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Life-cycle assessment of a charging hub for electric trucks

Master’s thesis in Industrial Ecology

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Life-cycle assessment of charging hub for electric trucks
An assessment of the environmental impacts of constructing and operating a charging hub

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Abstract

This thesis aims to quantify the environmental impacts of constructing and operating a charging hub for electric trucks. The research questions are: (i) What are the life cycle environmental impacts of a charging hub?, and (ii) In what stage of the life cycle do the highest environmental impacts occur?

A life cycle assessment (LCA) of the collaborating company's charging hub is conducted, from cradle to grave. Four different scenarios are examined to evaluate the impacts: (i) a 7-year operational lifetime with low usage, (ii) a 7-year operational lifetime with high usage, (iii) a 21-year operational lifetime with low usage, and (iv) a 21-year operational lifetime with high usage. The LCA was performed using the openLCA software with the Ecoinvent 3.9.1 cutoff database. Inventory data was obtained directly from the company as well as adapted from literature. The impacts were evaluated for two impact categories: climate change using the global warming indicator, and mineral resource scarcity, using two different impact assessment methods – the surplus ore indicator and the crustal scarcity indicator.

The results showed that the production and use phases are the most impacting phases in terms of climate change, with the highest production-related emissions owing to the production of electrical hardware, such as charging power units and the compact secondary substation. Furthermore, the production stage has the greatest impact for both the crustal scarcity and the surplus ore indicators in relation to mineral resource scarcity. A sensitivity analysis was performed by varying the amount of the printed circuit boards (PCBs). A decrease in PCBs showed a notable decrease in the overall environmental impacts of the hub.

Keywords: Life cycle assessment, charging station, environmental impacts, electric truck, fast charging

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Abbreviations

Abbreviation	**Definition**
ICE	Internal combustion engine
EV	Electric vehicle
DC	Direct current
AC	Alternating current
DCFC	Direct current fast charging
LCA	Life cycle assessment
GWP100	Global warming potential for 100 years
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
USLCI	United States Life Cycle Inventory
GHG	Greenhouse gas
CSS	Compact secondary substation
MV	Medium voltage
LV	Low voltage
LCIA	Life cycle impact assessment
SOP	Surplus ore potential
PCB	Printed circuit board
OEM	Original equipment manufacturers

1 Introduction

Truck freight transport serves a vital role in society, transporting all types of goods across both short and long distances. Given that the vast majority of the trucks used for road freight are currently internal combustion engine (ICE) vehicles, the transportation sector causes considerable exhaust emissions. Road freight currently accounts for around 15% of European greenhouse gas (GHG) emissions, 70% of which is generated by medium- and heavy-duty trucks (Becker et al., 2022). With the ever-growing threat of climate change, there is a strong need to transition the road transportation sector in order to dampen its environmental impacts.

The use of electric vehicles (EVs) in the freight sector has been proposed as a solution to this need (Krim et al., 2022). Company X is at the forefront of such a solution, offering fully electric freight, both autonomous and non-autonomous. Their product is a large step towards decarbonizing the truck freight sector. While the electric trucks do not cause GHG exhaust emissions during operation, the production of the EVs and its required infrastructure, as well as generating electricity to charge the EVs, cause emissions. As opposed to its ICE counterpart, the infrastructure needed to support a fleet of electric trucks is in its early stages of development and diffusion. It will have to be greatly expanded in the future in order to decarbonize the freight industry and ensure that EV trucks can operate effectively. The environmental impacts of these charging stations are not as well covered in literature as the EVs themselves. To fully understand the environmental implications of operating electric truck fleets, as well as the implications of transitioning to EV trucks in the freight sector, the charging infrastructure's impact needs to be evaluated.

Electric trucks require the batteries to be charged by electricity from the power grid. The batteries on-board EVs require direct current (DC), but power supplied from the power grid is alternating current (AC). Thus, a conversion from AC to DC must take place. Charging of EVs can be categorized in two ways: AC and DC charging. With AC charging, the vehicle is connected to an AC outlet, and the AC/DC conversion is performed by the onboard power electronics. AC charging is usually quite slow, and thus most suitable for overnight charging (Virta, 2022a). AC charging encompasses Level 1 (1.3-2.4 kW) and Level 2 (3-19 kW) charging (Charette, 2022). DC charging is when the conversion from AC to DC takes place outside of the vehicle, at the charging point. DC charging is faster and conducted at higher power than AC charging. Hence, it is ideal for charging shortstops (Virta, 2022a). Direct current fast charging (DCFC) is referred to as Level 3 charging (50-350 kW) (Charette, 2022). For freight trucks, DC charging is preferred due to the higher speed and power. Consequently, these vehicles require infrastructure in the form of DC charging stations.

1.1 Aim and research questions

The aim of this project is to quantify the environmental impacts of the charging station's life cycle from cradle to grave. A life cycle assessment (LCA) is performed, covering material extraction and acquisition, component manufacturing, assembly of equipment at different factories, on-site installation, use of the charging station, and its decommissioning during end of life. The energy use in all stages, as well as transportation of materials and parts, are included. The LCA can be used to identify hotspots and areas of improvement within the life cycle. The research questions are: (i) What are the life cycle environmental impacts of a charging hub?, and (ii) In what stage of the life cycle do the highest environmental impacts occur? The impact assessment focuses on potential burdens related to two impact categories, contributions to climate change and mineral resource scarcity, using two separate methods to evaluate the latter. The project considers Sweden as the country to which the equipment will be transported, installed, and used. The model therefore considers the Swedish average energy mix during the use phase, as the charging station is connected to the Swedish grid. This implies that the station does not generate its own energy nor rely on a specific supplier for its power supply. The use phase was modeled as the losses that occur in the charging hardware, i.e., not the energy delivered to the trucks. Four scenarios are used to evaluate the charging hub, with a timeframe of either 7 or 21 years, and average use rates of 30% or 60%.

2 Literature review

There are a few studies that assess the life cycle impacts of charging infrastructure, focusing on electric passenger cars (Kabus et al., 2020; Lucas et al., 2011; Nansai et al., 2001; Wohlschlager & Neitz-Regett 2022; Z. Zhang et al., 2017; Z. Zhang et al., 2019), electric buses (Bi et al.,2015; Zhao et al., 2021) and two-wheelers (Mendoza et al., 2016) as use cases for the aforementioned product. Table A1 summarizes some aspects of all the literature where an LCA of charging infrastructure is performed. One must be cautious when comparing the results of these papers, as they assess a wide variety of vehicles, chargers and scopes. As the project focuses on electric freight and fast chargers, it is relevant to look at Zhao et al. (2021) and Bi et al. (2015). Those papers investigate buses that use DC chargers with power ranging between 60 and 350 kW.

The goal of Zhao et al. 's (2021) paper is to assess the GHG emissions of implementing a charging station in an existing bus depot in Sydney. In their scope, they consider the equipment production, transportation, installation of the chargers, use phase, and equipment end-of-life (recycling and disposal). They use a Tritium BEV charging station as a reference (model Veefil), which has a user unit, a power unit, and a control unit. In the production phase inventory, an input-output approach is used, and to estimate emissions, the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET® 2019) model is employed. For the transportation phase inventory, they consider the transportation of the finished product from the loading site to the bus depots by an Isuzu NLR 45-150 truck. They also include the transportation from the bus depot to the recycling facility and landfill after the decommissioning of the charging equipment by the same truck.

In the installation phase, Zhao et al. (2021) consider the placing of the charging equipment. This process requires laying down cables to connect the control unit to the electricity grid. For the use-phase inventory, they consider three different routes and that the buses operate for 16 hours per day. The electricity emissions are based on the Australian energy mix, which mostly originate from fossil fuels. For the recycling and disposal phase, Zhao et al. (2021) model this stage as the treatment of all recovered materials for reuse in another product. Due to lack of data, they assume that most materials have a similar treatment impact as their initial production. However, it is worth noting that aluminum and steel are the only exceptions to this assumption. Table 1 summarizes the GHG emissions reported by Zhao et al. (2021). Most of the emissions come from the operations (use phase) as Australia uses fossil fuels to produce their energy. In the paper, they also discuss a scenario whereby improving the energy mix, emissions could be potentially reduced to 3,048 kg CO_2-eq.

Table 1. Life-cycle emissions of a charger (adapted from Zhao et al., 2021)

Life-cycle step	**Global warming (kgCO$_2$-eq.)**	**% of total emissions**
Production	4.74E+03	0.69%
Transportation	7.10E+01	0.01%
Installation	8.63E+01	0.01%
Operations	6.82E+05	98.8%
Recycling & disposal	3.31E+03	0.48%
Total emissions (kg)	6.91E+05	100%

Bi et al. (2015) carried out an LCA study contrasting the environmental impacts of a stationary wireless charger to that of a plug-in charger. Their study focused on the extraction, processing, and manufacturing of batteries and chargers as well as the energy required for their use. The functional unit is 1 km of transport service. In each scenario, 67 buses provide 48,034,407 vehicle kilometers for 12 years across 21 different routes. The end-of-life stage was excluded due to a lack of data. For the wireless scenario, the buses can be charged with AC at the bus depot (67 chargers), or DC while being at a bus stop or transit hub (428 spread across relevant areas). For the plug-in scenario, 67 plug-in chargers were located at the bus depot for overnight charging.

Bi et al.'s (2015) study used the low-voltage grid average data from the United States Life Cycle Inventory (USLCI) to calculate the life cycle energy use and GHG emissions. Their results indicate that there is no significant difference in terms of environmental impacts between the wireless charging system and the plug-in charging system throughout their entire life cycle. Most of the impacts are caused by the use phase in this study, as the US uses fossil fuels to produce their energy. While the base case does not distinguish between day- and nighttime charging, the sensitivity analysis does. The study also discovered that the analysis was most sensitive to the wireless charging efficiency and the carbon intensity of electricity during day- and nighttime. Improvements or deteriorations in these conditions could potentially favor one technology over the other.

3 System under study

The following section presents a description of the charging hub. It includes all components that are included in the scope of the project. Information has been gathered from the installation manuals of suppliers, from descriptions of the components in academic and grey literature, and from representatives at Company X.

3.1 Outline of charging hub

The components included for the analysis are depicted in Figure 1. In this system, AC power from the electric grid is first delivered to the compact secondary substation (CSS). This energy is then transformed to a lower voltage and distributed to the charging power units. The charging power units convert the AC power to DC power and distribute it to the satellites via cables. The hub houses eight satellites. The satellites are positioned on concrete islands that are flanked by support pillars and a collision barrier. The concrete islands, as well as the parking spots for charging, are covered by a roof. The area where the trucks park to charge is also made of concrete blocks. The rest of the hub area is paved with asphalt.

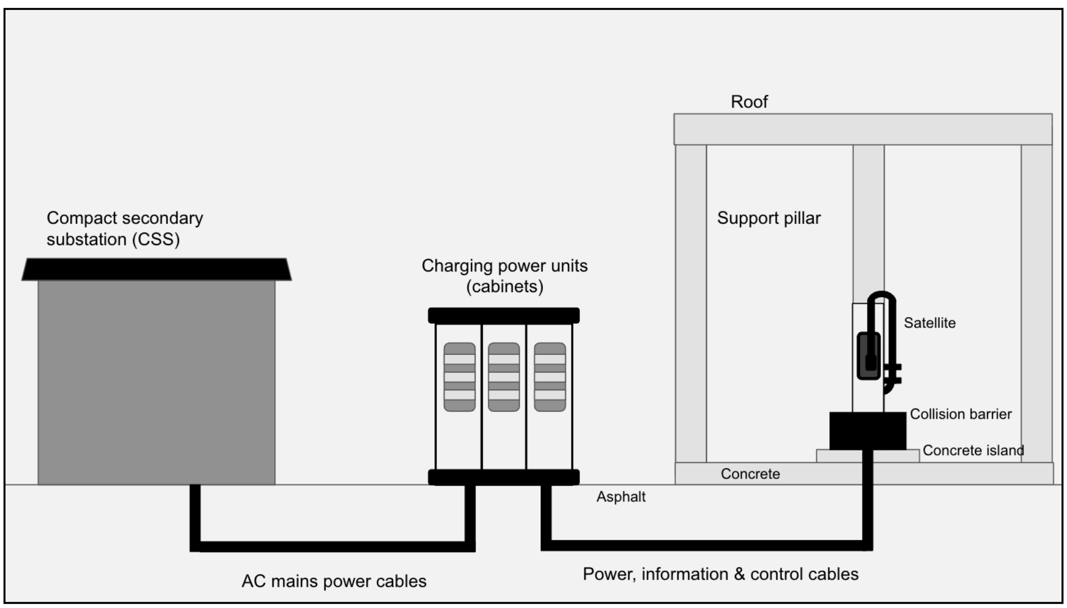


Figure 1. Charging hub visualization

3.1.1 Compact secondary substation (CSS)

The purpose of a compact secondary substation (CSS) is to supply low-voltage energy from a medium-voltage system. A typical CSS includes medium-voltage (MV) switchgear, distribution transformers, low-voltage (LV) switchboards, connections, and auxiliary equipment. This is housed in an enclosure made of concrete, sheet metal, or glass-reinforced plastic (Raghavan et al., 2023). For this specific scenario, a substation of 1,600 kVA is used (Harju Elekter, 2021). This specific design has a sheet-metal housing, made with galvanized steel sheets, and polyester paint (Harju Elekter, 2021).

3.1.2 AC mains power cables

These cables are used to transfer energy from the CSS to the charging power unit. Typical power cables for charging are made out of copper or aluminum. The size and length of the cable depends on the power and layout of the charging hub (Raghavan et al., 2023).

3.1.3 Charging power unit (cabinet)

A charging power unit (cabinet) transforms the AC energy into DC energy and distributes it to the satellites. In this specific setup three cabinets are to be used. Each cabinet has four internal power modules with 50 kW each. The maximum power using this setup is 600 kW and can supply up to eight dynamic outputs. The specific charging power unit model is C803-P480-D8 (Kempower, 2022a).

Inside the charging power unit, there are four power modules, one dynamic power distribution module, a control module and a mains module, as seen in Figure 2. The next section describes in more detail these components and their purpose.

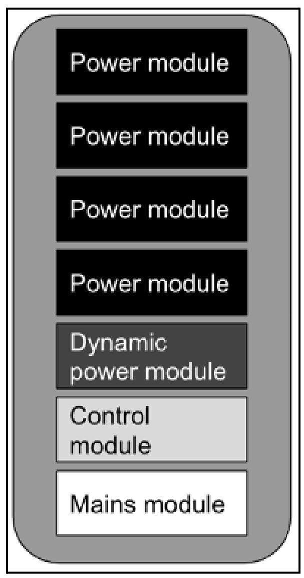


Figure 2. Charging power unit diagram

3.1.3.1 Power module

A power module houses several electronic components. For electric vehicle charging, they typically include a transformer, rectifier, filter, inverter, power switches and a cooling system (Rectifier Technologies, 2022; Infineon, 2021; Semikron, 2018; Sinexcel, 2020). Depending on the design and use of the power module, those components can be located in other parts of the charging system. A power module typically has 25-50 kW power depending on the design.

3.1.3.2 Dynamic power distribution module

A dynamic power distribution module routes and re-routes the power channels to the charging points. It includes a cooling system and electronic components. All these components are contained within a box, in turn integrated into the charging power unit.

3.1.3.3 Control module

A control module is responsible for the communication system. Some charging systems can have the communication system as a communication cabinet (Tritium, 2020) or like in this case as a control module inside the charging power cabinet (Kempower, 2022a). It contains all the ports to which communication cables are connected, such as an Ethernet port, a USB port, and antenna cable connectors.

3.1.3.4 Mains module

The mains module is the compartment where the AC mains power cables are connected. It includes some safety features like a main switch and a miniature circuit breaker for voltage control.

3.1.4 Power, control, and communication cables

The power cables transfer the energy from the cabinets to the satellites. The control and communication cables are used to manage the communication between the cabinet and satellite.

3.1.5 Satellite

In this case, eight single satellites are used, with the specific model being S-C-5E-S (Kempower, 2022b). This satellite type has only one charging cable and one vehicle connector, i.e., the handle that is plugged into the truck. The charging cable is supported by a spring.

3.1.6 Collision barrier

A collision barrier is a component used to protect the satellite from possible crash impact by a truck. Company X has designed its own collision barriers, with each satellite having one collision barrier. The barriers are composed of thin metal sheets and are located next to the satellite over the concrete island.

3.1.7 Concrete island

The concrete island is a structure made of concrete where the satellite, the collision barriers and the support pillars of the roof are located. A thin sheet of steel surrounds the sides of the concrete island.

3.1.8 Roof

The roof is a covering structure that provides shelter and protection for the charging equipment and the vehicles. For each concrete island, the roof has two supporting pillars that flank the charging satellite. The roof is constructed with glued laminated wood.

3.1.9 Concrete drainers & asphalt

Concrete drains are blocks of concrete with good draining capabilities, which are specifically intended for heavy traffic. These concrete drains are placed on the charging parking spots and adjacent space. Some of the hub site is also covered by asphalt road for the vehicles to enter and exit the hub area.

4 Life cycle assessment methodology

The project follows conventional LCA methodology according to the ISO (2006) standard to examine the environmental impacts of a product. The LCA consists of four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation of results. The steps of the LCA methodology are presented in Figure 3. This section will outline the four LCA steps in further detail.

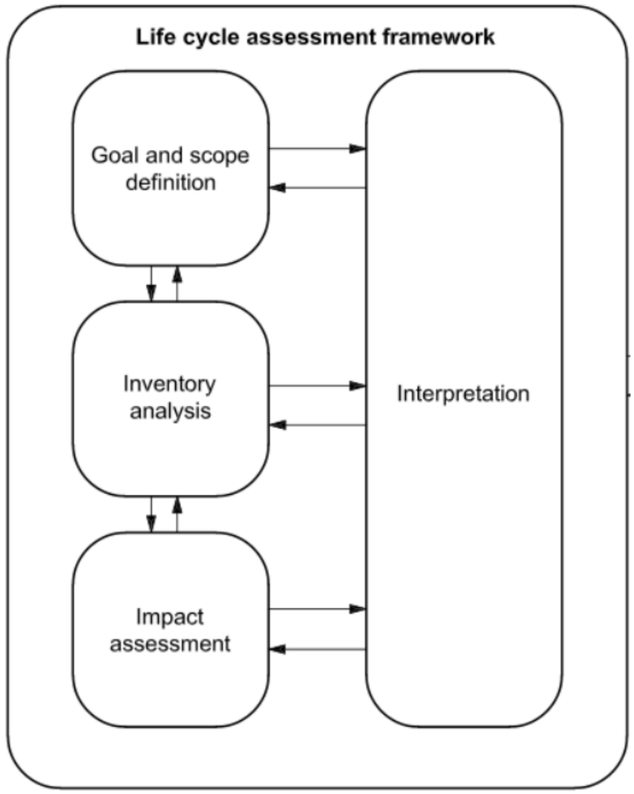


Figure 3. The four steps of the LCA framework. Modified from ISO (2006)

The definition of goal and scope is the first step of the LCA methodology. The purpose of this step is to clearly define the objective of the study and the questions that are going to be answered within the project. When it comes to the scope, the model options, functional unit, choice of impact categories, method of impact assessment, system boundaries, principles for allocation and data quality requirements have to be decided upon (Baumann & Tillman, 2004).

The second step in an LCA, inventory analysis, is where the inventory of flows of emissions and extractions are quantified. One of the main ways of calculating the inventory is through the process-based approach, in which physical reference flows are used to describe and quantify the system (Arvidsson & Ciroth, 2021). A flowchart is created, consisting of the core, foreground unit processes, with both upstream and downstream flows included.

The life cycle impact assessment (LCIA) is the third phase in an LCA. The purpose of the LCIA is to use the results quantified in the inventory analysis to determine the impacts caused by the extraction of material and energy use, and various emissions. The LCIA consists of three steps: classification, midpoint characterization, and damage characterization (Jolliet et al., 2015). In the first step, classification, a set of midpoint environmental impact categories are chosen. The substances emitted in the life cycle are placed into the categories in which they have an effect. In many cases, substances do not exclusively affect only one category. The second step in the LCIA is midpoint characterization, in which the inventory flows are multiplied by category-dependent characterization factors to calculate impacts for each impact category. A third step can also be applied, damage characterization, where impact results are aggregated further to directly represent the harmful effects that the emissions cause. Midpoint indicators from the second LCIA step can be used to obtain damage indicators. Midpoint impacts can contribute to more than one damage category.

The fourth and final stage of an LCA is the interpretation of results. The interpretation phase is not only to be performed at the end of the project, but should rather be done iteratively in parallel with the three preceding steps (Jolliet et al., 2015). One objective of the interpretation phase could be to identify the hotspots within the life cycle, from which to draw conclusions and suggestions. This step should provide ample information to support decision-making by describing where in the system the environmental impacts can be reduced most effectively. Another important part of the interpretation step is to evaluate the robustness of the results, i.e., performing sensitivity analysis, uncertainty analysis, and looking at the implications of the system boundary definitions.

5 Method

This section of the thesis details the case study method. It is split into two main subsections. Section 5.1 outlines the goal and scope, and other specifics of the project. Section 5.2 details data sources and data acquisition used for the inventory analysis, with an in-depth description of each system component. Section 5.3 outlines the LCA modeling in the openLCA software.

5.1 Goal and scope

This goal and scope description is split up into seven subsections, detailing the goal, scope, functional unit, modeled system, impact categories, scenarios and limitations.

5.1.1 Goal

The goal of this thesis is to quantify the environmental impacts of a charging hub constructed and operated by Company X. The analysis will be used to identify hotspots within the system, which can help guide future efforts towards reducing environmental impacts. A secondary purpose is to describe the system, compile relevant data and provide analysis which lays the foundation for future environmental reporting for Company X.

The project's two research questions, as mentioned in Section 1.1, are: *(i) What are the life cycle environmental impacts of a charging hub? (ii) In what stage of the life cycle do the major environmental impacts occur?* This is investigated by conducting LCA of four different scenarios.

5.1.2 Scope

In this study, a cradle-to-grave LCA of the Company X's charging hub is performed. The LCA covers raw material extraction, production, installation, use, and end-of-life stages of the hub.

5.1.2.1 Geographical scope

The geographical scope is Sweden as this is where the hub will be situated. However, this chiefly concerns the installation and use of the hub, while many of the components are sourced and assembled outside of Sweden. For example, assembly of charging hardware takes place in Finland, and the hardware is then transported to the site location for installation.

5.1.2.2 Temporal scope

To further understand the environmental burden, it was decided to evaluate the performance of the charging hub using two temporal scopes. The first one is set to 7 years, as it corresponds to the expected lifetime of the charging equipment (cabinets and satellites) after which it will need to be changed. This can help the company understand the environmental impacts in a scenario where the charging equipment is replaced with another technology when the replacement is needed and therefore demands a full reconstruction of the site, or when the site is no longer used. The second time scope is set to 21 years, as it is roughly the expected lifetime of the entire hub. In this case, the charging equipment needs to be replaced two times with exactly the same technology. From this scenario, the company can understand the environmental impacts of the site during its whole expected lifetime.

5.1.2.3 Data acquisition

The modeling of the system and its flows are made using the openLCA software. For general background data, such as processes for material extraction and refinement of materials, the Ecoinvent 3.9.1 cutoff database is used. The dataset includes recycled fractions typical for the materials. Foreground data, such as the material composition of components in the charging hub, is obtained both from literature research and from the collaborating company directly. Data acquisition specifics are covered in detail in Section 5.2.

Since the geographical origin of most materials is not easily traced, but traded on a global market, they are modeled with Ecoinvent data with the geographical location GLO (global), as it was found to be the best available representation. In cases where the material's origin is known, it is modeled with this specific geographical location selected, when Ecoinvent data representing this particular geographical origin exists.

5.1.3 Functional unit

The functional unit of this study is 1 kWh of delivered energy to an electric truck with an average power of 150 kW requiring 430 m^2 of operating area. The operating area includes the space needed for the truck to enter and exit the site safely even when all the eight satellites are in use. The site is assumed to be fully operational 20 hours per day.

5.1.4 Modeled system for the hub

A visualization of the processes included in this project is presented in Figure 4, with background and foreground system boundaries marked. The background system denotes processes that precede the foreground system, i.e., producing energy as well as extraction and refinement of raw materials, for which already available datasets exist. Unmodified datasets from Ecoinvent are used for background data, as this is not the primary focus of the thesis. The foreground system encompasses the products and processes specific to this study, for which no corresponding database datasets exist prior to this study. Included in the foreground system are processes such as assembly of the specific charging hardware and construction of various civil engineering components. The whole system is split up into four phases: the production phase, installation phase, use phase and end-of-life phase.

In the first phase, the production phase, materials can be placed into two main material categories. The first category covers the construction materials for the hub's site, including materials such as asphalt and concrete, and processes like excavation and paving. The second category encompasses the electronic hardware required for the charging, including various metals and plastics. Note that part of the production phase lies in the background system, namely the production of various metals, plastics, wood, concrete and asphalt. The production processes in the foreground system include the compact secondary substation (CSS), the charging power units, cables and satellites. As shown in Figures 5-7, the CSS and power cabinet are further broken down into internal components.

The second phase is the installation phase, in which all materials and components are installed on site. This step involves installation processes of the various electrical components, as well as paving of asphalt, installation of concrete islands and drainers, and construction of the roof. The energy used by various machinery and vehicles is the primary concern in this phase. Included processes are specific for the hub and are thus a part of the foreground system.

The third phase is the use phase, during which the hub is being utilized for charging by electric trucks. This phase represents the 7 or 21 years of operating time for the hub and it is modeled with electricity use corresponding to the losses caused by the charging equipment when delivering 1 kWh of electricity for charging a truck. The reason that the model only accounts for losses, and not the full throughput of electricity at the hub, is that the transportation work conducted by the electric trucks is not a part of the system under study. As the hub is located in Sweden, the use phase utilizes a Swedish electricity mix exclusively.

The fourth final phase is the end-of-life phase, in which the infrastructure is disassembled. This also encompasses the waste management, in which the various disassembled materials are sorted for recycling or disposed of.

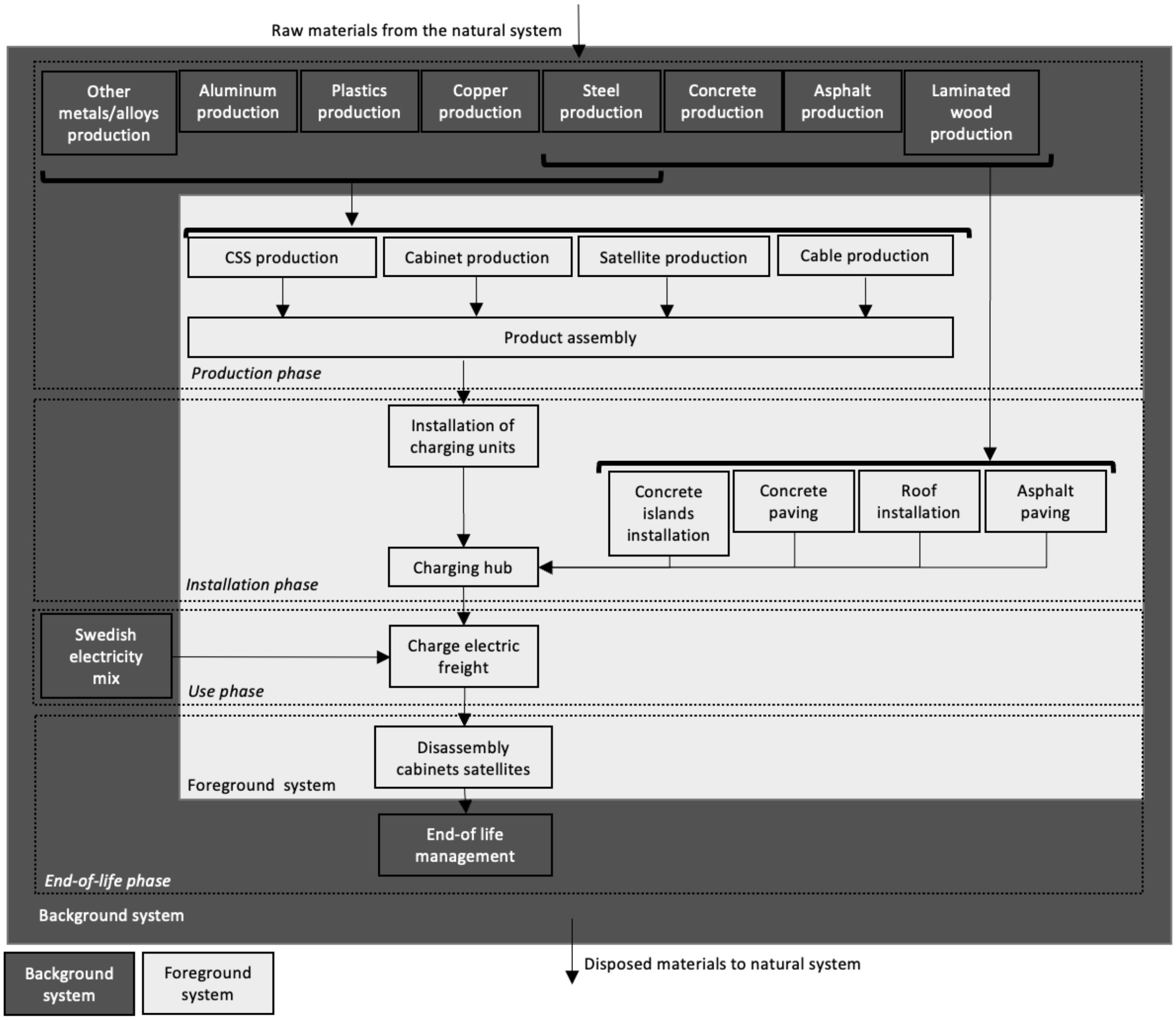


Figure 4. Flowchart of the system

As shown in Figure 5, the CSS was modeled as an assembly containing a transformer, a switchboard, switchgear, a busbar, and a housing. Further details on how each of these components was modeled is explained in Section 5.2.1.1

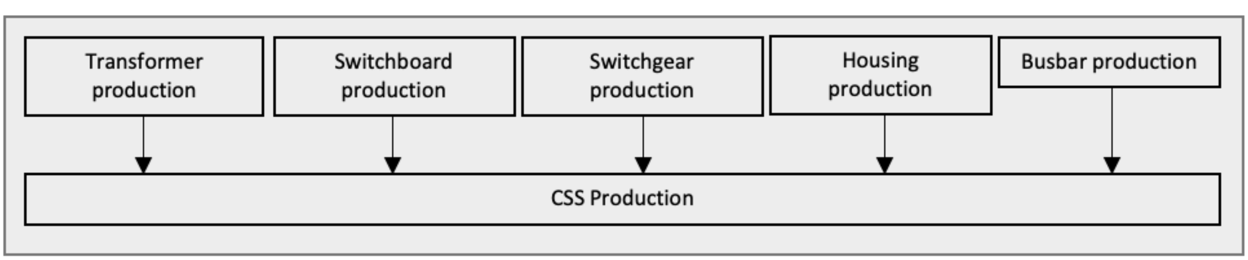


Figure 5. Component breakdown of the CSS

The cabinet was modeled as four power modules, a dynamic power distribution module, a control module, a mains module, and a housing as shown in Figure 6. Further details on how each of these components were modeled is explained in Section 5.2.1.3.

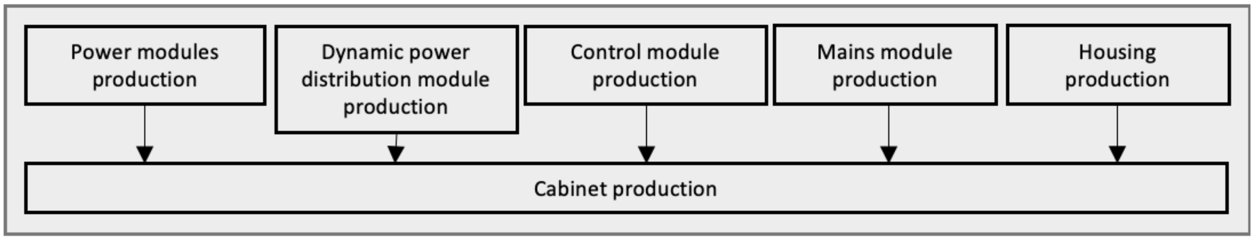


Figure 6. Component breakdown of the power cabinet

Figure 7 details on how each of the modules was modeled for this study. The housing is assumed to be made completely from steel and is therefore not broken down further.

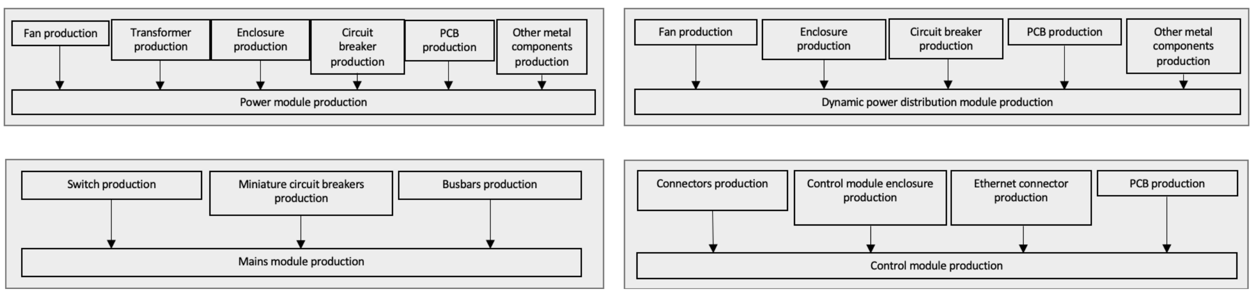


Figure 7. Breakdown of cabinet modules

5.1.5 Impact categories

Two impact categories are selected for the evaluation of the impact of the hub. The global warming indicator covers climate change impact, while the surplus ore and crustal scarcity indicators are used as two alternative approaches to measure mineral scarcity impact (Arvidsson et al., 2020; Huijbregts et al. 2017). The following sections elucidate each indicator further. The global warming and surplus ore indicators used in this study were applied as implemented by the ReCiPe 2016 v1.03, midpoint hierarchist (H), impact assessment method package. The midpoint hierarchist (H) version was selected since it has a 100-year timeframe horizon. The crustal scarcity indicator assessment method was applied as implemented among the LCIA methods in Ecoinvent – referred to as Crustal Scarcity Indicator 2020 there.

5.1.5.1 Global warming

Anthropogenic global warming is the result of GHGs being released into the atmosphere. These GHGs are able to trap heat that originally derives from incoming solar radiation within the atmosphere, which otherwise would have radiated back into space, thus contributing to a warming effect on Earth. There are several different GHGs that contribute to global warming with differing severity. Some of the main GHGs are carbon dioxide, methane, nitrous oxide, and ozone.

The global warming indicator quantifies emissions based on characterization factors called global warming potentials (GWP), expressed in units of kilograms of carbon dioxide equivalents per emitted GHG x (kg CO_2-eq./kg x), over a timeframe of 100 years. It is selected for the analyses in this study since many, if not all, the processes along the charging hub's life cycle emit GHGs to some degree, and it is of particular interest to the collaborating company to quantify these emissions. Furthermore, GWI100 is a commonly used indicator to assess the performance of a product in LCA studies, i.e., including this indicator will enable the company to compare the results for their hub to that of other studies more easily.

5.1.5.2 Surplus ore

Earth's crust contains a finite number of mineral resources, some of which are crucial for society. One important concern relates to ore grade, which deteriorates as a result of mineral extraction (Vieira & Huijbregts, 2020). The lower the ore grade, the more ore has to be extracted in order to obtain the same amount of minerals. This is described by the "Surplus Ore Potential" (SOP) indicator, which is defined as the extra number of ore mined in the future per unit of extracted mineral (Vieira & Huijbregts, 2020). The SOP characterization factors are expressed in kilograms of copper equivalents per kilogram of extracted material x (kg Cu-eq./kg x).

This indicator for mineral resource scarcity is selected for this study as it provides information about the short-term scarcity of materials in the charging hardware, i.e., the electrical components containing valuable and important metals and minerals. This is a relevant indicator to account for when considering that the number of charging hubs is likely to be greatly expanded as the company expands its operations, as well as that the future of electric freight depends heavily on building an extensive network of charging hubs.

5.1.5.3 Crustal scarcity indicator

The surplus ore indicator has been critiqued in literature as it has some methodological shortcomings, such as low temporal reliability, low methodological coherence, and medium practical applicability in terms of capturing scarcity on a general level (Arvidsson et al., 2020). Therefore, to enable a broader mineral resource scarcity assessment, the crustal scarcity indicator is also used in this study to include a long-term perspective for resource scarcity.

The crustal scarcity indicator is a measure of elemental geochemical scarcity that applies the average crustal concentration of elements. Its characterization factors, called crustal scarcity potentials, are expressed in kilograms of silicon equivalent (kg Si-eq./kg x) (Arvidsson et al., 2020).

5.1.6 Scenarios

Four scenarios are applied to understand the environmental impacts when the environmental burden is distributed amongst two different time frames for the use phase (as explained in Section 5.1.2.2) and for when the hub utilization rate changes. This second aspect is considered as it provides information about what will happen with the environmental impacts depending on the hub's utilization. For this analysis, a 30% and 60% average usage is modeled as low and high usage scenarios, respectively. These rates are selected as the company is expecting to have a 30% usage on average during the first seven years and then a 60% average usage until decommissioning after year 21. The following table details each scenario and its implications.

Table 2. Scenarios

Scenario	**Usage**	**Timeframe**	**Implications**
Scenario 1: Short-term meets expectations	Low (30%)	7 years	This is a short-term scenario with the expected average usage of the hub as defined by the company for the first seven years. With this scenario, the company can assess whether the environmental burden could be compensated in case they want to change the technology when the charging equipment must be changed.
Scenario 2: Short-term exceeds expectations	High (60%)	7 years	This is a short-term scenario including an increased usage. With this scenario, the company can assess how much the environmental burden is reduced if the usage of the hub exceeds their expectations.
Scenario 3: Long-term under expectations	Low (30%)	21 years	This is a long-term scenario with a lower usage average than expected. The company can determine the environmental impacts in case they do not achieve the expected usage.
Scenario 4: Long-term meets expectation	High (60%)	21 years	This is a long-term scenario with the expected average usage of the hub defined by the company. The company can assess the environmental impacts of the hub during its whole lifetime.

Since it is assumed that the lifetime of the cabinets and satellites is 7 years, these components will have to be replaced twice during the 21-year scenarios. This means a total of 9 cabinets and 28 satellites will be produced in these scenarios.

5.1.7 Limitations and assumptions

There are several limitations and assumptions in this project. First, most transport processes that take place in the life cycle are accounted for using unmodified weight*distance numbers already existing in Ecoinvent market processes, as transport modes and distances are not known for most materials. The only transports that are manually added are the known transports within the foreground system, mainly the transport from the supplier's manufacturing facility to the hub's site.

When determining the impact of the electricity generation in the use phase, the current Swedish energy mix in Ecoinvent is applied for the whole 7- or 21-years life cycle of the product. This means the project does not use predictions of the future energy mixes in the evaluation.

The impacts of the production, installation and end-of-life phases are considered to happen once, and those impacts are spread out evenly to all 7 or 21 years in use. Therefore, there is no allocation of emissions or material extraction to a specific year and there is no time consideration for the emissions.

The hub schematics used as a basis for asphalt and concrete areas are specific to a site in which a total of ten satellites are installed. Thus, for the project case under study (eight satellites in total), the original approximations for area of asphalt and concrete are over dimensioned. To account for this, the asphalt and concrete areas are scaled with a fraction of 8/10 (size of hub with eight chargers / size of hub with ten chargers).

5.2 Inventory analysis

This section describes in detail the data acquisition and calculations involved in the inventory stage. The inventory analysis section is split up into four subsections covering each of the life cycle phases: production, installation, use, and end of life.

5.2.1 Production phase

This section details the production phase. It is split into subsections for each system component.

5.2.1.1 Compact secondary substation (CSS)

The compact secondary substation material composition is calculated using data from product environmental profiles, which is upscaled for the analyzed scenario. The components included for the analysis are a switchgear (ABB, 2019), a transformer (Legrand, 2021), a switchboard (SE, 2021c) and a busbar (SE, 2020a) following a similar approach as Raghavan et al. (2023). The CSS is upscaled to fit the weight specified by the supplier (Harju Elekter, 2021).

The energy in the assembly step of the CSS is approximated by using the same energy estimates from the manufacturer of the satellites and cabinets (CICERO Shades of green, 2022). The energy required to produce one charging unit was applied to the CSS, and was estimated to be 1 MWh of district heating, and 1.07 MWh of electricity, as explained in Section 5.2.1.3.

5.2.1.2 AC mains power cables

The AC mains power cables supply AC power to the charging power units (cabinets) from the CSS. Each cabinet has one AC input, thus three cables are connected from the CSS to the power unit. Using hub schematics, it was estimated that the cable length from the CSS to the power unit was four meters. A total of three cables results in 12 meters of cable. As there are many power cables in the market, a representative cable was chosen for the analysis (Helukabel, 2021a), following the specifications provided by the supplier. The Ecoinvent flow used to represent the cable in the model is *Cable, unspecified*, scaled to fit the calculated copper weight.

5.2.1.3 Charging power unit (cabinet)

The cabinet is modeled using data from environmental product declarations and data provided by the supplier. Each of the module's material composition is estimated using schematics of the cabinet (Kempower, 2022a) and original equipment manufacturers (OEMs) (Infineon, 2021) to determine which components could potentially be used in this design.

The power module is modeled as four fans (SE, 2021b), a transformer (SE, 2016a), a 20-inch enclosure (Legrand, 2018), a circuit breaker (SE, 2018a), printed circuit boards, and other metal components. Due to lack of data and the variability of designs, it is assumed that share categorized as "other metal components" have the same average metal composition as the parts of the power module which have been reported. The weight of these other metals is estimated using suppliers' data on the total weight of the power module.

The dynamic power distribution module is modeled as a power module but without the transformer and only using three fans. As with the power module, it was assumed that the category for "other metal components" have the same metal composition as the already reported parts of the dynamic power distribution module. Again, the weight of the other metals is estimated using suppliers' data on the total weight of the dynamic power distribution module.

The control module is modeled as four connectors (ABB, 2020), eight ethernet connectors (SE, 2016b), a control module enclosure (SE, 2020a) and printed circuit boards. The mains module is modeled as a switch (SE, 2018b), three miniature circuit breakers (SE, 2022) and three busbars with connectors (SE, 2021a). To model the printed circuit board, the *printed wiring board, surface mounted, unspecified, Pb free* dataset from Ecoinvent is used. The remaining weight of the cabinet is allocated to the enclosure, and it is assumed to be completely made from steel.

The energy used for final assembly of the charging power unit at site is estimated using an assessment done by a third party to the charger manufacturer (CICERO Shades of green, 2022). At the facility, the supplier uses district heating with an emission factor of 0.158 tonCO_2-eq./MWh (SITRA, 2021), natural gas with a 0.185 tonCO_2-eq./MWh mission factor (DEFRA, 2007), and electricity with a grid factor of 0.156 tonCO_2-eq./MWh (CICERO Shades of green, 2022). The document presents the total CO_2-eq. emissions per unit but it does not disclose the percentage use for each of the aforementioned energy sources and it does not specify the exact amount of charger units produced per year. Thus, for simplicity, it is assumed that 50% energy use is electricity and 50% belongs to district heating and that the number of chargers produced is 700. This is based on the scope 1-2 CO_2 emissions for year 2021 reported by CICERO Shades of green. In that year, less than 1000 units were produced. From this, it is estimated that the energy used to produce one cabinet and one satellite is 1 MWh of heating and 1.07 MWh of electricity. The data is reported per unit, and one unit is assumed to be one cabinet and one satellite. Since the share of energy required for each respective component is not reported, the energy was weight-scaled using the percentage share of the component in question. The resulting energy to assemble one cabinet is 0.8 MWh district heating and 0.856 MWh of electricity.

5.2.1.4 Power, control, and communication cables

A set of three cables is connected from the power unit to each of the satellites. Each satellite has one DC cable, one ethernet cable, and one control cable connected to it. The length of cables is estimated by looking at the hub schematic.

As there are many power, control, and communication cables on the market, a representative one is chosen for each of them to estimate their material composition. All cables are modeled using data from Helukabel: power cable (Helukabel, 2021a), control cable (Helukabel, 2019), and communication cable

(Helukabel, 2018). *Cable, unspecified* from the Ecoinvent database is used to model upstream impacts of the cables. The amount of cable added in the model is decided based on the calculated copper weight.

5.2.1.5 Satellite

The charging satellite is modeled as three parts: the housing, the spring, and the charging cable. The housing was assumed to be completely made from steel. The remaining weight of the satellite is assumed to be distributed between the charging cable and the spring. The spring was assumed to be completely made from aluminum and the charging cable is modeled using data from Helukabel, (2021b).

The energy for final assembly was calculated by mass scaling of the estimated district heating and electricity covered in Section 5.2.1.3. The resulting energy to produce one satellite is 0.2 MWh and 0.214 MWh for district heating and electricity respectively.

5.2.1.6 Collision barriers

The collision barrier is constructed with steel sheets. Dimensions were reported by Company X. By using the dimensions supplied, the total volume is calculated and subsequently multiplied by the density to obtain the weight. The density for stainless steel used is 7500 kg/m^3 (Thyssenkrupp, 2022).

5.2.1.7 Concrete islands

The dimensions of the concrete islands were obtained through the hub schematic. There are two types of concrete islands. Type one is located at both ends of the charging area. This is where the main support of the roof is located. Type two houses the charging satellites and has only two support pillars. A total of nine concrete islands are used for the case with eight satellites: two of type one and seven of type two. The volume was first calculated from the dimensions given in the schematic.

The concrete islands are enclosed by a thin metal sheet. The volume was calculated by multiplying the circumference of the island by the thickness of the sheet, which is then multiplied by the depth. The volume is converted to weight by using a density of 7500 kg/m^3 for stainless steel (Thyssenkrupp, 2022).

5.2.1.8 Roof

The specifications for the roof structure were acquired through a hub schematic document. The schematic included the amount of each glued laminated wood plank, as well as their dimensions in millimeters. The amount of wood that had to be added is calculated from studying the available schematic. The total volume is then obtained by summing the volume of all wooden planks.

5.2.1.9 Asphalt

The area of asphalt that covers part of the hub site was provided in square meters by the company. The number was multiplied by 0.8 according to the outlined assumptions (see Section 5.1.7), resulting in 1520 m^2. The materials needed for the road are adapted from the Ecoinvent process *road, company, internal*. The input unit for this dataset is square meters times years of use. Thus, for both the 7- and 21-year cases, the total area 1520 m^2 is multiplied by the number of years the site will be used. The excavation and gravel are omitted from this dataset as they fall under site preparation step in this project. Similarly, the diesel consumed in the paving process is omitted, as it falls under the asphalt installation step.

5.2.1.10 Concrete drainers

The area of concrete drainers that covers part of the site was provided in square meters by Company X, and subsequently scaled by 0.8 as outlined in Section 5.1.7 . The weight in kilograms per square meter is available from the manufacturer's website (Benders, 2019). The concrete drainers were modeled using the *concrete block* flow in Ecoinvent as input.

5.2.2 Installation phase

The installation phase consists of three separate activities: the transportation of charging hardware from manufacturers to the site, the site excavation and preparation, and the installation of asphalt and concrete drainers. Sections 5.2.2.1, 5.2.2.2 and 5.2.2.3 provide details of each of these activities respectively.

5.2.2.1 Transportation

As outlined in Section 5.1.7, the transportation processes explicitly modeled cover the transportation of charging hardware (power cabinets, satellites, and CSS) from the manufacturer's facility to the hub's site. The transportation is modeled with two flows: road freight and sea freight. For power cabinets and satellites, which are produced in Lahti, Finland (Kempower, 2023), the distance was estimated to be 206 km and 353.5 km for sea and road freight, respectively. The weight transported is that of eight satellites and three cabinets, which equals 2000 kg. The CSS is provided by another manufacturer located in Keila, Estonia (Harju Elekter, 2023). The distance was estimated to be 286 km and 112.2 km for sea and road freight respectively. The weight of the CSS is 8600 kg. Table 4 details the inputs and the specific flows included.

Table 4. Transportation to hub location

Transportation of power cabinets and satellites	**Flow**	**Amount**	**Unit**
	Transport, freight, sea, container ship	2*206	t*km
	Transport, freight, lorry 16-32 metric ton, EURO4	2*353.5	t*km
Transportation of CSS	**Flow**	**Amount**	**Unit**
	Transport, freight, sea, container ship	8.6*286	t*km
	Transport, freight, lorry 16-32 metric ton, EURO4	8.6*112.2	t*km

5.2.2.2 Site preparation

Site preparation is modeled with two flows, one for the excavation, and one for the gravel used to fill the excavated volume. A document containing details on the number of cubic meters subject to excavation was provided by Company X. This number is multiplied with the same scaling factor as the asphalt and concrete drainers (i.e., 8/10). The excavation is modeled using *excavation, skid-steer loader* flow in Ecoinvent. The amount of crushed gravel required for the excavated volume is adapted from the *road* *construction, company, internal* process in Ecoinvent, in which one cubic meter of excavation requires 700 kg of crushed gravel. The crushed gravel is modeled with the Ecoinvent flow *gravel, crushed.*

5.2.2.3 Asphalt and concrete installation

The paving of asphalt requires diesel burned in paving and rolling machines. The energy demanded per square meter of installed road is adapted from Stripple (2001). The numbers are taken specifically for the models Dynapac CC 421 and Dynapac F16 of an asphalt compaction machine and a paving machine, respectively, as it is assumed that the machine models with the highest effective m^2/h capacity are used. The total number of MJ for both machines was multiplied by three, to account for the fact that the road consists of three layers (Stripple, 2001). The Ecoinvent flow used to represent the work conducted by the machines is *diesel, burned in building machine*.

The installation of concrete drains is conducted with a small vehicle with a crane. To approximate the diesel burned in this machine, the same amount of MJ per square meter as the paving machine is used. It is scaled up to fit the amount of m^2 covered by the concrete drains. Like the asphalt installation, the *diesel, burned in building machine* flow is used.

The installation of other components, such as the cabinets, CSS, and roof, are not included as their installation impacts are assumed to be negligible in comparison to the larger scale excavation and paving/installation activities.

5.2.3 Use phase

The used energy for the use phase is calculated according to the utilization and time frame for each scenario. An assumed charge of 150 kW per charging point is considered to calculate the maximum amount of energy per month that could be charged in the hub, using eight satellites.

The use phase is modeled as the losses that occur in the system. To obtain the total losses, the total kWh of energy consumed in the use phase is calculated using an efficiency of 85% from grid to vehicle estimated by Company X. Traut et al. (2012) considered a similar value of 88% vehicle charging efficiency in their study to design an optimal allocation for electrified vehicles and their charging infrastructure. Similarly, Bekel et al. (2022) calculated that only 83.07% of the generated energy reaches a car when using a fast public charger (50 kW). Therefore, 85% seemed to be a reasonable estimate for this case.

The flow used in the model is *electricity, medium voltage* with the specific geographical location in the provider process being Sweden. This means that the charging electricity corresponds to an average Swedish supply mix over a full year. The use phase was modeled as four different use case scenarios, as outlined in Section 5.1.6.

For scenario 1, the use is broken down per month for all the seven years. A use rate is assigned to each month starting from 5% use, when the hub opens, going all the way up to 60% when the 7-year timeframe ends. The average use is 30%. The company provided insight into the utilization per month and its increase during these years. For scenario 2, it is assumed that the hub has a 60% utilization rate during the whole 7 years. For scenario 3, the first seven years are modeled in the same way as scenario 1. From year 8, it is assumed that the use will be 30% for the rest of the years. For scenario 4, the first seven years are modeled in the same way as scenario 1. From year 8, it is assumed that the use will be 60% for the rest of the years.

5.2.3.1 Electricity market comparison

The impacts of operating the hub in different countries is investigated further by applying different countries' electricity mixes to the use phase. The countries to be compared to the Swedish use case are the Netherlands, the UK, USA, and Germany. This comparison only encompasses the use phase, with the other phases remaining unmodified.

5.2.4 End-of-life phase

The end of life is modeled using unmodified Ecoinvent waste treatment processes as well as a number of flows to represent disassembly and transport of dismantled materials. All components except the asphalt and concrete drains are assumed to be disassembled/dismantled after the use phase. The asphalt road and concrete drainers are not included in the EoL phase as it is assumed that these foundations will remain for other uses after the hub is decommissioned.

Flows are added to the end-of-life process to represent the transportation of the dismantled components. The transport is modeled with train and lorry freight flows adapted from *market for scrap steel, Europe without Switzerland*.

Steel, aluminum, and copper not part of internal components are assumed to be disassembled and directly sent to final sorting and recycling. The disassembly and sorting processes of these materials are modeled using the flows *diesel burned in building machine*, *electricity medium voltage,* and *waste preparation facility.* These flows are adapted from *treatment of metal scrap, mixed, for recycling, unsorted, sorted*. The flows are multiplied by the total weight for steel, aluminum, and copper. After the final sorting, these materials are assumed to go further to recycling. At this point, these flows are cut off from the life cycle of the studied product and therefore not modeled further.

It is assumed that internal materials in the components are not individually separated and sorted. Instead, all internal components are assumed to be shredded. This is modeled with *shredding fraction after manual dismantling of used electronic product* as a waste outflow for further treatment.

The waste concrete is modeled with *treatment of waste concrete, inert landfill - Europe without Switzerland.* As the concrete for the islands is added as volume in the production phase, the concrete had to be converted into weight. The density used is 2350 kg/m^3 (Tarmac, 2020). Waste plastic is modeled with *treatment of waste plastic, consumer electronics, municipal incineration - Switzerland*. For waste wood, *treatment of wood pole, chrome preserved - Switzerland* was used. Wood was also added as a volume in the production step. The density number used is 650 kg/m^3 (Glued laminated timber, n.d.). Switzerland has been selected for both datasets described earlier due to the unavailability of GLO or European (RER) datasets.

5.3 Background data modeling

The basic principle of the LCA modeling is adding various input flows to a process to create a predefined outflow. This outflow is then linked further downstream in the system. This principle is easily modeled using openLCA and Ecoinvent. When using the Ecoinvent database, all flows have provider processes, which can vary from pure production processes to market processes. Market processes represent the current market for a specific geographical region, generally including the material from various geographical origins. In addition to this, some average transportation is also included.

For this study, market processes are generally selected in the model in order to account for transportation of the materials. For electric components, global markets are used as providers for the materials. This is applied as the origin of the materials is unknown. For civil engineering materials, it is assumed that they are sourced from a European market. Exceptions to this occasionally occurred when a European market process was not available.

A set of custom processes is created in order to more accurately represent the production of parts. Materials need to be worked or refined in some way before it can be assembled to parts. Custom processes are created for two categories of materials: metals and plastics. The custom metal processes include the raw metal, a generic metalworking process for said material, and an additional process such as wire drawing or sheet rolling. The custom processes are made for three commonly occurring metals in the products: steel, aluminum, and copper. Custom processes were also created for two types of plastic: polyethylene terephthalate and polycarbonate.

For steel, the *steel chromium steel 18/8*, *sheet rolling chromium steel,* and *metalworking average for chromium steel product manufacturing* flows from Ecoinvent are applied. The providers are selected as global market processes. All steel in the various components is assumed to be stainless steel, thus the custom steel process is used to represent all steel flows.

For copper wire, the *copper cathode*, *metal working average for copper product manufacturing,* and *wire drawing copper* flows in Ecoinvent are used, with global markets as the providers. For copper sheet, *copper cathode*, *metal working average for copper product manufacturing,* and *sheet rolling copper* are used, with global markets chosen as providers. Copper content is generally assumed to be copper wire, with the custom copper wire being used. The exception to this is the copper content in various enclosures and chassis, in which the custom copper sheet is used instead.

For aluminium, *aluminium wrought alloy, metal working average for aluminium product manufacturing,* and *sheet rolling aluminium* Ecoinvent flows are used, with global market processes selected as providers. The custom aluminium flow is used for all cases where aluminium is present.

The plastic materials are assumed to have been injection molded. Thus, the custom processes included the plastic itself as well as an injection molding process. The polycarbonate process used *polycarbonate* and *injection moulding* flows with global markets as provider processes. The polyethylene process used *polyethylene terephthalate granulate amorphous* and *injection moulding* flows with global market providers.

6 Life cycle impact assessment results and interpretation

This section presents the results from the life cycle impact assessment. Tables 5-7 show the contributions of each phase and present the results for each impact category. The results are then examined in more detail in Sections 6.1, 6.2, and 6.3, for the global warming, surplus ore, and crustal scarcity indicators, respectively.

Table 5 shows the climate change impacts for each scenario and life cycle phase. The production phase is broken down further into each system component. As can be seen in the table, the lowest total life cycle impact is in scenario 4, owing to the large amount of electricity supplied during the 21-year lifetime. In contrast, the highest overall impact is caused in scenario 1, which has a low overall amount of electricity delivered, coupled with a low hub lifetime. Interestingly, scenarios 2 and 3 yield very similar results, despite the third scenario requiring more electronic equipment. All the phases' impacts are slightly lower in scenario 3 compared to scenario 2, except for the production phase, which is slightly higher. The impacts are lower in scenario 3 as a result of the longer lifetime and subsequent larger amount of electricity delivered compared to scenario 2. The impacts from the use phase are identical for all four scenarios. This is to be expected as the use phase is calculated by dividing the lifetime losses by the total amount of electricity supplied to the trucks.

Table 5. Results for the GWI100 for each life cycle phase, in kg CO_2eq./kWh

Life cycle phases	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Production phase				
CSS	4.20E-03	2.22E-03	1.45E-03	8.80E-04
Cabinets	2.58E-03	1.37E-03	2.68E-03	1.62E-03
Cable	3.74E-04	1.98E-04	1.29E-04	7.82E-05
Satellites	5.58E-04	2.95E-04	5.80E-04	3.50E-04
Collision Barrier	2.25E-04	1.19E-04	7.79E-05	4.71E-05
Concrete Islands	1.68E-03	8.90E-04	5.82E-04	3.52E-04
Roof	2.10E-04	1.11E-04	7.27E-05	4.40E-05
Asphalt	4.98E-04	2.63E-04	5.17E-04	3.12E-04
Concrete drainers	2.58E-03	1.37E-03	8.94E-04	5.40E-04
Total contribution	1.29E-02	6.84E-03	6.99E-03	4.23E-03
Installation phase				
Installation phase	5.91E-04	3.13E-04	2.18E-04	1.32E-04
Total contribution	5.91E-04	3.13E-04	2.18E-04	1.32E-04

Use phase				
Use phase	6.56E-03	6.56E-03	6.56E-03	6.56E-03
Total contribution	6.56E-03	6.56E-03	6.56E-03	6.56E-03
EoL				
EoL	4.43E-04	2.35E-04	1.79E-04	1.08E-04
Total contribution	4.43E-04	2.35E-04	1.79E-04	1.08E-04
Total life cycle contribution	2.05E-02	1.39E-02	1.39E-02	1.10E-02

Table 6 shows the results for the surplus ore indicator, for each scenario and life cycle phase. The production phase is broken down further into each system component. The results resemble those of the global warming impact category, with the lowest impact achieved in scenario 4. The highest impact is in scenario 1. Scenarios 2 and 3 show very similar results. Again, as in Table 5, the impacts from the use phase losses are identical, as the impacts of the losses are divided by the total amount of delivered electricity.

Table 6. Surplus ore indicator results, for each life cycle phase, in kg Cu-eq./kWh

Life cycle phases	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Production phase				
CSS	2.37E-04	1.26E-04	8.21E-05	4.96E-05
Cabinets	1.11E-04	5.89E-05	1.16E-04	6.99E-05
Cable	6.87E-05	3.64E-05	2.38E-05	1.44E-05
Satellites	2.37E-05	1.26E-05	2.47E-05	1.49E-05
Collision Barrier	1.60E-05	8.50E-06	5.56E-06	3.36E-06
Concrete Islands	4.39E-05	2.33E-05	1.52E-05	9.19E-06
Roof	6.94E-07	3.68E-07	2.40E-07	1.45E-07
Asphalt	5.53E-06	2.93E-06	5.75E-06	3.47E-06
Concrete drainers	1.47E-05	7.76E-06	5.07E-06	3.07E-06

Total contribution	6.21E-04	3.73E-04	3.74E-04	2.64E-04
Installation phase				
Installation phase	3.84E-06	2.03E-06	1.56E-06	9.42E-07
Total contribution	3.84E-06	2.03E-06	1.56E-06	9.42E-07
Use phase				
Use phase	9.44E-05	9.44E-05	9.44E-05	9.44E-05
Total contribution	9.44E-05	9.44E-05	9.44E-05	9.44E-05
EoL				
EoL	4.15E-07	2.20E-07	1.60E-07	9.69E-08
Total contribution	4.15E-07	2.20E-07	1.60E-07	9.69E-08
Total life cycle contribution	6.21E-04	3.73E-04	3.74E-04	2.64E-04

Table 7 shows the results for the crustal scarcity indicator, for each scenario and life cycle phase. Again, as for the previous categories, the highest and lowest impact are seen in scenario 1 and 4, respectively. However, unlike for the previous categories, scenarios 2 and 3 differ substantially. The impact of scenario 3 greatly exceeds that of scenario 2. This indicates that the increased toll caused by the larger number of cabinets and satellites is not offset by the larger amount of electricity delivered. The results of the use phase are again identical between the four scenarios.

Table 7. Crustal scarcity indicator results, for each life cycle phase, kg Si-eq./kWh

Life cycle phases	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Production phase				
CSS	1.17E+00	6.18E-01	4.04E-01	2.44E-01
Cabinets	4.10E+00	2.17E+00	4.26E+00	2.57E+00
Cable	1.35E+00	7.16E-01	4.68E-01	2.83E-01

Satellites	2.28E-01	1.21E-01	2.37E-01	1.43E-01
Collision Barrier	5.82E-02	3.08E-02	2.01E-02	1.22E-02
Concrete Islands	2.50E-01	1.32E-01	8.64E-02	5.23E-02
Roof	1.97E-02	1.04E-02	6.81E-03	4.12E-03
Asphalt	2.08E-01	1.10E-01	2.16E-01	1.30E-01
Concrete drainers	2.86E-01	1.52E-01	9.91E-02	5.99E-02
Total contribution	9.10E+00	5.37E+00	7.06E+00	4.73E+00
Installation phase				
Installation phase	2.45E-01	1.30E-01	9.21E-02	5.57E-02
Total contribution	2.45E-01	1.30E-01	9.21E-02	5.57E-02
Use phase				
Use phase	1.17E+00	1.17E+00	1.17E+00	1.17E+00
Total contribution	1.17E+00	1.17E+00	1.17E+00	1.17E+00
EoL				
EoL	1.38E-02	7.33E-03	5.12E-03	3.09E-03
Total contribution	1.38E-02	7.33E-03	5.12E-03	3.09E-03
Total life cycle contribution	9.10E+00	5.37E+00	7.06E+00	4.73E+00

6.1 Global warming

This section presents the results for the global warming indicator in more detail, with percentage breakdowns for the entire life cycle as well as for the production phase.

Figure 8 details the contribution of each of the life cycle phases for GWI100, for all four scenarios. It can be observed that for scenario 1, the majority of the total impact is caused by the production phase. This overrepresentation of the production phase is caused by the low use rate and low lifetime. Conversely, for scenario 2 and three, the production phase accounts for roughly half of the impact, with the other half being caused by the use phase. For scenario 4, the impacts caused in the use phase accounts for the majority of the impacts. This can also be clearly seen in Figure 9, which details the percentage contribution of each life cycle phase. The installation and EoL phases have a minor impact on the total results.

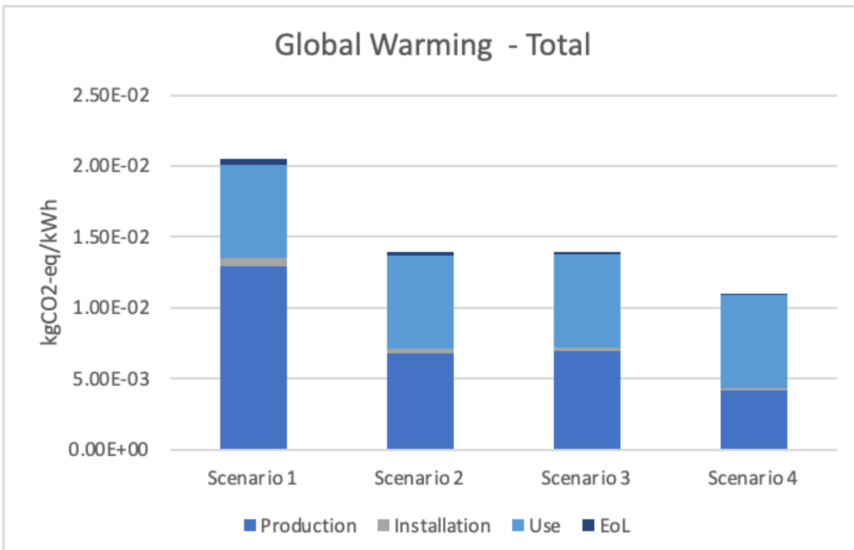


Figure 8. Global warming results for the entire life cycle, $kgCO_2$-eq./kWh

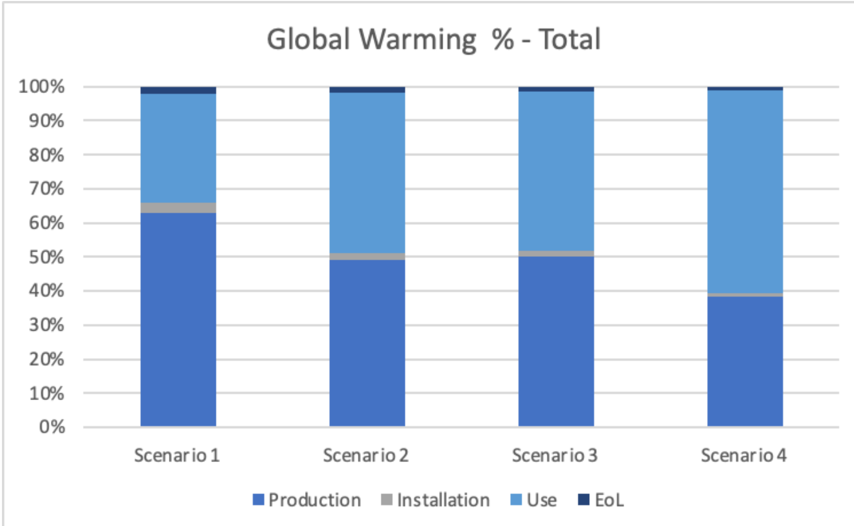


Figure 9. Global warming results for the entire life cycle, % of contribution

In Figure 10, the production phase is broken down further, with the percentage contribution of each component being shown. The percentages are identical between scenario 1 and 2, and between scenario 3 and 4, as the production requirements are the same for the same time frames. For scenario 1 and 2, the CSS and cabinets account for a little over 50% of the total impact. They are followed by the concrete drainers, concrete islands and satellites. Asphalt, cables, collision barriers and roof play a far less significant role, accounting for around 10% of the impact altogether. For scenarios 3 and 4, the CSS and cabinets account for 60% of the total impact. Notably, the cabinets have the biggest percentage impact of all components, which is caused by the fact that these scenarios have a total of nine cabinets produced, while CSSs is not replaced.

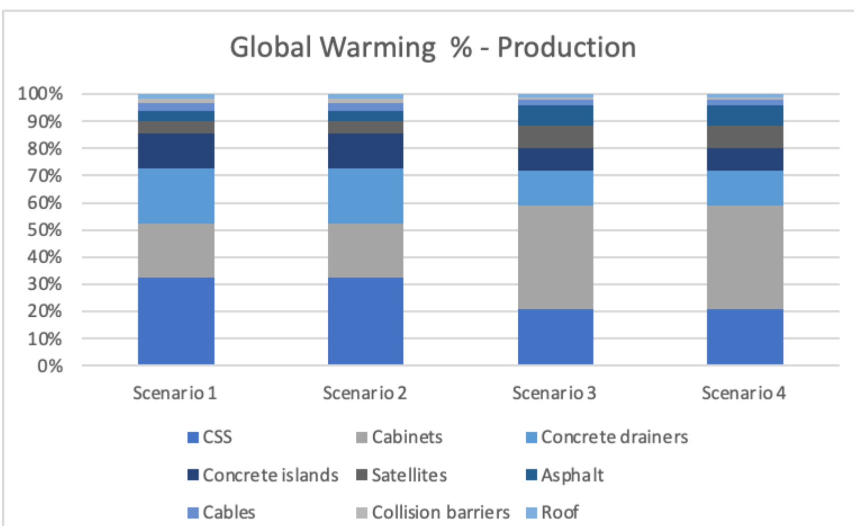


Figure 10. Global warming results for the production phase, % contribution of each component

6.2 Surplus ore

This section takes a closer look at the surplus ore results, including a percentage breakdown of the entire life cycle as well as for the production phase.

Figure 11 shows the total impact in kg Cu-eq./kWh for each scenario. As can be observed in the figure, the production phase is the predominant cause of the impact for all scenarios. The use phase has a much lower impact, due to the fact that electricity generation, transmission and distribution do not require much mineral resources in a short-term perspective. The biggest contributors in the use phase are caused by electricity generation from nuclear, wind, and hydro. Installation and EoL phases have almost no impact in comparison to production and use phases. This can also be observed in Figure 12.

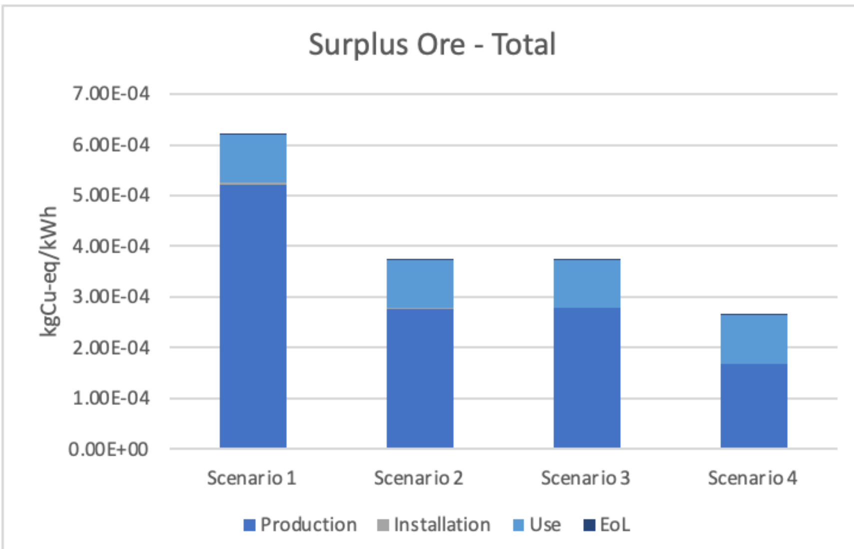


Figure 11. Surplus ore results for the entire life cycle, for all four scenarios, kg Cu-eq./kWh

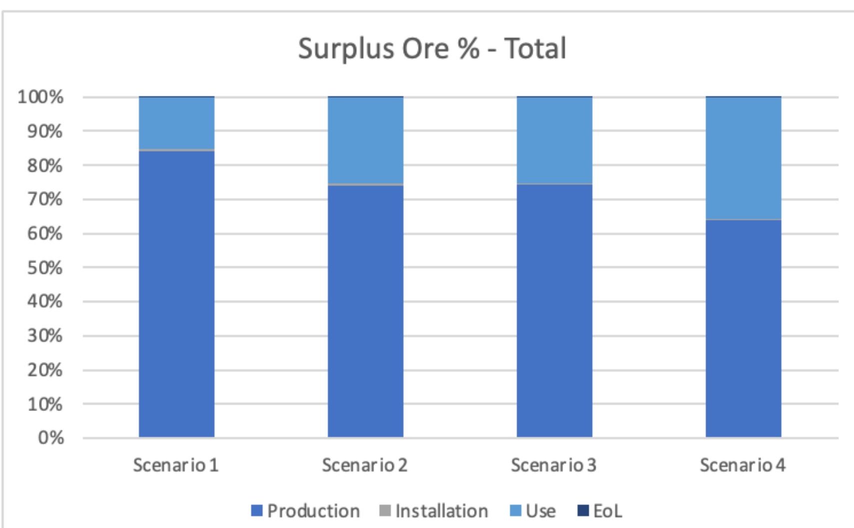


Figure 12. Surplus ore results for the entire life cycle, % contribution

Studying figure 13, it can be observed that the CSS is the component with the highest share of the impact for scenario 1 and 2. The CSS and cabinets account for around 70% of the total impact in all scenarios. The share of the CSS and cabinets are only slightly higher in scenario 3 and 4, however the cabinets have a much more pronounced impact, as this case uses nine cabinets. The cabinets themselves include a large amount of printed circuit boards, which are quite resource intensive for rare minerals and metals like gold, silver, and palladium.

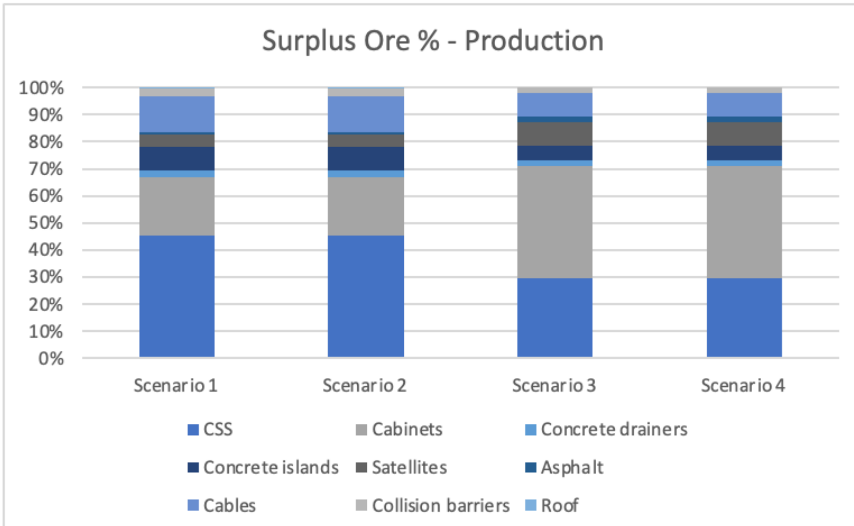


Figure 13. Surplus ore results for the production phase, % contribution of each component

6.3 Crustal scarcity indicator

This section describes the crustal scarcity indicator results, including percentage breakdowns of the entire lifecycle, as well as for the production phase.

By analyzing Figure 14 and 15, it can be observed that much like for the SOP, the biggest impact on crustal scarcity comes from the production phase. Installation and end.-of-life phases have no significant impact. This is the case for all four scenarios. It is evident from these figures that the use phase does not pose a significant impact on the whole compared to the production phase, owing to the low intensity of mineral resources in energy production and distribution.

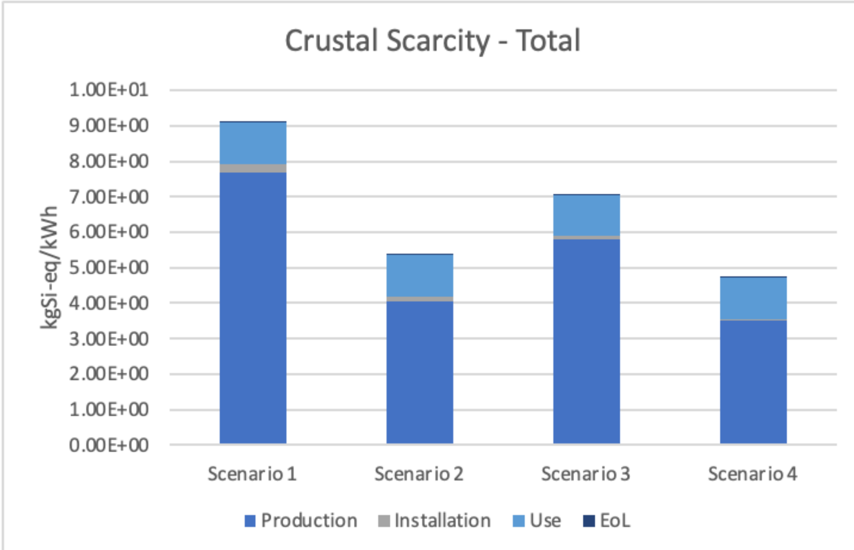


Figure 14. Crustal scarcity results for the entire life cycle, kg Si-eq./kWh

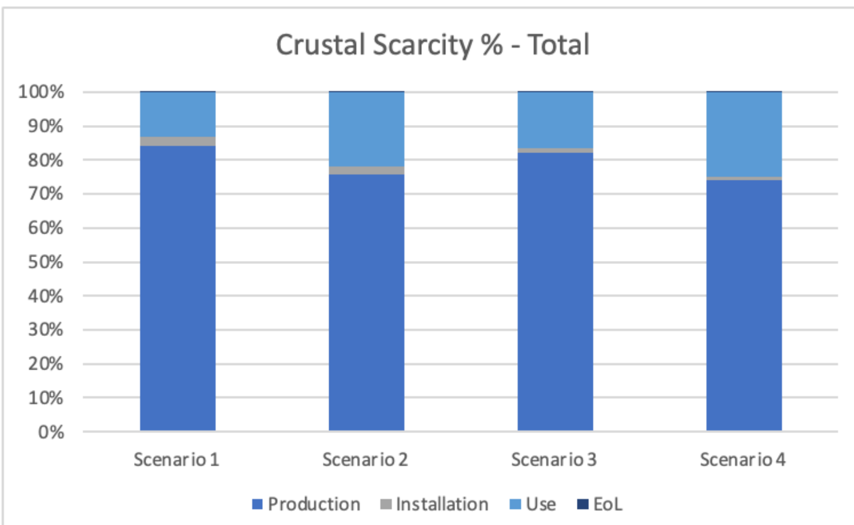


Figure 15. Crustal scarcity results for the entire life cycle, % contribution

In Figure 16, the cabinets by far have the highest share of the impact, even more so in scenario 3 and 4. Much like in the case of surplus ore indicator, this lies in the use of precious and scarce resources in the cabinets' PCBs. It results in a very high contribution in scenario 3 and four due to a total of nine cabinets needed for the 21-year time frame. The impacts of the rest of the components are heavily reduced as a result of the longer lifetime of the hub, with the exception of the satellites, a total of 24 of which is used in the last two scenarios.

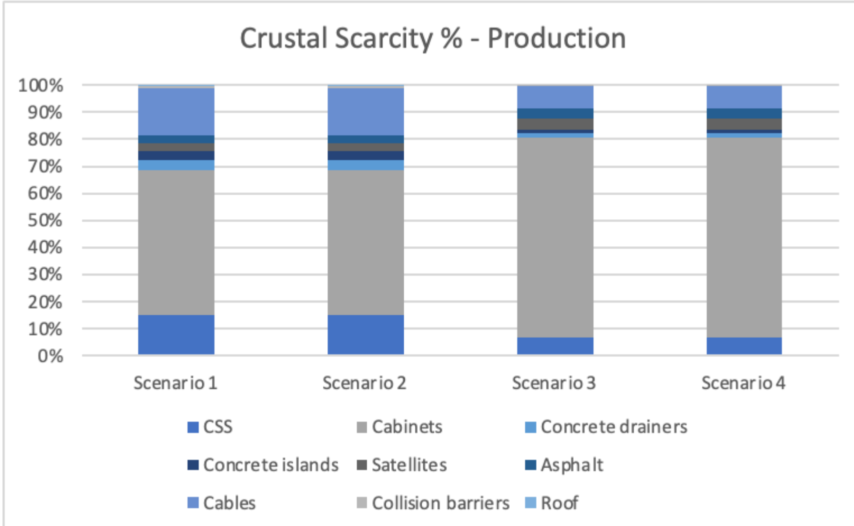


Figure 16. Crustal scarcity results for the production phase, % contribution of each component

6.4 Electricity market comparison

The results for the energy market comparisons are presented in this section. The results are presented for global warming, surplus ore, and crustal scarcity indicators. The comparison is carried out on the fourth scenario, where the highest share of the impacts is caused by the use phase.

As seen in Figure 17a, the total life cycle impact varies heavily based on the chosen electricity market. Sweden has by far the lowest impact, owing to low CO_2-eq. per kWh. The life cycle impacts using electricity from the US, Germany, and the Netherlands are roughly nine times higher than for Sweden. As can be observed in Figure 17b, the production phase has a very low overall impact in all cases except Sweden. The installation and EoL phases are insignificant for all cases.

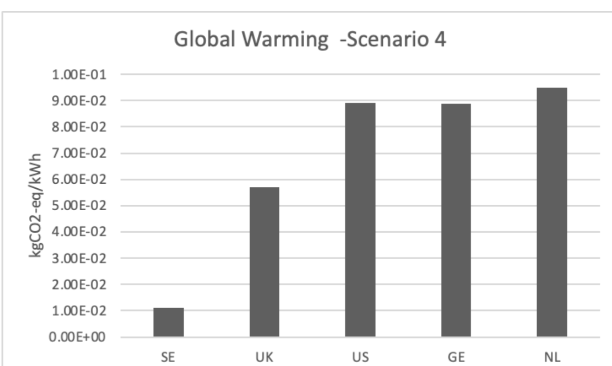


Figure 17a. Global warming results for electricity markets

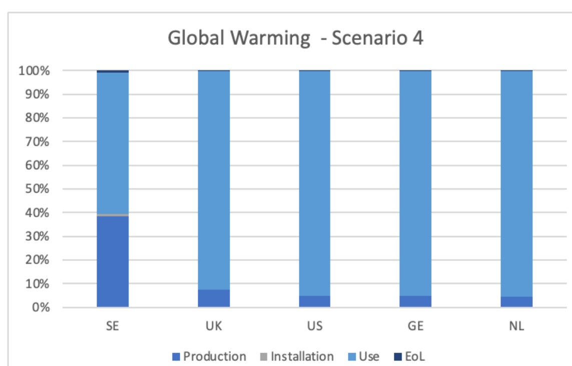
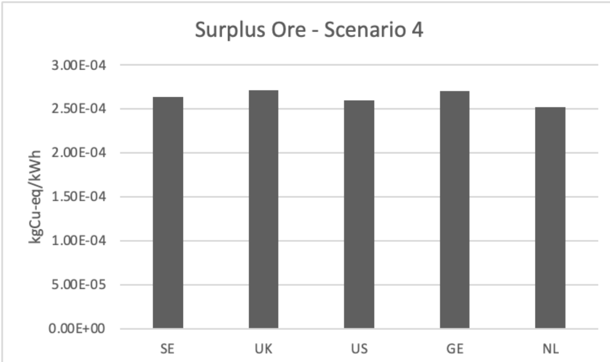


Figure 17b. Global warming results for electricity markets

As seen in Figure 18a, the surplus ore results vary only slightly depending on the energy market. The lowest impact for the surplus ore is caused by using the electricity mix of the Netherlands. The highest impact is caused by the UK electricity mix, followed closely by the German electricity mix. As can be seen in Figure 18b, the majority of the impact is still caused by the production phase, regardless of energy mix applied.



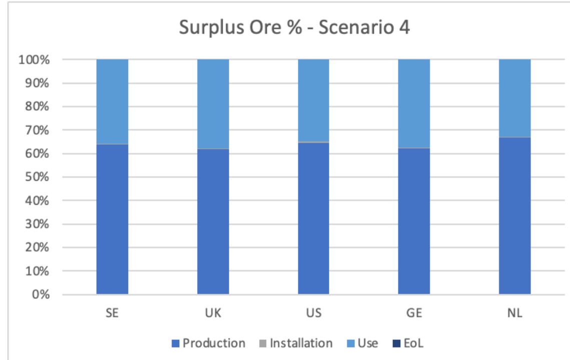
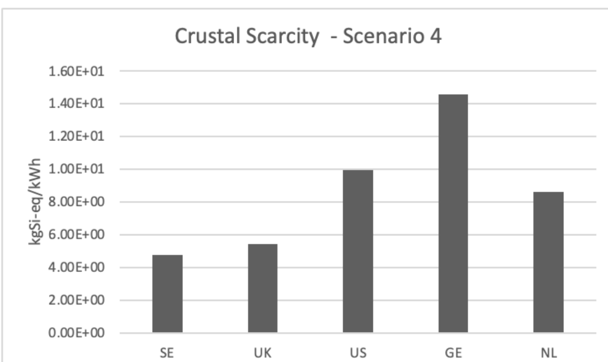


Figure 18a. Surplus ore results for electricity markets

Figure 18b. Surplus ore results for electricity markets

By analyzing Figure 19a, it is evident that the crustal scarcity indicator varies quite heavily depending on the energy mix. The highest is caused by the German mix, and the lowest attributed to the Swedish mix. Figure 19b shows mixed results, with some having production as the predominant contributor, while others have the use phase as the largest contributing phase. Like the categories before it, the installation and EoL phases have an insignificant impact on the crustal scarcity indicator.



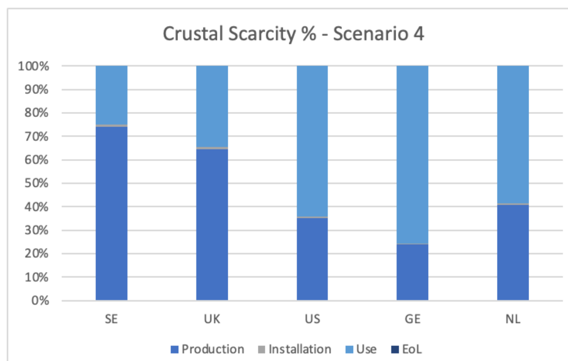


Figure 19a. Crustal scarcity indicator results for electricity markets

Figure 19b. Crustal scarcity indicator for electricity markets

6.5 Sensitivity analysis

Due to the variability in percentage contribution of the components on each scenario, a sensitivity analysis is performed for two parameters. The first check is performed for the PCBs mass in the cabinet, as it was shown to have the biggest influence on the impact of the cabinet, which in turn had a large impact on the production phase, particularly for the third and fourth scenarios. The sensitivity analysis was performed by varying the percentage mass of PCBs in the cabinet with four different percentage levels: -60%, -20%, +20%, and 60%. The aim of this is to assess the changes arising from varying the amounts. The results are presented for the global warming, surplus ore, and crustal scarcity indicator.

The second check is performed for the CSS, which stood for a large share of the production phase's impact in scenarios 1 and 2. The sensitivity analysis is performed by reducing the mass of the complete

CSS by 60% and 20%, and then by increasing it by 20%, and 60%. The results are presented for the global warming, surplus ore, and crustal scarcity indicator.

6.5.1 Sensitivity analysis - PCBs

Figures 20a, 20b and 20c show the results for the sensitivity analysis varying the mass of PCBs. For the global warming indicator, scenario 3 is the most sensitive to the PCB change. When reducing the PCB mass by 60%, the total environmental impacts in scenario 3 are reduced by around 9%, while in scenario 2 it is only reduced by 4.5%. This is because in scenario 3, nine cabinets are used in comparison to scenario 2 where only three cabinets are used.

When it comes to the result for the surplus ore and crustal scarcity indicators, the same pattern is seen. Scenarios 2 and 3 are the least and most sensitive to the PCB change, respectively. For the surplus ore results, when reducing 60% of the PCB mass the total environmental impacts are reduced by about 12% in scenario 3, while in scenario 2 it is reduced by a little more than 6%. For the crustal scarcity indicator, the impact is reduced by 34% in scenario 3, while in scenario 2 it is reduced by 23%.

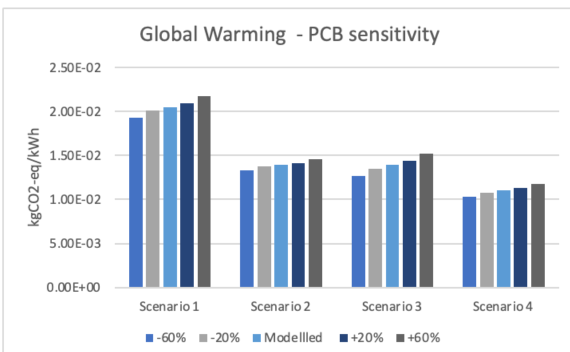


Figure 20a. PCB sensitivity check for global warming.

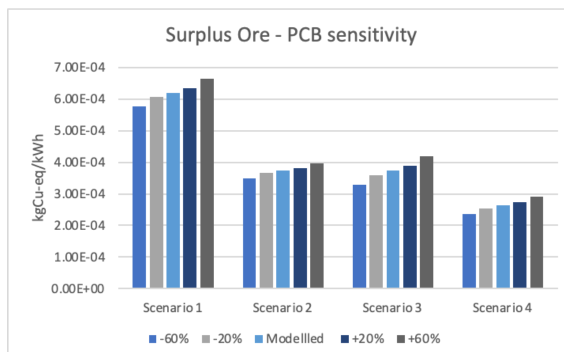


Figure 20b. PCB sensitivity check for surplus ore.

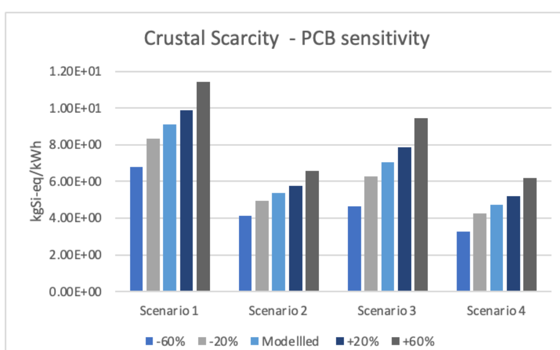


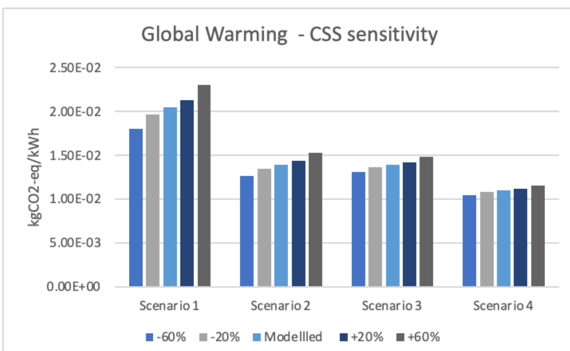
Figure 20c. PCB sensitivity check for the crustal scarcity indicator.

This behavior is explained by the relevance of each of the components in each scenario. When it comes to scenario 1, the CSS has the greatest contribution in the production and therefore the PCBs do not contribute to the environmental impacts as much. In the case of scenario 4, the use phase also plays a relevant role as the impact of the production is distributed over a greater amount of electricity supplied to the trucks, so each percentage impact reduction is smaller in comparison to scenario 3, when reducing the mass of PCBs.

6.5.2 Sensitivity analysis - CSS

Figure 21a, 21b, and 21c show the results for the sensitivity analysis varying the amount of CSS. For the global warming indicator, scenario 1 is the most sensitive to the CSS change. When reducing 60% of the CSS mass, the total environmental impacts in scenario 1 are reduced by around 12%, while in scenario 4 it is only reduced by 4.8%. This is because in scenario 1, the impact of the CSS is distributed amongst seven years in comparison to scenario 4 where the impact is distributed amongst 21 years.

When it comes to the results for the surplus ore and crustal scarcity indicators, the same behavior is seen again. Scenarios 4 and 1 are the least and most sensitive to the CSS change, respectively. For the surplus ore results, when reducing 60% of the CSS mass, the total impact is reduced by 23% in scenario 1 while in scenario 4, it is reduced by roughly 11%. For the crustal scarcity indicator, the impact is reduced by 8% in scenario 1 while in scenario 4, it is reduced by 3%.



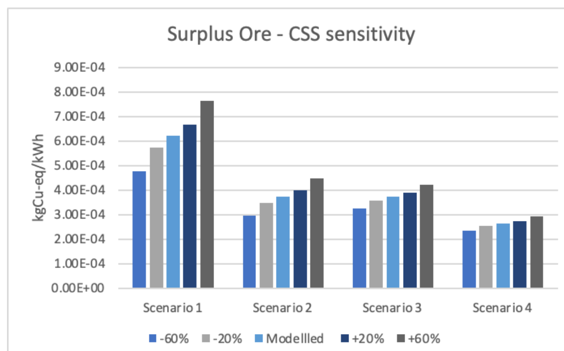


Figure 21a. CSS sensitivity check for global warming. Figure 21b. CSS sensitivity check for surplus ore.

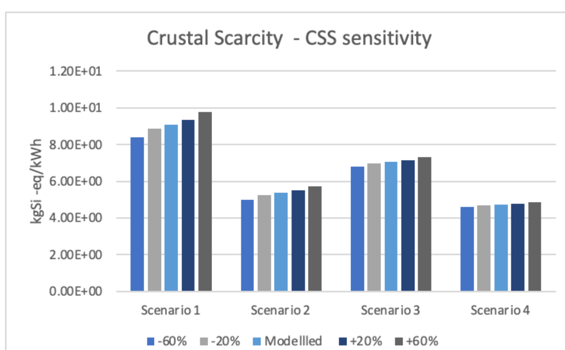


Figure 21c. CSS sensitivity check for the crustal scarcity indicator.

As mentioned before, scenarios 3 and 4 have a larger number of cabinets, which make PCBs the greatest contributor to the impact in the production phase. Therefore, the CSS mass reduction does not contribute to the reduction of the impact as much in comparison. When comparing scenario 1 against scenario 2, the use phase plays a relevant role. In scenario 2, the total impact is distributed over a larger amount of kWh in comparison to scenario 1. Therefore, the reduction of CSS mass leads to a smaller per-unit reduction of the overall impact. That is why, in this case, scenarios 4 and 1 are the least and most sensitive scenarios to the CSS change, respectively.

7 Discussion

As observed in the results, the highest impact per functional unit for all impact categories is in the first scenario. This is explained by the relatively small amount of electricity being supplied in this scenario, as well as that the impacts of the components are all spread out over a 7-year period in comparison to scenarios 3 and 4 where the impacts are spread out over 21 years. Notably, the second and third scenarios cause very similar impacts, even though the third scenario has more charging components. This is due to the impacts from the third scenario being reduced by the longer lifetime of the hub. The least amount of impact, for all indicators, is caused in scenario 4, owing to the high utilization of the hub.

From the results, for scenario 3 and 4, the cabinets are the largest contributor to impacts in the production phase. The impact is particularly large since these scenarios require a total of nine cabinets to be produced. This is one consequence of the operational lifetime of the cabinets, which is assumed to be 7 years in these scenarios. One option to further lower production-phase impacts is to prioritize using products with high lifetimes, combined with regular maintenance to maximize utilization. However, increasing the efficiency of the system could also play a relevant role in reducing the environmental impacts. In the long-term perspective, there is a possibility that more efficient chargers are released to the market. When changing the charging equipment, Company X could choose to substitute the charger for a more efficient one instead of opting for maintenance for their current chargers. A study that compares both scenarios could help Company X to further understand the implications of both strategies.

Moreover, this study focused on the production and use phases, aligning with existing models in the literature that showed that installation and end-of-life do not contribute considerably to the overall impact. Although it could be argued that focusing on the production or the use phase could make these stages more prone to greater environmental impacts, it is unlikely that increasing the level of detail for the end-of-life or installation would have a notable influence on the overall impact when compared to other phases.

The electricity market comparison results are consistent with the reviewed literature as most papers conclude that the use phase has the greatest impact and that the electricity mix has a considerable influence on the global warming of the charging equipment (Bi et al., 2015; Zhao et al., 2021; Z. Zhang et al., 2019). Wohlschlager and Neitz-Regett (2022) evaluated the sensitivity of the production and use of smart chargers in Germany. They concluded that by increasing the utilization of cleaner electricity in the use phase, they could reduce up to 72% of the total environmental impacts. By increasing the lifetime and efficiency of the components in the long term, there could be up to a 39% reduction. These results are consistent with what is reported in this study. However, it should also be noted that the charging equipment in the aforementioned study is different from this study. Bi et at. (2015) also assessed the sensitivity of the efficiency and concluded that if the efficiency of the wireless charger is increased, it becomes favored over the plug-in charger. In this study, the efficiency of the charging equipment could also play an important role when it comes to the use phase. This possibility needs to be further studied.

Operating the hub in Sweden has a much lower impact compared to other countries in terms of global warming. When it comes to the crustal scarcity indicator, the impacts also differ significantly between each country, and this is explained by the differences in the metal demand from the electricity generation.

However, this is not the case for the surplus ore indicator, where there is no significant difference in impact between the different countries, and the share of impact is thus roughly equal. This means that the short-term consequences of operating the hub are fairly similar, whereas the long-term effects are quite different in terms of mineral scarcity.

It is worth noting that none of the reviewed literature evaluated mineral resource scarcity for a charging hub. As this technology expands, the need for these scarce materials could pose a potential risk to the development and construction of new charging hubs. Company X needs to be aware that although global warming is a relevant indicator, decisions on how to move forward also need to take both short and long-term strategies for metal scarcity into account.

As mentioned before, the sensitivity analysis shows that the model is most sensitive to the CSS in a short-term perspective and more sensitive to the PCBs in a long-term perspective. For this reason, one potential strategy to reduce the impact is to focus on the CSS and the cabinets production. As the CSS has the greatest short-term contribution, a reduction of the material use could decrease the global warming and surplus ore results. When it comes to the cabinets, reducing the quantity of PCBs could be considered as a strategy to reduce long-term scarcity challenges. Specifically, by extending the lifetime of the cabinets and by evaluating other suppliers, these could have a considerable reduction in overall impact of the charging hub. However, further research would have to be done in order to validate these strategies.

The electricity market selected for the use phase is based on the current electricity mix and does not consider potential future electricity mixes. Given Sweden's commitment to achieve carbon neutrality by 2050, there may be an overestimation of the impacts of use phase losses, particularly for scenario 3 and 4. Modeling the use phase for different future electricity scenarios in Sweden and elsewhere would be interesting for future studies.

The inventory for charging components was constructed using product EPDs and documents from other manufacturers, and not constructed with data directly from the manufacturer in question. This means that the results are less case specific but still representative for a charging hub. To make it more case specific, obtaining detailed first-hand data is imperative.

The Ecoinvent database used was chosen to represent its real-world counterparts to a reasonable degree but are likely not exact. Approximations, assumptions, and lack of data can therefore always affect results in the end. To increase the accuracy of the model and its results, obtaining more detailed information of the components, and assessing the suitability of the data is highly recommended. This is particularly important for materials or products with a high contribution.

8. Conclusion

This study has improved the understanding of the potential impacts associated with the deployment of a charging hub designed for electric trucks. The results showed that a charging hub contributes to climate change and mineral resource depletion. Thus, impacts related to the hub include GHG emissions and the use of scarce metals, such as gold, silver, and palladium.

Furthermore, it was found that the production phase is the stage of the life cycle where the highest impacts occur. However, the use phase becomes relevant when looking at a longer time perspective. The installation and EoL phases of the life cycle proved to have a negligible impact in all examined scenarios.

The highest overall impact in all three impact categories is seen in scenario 1, which uses a low utilization rate and lifetime. The lowest impact in all three impact categories is seen in scenario 4, which uses a high utilization rate and lifetime. This suggests that it is crucial to ensure a high utilization rate coupled with a long lifetime for a charging hub, in order to reduce the impacts attributed to the life cycle of the hub.

The production phase was examined in more detail than the other phases, of which results showed production hotspots pertaining to charging equipment, namely the compact secondary substation and power cabinets. The impacts caused by the civil engineering components were predominantly caused by the various concrete components.

The electricity mix comparison showed large differences in impacts. This highlights the importance of careful selection of the electricity provider in order to reduce impacts. Finally, it was concluded that the model is most sensitive to the production of the CSS and the PCBs. By reducing the amount of these, the largest reductions of the impacts can be achieved in comparison to other components in the hub.

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Appendix A

A.1 Literature review

Table A.1 Literature review

	Goal and scope definition	Inventory analysis	Impact assessment	Results
Bi et al. (2015)	Vehicle: Bus Geography: Michigan, USA Type of charger: Comparing on-board plug-in charger against off-board wireless charger Time frame: 12 years Functional unit: 67 buses - 48,034,407 vehicle kilometers Material extraction, manufacturing of chargers and batteries and use-phase.	Method: Inventory of elementary flows or emissions and extractions Power: 60kW	Method: CED and GW	Wireless charging system consumes 0.3% less energy and emits 0.5% less GHGs than plug-in charging system in the total lifecycle. The use-phase electricity consumption dominates the life cycle energy demand and GHG emissions, accounting for about 97–98% of CED and GW. Charger production: - Plug-in: 0.075 TJ and 4.56 t CO_2-eq. - Wireless charger: 0.018 TJ and 1.03 t CO_2-eq.
Kabus et al. (2020)	Vehicle: Electric vehicles Geography: Germany Type of charger: At home on-board charging and public off-board charging. Time frame: 10 years Functional unit: kWh Production, transport, and use phase including some charging infrastructure	Method: Inventory of elementary flows or emissions and extractions Power: 3.7 kW OBC, 22 kW OBC, and 50 kW OfBC	Method: ReCiPe 2016 (midpoint)	Use phase is responsible for more than 50% of the environmental impacts in 12 impact categories for the AC system. DC system, solely mineral resource depletion is dominant during production, while all other environmental impacts are mainly emitted during the use phase.

Mendoza et al. (2016)	Vehicle: Two wheelers Geography: Barcelona, Spain Type of charger: Comparing outdoor recharge post with two-sockets available against one with six-sockets available (on-board) Time frame: 10 years Functional unit: kWh Production of charging equipment, construction, transportation, installation, maintenance and use phase including charging infrastructure	Method: Inventory of elementary flows or emissions and extractions Power: 3.7 kW (230V AC / 16 A)	Method: PED and GW	The charging equipment makes the highest contribution to the overall environmental impacts of the charging facilities. The operation stage makes the second highest contribution. The six-sockets outdoor recharge post performs better than the two-sockets one.
Nansai et al. (2001)	Vehicle: Electric vehicles Geography: Japan Type of charger: Charger stand, charger and storage battery Time frame: - Functional unit: 100,000 km total driving distance Production, transportation, installation	Method: Input-Output life cycle assessment Power: -	Method: Air pollutant (CO_2, NO_x, SO_x and CO) emissions	The life-cycle environmental loads of an electric vehicle including the infrastructure were 0.45 t-C of CO_2, 2.2 kg of NO_2, 1.8 kg of SOx and 1.7 kg of CO Manufacturing, driving and installing infrastructure of the EV resulted in less CO_2, NO_x and CO emissions than manufacturing and driving the gasoline vehicle.

Wohlschlager & Neitz-Regett, (2022)	Vehicle: Electric vehicles Geography: Germany Type of charger: AC and DC wallbox including infrastructure for smart charging. Compare direct charging and smart charging on a household level. Time: 1 year Functional unit: Enabling the charging of a private vehicle for one year Production, transport, operation and end of life	Method: Inventory of elementary flows or emissions and extractions Power: 10-50 kW	Method: GW	The operation and production phases of the AC and DC wallbox contribute with the greatest share to the GW.
Zhao et al. (2021)	Vehicle: Bus Geography: Sydney, Australia Type of charger: Off-board fast charger Time: - Functional unit: $kgCO_2$-eq./kWh or $kgCO_2$-eq./kg. In operation it is defined as: $kgCO_2$-eq./100 km Production, transportation, installation, operations, and decommissioning	Method: Inventory of elementary flows or emissions and extractions Input-output approach for production phase Power: up to 350kW	Method: GW	The operations phase contributes the most to GHG emissions. It is then followed by production, recycling and disposal, installation, and transportation.
Z. Zhang et al. (2017)	Vehicle: Electric vehicles Geography: Belgium Type of charger: Comparing inductive and conductive technologies. Time: 14 years / 10000 km/year driven	Method: Inventory of elementary flows or emissions and extractions Power: 3.7 kW, 22 kW and 50 kW	Method: ReCiPe (midpoint and endpoint)	Inductive charging system has a higher impact on climate change, because it consumes more electricity due to it being less efficient.

	Functional unit: kWh Manufacturing stage, the use stage and end of life stage			
Z. Zhang et al. (2019)	Vehicle: Electric vehicles Geography: China Type of charger: AC home and public chargers, DC public charger Time: 8-12 years Functional unit: kWh Resource extraction to disposal	Method: Inventory of elementary flows or emissions and extractions Power: 7, 40, 60-360 kW	Method: CED and GW	During the life stages, the use stage causes most of the environmental impacts, which indicates that the electricity loss in the use stage is a major contributor.

CED: Cumulative energy demand, PED: Primary energy consumption, GW: Global Warming, OBC: On-board battery charger, OfBC: Off-board battery charger

A.2 Custom openLCA unit processes

Table A.2.1 Custom steel production

Input	*Amount*	*Unit*	*Provider*
steel, chromium steel 18/8	1	kg	Market for steel, chromium steel 18/8 - GLO
metal working, average for chromium steel product manufacturing	1	kg	Market for metal working, average for chromium steel product manufacturing - GLO
sheet rolling, chromium steel	1	kg	Market for sheet rolling, chromium steel - GLO
Output	*Amount*	*Unit*	
Custom steel	1	kg	

Table A.2.2 Custom aluminium production

Input	*Amount*	*Unit*	*Provider*
Aluminium, wrought alloy	1	kg	Market for aluminium, wrought alloy - GLO
metal working, average for aluminium product manufacturing	1	kg	Market for metal working, average for aluminium product manufacturing - GLO
sheet rolling, aluminium	1	kg	Market for sheet rolling, aluminium - GLO
Output	*Amount*	*Unit*	
Custom aluminium	1	kg	

Table A.2.3 Custom copper wire production

Input	*Amount*	*Unit*	*Provider*
Copper, cathode	1	kg	Market for copper, cathode - GLO
metal working, average for copper product manufacturing	1	kg	Market for metal working, average for copper product manufacturing - GLO
Wire drawing, copper	1	kg	Market for wire drawing, copper - GLO
Output	*Amount*	*Unit*	
Custom copper wire	1	kg	

Table A.2.4 Custom copper sheet production

Input	*Amount*	*Unit*	*Provider*
Copper, cathode	1	kg	Market for copper, cathode - GLO
metal working, average for copper product manufacturing	1	kg	Market for metal working, average for copper product manufacturing - GLO
Sheet rolling, copper	1	kg	Market for sheet rolling, copper - GLO

Output	*Amount*	*Unit*	
Custom copper sheet	1	kg	

Table A.2.5 Custom polycarbonate, injection moulded production

Input	*Amount*	*Unit*	*Provider*
Polycarbonate	1	kg	Market for polycarbonate - GLO
Injection moulding	1.00603	kg	Market for injection moulding - GLO
Output	*Amount*	*Unit*	
Custom polycarbonate, injection moulded	1	kg	

Table A.2.6 Custom polyethylene terephthalate, injection moulded

Input	*Amount*	*Unit*	*Provider*
Polyethylene terephthalate, granulate, amorphous	1	kg	Market for polyethylene terephthalate, granulate, amorphous - GLO
Injection moulding	1.00603	kg	Market for injection moulding - GLO
Output	*Amount*	*Unit*	
Custom polyethylene terephthalate, injection moulded	1	kg	

Table A.2.7 Custom: fan production (Adapted from SE (2021b))

Input	*Amount*	*Unit*	*Provider*
Custom aluminium	0.25480	kg	A.2.2
Custom steel	0.77420	kg	A.2.1
Epoxy resin, liquid	0.00245	kg	Market for epoxy resin, liquid Cutoff, U - RoW
Glass fibre	0.19845	kg	Market for glass fibre - GLO
Nylon 6	0.02205	kg	Market for nylon 6 - RoW
Nylon 6-6	0.59290	kg	Market for nylon 6-6 - RoW
Output	*Amount*	*Unit*	
Custom: fan	1	item	

Table A.2.8 Custom: enclosure production (Adapted from Legrand (2021))

Input	*Amount*	*Unit*	*Provider*
Custom polyethylene terephthalate, injection moulded	0.04000	kg	A.2.6
Custom steel	7.36000	kg	A.2.1
Polyvinylchloride, bulk polymerised	0.02000	kg	Market for polyvinylchloride, bulk polymerised - GLO
Output	*Amount*	*Unit*	
Custom: enclosure	1	item	

Table A.2.9 Custom road production

Input	*Amount*	*Unit*	*Provider*
Electricity, medium voltage	0.10600	kWh	Market for electricity, medium voltage - CH
Pitch	0.54600	kg	Market for pitch - CH
Reinforcing steel	0.09160	kg	Market for reinforcing steel - GLO
Sodium chloride, powder	0.29300	kg	Market for sodium chloride, powder - GLO
Steel, low-alloyed, hot rolled	0.00877	kg	Market for steel, low-alloyed, hot rolled - GLO
Removed inputs			
Excavation, skid-steer loader	-	-	-
Diesel, burned in building machine	-	-	-
Gravel, crushed	-	-	-
Output	*Amount*	*Unit*	
Custom road	1	m2*a	
Sodium	0.117	kg	
Chloride	0.176	kg	
NMVOC, non-methane volatile organic compounds	0.00655	kg	

A.3 Power cabinet

Table A.3.1 Power module components (circuit breaker adapted from SE (2021a); transformer adapted from SE (2016a) and other components estimated from data provided by Company X)

Power modules: circuit breaker production			
Input	*Amount*	*Unit*	*Provider*
Custom copper wire	0.09250	kg	A.2.3
Custom steel	0.10000	kg	A.2.1
Custom polyethylene terephthalate, injection moulded	0.00500	kg	A.2.6
Custom polycarbonate, injection moulded	0.00500	kg	A.2.5
Glass fibre reinforced plastic, polyamide, injection moulded	0.14750	kg	Market for glass fibre reinforced plastic, polyamide, injection moulded - GLO
Polyphenylene sulfide	0.02500	kg	Market for polyphenylene sulfide - GLO
Printed wiring board, surface mounted, unspecified, pb free	0.01500	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Output	*Amount*	*Unit*	
Power modules: circuit breaker	1	item	
Power modules: Transformer production			
Input	*Amount*	*Unit*	*Provider*
Brass	0.0415	kg	Market for brass - RoW
Custom copper wire	1.2533	kg	A.2.3
Custom steel	5.81	kg	A.2.1
Custom polyethylene terephthalate, injection moulded	0.0083	kg	A.2.6
Custom polycarbonate, injection moulded	0.1494	kg	A.2.5
Printed wiring board, surface mounted, unspecified, pb free	0.0083	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Glass fibre reinforced plastic, polyamide, injection moulded	0.1162	kg	Market for glass fibre reinforced plastic, polyamide, injection moulded - GLO
Polyvinylchloride, bulk polymerised	0.00415	kg	Market for polyvinylchloride, bulk polymerised - GLO
Output	*Amount*	*Unit*	
Power modules: Transformer	1	item	

Power module: PCB production			
Input	*Amount*	*Unit*	*Provider*
Printed wiring board, surface mounted, unspecified, pb free	Below 10kg	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Output	*Amount*	*Unit*	
Power modules: PCB production	1	item	
Power modules: metal parts production			
Input	*Amount*	*Unit*	*Provider*
brass	Below 0.05	kg	Market for brass - GLO
Custom steel	Below 15 kg	kg	A.2.1
Custom copper sheet	Below 5 kg	kg	A.2.4
Output	*Amount*	*Unit*	
Power modules: metal	1	item	

Table A.3.2 Power module production

Input	*Amount*	*Unit*	*Provider*
Power module: circuit breaker	1	item	A.3.1
Power module: transformer	1	item	A.3.1
Power module: PCB	1	item	A.3.1
Power module: metal parts	1	item	A.3.1
Custom enclosure	1	item	A.3.1
Custom fan	4	item	A.3.1
Output	*Amount*	*Unit*	
Power module	1	item	

Table A.3.3 Mains module components (Busbar adapted from SE, (2021a); miniature circuit breaker adapted from SE (2022) and switch adapted from SE (2018b))

Mains module: 3 busbars			
Input	*Amount*	*Unit*	*Provider*
Custom copper wire	0.2	kg	A.2.3
Custom steel	0.18	kg	A.2.1

Custom polycarbonate, injection moulded	0.54	kg	A.2.5
Glass fibre reinforced polymer, polyamide, injection moulded	0.04	kg	Market for glass fibre reinforced polymer, polyamide, injection moulded - GLO
Custom polyethylene terephthalate injection moulded	0.01	kg	A.2.6
Output	*Amount*	*Unit*	
3 busbars	1	item	
Mains module: 3 miniature circuit breaker			
Input	*Amount*	*Unit*	*Provider*
Custom steel	0.12	kg	A.2.1
Custom copper wire	0.01	kg	A.2.3
Glass reinforced polymer, polyamide, injection moulded	0.13	kg	Market for glass reinforced polymer, polyamide, injection moulded - GLO
Custom polycarbonate, injection moulded	0.01	kg	A.2.5
Output	*Amount*	*Unit*	
Mains module: 3 miniature circuit breaker	1	item	
Mains module: Switch			
Input	*Amount*	*Unit*	*Provider*
Custom steel	0.68	kg	A.2.1
Custom copper wire	0.23	kg	A.2.3
silver	0.01	kg	Market for silver - GLO
Custom aluminium	0.01	kg	A.2.2
Printed wiring board, surface mounted, unspecified, pb free	0.03	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Glass fibre reinforced polymer, polyamide, injection moulded	0.13	kg	Market for glass fibre reinforced polymer, polyamide, injection moulded - GLO
Custom polycarbonate, injection moulded	0.12	kg	A.2.5
Custom polyethylene terephthalate injection moulded	0.01	kg	A.2.6
Output	*Amount*	*Unit*	
Mains module: Switch	1	item	

Table A.3.4 Mains module production

Input	Amount	Unit	Provider
Mains module: 3 busbar	1	item	A.3.3
Mains module: 3 miniature circuit breaker	1	item	A.3.3
Mains module: Switch	1	item	A.3.3
Output	*Amount*	*Unit*	
Mains module	1	item	

Table A.3.5 Dynamic power distribution module components (circuit breaker adapted from SE (2021a), PCB and other metal components estimated from data provided by Company X)

Dynamic power distribution module: circuit breaker production			
Input	*Amount*	*Unit*	*Provider*
Custom copper wire	0.09	kg	A.2.3
Custom steel	0.1	kg	A.2.1
Printed wiring board, surface mounted, unspecified, pb free	0.02	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Glass fibre reinforced polymer, polyamide, injection moulded	0.15	kg	Market for glass fibre reinforced polymer, polyamide, injection moulded - GLO
Polyethylene sulfide	0.01	kg	Market for polyethylene sulfide - GLO
Custom polycarbonate, injection moulded	0.01	kg	A.2.5
Output	*Amount*	*Unit*	
Dynamic power distribution module: circuit breaker	1	item	
Dynamic power distribution module: PCB production			
Input	*Amount*	*Unit*	*Provider*
Printed wiring board, surface mounted, unspecified, pb free	Below 10kg	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Output	*Amount*	*Unit*	
Dynamic power distribution module: PCB	1	item	
Dynamic power distribution module: other metal components			
Input	*Amount*	*Unit*	*Provider*

Custom steel	Below 15kg	kg	A.2.1
Custom copper sheet	Below 1kg	kg	A.2.4
Output	*Amount*	*Unit*	
Dynamic power distribution module: other metal components	1	item	

Table A.3.6 Dynamic power distribution module production

Input	*Amount*	*Unit*	*Provider*
Custom fan	3	item	A.2.7
Custom enclosure	1	item	A.2.8
Dynamic power distribution module: Circuit breaker	1	item	A.3.5
Dynamic power distribution module: PCB	1	item	A.3.5
Dynamic power distribution module: Other metal components	1	item	A.3.5
Output	*Amount*	*Unit*	
Dynamic power distribution module	1	item	

Table A.3.7 Control module components production (connectors adapted from ABB (2020); enclosure adapted from SE (2020b) and ethernet connectors adapted from SE (2016b))

Control module: 4 connectors production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	0.108	kg	A.2.1
brass	0.4	kg	Market for brass - RoW
Custom copper wire	0.048	kg	A.2.3
tin	0.024	kg	Market for tin - GLO
Output	*Amount*	*Unit*	
Control module: 4 connectors	1	item	
Control module: enclosure production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	0.59	kg	A.2.1
Custom aluminium	0.17	kg	A.2.2

Printed wiring board, surface mounted, unspecified, pb free	0.17	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Output	*Amount*	*Unit*	
Control module: enclosure	1	item	
Control module: Ethernet connectors production			
Input	*Amount*	*Unit*	*Provider*
zinc	0.17	kg	Market for zinc - GLO
Custom steel	0.01	kg	A.2.1
Custom polycarbonate, injection moulded	0.02	kg	A.2.5
Output	*Amount*	*Unit*	
Control module: ethernet connectors	1	item	
Control module: PCB production			
Input	*Amount*	*Unit*	*Provider*
Printed wiring board, surface mounted, unspecified, pb free	Below 10kg	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Output	*Amount*	*Unit*	
Control module: PCB	1	item	

Table A.3.8 Control module production

Input	*Amount*	*Unit*	*Provider*
Control module: enclosure production	1	item	A.3.7
Control module: Ethernet connectors production	1	item	A.3.7
Control module: PCB production	1	item	A.3.7
Control module: 4 connectors production	1	item	A.3.7
Output	*Amount*	*Unit*	
Control module	1	item	

Table A.3.9 Power cabinet housing production (Estimated from data provided by Company X)

Input	*Amount*	*Unit*	*Provider*
Custom steel	Below 200kg	kg	A.2.1
Output	*Amount*	*Unit*	
Power cabinet housing	1	item	

Table A.3.10 Power cabinet production

Input	*Amount*	*Unit*	*Provider*
Power module	4	item	A.3.2
Mains module	1	item	A.3.4
Power cabinet housing	1	item	A.3.9
Dynamic power distribution module	1	item	A.3.6
Control module	1	item	A.3.8
Electricity, medium voltage	0.856	MWh	Market for electricity, medium voltage - FI
Heat, district or industrial, natural gas	0.80	MWh	Market for heat, district or industrial, natural gas - Europe without Switzerland
Output	*Amount*	*Unit*	
Power cabinet	1	item	

A.4 CSS production

Table A.4.1 CSS component production (transformer adapted from Legrand (2021); switchgear adapted from ABB (2019); switchboard adapted from SE (2021c) and busbar adapted from SE (202a))

Transformer production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	2743.62	kg	A.2.1
Custom aluminium	734.76	kg	A.2.2
Custom copper wire	3.91	kg	A.2.3
Epoxy resin, liquid	83.97	kg	Market for epoxy resin, liquid - RoW
Glass fibre reinforced plastic, polyamide, injection moulded	55.70	kg	Market for glass fibre reinforced plastic, polyamide, injection moulded - GLO
Custom polyethylene terephthalate, injection moulded	39.78	kg	A.2.5
Glass fibre	11.93	kg	Market for glass fibre - GLO

Aluminium oxide, non-metallurgical	63.65	kg	Market for aluminium oxide, non-metallurgical - RoW
Silica sand	162.69	kg	Market for silica sand - GLO
Output	*Amount*	*Unit*	
Transformer	1	item	
Switchgear production			
Input	*Amount*	*Unit*	*Provider*
Cast iron	205.46	kg	Market for cast iron - GLO
Custom steel	128.72	kg	A.2.1
Custom copper wire	68.04	kg	A.2.3
Brass	3.56	kg	Market for brass - RoW
Custom aluminium	13.23	kg	A.2.2
Zinc	6.03	kg	Market for zinc - GLO
Silver	0.12	kg	Market for silver - GLO
Sulfur hexafloride, liquid	4.78	kg	Market for sulfur hexafloride - RoW
Epoxy resin insulator, SiO2	41.39	kg	Market for epoxy resin insulator, SiO2 - GLO
Synthetic rubber	2.09	kg	Market for synthetic rubber - GLO
Output	*Amount*	*Unit*	
Switchgear	1	item	
Switchboard production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	186.07	kg	A.2.1
Custom copper wire	15.97	kg	A.2.3
Custom aluminium	19.62	kg	A.2.2
Glass fibre	13.45	kg	Market for glass fibre - GLO
Printed wiring board, surface mounted, unspecified, pb free	0.28	kg	Market for printed wiring board, surface mounted, unspecified, pb free - GLO
Glass fibre reinforced plastic, polyamide, injection moulded	8.50	kg	Market for glass fibre reinforced plastic polyamide, injection moulded - GLO
Polyvinylchloride, bulk polymerised	3.04	kg	Market for polyvinylchloride, bulk polymerised - GLO
Custom polycarbonate, injection moulded	3.04	kg	A.2.5
Output	*Amount*	*Unit*	

Switchboard	1	item	
Busbar production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	355.81	kg	A.2.1
Custom aluminium	214.66	kg	A.2.2
Custom copper wire	32.35	kg	A.2.3
brass	0.37	kg	Market for brass - GLO
Glass fibre reinforced plastic, polyamide, injection moulded	58.54	kg	Market for glass fibre reinforced plastic, polyamide, injection moulded - GLO
Polyurethane adhesive	9.01	kg	Market for polyurethane adhesive - GLO
Custom polycarbonate, injection moulded	2.25	kg	A.2.5
Polypropylene, granulate	1.50	kg	Market for polypropylene, granulate - GLO
Polystyrene, high impact	0.38	kg	Market for polystyrene, high impact - GLO
Output	*Amount*	*Unit*	
Busbar	1	item	
CSS Housing production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	3300	kg	A.2.1
Output	*Amount*	*Unit*	
CSS Housing	1	item	

Table A.4.2 CSS production

Input	*Amount*	*Unit*	*Provider*
Transformer	1	item	A.4.1
Switchgear	1	item	A.4.1
Switchboard	1	item	A.4.1
Busbar	1	item	A.4.1
CSS Housing	1	item	A.4.1
Electricity, medium voltage	1.07	MWh	Market for electricity, medium voltage - FI
Heat, district or industrial, natural gas	1.00	MWh	Market for heat, district or industrial, natural gas - Europe without Switzerland
Output	*Amount*	*Unit*	
CSS	1	item	

A.5 Satellite production

Table A.5.1 Satellite component production (satellite cable production adapted from Helukabel (2021b) and other components estimated from data provided by Company X)

Satellite housing production			
Input	*Amount*	*Unit*	*Provider*
Custom steel	Below 60kg	kg	A.2.1
Output	*Amount*	*Unit*	
Satellite housing	1	item	
Satellite cable production			
Input	*Amount*	*Unit*	*Provider*
Custom copper wire	8.98	kg	A.2.3
Polyethylene, high density, granulate	2.53	kg	Market for polyethylene, high density, granulate - GLO
Extrusion, plastic pipes	2.54	kg	Extrusion, plastic pipes - GLO
Output	*Amount*	*Unit*	
Satellite: cable	1	item	
Satellite spring production			
Input	*Amount*	*Unit*	*Provider*
Aluminium, wrought alloy	Below 40kg	kg	Market for aluminium, wrought alloy - GLO
Metal working, average for aluminium product manufacturing	Below 40kg	kg	Market for metal working, average for aluminium product manufacturing - GLO
Section bar extrusion, aluminium	Below 40kg	kg	Market for section bar extrusion, aluminium - GLO
Output	*Amount*	*Unit*	
Charging satellite: spring	1	item	

Table A.5.2 Satellite production

Input	*Amount*	*Unit*	*Provider*
Satellite housing	1	item	A.5.1
Satellite spring	1	item	A.5.1
Satellite cable	1	item	A.5.1
Electricity, medium voltage	0.214	MWh	Market for electricity, medium voltage - FI

Heat, district or industrial, natural gas	0.200	MWh	Market for heat, district or industrial, natural gas - Europe without Switzerland
Output	*Amount*	*Unit*	
Satellite	1	item	

A.6 Cables production

Table A.6.1 Cables (AC main cables production adapted from Helukabel (2021a); DC power cable production adapted from Helukabel (2021a); Ethernet cable production adapted from Helukabel (2018) and Ethernet cable production adapted from Helukabel (2019))

AC mains cables production			
Input	*Amount*	*Unit*	*Provider*
Cable, unspecified	41.83	kg	Market for cable, unspecified - GLO
Output	*Amount*	*Unit*	
AC mains cables	1	item	
DC power cables production			
Input	*Amount*	*Unit*	*Provider*
Cable, unspecified	1060	kg	Market for cable, unspecified - GLO
Output	*Amount*	*Unit*	
DC power cables	1	item	
Ethernet cables production			
Input	*Amount*	*Unit*	*Provider*
Cable, unspecified	24.9	kg	Market for cable, unspecified - GLO
Output	*Amount*	*Unit*	
Ethernet cables	1	item	
Control cables			
Input	*Amount*	*Unit*	*Provider*
Cable, unspecified	44.71	kg	Market for cable, unspecified - GLO
Output	*Amount*	*Unit*	
Control cables	1	item	

A.7 Civil engineering components

Table A.7.1 Concrete islands production (calculated based on schematic from Company X)

Input	*Amount*	*Unit*	*Provider*
Concrete, 35 MPa	59.137	m^3	Market for concrete, 35 MPa - RoW
Custom steel	1256.65	kg	A.2.1
Output	*Amount*	*Unit*	
Concrete islands	1	item	

Table A.7.2 Roof material production (calculated based on schematic from Company X)

Input	*Amount*	*Unit*	*Provider*
Glued laminated timber, average glue mix	26.15	m^3	Market for glued laminated timber, average glue mix - Europe without Switzerland
Output	*Amount*	*Unit*	
Roof	1	item	

Table A.7.3 - Concrete drainers production (calculated based on schematic from Company X)

Input	*Amount*	*Unit*	*Provider*
Concrete block	314880	kg	Market for concrete block - DE
Output	*Amount*	*Unit*	
Concrete drainers	1	item	

Table A.7.4 - Collision barrier production (calculated based on schematic from Company X)

Input	*Amount*	*Unit*	*Provider*
Custom steel	63.75	kg	A.2.1
Output	*Amount*	*Unit*	
Collision barrier	1	item	

Table A.7.5 - Road production for scenarios (calculated based on schematic from Company X)

Hub road production, 7 year case			
Input	*Amount*	*Unit*	*Provider*
Custom road	1520*7	m2*a	A.2.9
Output	*Amount*	*Unit*	
Hub road, 7 year case	1	item	
Hub road production, 21 year case			

Input	*Amount*	*Unit*	*Provider*
Custom road	1520*21	m2*a	A.2.9
Output	*Amount*	*Unit*	
Hub road, 21 year case	1	item	

Table A.7.6 - Site preparation and on-site installations (calculated based on schematic from Company X)

Site excavation			
Input	*Amount*	*Unit*	*Provider*
Excavation, skid-steer loader	1902.4	m^3	Excavation, skid-steer loader - RER
Gravel, crushed	1331	t	Market for gravel, crushed - CH
Output	*Amount*	*Unit*	
Site, excavated	1	item	
Asphalt installation/paving			
Input	*Amount*	*Unit*	*Provider*
Diesel, burned in construction machine	1764.21	kWh	Market for diesel, burned in construction machine - GLO
Output	*Amount*	*Unit*	
Asphalt installation/paving	1	item	
Concrete drainers installation			
Input	*Amount*	*Unit*	*Provider*
Diesel, burned in construction machine	316.80	kWh	Market for diesel, burned in construction machine - GLO
Output	*Amount*	*Unit*	
Concrete drainers installation	1	item	

Table A.7.7 - Transportation

Transportation of CSS			
Input	*Amount*	*Unit*	*Provider*
Transport, freight, lorry 16-32 metric ton, EURO4	8.6*112.2	t*km	Market for transport, freight, lorry 16-32 metric ton, EURO4 - RER
Transport, freight, sea, container ship	8.6*286	t*km	Market for transport, freight, sea, container ship - GLO
Output	*Amount*	*Unit*	
Transportation of CSS	1	item	
Transportation of cabinets and			

satellites			
Input	*Amount*	*Unit*	*Provider*
Transport, freight, lorry 16-32 metric ton, EURO4	2*353.5	t*km	Market for transport, freight, lorry 16-32 metric ton, EURO4 - RER
Transport, freight, sea, container ship	2*200	t*km	Market for transport, freight, sea, container ship - GLO
Output	*Amount*	*Unit*	
Transportation of cabinets and satellites	1	item	

A.8 End-of-life processes

Table A.8 EoL processes

EoL: 7 year case			
Input	*Amount*	*Unit*	*Provider*
Used hub, ready for decommissioning, 7 year case	1	item	
Diesel, burned in building machine	117.45	MJ	Market for diesel, burned in building machine - GLO
Electricity, medium voltage	67.9	kWh	Market for electricity, medium voltage - Europe without Switzerland
Transport, freight train	1892.66	t*km	Market for transport, freight train - Europe without Switzerland
Transport, freight, lorry >32 metric ton, EURO4	3264.85	t*km	Market transport, freight, lorry >32 metric ton, EURO4 - RER
Waste preparation facility	1.11E-5	item	Market for waste preparation facility - GLO
Output	*Amount*	*Unit*	*Provider*
Shredder fraction after manual dismantling of used electronic product	5946.74	kg	Treatment of shredder fraction from manual dismantling, shredding | shredder fraction after manual dismantling of used electronic product | - GLO
Waste concrete	138971.95	kg	Treatment of waste concrete, inert material landfill - Europe without Switzerland
Waste plastic, consumer electronics	417.88	kg	Treatment of waste plastic, consumer electronics, municipal incineration - CH
Waste wood pole, chrome preserved	16997.09	kg	Treatment of waste wood pole, chrome preserved, municipal incineration - CH
EoL: 21 year case			
Input	*Amount*	*Unit*	*Provider*

Used hub, ready for decommissioning, 21 year case	1	item	
Diesel, burned in building machine	164.17	MJ	Market for diesel, burned in building machine - GLO
Electricity, medium voltage	94.85	kWh	Market for electricity, medium voltage - Europe without Switzerland
Transport, freight train	1937.23	t*km	Market for transport, freight train - Europe without Switzerland
Transport, freight, lorry >32 metric ton, EURO4	3341.72	t*km	Market transport, freight, lorry >32 metric ton, EURO4 - RER
Waste preparation facility	1.65E-5	item	Market for waste preparation facility - GLO
Output	*Amount*	*Unit*	*Provider*
Shredder fraction after manual dismantling of used electronic product	7240.22	kg	Treatment of shredder fraction from manual dismantling, shredding | shredder fraction after manual dismantling of used electronic product | - GLO
Waste concrete	138971.95	kg	Treatment of waste concrete, inert material landfill - Europe without Switzerland
Waste plastic, consumer electronics	458.27	kg	Treatment of waste plastic, consumer electronics, municipal incineration - CH
Waste wood pole, chrome preserved	16997.08	kg	Treatment of waste wood pole, chrome preserved, municipal incineration - CH

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