors. Which of these components that are contained within, or permanently mounted on, the charging unit already before installation, varies from model to model. For this study, the two charging units are complemented with such additional components as presented in Table 1, to become functionally equivalent installations which are compliant with existing standards. At this point, when all necessary components are included to safely use the charging unit, the complete installation is referred to as “electric vehicle supply equipment” (EVSE).

***Table 1**: Safety components and auxiliaries complementing the wallbox unit as a part of the EVSE.*

Additional components	*Ensto*	*EVlink*
Charging cable including connector		*X*
Energy meter	*X*	
Overcurrent protection		*X*
Undervoltage protection[a]	*X*	
Surge protection device	*X*	*X*
Load management controller[b]	*X*	*X*

[a] *Undervoltage protection is not necessary to include to be up to standards, but as the EVlink EVSE has it integrated, it is added to Ensto as well, to make the EVSEs as comparable as possible.*
[b] *A Load management controller is not necessary to include to be up to standards, but it is recommended to ensure efficient, reliable and sustainable charging.*

Two different functional units are used in this study depending on the system boundaries in terms of life cycle scope, as defined by the research questions stated in section 2.1:

1. For question 1, the functional unit is *one set of EVSE ready for installation for a single parking place*, defined as one wall-mounted EV charging unit with a maximum power rate of 7.4 kW, along with additional necessary safety components and auxiliaries.
2. For question 2, the functional unit is *kWh of energy delivered to the vehicle* over the complete operational lifetime of the charging unit.

2.3 Assumptions and limitations

In this study, only the EVSE is accounted for, which is the part of the charging infrastructure that works as a bridge between the grid and the EV. However, in addition to the EVSE, there is equipment located inside the EV that also needs to be in place for the charging to succeed. One such component is the onboard charger, which converts the ingoing AC electricity to DC electricity to charge the vehicle's battery. Although crucial in the charging process, the equipment located inside the EV is not considered in this study.

The EVSE units considered are wall mounted. The same type of units can be installed as floor-standing, but that requires additional components which are not included in this study.

2.4 Technical, temporal, and geographical boundaries

The study is an attributional Life Cycle Assessment (LCA), relying on average data from two different EVSEs, in order to account for variability in technical design and construction. In cases where a process generates multiple products in the same step, allocation of the environmental burden is carried out based on physical parameters such as mass or economic value.

The foreground data used is retrieved from the report *Unit Process Inventory Data for Residential Electric Vehicle Charger Life Cycle Assessment* by Raghavan et al. (2023). Background data is modelled using the database *Ecoinvent 3.10 cutoff* (Spindler, 2024; Wernet et al., 2016). The term cutoff refers to the practice of allocating all primary production of materials to the primary user (Ecoinvent, n.d.).

2.4.1 Technical system boundaries

In this study, only 1-phase charging units with a maximum charging rate of 7.4 kW are included. This is representative of a typical wall mounted charging unit, intended for residential or workplace charging. Furthermore, the study only considers charging of one vehicle at a time, and only in mode 3. For further explanations see Raghavan et al. (2023). Only the equipment located outside of the EV is considered. This means that for example the on-board-charger, which is located inside the EV but necessary for AC charging to work, is not considered. Additional things not included are the packaging, smaller bolts and screws, as well as production and maintenance of capital goods. The parts included are described more in detail in the before-mentioned report presenting the foreground data (Raghavan et al., 2023).

2.4.2 Geographical system boundaries

The modelling of production represents average manufacturing in Europe. This align well with real-world situation for the studied options which are produced in Finland and France respectively (Ensto, n.d.-b; Schneider Electric, n.d.-a). More specifically, heating processes in are assumed to be natural gas, and the electricity used in component production and charger unit assembly is modelled with an average European electricity mix. Components or materials entering the system are assumed to come from a general global market. The usage and End-of life (EoL) of the EVSEs are then modelled for two different countries in Europe – Sweden and Germany. These countries were selected for their different electricity mixes, enabling a comparison of choices in electricity production and their respective effects on environmental impacts (Statistisches Bundesamt [Destatis], 2023; Statistiska centralbyrån [SCB], 2023).

The transportation of materials is integrated into the background system by choosing an average market provider, supplied by Ecoinvent, for each process flow. This approach automatically considers the average transportation associated with the system. When available, the average market for Europe (RER) is selected, otherwise the global (GLO) market is chosen. In the absence of both, the rest of the world (RoW) market is utilized. To model a general distance of transport in the foreground system, a generic transportation process was created. According to Eurostat (2023), the majority of freight transport in Europe (around 77% in 2021) is conducted by road, and therefore lorry is chosen as transportation mode. The transport length is assumed to be 150 km, which is in line with the average reported statistics for the transport of goods in EU (Eurostat, 2023).

2.4.3 Temporal system boundaries

In terms of the time scope, all steps in the life cycle represent the current state of technology, including the background supply of energy and materials, meaning that the data for the use phase and EoL handling in the cradle-to-grave system model does not change over time. Currently, very few charging units reach EoL handling, and it is only now that there is a strong growth in the number of installed units. Nevertheless, they consist of components for which there are established separation technologies, and these are assumed to remain the same also for the foreseeable future, at least until the cutoff point of the product life cycle. This also means that changes in terms of energy supply, and specifically, the electricity supply during the use phase, do not alter over time.

The lifetime of an EV charging unit is dependent on usage. On average, according to data from Eurostat (2021), a car is driven 4,529 km per year in EU. A common estimation for the average energy consumption of an EV passenger car is 0.2 kWh per km driven (Vattenfall, 2021; Virta, 2023). Taken together, this implies an average yearly delivery of 905 kWh to the EV via the charging unit. The lifetime of an EV unit station can also vary substantially. Nevertheless, a common estimate is 10 years (Edvall, 2021). As this technology is relatively new, there is little to no real data on the average lifespan. The charging unit could possibly be in use for much longer than 10 years. Therefore, two different time spans are used in the cradle-to-grave LCA – 10 years and 20 years.

2.4.4 Scenarios and flow chart

In total, ten different scenarios are modelled, to answer the two specific questions. They are summarized in Table 2.

Table 2*: This table presents the eight different scenarios to be modelled. The first two scenarios aim to answer question 1, while scenario three through ten aim to answer question 2.*

Scenario	***Wallbox***	***Functional unit***	***Type of LCA***	***Production geography***	***Lifetime***	***Usage geography***	***EoL geography***
1	*Ensto*	*1 set of EVSE*	*Cradle-to-factory*	*Europe mix*	-	-	-
2	*EVlink*	〃 〃	〃 〃	〃 〃	-	-	-
3	*Ensto*	*kWh delivered*	*Cradle-to-grave*	〃 〃	*10*	*Sweden*	*Europe*
4	〃 〃	〃 〃	〃 〃	〃 〃	〃 〃	*Germany*	〃 〃
5	〃 〃	〃 〃	〃 〃	〃 〃	*20*	*Sweden*	〃 〃
6	〃 〃	〃 〃	〃 〃	〃 〃	〃 〃	*Germany*	〃 〃
7	*EVlink*	〃 〃	〃 〃	〃 〃	*10*	*Sweden*	〃 〃
8	〃 〃	〃 〃	〃 〃	〃 〃	〃 〃	*Germany*	〃 〃
9	〃 〃	〃 〃	〃 〃	〃 〃	*20*	*Sweden*	〃 〃
10	〃 〃	〃 〃	〃 〃	〃 〃	〃 〃	*Germany*	〃 〃

Figure 1 shows a simplified flow chart for the two different types of LCAs. The cradle-to-gate scenario is shown in the dotted box, whereas the cradle-to-grave scenario is comprised of all flows and processes. Transportation between all processes is not shown in the flow chart, but it is included in the LCA model.

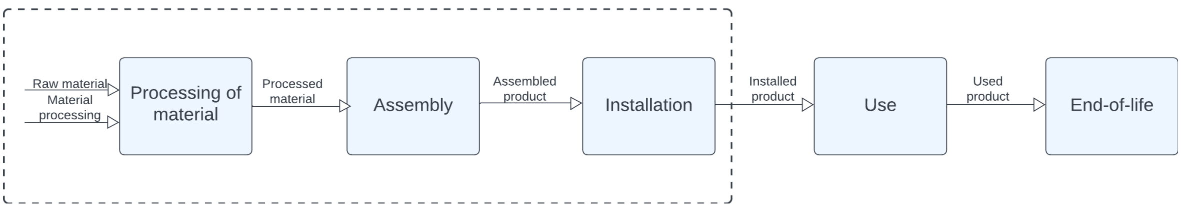

Figure 1: *Flow chart for an EVSE. In the cradle-to-grave scenarios all flows and processes are included. In the cradle-to-gate scenarios, only the flows and processes within the dotted line are included.*

2.5 Selection of life cycle impact assessment method

The environmental impact assessment will be based on the LCIA method ReCiPe from 2016 (Huijbregts et al., 2017), using 18 different midpoint impact categories with hierarchist perspective. In this report we give specific attention to three of these impact categories – climate change, acidification and mineral resource use. Two impact indicators are used for the mineral resource use category, namely the Crustal Scarcity Indicator (CSI) (Arvidsson et al., 2020) and the Surplus Ore Potential (SOP) indicator (Vieira et al., 2017)

3. Data and modelling

3.1 Design and assembly of EVSEs

Figure 2 presents a block diagram illustrating the process of EV charging, specifically the role of the EVSE within the system.

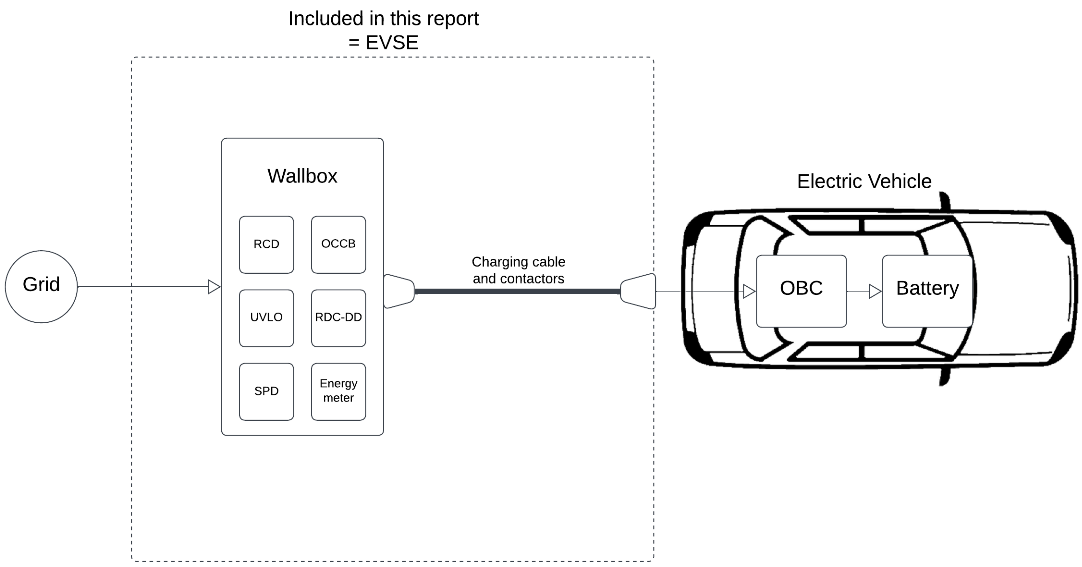

Figure 2: *Block diagram representing the process of EV charging, with a particular focus on the role of the EVSE, highlighted by a dotted box.*

The results were calculated using the software tool openLCA and the database ecoinvent 3.10 cutoff. The unit process data underpinning the inventory analysis is based on the report by Raghavan et al. (2023), which presented the build-up of the two EVSEs. This also included

The EVSE assembly was modeled using data from the report by Raghavan et al. (2023) which provides data for cradle-to-gate. The data is based on reports from Mitsubishi Electric Corporation (2022, 2024) and Ministry of the Environment [Japan] (2017)

3.2 Electricity and energy losses for use phase

In the use phase of the EVSE, there will be energy losses, in the wallbox, load management and the cable. The losses will be identical for the different EVSEs.

3.2.1 Losses in wallbox

When using a wallbox, some of the energy will be lost. The losses were measured on a wallbox of the German brand WALL-E, which had been in use for about 10 years at the time of the measurement. The wallbox had capacities similar to the ones in the LCI, specified for a maximum current of 16A. The voltage drop was measured in weather around 0 °C giving a total of 0.86 V when using maximum current (16A). The complete loss can be calculated to watt by using the equation

$$P = V * I \tag{1}$$

where P stands for power measured in *watt*, V stands for voltage measured in *volt*, and I stands for the electric current measured in *ampere*. This results in a total loss of 13.8 W. The losses in a wallbox can be considered constant during its lifetime (T. Thiringer, personal communication, 2024). Taking the loss divided by the charge input 3.7kW, this translates to a loss of 0.37%. Apart from the losses measured, the load management have losses when in standby of around 2 W. (Schneider Electric, n.d.-b)

3.2.2 Losses in cable

The losses in the charging cable are dynamic and depend on the charging power (M. Alatalo, personal communication, December 20, 2023). In the scenario modelled in this study, the wallbox and cable are designed to handle charging up to 7.4 kW. However, the household is assumed to only be able to deliver a charge input of 3.7 kW and is therefore the limiting factor.

The loss in the cable is calculated using the formula:

$$Losses = R * I^2 \tag{2}$$

where R stands for resistance in the conductive material and I for the electric current in *ampere*. The resistance is calculated using the formula:

$$R = \frac{\rho * L}{a} \tag{3}$$

where ρ is the resistivity in *mΩ,* L is the length in *m*, and a is the cross-sectional area in m^2 of the conductive material.

The conductive material in the cable is copper, which is assumed to be working at around the same temperature as the surrounding environment, assumed to be 20 degrees. This gives a resistivity of $1.7*10^{-8}$ mΩ. The cross-sectional area of the copper wire in the cable is given in the datasheet, as $6*10^{-6}$ m^2. The cable itself is 5 m long, but it contains both a live (active) wire and a neutral wire, therefore the total length of the copper wire is 10 m. From these measurements we can calculate the resistance, 0.03 Ω. The current flowing into the cable is assumed to be 16 A, which when using equation (4) gives a total loss of 7.68W. Taking the loss divided by the charge input 3.7 kW, this translates to a loss of 0.21%.

3.3 Material separation, energy recovery, and preparations for material recycling

The End-of-Life (EoL) modeling of EVSEs was performed using a cut-off method.
The data for heat and energy used during the shredding and sorting process were taken from the report by Tillman et al. (2020), representing sorting and separation in Stena Nordic Recycling Center (SNRC) in Halmstad, Sweden.

All material in the EoL process was categorized into one of the following categories:

- Plastics – Recovery
- Plastics – Incineration
- Plastics, ceramics, and glass – Landfill
- Metals – Recovery

The material in the LCI that could be categorized as "unmixed plastics" (i.e. plastic not integrated into other components), such as polyamide, polycarbonates, elastomers etc., were all sorted in the EoL processes into material recovery (50%), incineration (40%) and landfill (10%). The percentage values are based on a report by the Swedish Environmental Protection Agency (Anderson, 2022), and are applied uniformly to all plastics.

Electronic cards were separated into plastics (30%), ceramics (30%) and metals (40%), in accordance with Luda (2011). All plastics in the electronic cards are assumed to be incinerated, as a step in recovering the metals. The metals are assumed to be recovered, and the ceramics to be sent to a landfill. Similarly, the plastics in the electric cables/wires are assumed to be incinerated, and the metals recovered. The material composition of the electrical wires/cables were taken from the Ecoinvent process, listing 34% as polyethylene and 66% as copper.

The charging cable has a material composition of copper and plastics. The copper is modelled as 100% recycled, whereas the plastic is considered to all be incinerated as a part of the recovery of metal. The plastic in the contactors is assumed to be split into material recovery, incineration and landfill as previously described (Anderson, 2022)

4. Results

Results for selected impact categories are presented from both a cradle-to-gate and a cradle-to-grave perspective for the wall-mounted EV charging units. The cradle-to-gate perspective corresponds to RQ1 and impacts up to the factory gate, while cradle-to-grave corresponds to RQ2 and impacts over the complete lifetime. More information for RQ1 is provided in Appendix B, Table A and for RQ 2 in Appendix C, tables B–E.

4.1 Cradle-to-gate for one EV charging unit

4.1.1 Climate Change

Climate change is reported in terms of global warming potential (GWP). The parts of the wallbox that accounted for most of the impact were the so-called electronic cards, i.e. surface mounted printed circuit boards (PCBs). In these electronic cards, the integrated circuits (ICs) were the major contributor, with 34% and 57% of the total climate change impact for the two EVSE installations respectively. In Figure 3 (reported as Figure 3a and Figure 3b), the breakdown of the results for the two EVSE installations can be seen. The total impact from the EVSE 1 (Ensto wallbox) is 241 kg CO_2-equivalents, and the total impact for EVSE 2 (EVlink wallbox) is 500 kg CO_2-equivalents.

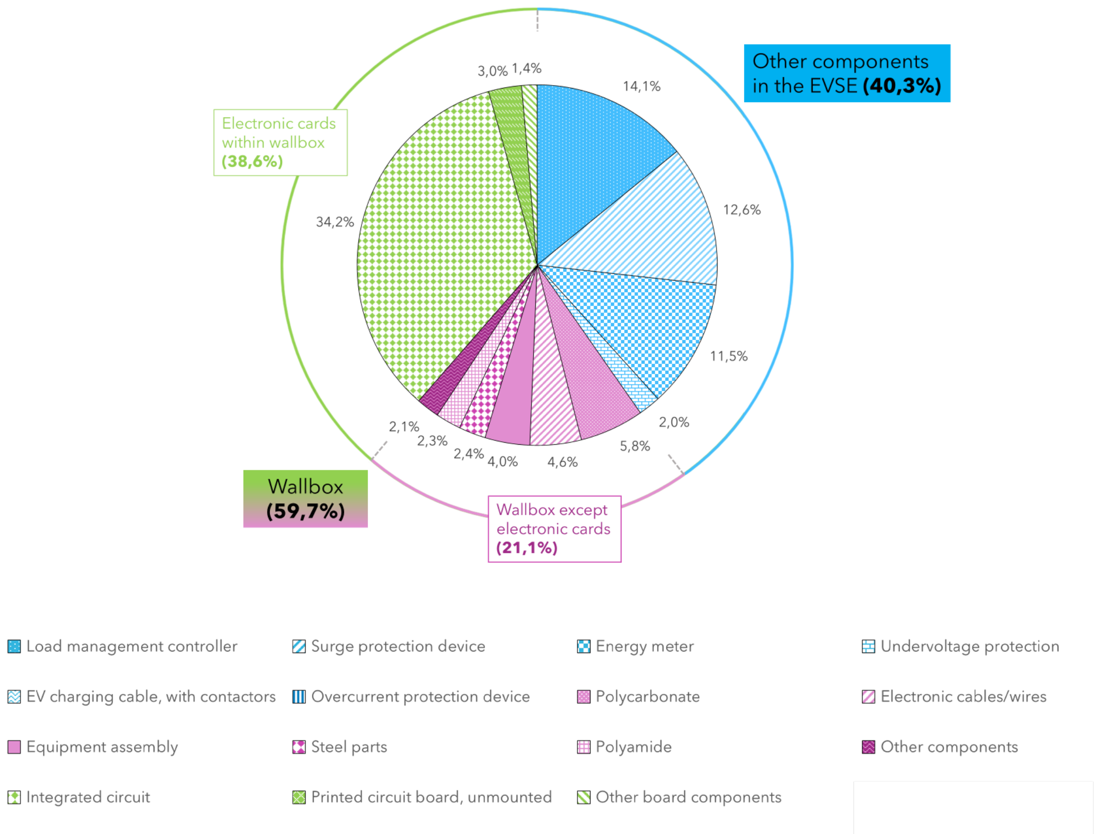

Figure 3a: *Climate change impact of EVSE 1 (Ensto wallbox), cradle-to-gate.*

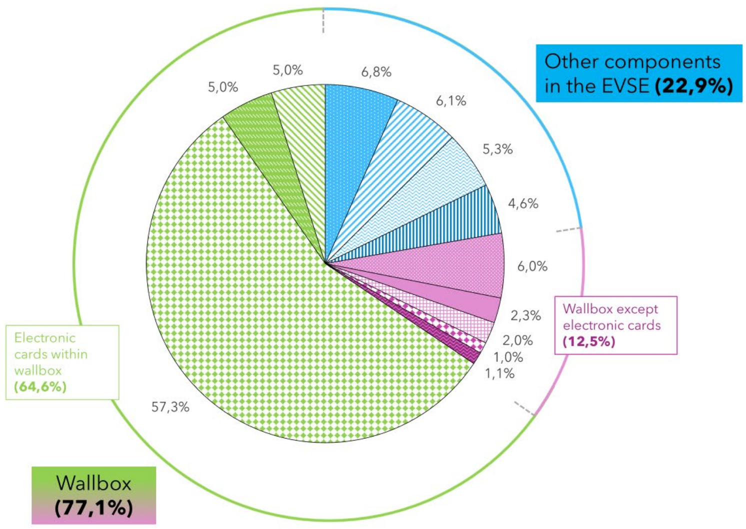

Figure 3b: *Climate change impact of EVSE 2 (EVlink wallbox), cradle-to-gate. See legend on previous page, with Figure 3a.*

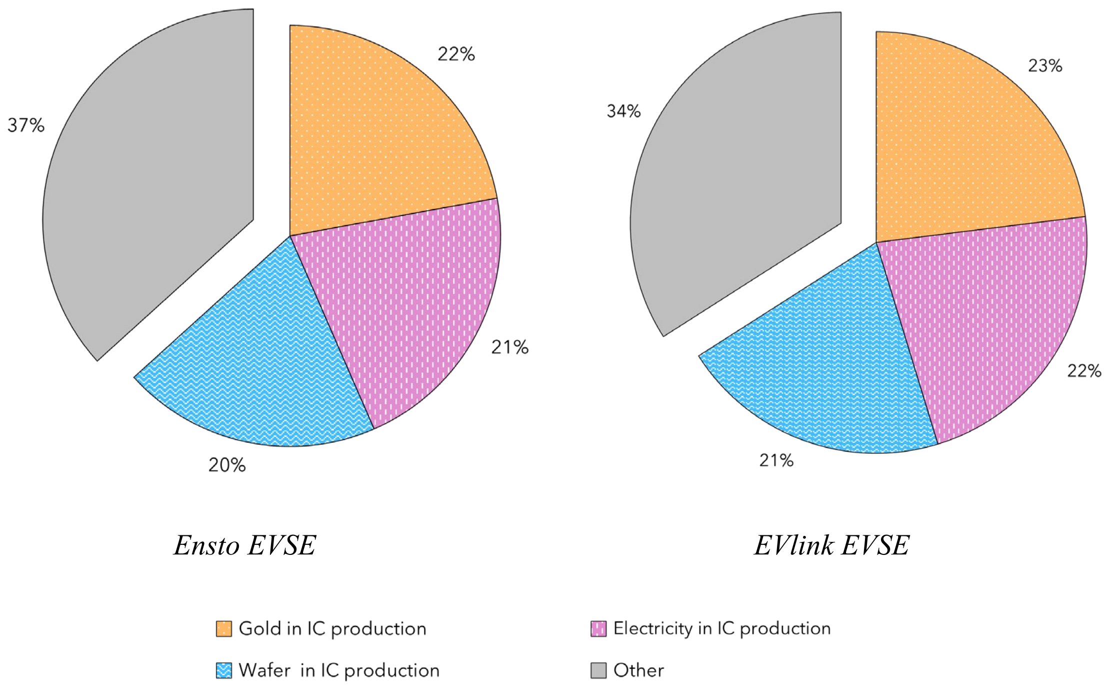

Figure 4: *Climate change impact of ICs in electronic cards in EVSEs.*

4.1.2 Acidification

Terrestrial acidification is measured in SO_2-equivalents. As for the global warming, electronic cards are responsible for a lot of emissions, but contributions from copper in the cables and wires are also significant.

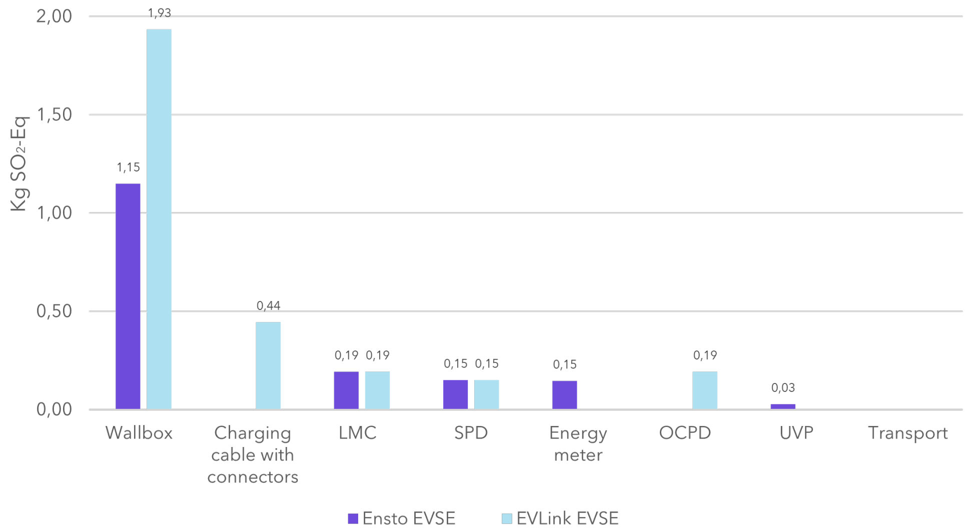

Figure 5: *Acidification impacts of EVSEs 1 and 2.*

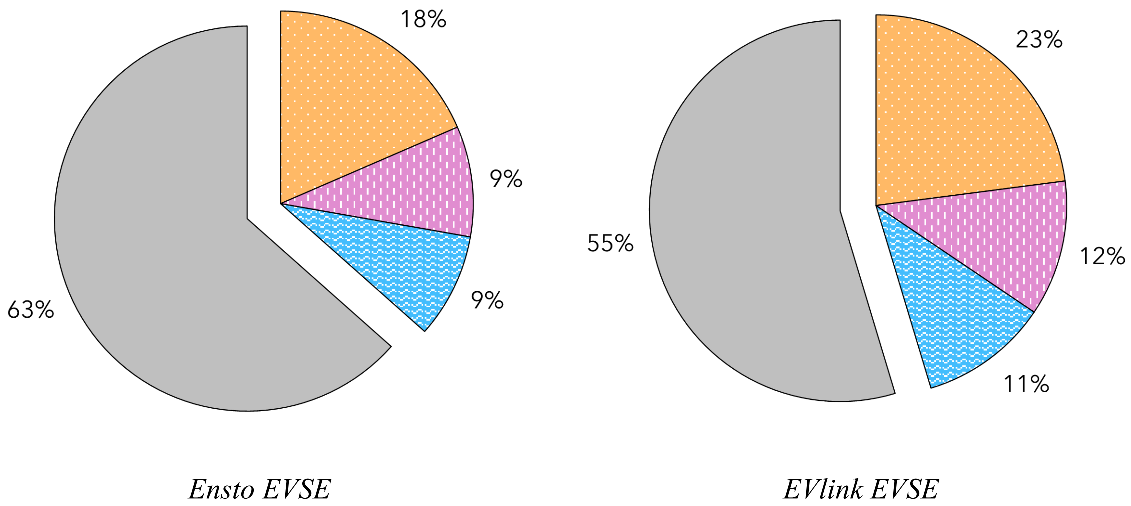

Figure 6: *Acidification impacts of ICs in electronic cards in EVSE 1.* *See legend on page 11, with Figure 4.*

4.1.3 Mineral Resource Use – Surplus Ore Indicator

This indicator for mineral resource use is reported in terms of surplus ore potential (SOP), which is measured in Cu-equivalents. The results look different compared to those for the acidification and climate change impact categories. For the ICs in the electronic cards, gold has a much bigger impact than wafer production or the electricity used in the IC fabrication.

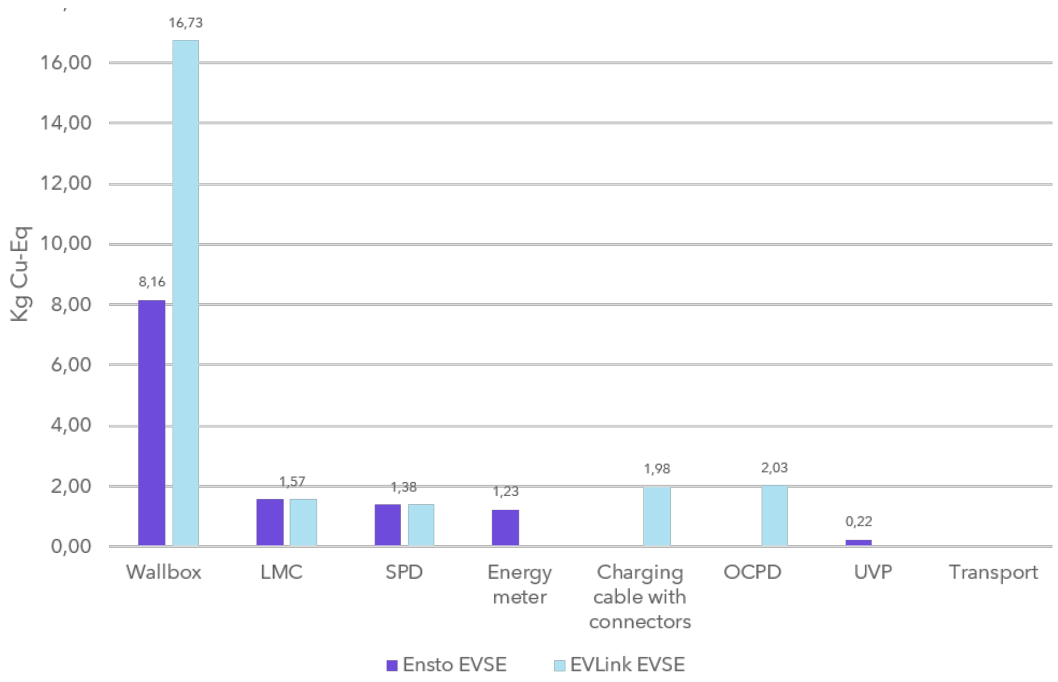

Figure 7: *Surplus ore impacts of EVSEs 1 and 2.*

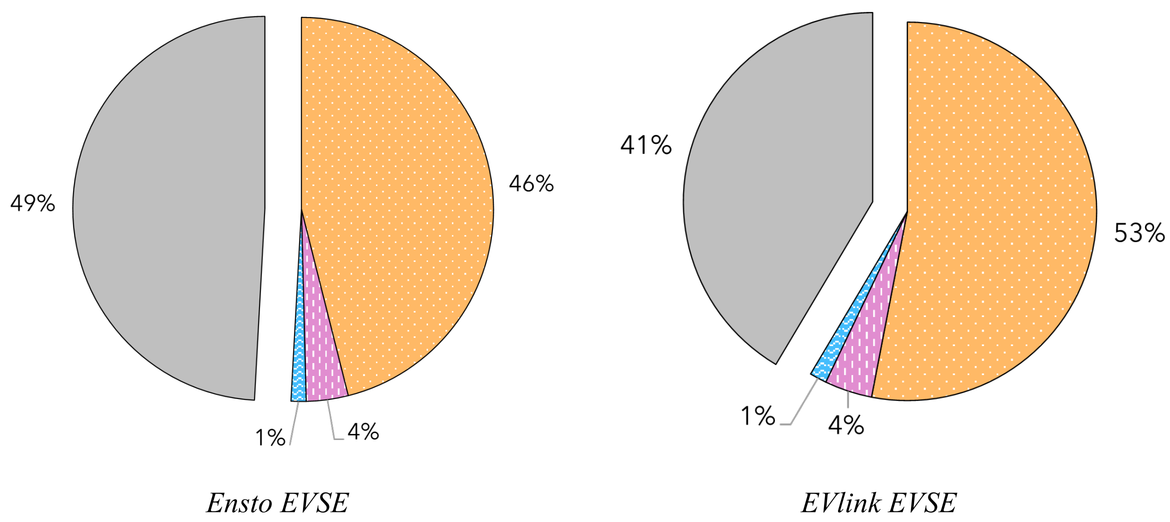

Figure 8: *Surplus ore impacts of ICs in electronic cards in EVSEs.*
See legend on page 11, with Figure 4.

4.1.4 Mineral Resource Use – Crustal Scarcity Indicator

CSI is a mineral resource use indicator that reports results in terms of Si-equivalents. It provides a different time perspective than the surplus ore indicator and captures the risk for long-term scarcity. As for the SOP score, gold is the main contributor to CSI results, with an even larger dominance.

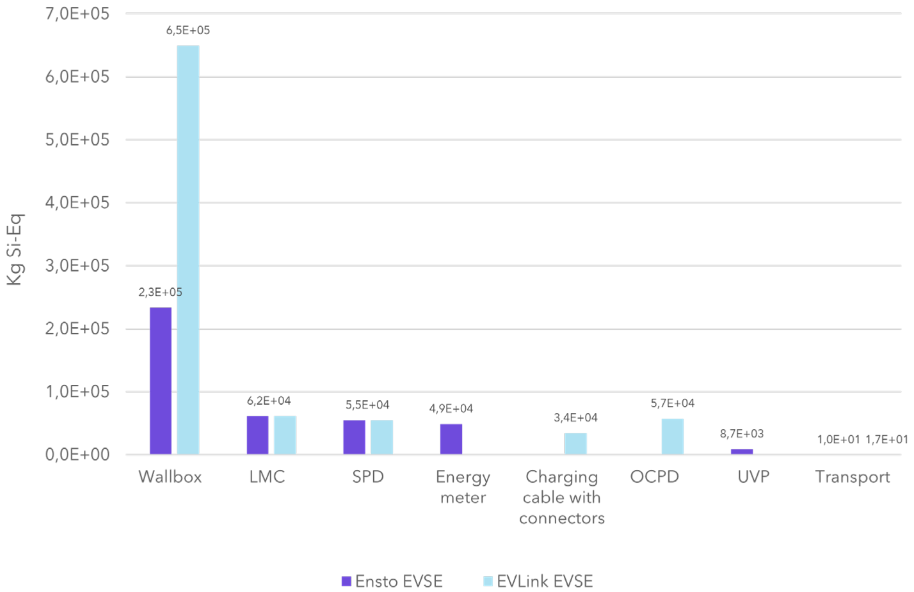

Figure 9: *Crustal scarcity impacts of EVSEs 1 and 2.*

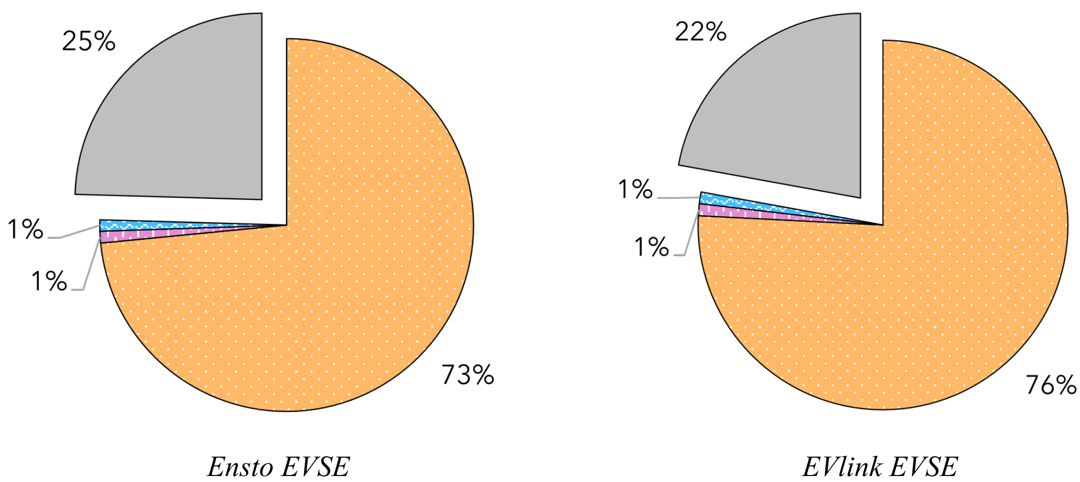

Figure 10: *Crustal scarcity impacts of ICs in electronic cards in EVSEs. See legend on page 11, with Figure 4.*

4.1.5 Other impact categories

Other impact categories were also analyzed. Overall, ICs contribute significantly to most environmental impact categories. In most cases, gold used in ICs is the largest contributing factor. Eutrophication (freshwater) and freshwater ecotoxicity show similar patterns as the surplus ore and crustal scarcity results, in that gold in IC production is highly dominant, accounting for approximately 54–59% of the total impact. For human toxicity (carcinogenic), steel parts also have a considerable influence. In the case of the Ensto wallbox, this impact is larger than that caused by the electronic cards in the wallbox.

4.2 Complete life cycle results

The use phase was modelled for Sweden and Germany separately, over 10 and 20 years, giving four scenarios per EVSE. However, the use phase energy consumption, i.e. energy needed to cover for the losses in the equipment during charging, is estimated to be the same for both types of EVSEs. These losses are dependent on power only and the two EVSEs deliver the same power. They also use the same cable. Losses are assumed constant over the lifetime, so 20 years results in twice the impact of 10 years. Consequently, both EVSEs show identical use phase results, and the overall pattern for complete life cycle results, when the production and EoL stages also are included, are very similar for the two EVSEs. Therefore, only the cradle-to-grave result and the two lifetime scenarios of the Ensto EVSE are presented and discussed in this section. Full results are reported in Appendix C.

4.2.1 Climate Change

Figure 11 shows the Ensto EVSE cradle-to-grave climate impacts. The country of use, and thus the electricity mix, strongly influences results. The use phase in Sweden accounts for about one-tenth of that in Germany. Extending the lifetime nearly halves the total impact per kWh, while end-of-life contributions are minor in both countries. A similar pattern is

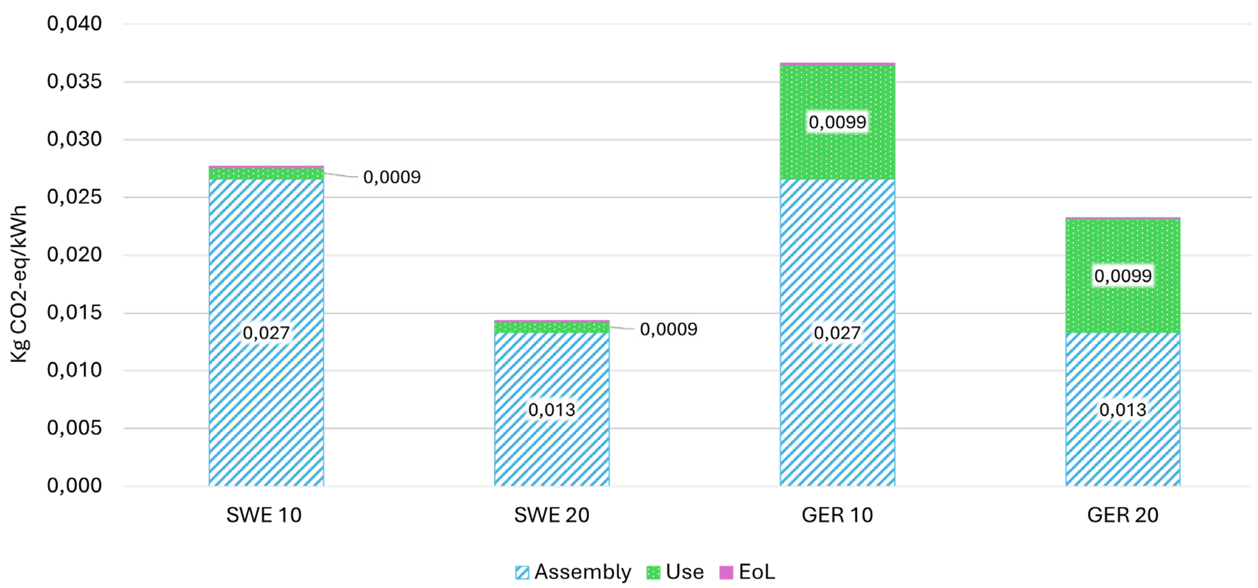

Figure 11: *Climate change cradle-to-grave impact variations for different usage scenarios, shown for the Ensto EVSE.*

observed for eutrophication, where the country of use and electricity mix play major roles and the distribution of impacts is comparable to that of climate change.

4.2.2 Acidification

Figure 12 shows that the overall pattern for acidification broadly aligns with that of climate change in Sweden, where extending the lifetime again nearly halves the impact per kWh. However, the use phase contributes less to total impacts for acidification, a difference that is particularly noticeable in Germany. As a result, the overall difference between Sweden and Germany is relatively small. Ecotoxicity exhibits a similar distribution to acidification, suggesting that user location has a more limited influence on total impacts.

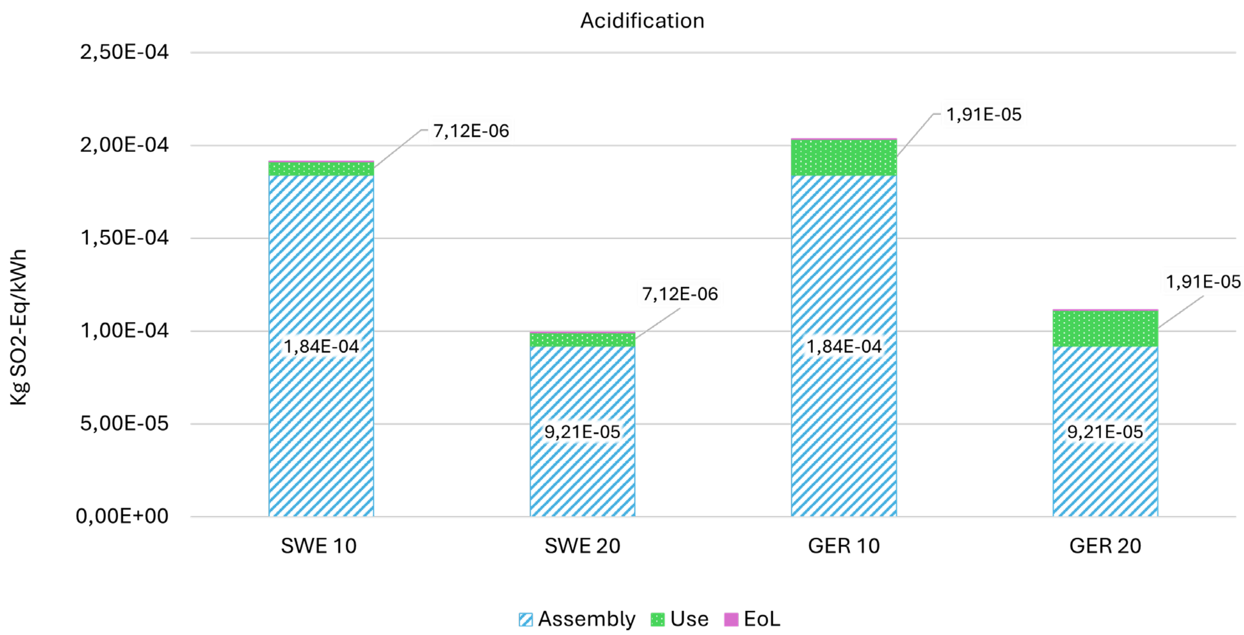

Figure 12: *Acidification cradle-to-grave impact variations for different usage scenarios, shown for the Ensto EVSE.*

4.2.3 Mineral Resource Use

Figures 13 (surplus ore) and 14 (crustal scarcity) present the mineral resource use indicators and how their cradle-to-grave results vary with the lifetime of the Ensto EVSE. In both cases, impacts are dominated by resource use during production, while the use phase plays a minor role. For the surplus ore results, end-of-life makes a more noticeable contribution, but otherwise the pattern is consistent; results for Sweden and Germany are very similar, and doubling the lifetime leads to roughly half the impact per kWh

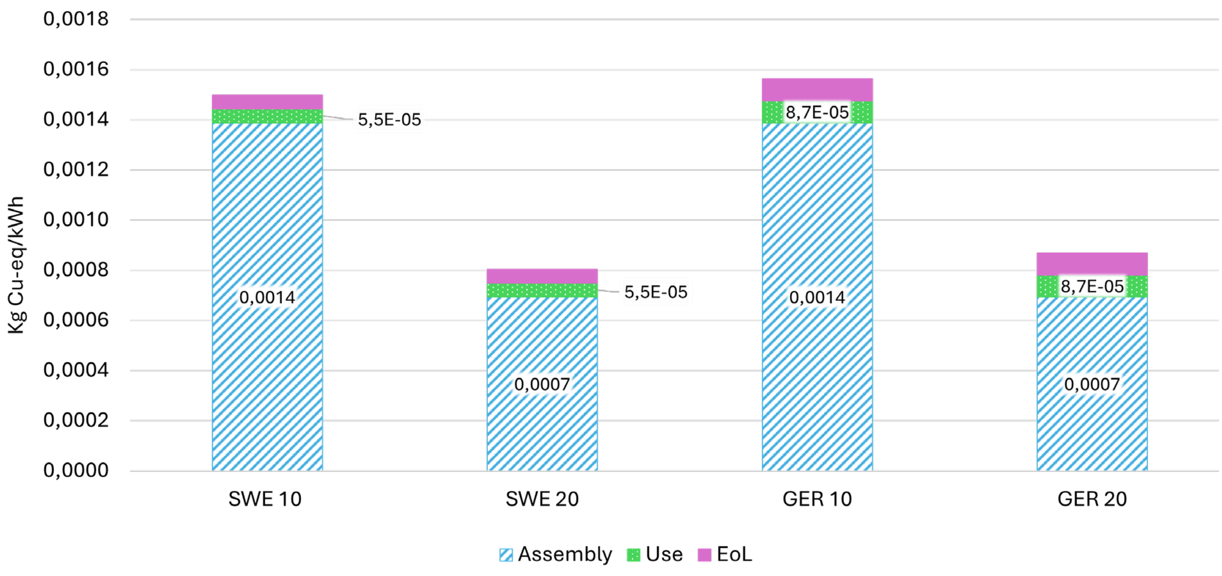

Figure 13: *Surplus ore cradle-to-grave impact variations for different usage scenarios, shown for the Ensto EVSE.*

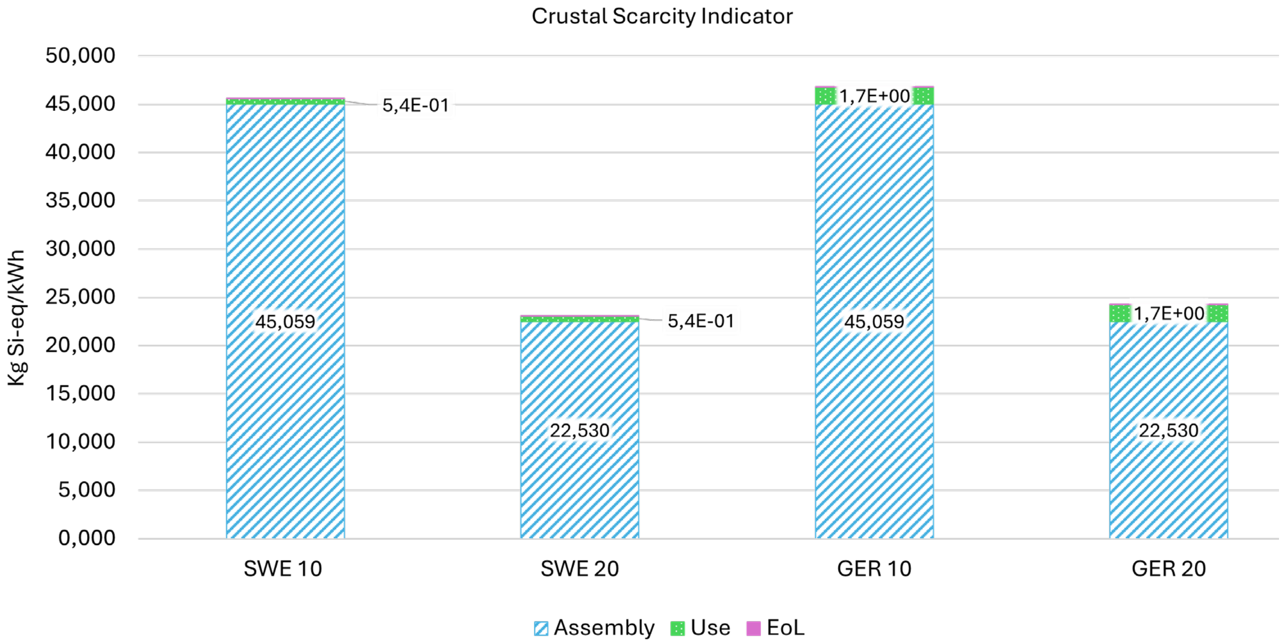

Figure 14: *Crustal scarcity cradle-to-grave impact variations for different usage scenarios, shown for the Ensto EVSE*

5. Exploring the role of Integrated Circuits

In the analysis of results established to answer the first research question, it was found that large shares of the impacts in most categories are caused by the PCBs. More precisely, the ICs in the PCBs cause significantly large impacts. To better understand why, a more detailed exploration was made regarding the role of the ICs. The Ecoinvent documentation for the dataset indicates that the data for IC processing is from the early 2000s (Hischier et al., 2007). In a thesis by Teehan (2014), where modern electric devices were studied by teardown analysis, results showed that newer products had a significant reduction of ICs compared to what the Ecoinvent dataset provided. This suggests that the data provided by Ecoinvent may not be representative of modern PCBs. Continuous advancements are constantly being made in the field of electronics; consequently, the situation may likely have changed furhter since 2014 to the present.

5.1 Three scenarios

To analyze how changes in the data could affect the impact from ICs, three different scenarios with adjusted values in Ecoinvent were calculated and compared. In the first scenario, the gold wires in ICs were changed to copper wires. In the second scenario, the electricity used in the processing of ICs was changed from high-carbon to low-carbon. In the third scenario, the total amount of wafer used in ICs was decreased.

5.1.1 Change from gold to copper wire

According to the data in Ecoinvent, the wires in ICs are made from gold. The possibility to change these to copper was being researched already in 1990 (Khoury et al., 1990). There are advantages in terms of performance both with gold and copper. Copper has a lower resistance than gold wire and therefore also somewhat better conductivity, meaning copper wires can be thinner than gold ones (Khoury et al., 1990). The main disadvantage of using copper is that, unlike the precious metal gold, it can oxidize. The processing of the material requires more control, and the Automotive Electronics Council (2016) have developed requirements for components using copper wire interconnections.

In the last years, copper wires seem to have become the default in new automotive ICs, and several improvements have been made to prevent oxidation, such as coating copper wire in gold and palladium, and/or doping the copper with other material to make it more resistant (Dhond, 2022). As one of the scenarios, the gold wire was changed to copper wire.

By setting length (l) and resistance (R) to equal for the two types of wires, a mass (m) relationship could be found, by calculating the product of resistivity (r) quotient and density (ρ) quotient:

$$\frac{m_2}{m_1} = \frac{r_2}{r_1} * \frac{\rho_2}{\rho_1} \tag{4}$$

The equation to calculate the mass of gold when changing from copper is therefore:

$$m_{Cu} = \frac{r_{Cu}}{r_{Au}} * \frac{\rho_{Cu}}{\rho_{Au}} * m_{Au} \tag{5}$$

The values of different parameters are shown in Table 3.

***Table 3**: Values of parameters for calculation of the mass of copper to replace 1 kg gold, with the same conductivity and length of wire. (Nordling & Österman, 2006)*

Material	***Mass (m)[kg]***	***Resistivity (r) [Ω*m]***	***Density (ρ)[kg/m³]***
Copper (Cu)	*X*	$1.67*10^{-8}$	$8.96*10^{3}$
Gold (Au)	*1*	$2.35*10^{-8}$	$19.32*10^{3}$

By calculation, the mass of copper needed to replace 1 kg of gold under the stated conditions is 0.330kg.

5.1.2 Change from electricity with high environmental impact to low environmental impact.

The Ecoinvent flow used to model the electricity used in the production of ICs is *electricity, medium voltage* with the provider being *market group for electricity, medium voltage – GLO.* It represents an average of the electricity used globally and is constructed by representative percentages of other electricity markets.

As the electricity used in the production of ICs make up around 20% of the total environmental impact (GWP100) for the entire EVSE, changing it to a low-carbon alternative could have a significant impact.

The Ecoinvent documentation (Hischier et al., 2007) base the amount of electricity and heat used in IC production on a report on semiconductor production from Japan Electronics Industry Development Association (JEIDA) from 1997 (Williams et al., 2002). The report states that 83% of total energy consumption is electricity, and the remaining 17% is a mix of heavy oil, gas, LPG and kerosene. Williams et. al. (2002), states that a similar ratio of electricity and fossil fuel was used in the US at that time, according to the U.S. Census Annual Survey of Manufacturers.

The total energy consumption during the production of an IC is based on data for a "32 MB DRAM chip" (Williams et al., 2002). This is a memory type IC but is used to estimate logic type IC energy consumption as well.

The effect that a more environmentally friendly electricity used in the production of ICs could have, was estimated by changing the provider of the flow *"electricity, medium voltage"* in the process "*integrated circuit production, logic type"* in Ecoinvent. The original provider was *"Market group for electricity, medium voltage | electricity, medium voltage | Cutoff, U – GLO"*. It was changed to a process and provider representing wind electricity in Sweden. The process was based on the residual mix market for electricity in Sweden, which was changed to include only wind electricity.

5.1.3 Change in die size

Already in 1965, "Moore's law" was coined, when Gordon Moore predicted that the number of transistors per chip would continue to double every other year (The Electrochemical Society, n.d.). This has been proven to be correct for decades, although some experts believe it may be in its end stage (Hao et al., 2021). The number of transistors per chip has been able to increase as new process techniques have made miniaturization possible, enabling fitting more transistors per chip area, and consequently more functionalities integrated per chip (Teehan, 2014).

The die, which is the fundamental part of a chip, is cut from wafers. Wafers are "sheets" cut from grown crystals (usually made of silicon) in the shape of a cylinder, and several dies are produced on each sheet through different treatments (Zant, 2014). The size of the wafers is measured in diameter, and according to the Ecoinvent documentation, the wafer in their model is a 200 mm-wafer (Hischier et al., 2007). According to Zant (2014), manufacturers are constantly trying to increase the wafer sizes, for a more efficient production. Nowadays, 300mm-wafers are more prevalent than 200 mm-wafers (Hattori, 2015). In theory, this means more dies should be produced per wafer, as there is both the decrease in die size and increase in wafer size. This means less spill per die, and more efficient production.

Two real examples of microchips were used by Ecoinvent to estimate mass content, both encapsulated in Plastic Ball Grid Array (PBGA) (Hischier et al., 2007). One of them was fabricated by ST Microelectronics, called PGBA256, and the other was fabricated by Philips Semiconductor, called SOT514. Philips semiconductor is now named NXP, and they still have "chemical content" with mass presented for certain products on their website (NXP Semiconductors, 2024). Two contemporary example ICs from NXP were identified, both of type MCU, which is an IC that combines logic and memory type ICs (NXP Semiconductors, 2023a, 2023b). While it might not perfectly match the logic type IC in the Ecoinvent documentation, the classification that Ecoinvent has decided upon – logic and memory – is highly simplified, as there are a multitude of different types of ICs that can be categorized in various ways. In Table 4, the total weight for the IC and weight of wafer is presented, both for the two ICs chosen as a representative by Ecoinvent as well as the two newer types.

***Table 4**: Comparison of IC and die weight between modern microchips and older types used by Ecoinvent.*

IC	*Comment*	*Total weight*	*Weight die*	*Wt% of die*
SOT514 (Hischier et al., 2007)	*Used in Ecoinvent*	*3596 mg*	*15 mg*	*0.4%*
PBGA256 (Hischier et al., 2007)	*Used in Ecoinvent*	*2620 mg*	*71 mg*	*2.7%*
MCU 1 SP5747GK0AMMJ6R (NXP Semiconductors, 2023a)	*Newer type of IC*	*471 mg*	*21 mg*	*4.5%*
MCU 2 SPC5646CCF0MMJ1 (NXP Semiconductors, 2023b)	*Newer type of IC*	*697 mg*	*41 mg*	*5.9%*

As can be seen in Table 4, the die mass in the ICs varies significantly. What can be noted is that the newer ICs have around 5 times lower total weight than those found in Ecoinvent, while the weight percentage of the die is a lot higher. As a result, the actual weight of die per

IC cannot be seen to either decrease or increase. However, something not considered in the specifications of the ICs above is the computational power per weight. As the transistors have become smaller, more computational power should be available in a smaller space. Therefore, it is likely that the die mass in total would be less in today's ICS compared to what Ecoinvent reports. However, no information about *how much* the computational power per area or weight has improved has been found. To explore such a hypothetical case, a scenario for halving die weight in the logic type IC from Ecoinvent is modelled, expressed as a 50% reduction of wafer input per die.

5.2 Results for integrated circuit scenarios

This section presents the results for some of the impact categories when exploring different scenarios for alternative IC production and design – climate change, acidification and and resource use. Complete results can be found in Appendix D, Table F and Table G.

5.2.1 Climate Change

Climate change is the impact category on which the selected scenarios are based, and, expectedly, all three scenarios result in a reduction of impact. However, the replacement of gold bonding wires with copper bonding wires, as well as the switch from the global average electricity mix to wind power for electricity supply, provide the greatest improvements.

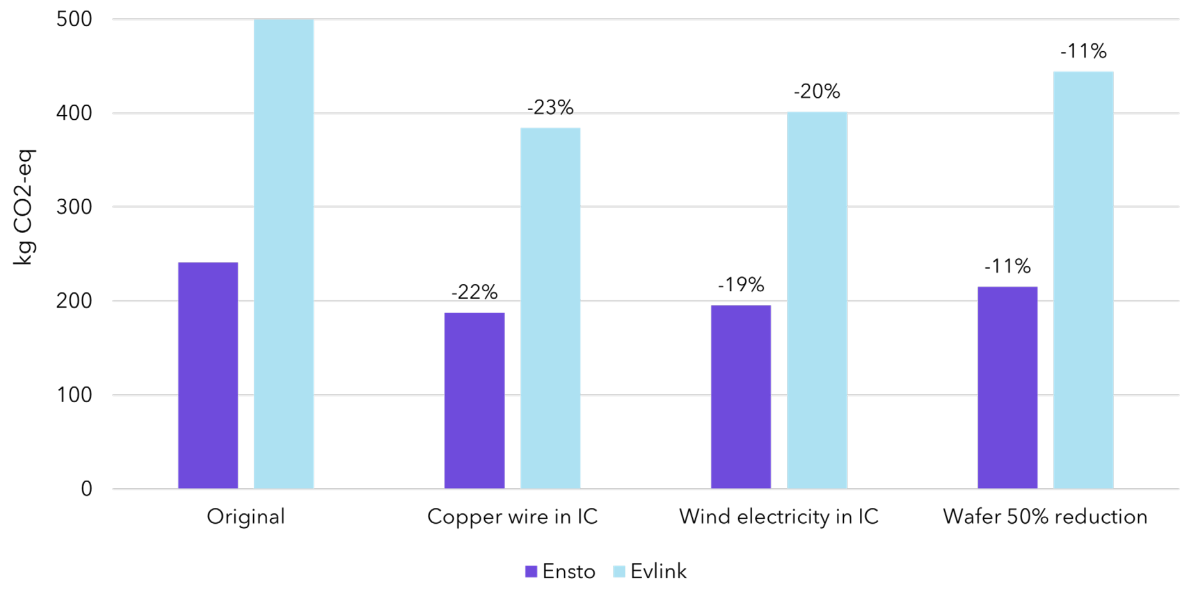

Figure 15: *Changes in climate change impact [kg CO_2-eq] for the whole EVSE in the three different scenarios.*

5.2.2 Acidification

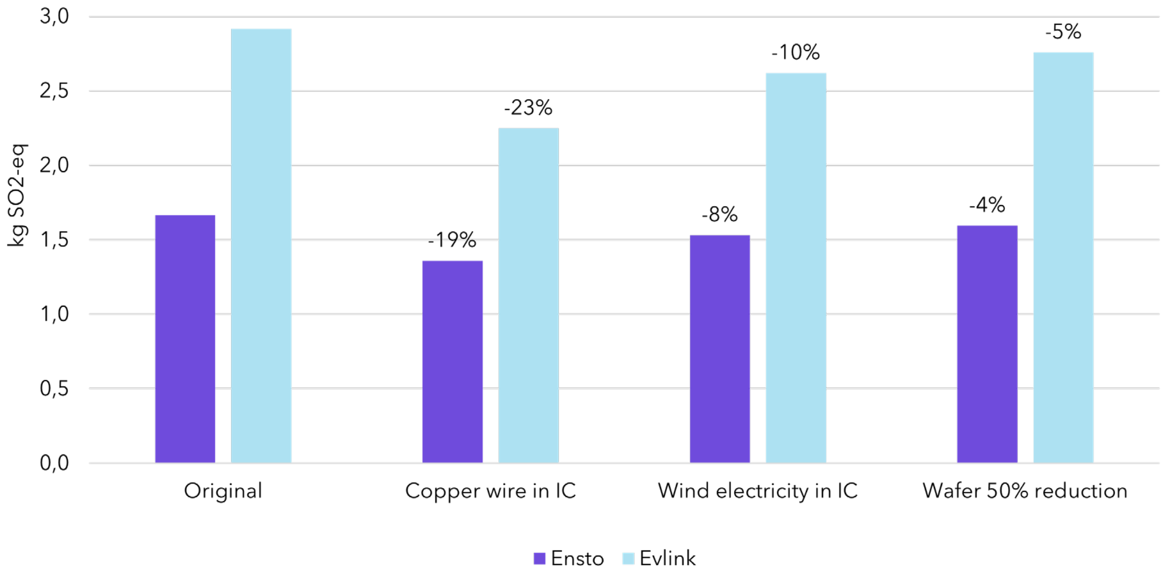

Figure 16: *Changes in acidification [kg SO_2-eq] in the three IC scenarios.*

The acidification pattern is similar to that of climate change. However, switching the electricity supply to wind power and reducing the share of wafer area required for the chip have a somewhat smaller effect than for climate change. Particulate matter shows a similar pattern to acidification, with comparable relative reductions across the scenarios.

5.2.3 Mineral Resource Use

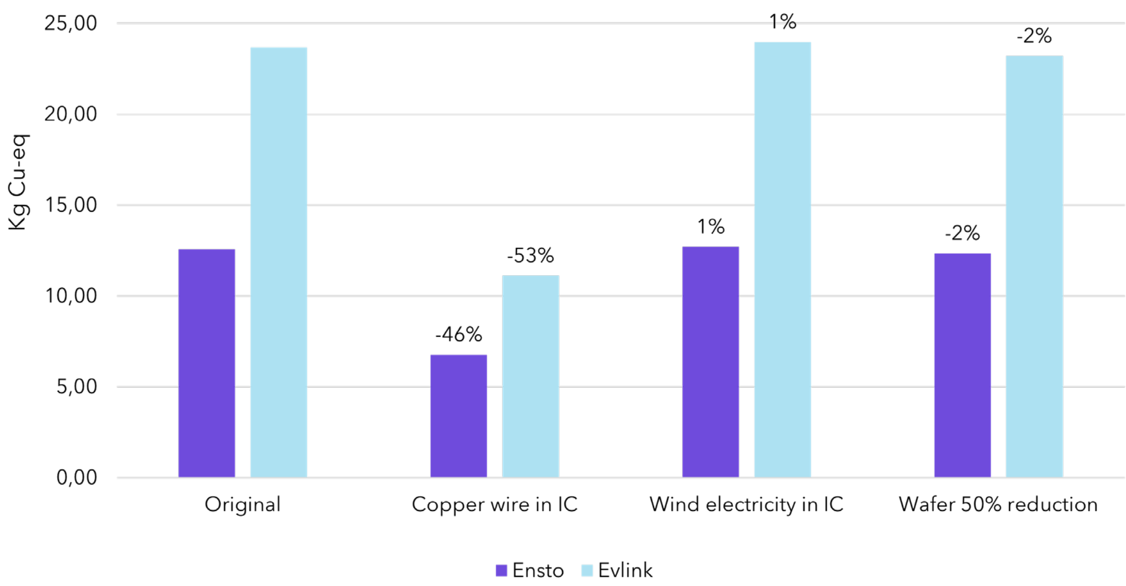

Figure 17: *Changes in surplus ore impacts [kg Cu- eq] in the three IC scenarios.*

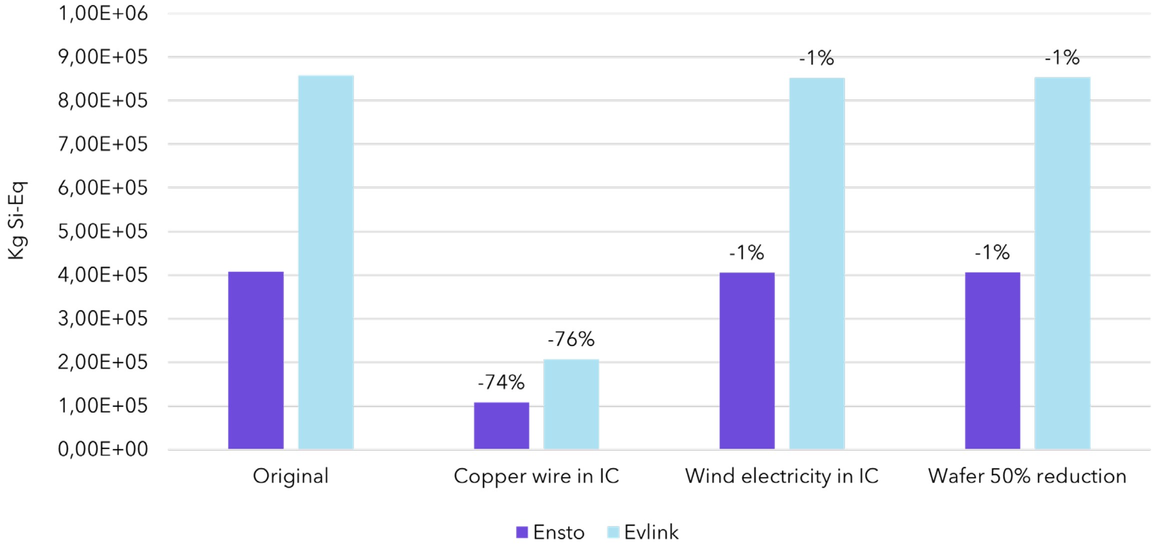

Figure 18: *Changes in crustal scarcity impacts [kg Si- eq] in the three IC scenarios.*

The effect of the three IC scenarios for the two for mineral resource use indicators are shown in figures 17 (surplus ore results) and 18 (crustal scarcity results), which show similar patterns. For both indicators, most of the reduction in impact is achieved by replacing gold bonding wires with copper bonding wires, with the effect being particularly pronounced for crustal scarcity. This is consistent with the results presented in sections 4.1.3 and 4.1.4, where the pie charts show that gold is the dominant contributor to the impacts when the original design is used.

Among other impact categories, freshwater eutrophication and freshwater ecotoxicity results are similar to those of the surplus ore impacts. In both these categories, substantial impact reductions are achieved when the IC bonding wire material is changed from gold to copper.

6. Conclusions

This study assessed the environmental impacts associated with a typical EVSE, i.e. a wall-mounted EV charging unit and the additional equipment required for metering and electrical protection to safely use the unit, both at the factory gate and over its complete lifetime.

With respect to RQ1, the results show that the manufacturing stage is dominated by electronic components, particularly ICs, which contribute substantially to most impact categories. In several categories, and particularly for mineral resource use, gold used in IC production is a major contributor to the overall impact. The analysis therefore identifies electronic components as important hotspots for environmental improvement at the factory-gate stage. However, the robustness of these findings is affected by the age and uncertainty of the available life cycle inventory data for IC production. Since the underlying Ecoinvent datasets are based on data collected approximately two decades ago, updated datasets reflecting modern semiconductor manufacturing would improve the reliability of future assessments.

Regarding RQ2, the results demonstrate that the use phase can play an important role for the lifetime environmental performance of an EVSE, depending on the impact category considered and the electricity mix used during operation. This is true for climate change and, to a lesser extent, acidification, where the country in which the EVSE is used substantially affect the total lifetime impact. In contrast, manufacturing-related impacts remain dominant for several other impact categories, and the influence of the use phase is then relatively small.

The scenario analysis further shows that environmental impacts can be reduced through both design improvements and changes in electricity supply. Among the evaluated measures, replacing gold bonding wires with copper bonding wires in ICs provides the largest reductions in resource-extraction-related impact categories, while switching to low-carbon electricity provides the greatest reductions for climate change impacts. These findings highlight that both product design and use-phase conditions are important for improving the environmental performance of EV charging equipment over its lifetime.

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Appendix

Appendix A: Impact categories

1. Climate change
2. Ozone depletion
3. Ionizing radiation
4. Fine particulate matter formation
5. Photochemical oxidant formation: ecosystem quality
6. Photochemical oxidant formation: human health
7. Terrestrial acidification
8. Freshwater eutrophication
9. Marine Eutrophication
10. Human toxicity: cancer
11. Human toxicity: non-cancer
12. Terrestrial ecotoxicity
13. Freshwater ecotoxicity
14. Marine ecotoxicity
15. Land use
16. Water use
17. Mineral resource scarcity
18. Fossil resource scarcity
19. Mineral resource use – Crustal scarcity indicator
20. Mineral resource use – Surplus ore (potential) indicator

Appendix B: Impact assessment cradle-to-gate

Table A. *Results of different impact assessments of EVSEs, from cradle-to-gate, per unit of EVSE*

Impact category	EVSE 1 (Ensto)	EVSE 2 (EVlink)	Unit	LCIA method
Acidification: terrestrial	1,67E+00	2,92E+00	kg SO_2-Eq/unit of EVSE	ReCiPe 2016
Climate change | Global warming potential (GWP100)	2,41E+02	5,00E+02	kg CO_2-Eq	IPCC2021
Ecotoxicity: freshwater	1,90E+02	3,56E+02	kg 1,4-DCB-Eq	ReCiPe 2016
Ecotoxicity: marine	2,49E+02	4,72E+02	kg 1,4-DCB-Eq	ReCiPe 2016
Ecotoxicity: terrestrial	5,15E+03	8,46E+03	kg 1,4-DCB-Eq	ReCiPe 2016
Energy resources: non-renewable, fossil	7,47E+01	1,49E+02	kg oil-Eq	ReCiPe 2016
Eutrophication: freshwater	3,50E-01	6,91E-01	kg P-Eq	ReCiPe 2016
Eutrophication: marine	1,60E-02	3,10E-02	kg N-Eq	ReCiPe 2016
Human toxicity: carcinogenic	7,75E+01	1,27E+02	kg 1,4-DCB-Eq	ReCiPe 2016
Human toxicity: non-carcinogenic	3,00E+03	5,65E+03	kg 1,4-DCB-Eq	ReCiPe 2016
Ionising radiation	2,25E+01	4,69E+01	kBq Co-60-Eq	ReCiPe 2016
Land use	8,75E+00	1,71E+01	m2*a crop-Eq	ReCiPe 2016
Mineral resource use – CSI	4,08E+05	8,57E+05	kg Si-Eq	CSI 2020
Mineral resource use – SOP	1,26E+01	2,37E+01	kg Cu-Eq	ReCiPe 2016
Ozone depletion	1,23E-04	2,53E-04	kg CFC-11-Eq	ReCiPe 2016
Particulate matter formation	6,94E-01	1,28E+00	kg PM2.5-Eq	ReCiPe 2016
Photochemical oxidant formation: human health	8,23E-01	1,67E+00	kg NOx-Eq	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	8,54E-01	1,73E+00	kg NOx-Eq	ReCiPe 2016
Water use	1,95E+00	4,06E+00	m3	ReCiPe 2016

Appendix C: Impact assessment cradle-to-grave

Table B. *Results of different impact assessments of EVSE 1 (**Ensto**), from cradle-to-grave, per kWh, with an assumed lifetime of 10 years*

Impact category	Assembly	Use Sweden 10 years	Use Germany 10 years	End-of-Life	Unit	LCIA method
Acidification: terrestrial	1,84E-04	7,12E-06	1,91E-05	1,24E-07	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	2,66E-02	9,41E-04	9,87E-03	1,47E-04	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	2,10E-02	8,99E-04	1,39E-03	1,25E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	2,75E-02	1,13E-03	1,80E-03	1,71E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	5,69E-01	3,64E-02	6,44E-02	1,02E-03	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	8,25E-03	1,40E-04	2,53E-03	9,77E-06	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	3,86E-05	7,37E-07	1,34E-05	5,86E-09	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	1,76E-06	1,31E-07	8,93E-07	4,63E-08	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	8,57E-03	6,04E-04	1,59E-03	1,14E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	3,31E-01	8,60E-03	2,20E-02	2,57E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	2,49E-03	5,82E-03	2,36E-03	7,62E-07	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	9,67E-04	2,40E-04	2,62E-04	2,09E-06	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	4,51E+01	5,38E-01	1,72E+00	4,42E-03	kg Si-Eq/kWh	CSI 2020
Mineral resource use – SOP	1,39E-03	5,49E-05	8,74E-05	9,28E-07	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	1,36E-08	2,07E-09	5,07E-09	6,25E-11	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	7,67E-05	2,65E-06	6,94E-06	5,65E-08	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	9,09E-05	2,90E-06	1,20E-05	2,18E-07	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	9,43E-05	2,98E-06	1,24E-05	2,58E-07	kg NOx-Eq/kWh	ReCiPe 2016
Water use	2,16E-04	1,43E-04	5,90E-05	2,64E-07	m3/kWh	ReCiPe 2016

Table C. *Results of different impact assessments of EVSE 1 (**Ensto**), from cradle-to-grave, per kWh, with an assumed lifetime of 20 years*

Impact category	**Assembly**	**Use Sweden 20 years**	**Use Germany 20 years**	**End-of-Life**	**Unit**	**LCIA method**
Acidification: terrestrial	9,21E-05	7,12E-06	1,91E-05	6,19E-08	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	1,33E-02	9,41E-04	9,87E-03	7,36E-05	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	1,05E-02	8,99E-04	1,39E-03	6,24E-06	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	1,38E-02	1,13E-03	1,80E-03	8,56E-06	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	2,85E-01	3,64E-02	6,44E-02	5,10E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	4,13E-03	1,40E-04	2,53E-03	4,88E-06	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	1,93E-05	7,37E-07	1,34E-05	2,93E-09	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	8,82E-07	1,31E-07	8,93E-07	2,32E-08	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	4,28E-03	6,04E-04	1,59E-03	5,72E-06	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	1,66E-01	8,60E-03	2,20E-02	1,29E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	1,24E-03	5,82E-03	2,36E-03	3,81E-07	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	4,83E-04	2,40E-04	2,62E-04	1,04E-06	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	2,25E+01	5,38E-01	1,72E+00	2,21E-03	kg Si-Eq/kWh	CSI 2020
Mineral resource use	6,94E-04	5,49E-05	8,74E-05	4,64E-07	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	6,79E-09	2,07E-09	5,07E-09	3,13E-11	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	3,83E-05	2,65E-06	6,94E-06	2,82E-08	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	4,55E-05	2,90E-06	1,20E-05	1,09E-07	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	4,72E-05	2,98E-06	1,24E-05	1,29E-07	kg NOx-Eq/kWh	ReCiPe 2016
Water use	1,08E-04	1,43E-04	5,90E-05	1,32E-07	m3/kWh	ReCiPe 2016

Table D. *Results of different impact assessments of EVSE 2 (**EVlink**), from cradle-to-grave, per kWh, with an assumed lifetime of 10 years*

Impact category	Assembly	Use Sweden 10 years	Use Germany 10 years	End-of-Life	Unit	LCIA method
Acidification: terrestrial	3,22E-04	7,12E-06	1,91E-05	9,83E-08	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	5,52E-02	9,41E-04	9,87E-03	2,81E-04	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	3,93E-02	8,99E-04	1,39E-03	2,38E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	5,21E-02	1,13E-03	1,80E-03	3,24E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	9,34E-01	3,64E-02	6,44E-02	7,68E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	1,65E-02	1,40E-04	2,53E-03	6,30E-06	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	7,63E-05	7,38E-07	1,34E-05	3,87E-09	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	3,42E-06	1,31E-07	8,93E-07	1,03E-07	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	1,40E-02	6,04E-04	1,59E-03	1,08E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	6,24E-01	8,61E-03	2,20E-02	4,99E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	5,18E-03	5,82E-03	2,36E-03	5,86E-07	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	1,89E-03	2,40E-04	2,62E-04	1,33E-06	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	9,47E+01	5,38E-01	1,72E+00	2,98E-03	kg Si-Eq/kWh	Crustal Scarcity Indicator 2020
Mineral resource use – SOP	2,62E-03	5,49E-05	8,74E-05	6,85E-07	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	2,80E-08	2,07E-09	5,07E-09	1,18E-10	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	1,41E-04	2,65E-06	6,94E-06	5,52E-08	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	1,84E-04	2,90E-06	1,20E-05	2,40E-07	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	1,91E-04	2,98E-06	1,24E-05	2,97E-07	kg NOx-Eq/kWh	ReCiPe 2016
Water use	4,48E-04	1,43E-04	5,90E-05	4,43E-07	m3/kWh	ReCiPe 2016

***Table E**. Results of different impact assessments of EVSE 2 (**EVlink**), from cradle-to-grave, per kWh, with an assumed lifetime of 20 years*

Impact category	Assembly	Use Sweden 20 years	Use Germany 20 years	End-of-Life	Unit	LCIA method
Acidification: terrestrial	1,61E-04	7,12E-06	1,91E-05	4,92E-08	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	2,76E-02	9,41E-04	9,87E-03	1,40E-04	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	1,97E-02	8,99E-04	1,39E-03	1,19E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	2,61E-02	1,13E-03	1,80E-03	1,62E-05	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	4,67E-01	3,64E-02	6,44E-02	3,84E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	8,25E-03	1,40E-04	2,53E-03	3,15E-06	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	3,82E-05	7,38E-07	1,34E-05	1,93E-09	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	1,71E-06	1,31E-07	8,93E-07	5,13E-08	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	6,99E-03	6,04E-04	1,59E-03	5,41E-06	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	3,12E-01	8,61E-03	2,20E-02	2,50E-04	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	2,59E-03	5,82E-03	2,36E-03	2,93E-07	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	9,45E-04	2,40E-04	2,62E-04	6,63E-07	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	4,74E+01	5,38E-01	1,72E+00	1,49E-03	kg Si-Eq/kWh	CSI 2020
Mineral resource use – SOP	1,31E-03	5,49E-05	8,74E-05	3,42E-07	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	1,40E-08	2,07E-09	5,07E-09	5,92E-11	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	7,05E-05	2,65E-06	6,94E-06	2,76E-08	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	9,22E-05	2,90E-06	1,20E-05	1,20E-07	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	9,54E-05	2,98E-06	1,24E-05	1,49E-07	kg NOx-Eq/kWh	ReCiPe 2016
Water use	2,24E-04	1,43E-04	5,90E-05	2,21E-07	m3/kWh	ReCiPe 2016

Appendix D: IC scenarios

Table F. *Impact category results from various scenarios examining the role of ICs in Ensto EVSE, from cradle-to-gate, per unit of EVSE.*

Impact category	Ensto original values	Ensto copper wire in IC	Ensto wind electricty in IC production	Ensto wafer 50% reduction	Unit	LCIA method
Acidification: terrestrial	1,67E+00	1,36E+00	1,53E+00	1,59E+00	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	2,41E+02	1,88E+02	1,95E+02	2,15E+02	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	1,90E+02	7,84E+01	1,93E+02	1,89E+02	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	2,49E+02	1,02E+02	2,53E+02	2,48E+02	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	5,15E+03	4,78E+03	5,21E+03	5,05E+03	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	7,47E+01	6,07E+01	6,33E+01	6,82E+01	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	3,50E-01	1,62E-01	3,31E-01	3,35E-01	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	1,60E-02	1,26E-02	1,46E-02	1,41E-02	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	7,75E+01	6,60E+01	7,60E+01	7,44E+01	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	3,00E+03	1,29E+03	2,97E+03	2,97E+03	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	2,25E+01	1,74E+01	1,70E+01	2,00E+01	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	8,75E+00	5,24E+00	8,20E+00	8,42E+00	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	4,08E+05	1,08E+05	4,05E+05	4,06E+05	kg Si-Eq/kWh	CSI 2020
Mineral resource use – SOP	1,26E+01	6,77E+00	1,27E+01	1,23E+01	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	1,23E-04	9,07E-05	1,12E-04	1,11E-04	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	6,94E-01	5,58E-01	6,05E-01	6,50E-01	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	8,23E-01	5,29E-01	7,19E-01	7,69E-01	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	8,54E-01	5,55E-01	7,49E-01	7,98E-01	kg NOx-Eq/kWh	ReCiPe 2016
Water use	1,95E+00	1,55E+00	1,74E+00	1,70E+00	m3/kWh	ReCiPe 2016

***Table G**. Results from various scenarios examining the role of ICs in EVlink EVSE, from cradle-to-gate, per unit of EVSE.*

Impact category	Ensto original values	Ensto copper wire in IC	Ensto wind electricty in IC production	Ensto wafer 50% reduction	Unit	LCIA method
Acidification: terrestrial	2,92E+00	2,25E+00	2,62E+00	2,76E+00	kg SO_2-Eq/kWh	ReCiPe 2016
Climate change | Global warming potential (GWP100)	5,00E+02	3,84E+02	4,01E+02	4,44E+02	kg CO_2-Eq/kWh	IPCC2021
Ecotoxicity: freshwater	3,56E+02	1,14E+02	3,63E+02	3,54E+02	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: marine	4,72E+02	1,53E+02	4,80E+02	4,70E+02	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ecotoxicity: terrestrial	8,46E+03	7,66E+03	8,59E+03	8,25E+03	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Energy resources: non-renewable, fossil	1,49E+02	1,19E+02	1,25E+02	1,35E+02	kg oil-Eq/kWh	ReCiPe 2016
Eutrophication: freshwater	6,91E-01	2,84E-01	6,50E-01	6,60E-01	kg P-Eq/kWh	ReCiPe 2016
Eutrophication: marine	3,10E-02	2,36E-02	2,80E-02	2,69E-02	kg N-Eq/kWh	ReCiPe 2016
Human toxicity: carcinogenic	1,27E+02	1,01E+02	1,23E+02	1,20E+02	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Human toxicity: non-carcinogenic	5,65E+03	1,95E+03	5,60E+03	5,59E+03	kg 1,4-DCB-Eq/kWh	ReCiPe 2016
Ionising radiation	4,69E+01	3,58E+01	3,50E+01	4,14E+01	kBq Co-60-Eq/kWh	ReCiPe 2016
Land use	1,71E+01	9,50E+00	1,59E+01	1,64E+01	m2*a crop-Eq/kWh	ReCiPe 2016
Mineral resource use – CSI	8,57E+05	2,07E+05	8,52E+05	8,53E+05	kg Si-Eq/kWh	CSI 2020
Mineral resource use – SOP	2,37E+01	1,11E+01	2,40E+01	2,32E+01	kg Cu-Eq/kWh	ReCiPe 2016
Ozone depletion	2,53E-04	1,83E-04	2,29E-04	2,27E-04	kg CFC-11-Eq/kWh	ReCiPe 2016
Particulate matter formation	1,28E+00	9,80E-01	1,08E+00	1,18E+00	kg PM2.5-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: human health	1,67E+00	1,03E+00	1,44E+00	1,55E+00	kg NOx-Eq/kWh	ReCiPe 2016
Photochemical oxidant formation: terrestrial ecosystems	1,73E+00	1,08E+00	1,50E+00	1,61E+00	kg NOx-Eq/kWh	ReCiPe 2016
Water use	4,06E+00	3,17E+00	3,59E+00	3,52E+00	m3/kWh	ReCiPe 2016

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