# Unit Process Inventory Data for Residential Electric Vehicle Charger Life Cycle Assessment

SESHADRI SRINIVASA RAGHAVAN

ANDERS NORDELÖF

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Division of Environmental Systems Analysis

Department of Technology Management and Economics

Chalmers University of Technology

Gothenburg, Sweden 41296

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## Authors

*Seshadri Srinivasa Raghavan*

**Anders Nordelöf*

*contact: anders.nordelof@chalmers.se , +

Division of Environmental Systems Analysis,

Department of Technology Management and Economics

Chalmers University of Technology

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Division of Environmental Systems Analysis
Chalmers University of Technology
412 96 Gothenburg
Sweden
Phone + 46 (0)31-772 1684

sessri@chalmers.se

anders.nordelof@chalmers.se

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A | Amperes |
| AC | Alternating current |
| ACEA | Association des Constructeurs Européens d'Automobiles |
| AFDC | Alternative fuels data center |
| BEV | Battery electric vehicle |
| BMS | Battery management system |
| BOM | Bill of materials |
| CC/CV | Constant current/constant voltage |
| CCID | Charge communication interrupting device |
| CCS | Combined charging system |
| CHAdeMO | Fast charging system developed by the CHAdeMO association |
| CI/CC | Constant current/constant voltage |
| CNG | Compressed Natural Gas |
| CPO | Charge point operator |
| CRM | Critical Raw Material |
| CSR | Corporate Social Responsibility |
| CSS | Compact Secondary Substation |
| CV | Constant voltage |
| DC | Direct current |
| DCFC | Direct current fast charging |
| DoD | Depth of discharge |
| DSL | Declarable substance list |
| DSO | Distribution system operator |
| EAFO | European alternative fuels observatory |
| ECHA | European Chemical Agency |
| EMC | Electromagnetic compatibility |
| EMF | Electromagnetic force |
| EMI | Electromagnetic interference |
| EoL | End of Life |
| EPA | Environmental Protection Agency |
| EPD | Environmental product declaration |
| ESG | Environmental , Social and Governance |
| ESS | Energy Storage System |
| EU | European union |
| EV | Electric vehicle |
| EVCC | EV charging controller |
| EVCS/I | EV charging station/infrastructure |
| EVSE | Electric vehicle supply equipment |
| FCEV | Fuel cell electric vehicle |
| G2V | grid to vehicle |
| gal | Gallons |
| GB/T | National Standards of the People's Republic of China/Recommended |
| GHG | greenhouse gas |
| GRI | Global Resource Indicator |
| HEV | Hybrid electric vehicle |
| HMI | Human Machine Interface |
| HV | High voltage |
| HVAC | Heating, Ventilation and Air Conditioning |
| ICCB | In-cable control box |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| ILCD | International Reference Life Cycle Data System |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Organization of Standards |
| JRC | Joint Research Center |
| kg | Kilogram |
| kW | Kilowatt |
| kWH | Kilowatt hour |
| l | Litre |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| LCD | Liquid Crystal Display |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| LIB | Lithium Ion Battery |
| LPG | Liquified Petroleum Gas |
| LV | Low Voltage |
| MCB | Minature Circuit Breaker |
| MCCB | Molded Case Circuit Breaker |
| MCL | Material classes |
| MCR | Minature Contactor Relay |
| MEB | Material Energy Balance |
| MFA | Material Flow Analysis |
| MJ | Mega Joule |
| NEMA | National Electrical Manufacturers Association |

| | |
|---|---|
| NG | Natural Gas |
| NMC | Nickel-Manganese-Cobal Chemistry |
| OBC | Onboard Charger |
| OCPP | Open Charge Point Protocol |
| OEM | Original Equipment Manufacturer |
| P/M (SDS) | Product/Material Safety Data Sheet |
| PCR | Product Category Rules |
| PEF | Product Environmental Footprint |
| PEI | Power Electronic Interface |
| PEP | Product Environmental Profile |
| PFC | Power Factor Correction |
| PHEV | Plug-in hybrid electric vehicle |
| PSR | Product Specific Rules |
| RCCB | Residual Current Circuit Breaker |
| RCD | Residual Current Detection |
| RSL | Reference substance list |
| SAE | Society of Automotive Engineers |
| SIS | Swedish Institute of Standards |
| SoC | State of Charge |
| SoH | State of Health |
| SPD | Surge Protection Device |
| T1/T2 | Type 1/2 Connector |
| TSO | Transmission system operator |
| UFC | Ultrafast Charger |
| UL | Underwriters Laboratory |
| UNFCC | United Nations Framework Convention on Climate Change |
| UVLO | Undervoltage Lockout |
| V | Volts |
| V2G | Vehicle to Grid |
| VA | Volt-Ampere |
| VDE | Verband Deutscher Elektrotechniker |
| VOC | Volatile Organic Compounds |
| WEEE | Waste electrical and electronic equipment directive |
| xFC | Extreme Fast Charger |
| ZEV | Zero Emission vehicle |

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# CONTEXT

This technical report is associated with two interrelated research works: Swedish Electromobility Center's Environment and Society thematic project titled *"Environmental Assessment of Electromobility Charging Systems"*; and Chalmers University of Technology's Transport Area of Advance *"Anticipating Metal Scarcities in Mobility Transition",* hereafter ChargeSys and MetalMobil respectively. The collective objectives of both these projects has improved understanding of the impacts of transitioning to electromobility from our current fossil-fuel dominant road-transportation system, when addressing the raw material, especially metal requirements, and environmental life cycle perspectives.

Except for very few studies, prevalent literature excludes the infrastructure required for actualizing such a transition, namely electric vehicle supply equipment (EVSE) or chargers in metal demand assessments. This knowledge gap also extends into the domain of life cycle assessment of chargers. The existing body of work is limited in number and deviates notably from its practicalities and representativeness. A reason is a lack of unit process inventory data that is detailed, compatible, consistent, and compliant with market trends, normative specifications and guidelines embodied in international standards and sometimes even mandated by regulations governing EVSE installation and utility interfacing. This report attempts to fill this gap and advance the body of knowledge on residential EV charging by compiling unit process data and developing  a model coherent model file.

# 1 INTRODUCTION

## 1.1 BACKGROUND

Road transport decarbonization is critical to achieving climate action goals and a core constituent of regional and national sustainable transport policy frameworks (EU, 2021). The effectiveness of such frameworks and the underlying greenhouse gas (GHG) mitigation pathways hinges on the “three-legged stool” of improving vehicle efficiency, decreasing fuel carbon intensity, and reducing travel demand (Lewis et al., 2018). However, there is a growing gap between GHG abatement targets and projected emissions (EASAC, 2019). Meanwhile, passenger car and road freight transport demand is expected to grow by at least 30% in the next two decades (Raposo, 2019), which may further widen this gap (ACEA, 2020). This disconnect between long-term road transport GHG targets and the state-of-play has prompted the EU to intensify its pursuit of a fossil-free transport system, and new initiatives aim for a net-zero GHG road transport sector by 2050 (EC, 2021). However, this cannot be delivered by status-quo and a paradigm shift towards electrifying the road transportation and mass market adoption of battery electric vehicles (BEVs) is therefore vital.

Emission benefits of ZEVs cited in regulatory (EAFO, 2017) and stakeholder assessments (ACEA, 2021) are predicated upon the co-existence of infrastructure, namely chargers. Excluding the infrastructure decouples the influence of mobility (travel demand, energy consumption etc.) on macro-economic policy decisions and investments. Furthermore, it can be argued that any retrospectiveor prospective environmental life cycle assessment of electromobility precluding the infrastructure is incomplete.

There is a large amount of literature on the LCA of EVs (Ayodele and Mustapa, 2020; Bauer et al., 2015; Bicer and Dincer, 2018; Ellingsen and Strømman, 2017). There have also been efforts to develop standardized sets of LCA of EV guidelines (elCar, 2011; Ricardo, 2018). A common theme across most of these studies and recommendations is a lack of attention and inclusion of the infrastructure, in absolute terms and or relative to the vehicle. One likely reason is the fact that existing studies rely on widely used databases such as Ecoinvent, which do not present the use case specificities of EV chargers and surrounding systems. Varied notions, interpretations, and misconceptions about charger, charging station and charging infrastructure often leads to inaccurately characterizing and subsequently representing it within an LCA model, further compounding this research gap.

Access to charging, especially residential charging—both single and multi-unit home locations is a key enabler of EV adoption (Wolbertus et al., 2020). Convenience, secure and reliable access, cost-effectiveness, user’s flexibility and control over charging times, and availing utility incentives (Hall, 2017; IEA, 2022; Needell et al., 2023) are some of the attributable factors. Several studies indicate that home charging will be the most preferred charging location in the coming decades (McKinsey&Company, 2018; T&E, 2021), meeting 60%–90% of the total charging demand (Wood et al., 2018; Zink et al., 2020). The electricity supplied during this charging, unless entirely provided by renewables, could potentially be the dominating contribution to the overall life cycle environmental impacts of EVs (Hawkins, 2013; Temporelli et al., 2020; van Loon et al., 2017; Van Mierlo, 2017; Wu et al., 2020). These observations indicate the value and utility of compiling inventory data for chargers, given the limitations found in existing literature.

## 1.2 Report Objectives, Relevance and Structure

This report explains technical, operational and installation requirements of residential EV charging infrastructure, and proposes representative unit process data for LCA of residential EV chargers. It also explains how this data has been compiled into a cohesive model file which can be used to establish a complete  life cycle inventory.. The presented datasets are constructed based upon international standards, manufacturer recommendations and installation guidelines to ensure that the studied product/system is representative of its practical use.

- Intended application – serve as the foundation for estimating the life cycle environmental impact of residential EV charging infrastructure.
- Intended audience – mobility researchers and LCA practitioners within academia and industry, including OEMs, work for environmental label development, validation, and standardization efforts (ISO, 2018, 2020, 2021; P.E.P, 2020)

In addition to this introductory chapter, this report is organized as follows:

Chapter 2 presents the basic aspects of EV charging and introduces the reader to the relevant nomenclature and taxonomy of chargers used in practice. International standards and practices for EV charging installations are then synthesized. Chapter 3 elaborates the methodological approach adopted in this report in building the unit process inventory data and compiling the model file. Information outlined in the international standards is expanded and supplemented with manufacturer recommendations and electric utility compliance requirements. Subsystems, parts, and components of the charging infrastructure are then systematically identified followed by an overview of the data collection steps—from raw material composition to final assembly. Chapter 4 delves into the each of these individual parts/components/subsystems and their functions. Composition data, corresponding Ecoinvent flows and activities, as well as suitable strategies implemented to address the intermediary transforming and final assembly process are tabulated and detailed in Chapter 4. Key insights, limitations and future extensions of this work are discussed in the concluding Chapter 5 of this report.

# 2 Technical and Operational Fundamentals

The purpose of this chapter is to summarize key definitions formalized in international standards and several regional electromobility policy framework within the EU that are used in this report.

## 2.1 Terminology

An introductory overview of EV charging, charger types and what constitutes a charging infrastructure most pertinent to this report alongside the terms utilized in this report shortly follows.

EV Charging Modes and Levels: Several regional and international standards adopt a set of normative specifications and requirements and delineate the principles, technologies, and related self-contained aspects of EV charging. Common terms are Modes and Levels which are further explained in section 2.3.

EV Supply Equipment (EVSE): The National Electronics Manufacturers Association (NEMA, 2023) defines EVSEs as *"[Devices that] provide electric power to the vehicle and use that to recharge the vehicle's batteries. EVSE systems include the electrical conductors, related equipment, software, and communications protocols that deliver energy efficiently and safely to the vehicle."* The EVSE refers to the entire spectrum from home to workplace and fast chargers. It is situated between the vehicle and the grid, receives power from the grid and delivers it to the EV minimally consisting of charger and a charging cable to connect with the EV.

In addition to the physical hardware, the EVSEs also includes communication and control systems that allow the EV and the charging station to communicate with each other. This ensures that the charging process is safe, efficient, and optimized for the specific needs of the EV and the charging station.

EV Charging Station (EVCS): The definition of the EVCS has a little overlap with that of the EVSE (NEMA, 2023). The International Electrotechnical Commission (IEC) denotes the EVCS "*as the stationary part of the EV supply equipment (EVSE) that is connected to the supply network*" (IEC, 2017a).

EV Charging Pool: Is a collection of multiple charging stations or EVSEs in a specific location, ex. workplace, parking garage or shopping malls (NKL, 2019).

Connector (plugs): An EV connector, charge point or charge plug refers to the physical interface between an EVSE and the EV.

Grid Interfacing and Peripherals: List of devices, components and parts additionally required to for installing the stipulated by the manufacture, international standards, or local regulations. Details in section 4.2.

Charge Point Operators (CPOs): A CPO is a company or organization that owns, installs, operates, and maintains EVSEs. The CPO is responsible for managing the charging network, providing customer support, and ensure compliance with building, local, utility, permitting, safety, interconnection and related standards and regulations.

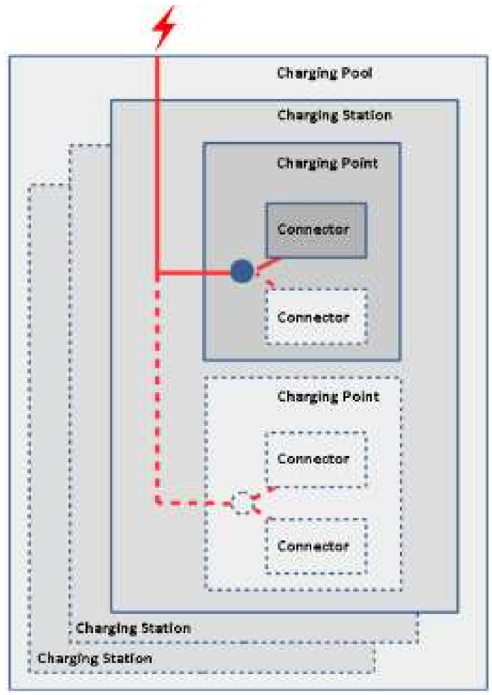


***Figure 1 Schematic illustration of a charging pool consisting of 3 charging stations, 2 charging points per station and 2 connectors per charge point reproduced from (EAFO, n.d.; NKL, 2019)***

Figure 1 depicts a high-level overview of the charging infrastructure illustrating the difference between some of these select terms from a connector to a charging pool with multiple charging station. Throughout the remainder of this report, unless otherwise explicitly mentioned, the following apply:

- EVSE – used synonymously and interchangeably with "charger", and "charging unit"
- EVCS – a collection of two or more EVSEs capable of charging multiple EVs simultaneously.
- EVCI – EV Charging Infrastructure: equipment, subsystem, parts and components as appropriate that are essential for the charger to function properly and fulfil its intended purpose, which is to safely, reliably, securely and efficiently deliver electricity to charge the EV battery. This includes EVSE, charging cable, grid interfacing and peripherals up to the AC mains which provides the input power supply.
- Connector – the physical interface between an EVSE and the EV, established using a charging cable

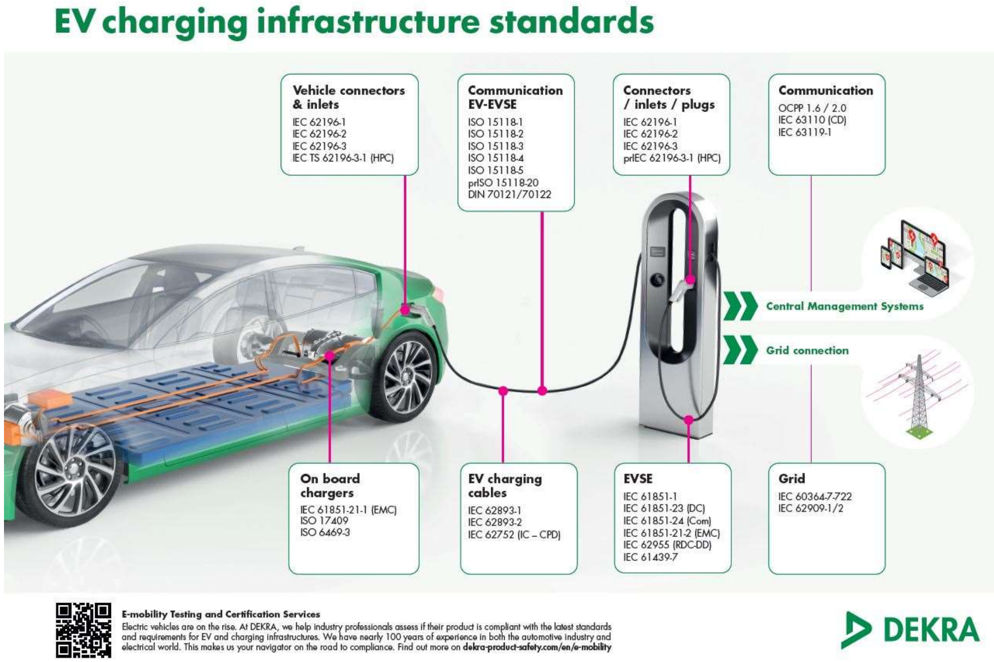

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***Figure 2 Suite of international standards for EV charging reproduced from  (DEKRA, n.d.)***

## 2.2 Governing Standards

Standards are essential for ensuring the safety, reliability, and interoperability of EVCSs. Standards enable EV and EVSE manufacturers and charging infrastructure providers to develop products that promote a harmonized set of performance, operational, reliability, and design criteria and can be used in different regions of the world. Figure 2 provides a snapshot of the major standardization initiatives undertaken by international and regional organizations such as the International Electrotechnical Commission (IEC), Underwriters Laboratory (UL), International Organization of Standards (ISO) and the Society of Automotive Engineers (SAE). This subsection summarizes some of the most widely adopted standards that are also directly related to the report.

The IEC Technical Committee TC 69 – *Electrical power/energy transfer systems for electrically propelled road vehicles and industrial trucks* is tasked in developing standards that cover all aspects of power/energy transfer between a rechargeable energy storage system (RESS) and the EV. It is supported by the Technical Committee TC 64 which frames the rules for electrical installations and protection against electrical hazards—faults, over currents, voltage fluctuations, and thermal runaway.

- IEC 61851: Defines the general and functional requirements for electric vehicle conductive charging systems, communication between the EV and the charging station, isolation requirements, electromagnetic interference/compatibility (EMI/EMC), safety and protection (IEC, 2020b).

- IEC 62196: Defines electrical, mechanical, thermal, and performative criteria of EV charging dedicated plugs, cables, socket-outlets, vehicle connectors/inlets, cable assemblies used in conductive charging systems up to 690 VAC/250 A and 1500 VDC/800A (IEC, 2022b).
- IEC 60364: Provides guidelines and requirements for the design, erection, inspection, and maintenance of electrical installations, including wiring, switchgear, and other equipment used in buildings and public premises broadly speaking. Planners, designers, installers, and maintenance personnel rely on this standard to ensure that electrical installations meet the necessary safety requirements and can be used in multi-use facilities and buildings such as residential units, apartment complex and commercial establishments (IEC, 2022a).
- SAE J1772: This is the North American standard for electric vehicle conductive charging systems. It includes specifications for the charging connector, communication protocol, and safety features (SAE, 2017).
- GB/T 20234: This is the Chinese standard for electric vehicle conductive charging systems. It includes specifications for the safety and reliability of EV charging systems, including the connectors, cables, and control devices used as well as testing procedures (GB/T, 2015).

## 2.3 TAXONOMY OF CHARGER AND CHARGING INFRASTRUCTURE

Attributes widely considered to categorize EV charging aspects are charging modes, charging levels, power, location and accessibility, and station design. Before going into the different classification and categorization of EV charging, it is helpful to look at charging from the perspective of the on-board power electronics interface (PEI). Figure 3 shows the constituents of a typical OBC (Infineon, 2020). Various topologies are differentiated by the degree of isolation, by the degree of integration between the AC and DC stages, and by the number of intermediate power conversion and regulation stages (Khaligh and D'Antonio, 2019). An OBC converts AC power from the electric grid into DC power to charge the vehicle's battery. It consists of a front-end filter (not shown) interfacing the grid supply, PFC rectifier and a DC-DC converter. The PFC rectifier filters, reduces the harmonic content of input AC, and converts it to DC. Once the AC power has been converted to DC power, OBC regulates the voltage depending on the DC link voltage and current to keep the charging rate within the safe physical, thermal, mechanical, and operational limits of the battery as well as communicates with the battery management system to continuously monitor the battery state of charge (SOC) and state of health (SOH).

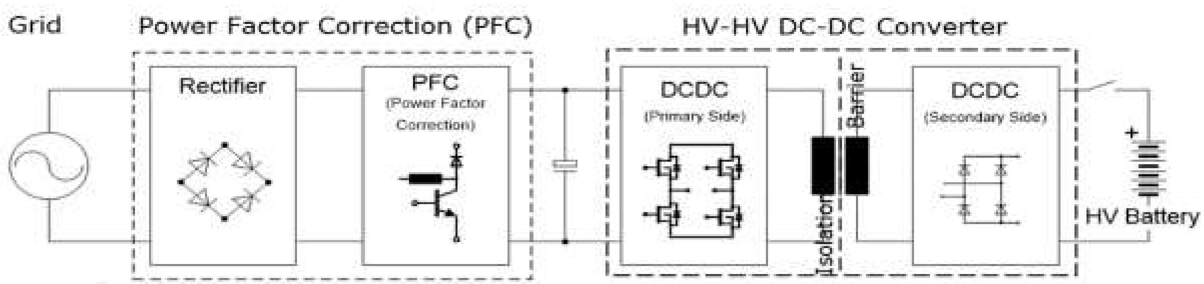



*Figure 3 On-board charger (OBC) –block diagram . Picture source: (Infineon, 2020)*

### 2.3.1 Charging Modes

Referring to Figure 3 , conductive chargers deliver AC or DC energy to the vehicle after one or more power conversion and or voltage transformations (Knez, 2019). There are four charging modes. Charging modes 1 – 3 represents slow AC charging (< 22 kW) of the EV battery using the OBC' power electronic interface (PEI) as shown in Figure 3. This means that the OBC is connected to a regular domestic single or 3-phase AC socket (NKL, 2019; RVO, 2019). Charging mode 4 refers to DC fast charging (DCFC) wherein the battery is directly charged using a PEI that is situated off-board, meaning outside the vehicle. All these modes are defined in accordance with the International Electrotechnical Commission (IEC) series of standards for EV conductive charging systems (IEC, 2020a).

- *Mode 1, non-dedicated circuit, and socket outlet*:
  In charging mode 1, the electric vehicle is directly connected to a standard household socket without any protection, safety, or control measures. It is an obsolete and the slowest charging rated less than a few kW.

- *Mode 2, non-dedicated circuit and socket outlet, cable-incorporated protection*:
  In charging mode 2, the electric vehicle is connected to single-phase, or three-phase AC supply Mode 2 also uses a standard household socket but is earthed in contrast to Mode 1 socket. In this mode, necessary protection and safety features are housed in the cable connecting the supply socket to the EV using an in cable-control box (IC-CB) or in-cable control and protecting device (IC-CPD).

- *Mode 3, Dedicated EV charging system dedicated outlet*:
  Requires a dedicated equipment for EV charging—EVSE, that is permanently connected to single or three-phase AC supply and equipped with all safety features and protection mechanisms offered by an IC-CB/IC-CPD as Mode 2 as well as establish active bi-directional communication between the EVSE and the vehicle—which makes controlled charging possible. Modes 1—3 apply to AC charging up to 22 kW

- *Mode 4, dedicated EV charging system, dedicated outlet and offboard DC charging*:
  In this mode battery is charged by avoiding the OBC with DC power from the charging station. This is different from other modes of charging, such as Mode 2 or Mode 3, where the OBC converts the AC power from the grid to DC. Mode 4 exclusively refers to off-board and or DC fast charging.

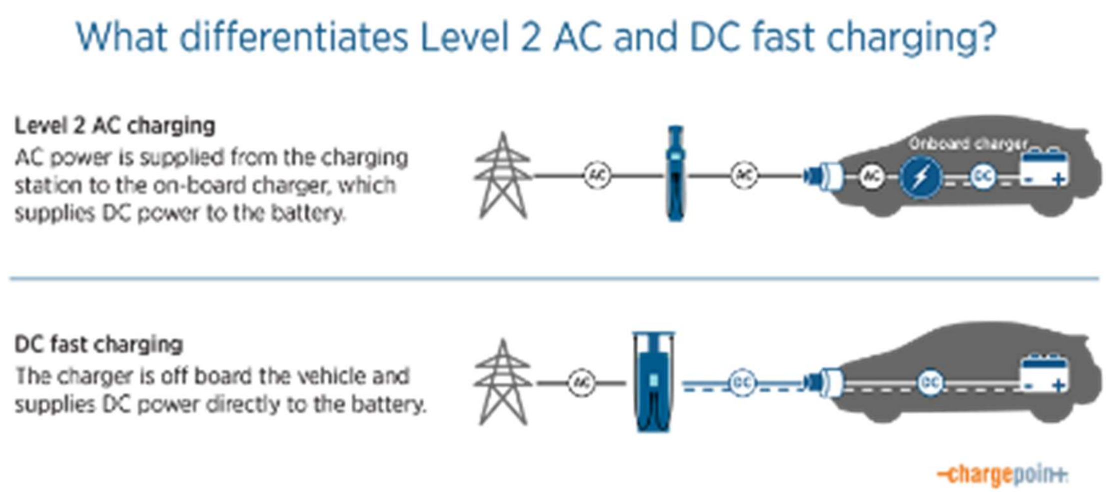
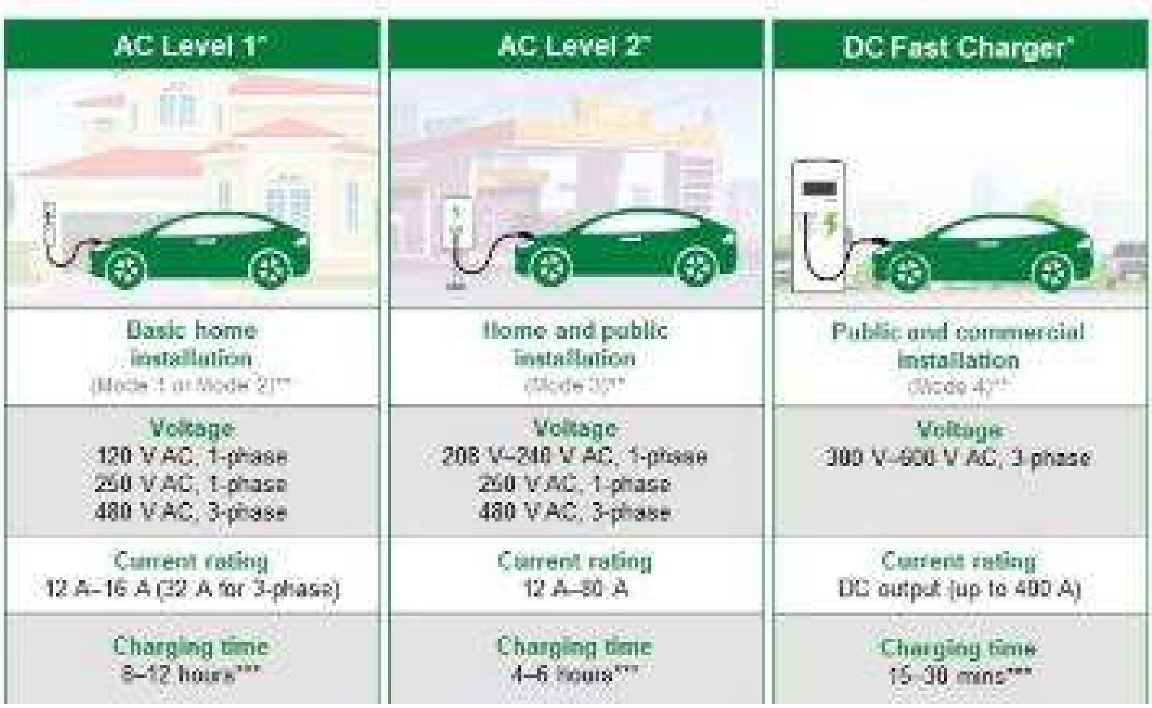



***Figure 4 Fundamental difference between AC and DC charging. Picture source: (chargepoint, 2023)***




*Note: Charging levels are defined by the Society of Automotive Engineers (SAE) and charging modes by the International Electrotechnical Commission (IEC) standards.*

***Figure 5 Charging levels and rated capabilities. Picture source: (littlefuse, 2022) .***

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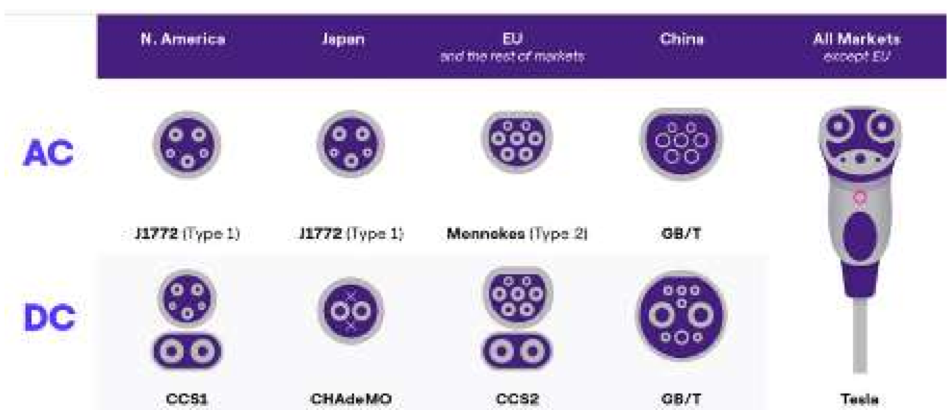


*Note: N. American and Japan generally follows the Society of Automotive Engineers (SAE), and EU, the International Electrotechnical Commission (IEC) connector standards. CCS – Combined Charging System, CHAdeMO and other DC charging out of scope*

***Figure 6 Overview of global EV connectors. Picture source: (EnelX, 2019; vattenfall, 2020).***

### 2.3.2 Charging Levels

The type of input of power supply (AC—single or 3 phase; DC), input voltage/current ratings and the charging modes determine the charging level (Khalid et al., 2019). These are formalized in the Society of Automotive Engineers (SAE) J1772 series of standards (SAE, 2017). Slow, normal or "Level 1 charging" denotes single or 3 phase AC charging up to 11 kW. Single or 3 phase AC charging up to 22 kW is known as "Level 2 charging". Figure 4 and Figure 5 show key points of difference according to power supply type and rated voltage/current levels of charging. Given the specificities, connectors vary by the charging level, manufacturer and geography (Virta, 2021), as shown in Figure 6.

### 2.3.3 Locational, Accessibility, and Station Design

Single or Multi-household Residential Chargers

At home is the most common place to charge as elaborated in the Chapter 1. Home charging is cost-effective and usually sufficient for daily trips. It is generally considered as more convenient than refueling ICE vehicles at gas stations. Residential (home) charging can be:

- single-family: low-rise individual houses with a private garage usually equipped with one or two charging points
- multi-family: residential buildings with multiple apartments (condominium), where charging points may be private (individual garage) or shared between condominium inhabitants (multiple EV charging points located in the common parking place).

Workplace or Commercial Facilities Parking Chargers

Workplace EV chargers are becoming available at a growing number of companies, especially those committed to the reduction of greenhouse gas emission (Zou, 2020). It can be attractive for employees, especially if the price for charging is equivalent or lower than the price for charging at home. Workplace charging can be an opportunity to encourage electric vehicle adoption for employees that do not have charging points at home or for employees needing to charge both at home and at work for their daily usage. Workplace charging is done mainly during the day. EV chargers in the workplace are usually 3-phase with a power range of 11kW and 22kW. Charging Mode 3 is recommended for safety reasons. Other destinations, such as supermarkets, shopping malls, restaurants, public car parks and commercial facilities equipped with EV charging points, can provide occasional charging opportunities for their users. Because a car is parked at these locations for a few hours only, fast charging is usually preferred, typically charging mode 3, 22 kW rated. Additional visuals from real-world visualizations can be found here Harvard (n.d.)

Corresponding to residential and or workplace charging, few additional variants are possible: based on the mounting—wall mount (indoor, garage) and floor standing (outdoor, curbside) in residential charging and pedestal mounted for workplace and or public charging (parking lots) ; and number of connectors which is essentially the number of EVs that can be simultaneously charged— single (dominant type for residential) and two (most prevalent in workplace and or public charging). Figure 7. shows some examples of different EVSEs considered in this report.

(a)

(b)


(c)

***Figure 7 Three different EVSEs: a) wall mount-garage . Picture source: (Ensto, 2021) ; b) outdoor-floor standing . Picture source: (legrand, 2022); and c) pedestal mount-parking location . Picture source: (SE, 2021)***

# 3 METHODOLOGICAL CONSIDERATIONS

## 3.1 APPROACH AND SCOPE

International standards, OEM guidelines and installation requirements (ABB, 2021; iskra, 2022; Rajendran, 2021) are the starting point for identifying all the parts, devices and equipment and essential for the complete charging infrastructure. Representative parts are then selected from OEM catalogs (ABB, 2020a, c; Helukabel, 2021a). For each of the identified representative part, corresponding eco-labels (ISO, 2018, 2020, 2021), also known as Environmental product declarations-EPD or product environmental profiles-PEP are then utilized for evaluating their material composition. Suitable assumptions are made to link these product/part material input (excluding packaging) with the ecoinvent 3.9.1 database (cutoff method). Due to the lack of a detailed assembly data, aggregate information reported in the annual sustainability report of a facility—Mitsubishi Electric Corporation (MELCO, 2023), that manufactures the range of parts and equipment is used to proxy final product assembly energy (electricity, natural gas, crude oil), water, chemical substance inputs and discharges (Section 4.3).

The LCI model developed covers the items presented in Table 1. *Quantity* denotes the number of individual parts needed for the complete charging infrastructure which includes the EVSE or charging unit, set of circuit protection and metering and monitoring devices as well as charging cable. Three EVSE variants differentiated by power level, mounting, or number of connectors are considered. Unless otherwise specified, remaining items are mandatorily included in the complete charging infrastructure installation.

***Table 1 Itemized list of parts and equipment for residential EV charging***

| *Item* | *Quantity* | *Comments* | *Details* |
|---|---|---|---|
| ***Charging unit-3 variants*** | | | Section 4.1 |
| *Indoor Wallbox-WALL* | 1 | | Section 4.1.2.1 |
| *Indoor/Outdoor Floor Standing-FLST* | | | Section 4.1.2.2 |
| *Outdoor Parking Pedestal Mounted-PRKG* | | | Section 4.1.2.3 |
| ***Circuit Protection*** | | | |
| *Residual Current Detection-RCD* | 1 | | Section 4.2.1 |
| *Overcurrent Circuit Breaker-OCCB* | 1 | | Section 4.2.2 |
| *Undervoltage Lockout-UVLO* | 1 | | Section 4.2.3 |
| *Surge Protection Device-SPD* | 1 | Optional for FLST | Section 4.2.4 |
| *Contactor Relay-MCR* | 1 | | Section 4.2.5 |
| ***Metering and Monitoring*** | | | |
| *EV Charging Controller-EVCC* | 1 | Required only when charging multiple EVs | Section 4.2.6 |
| *Smart Meter-METR* | 1 | | Section 4.2.7 |
| ***Charging Cable*** | 1 or 2 | 1 minimum ; 2 optional for FLST;<br>2 for PRKG | Section 4.2.8 |

## 3.2 ECOINVENT FLOW MAPPING ASSUMPTIONS

Though an EPD provides material composition details, instances where a particular material is categorized too broadly – "steel" , vague– "copper alloys", or incomplete – "various others/others" is very common. Since multiple activities could be linked to a flow, such complex interlinkages can only be captured in an LCA model by the manufacturer and even that is conditional upon the data resolution of upstream material acquisition, primary and secondary suppliers, transshipment activities and semi-processing steps. To address and reconcile these inconsistencies which poses LCA challenges in modeling a reasonably combination of raw material inputs and intermediate material transformation activities that convert raw materials to semi or finished products, simplifying assumptions are made, which are enumerated in Table 2. These are homogenous and uniformly applied based on material.

***Table 2 EPD to ecoinvent mapping assumptions for select materials or assembled products***

| *Methodological note* | *EPD* | *Ecoinvent material/product input* | *Ecoinvent material transformation^* |
|---|---|---|---|
| *MN-1* | Steel | Low alloyed steel[a] | Sheet rolling<br>Metal working, average for steel product |
| *MN-2* | Ferrous alloys<br>Stainless steel | Chromium 18/8 steel | Sheet rolling<br>Metal working, average for chromium steel product |
| *MN-3* | Other metals | Aluminium, wrought alloy | Sheet rolling/extrusion<br>Metal working, average for aluminium product |
| *MN-4* | Copper alloys<br>Brass | Brass[b] | Brass casting |
| *MN-5* | Iron<br>Cast iron | Cast iron | Casting removed by milling[c] |
| *MN-6* | Copper | Copper, cathode | Wire drawing |
| *MN-7* | All plastics | - | Injection molding[d] |
| *MN-8* | Electronic cards<br>Electronic circuits and components | Printed wiring board, surface mounted, unspecified, Pb free | |
| *MN-9* | Aluminium | Aluminium, wrought alloy | Sheet rolling/extrusion<br>Metal working, average for aluminium product |
| *MN-10* | Packaging plastics | HDPE[e] | Injection molding |
| *MN-11* | Glass fiber reinforced plastics (GFRP) | Glass fiber | Injection molding |
| *MN-12* | Bulk and sheet molding compounds (BMC/SMC) | Epoxy resin | - |

*[a] Own assumption*
*[b] Common in electrical equipments(CDA, 2000)*
*[c] (ABB, 2023)*
*[d] most dominant molding process (AMI Consulting, 2022)*
*^ if more than one, implies all transformation activities are needed*
*[e] properties better suit bulk, container, and heavy equipments (Dikobe, 2017)*

## 3.3 INSTALLATION HANDBOOK AND TECHNICAL GUIDELINES

The following manuals were extensively relied upon for describing the basic operational features and functions of low voltage parts, products and systems circuit protection and monitoring, measurement, and control (Section 4.2)

i. Electrical Installation Guide A practical guide for any professional who must design, install, inspect, and maintain electrical installations in accordance to IEC standards (SE, 2018)

ii. Technical guide - 6th edition 2010 Electrical installation handbook. Protection, control and electrical devices (ABB, 2010)

iii. British Standards Institution Requirements for Electrical Installations. BS 7671:2018. Institution of Engineering and Technology, London, United Kingdom in agreement with British Standards Institution (BSI, 2018).

# 4 COMPLETE CHARGING INFRASTRUCTURE

## 4.1 CHARGING UNIT-EVSE

In this section, a brief generalized description of an EVSE is first provided. Then, the compiled inventory including the recommended ecoinvent flows and transformation activities are presented for the three EVSE variants. The assembly and final product manufacturing related inputs and discharges are separately discussed and summarized in section 4.3. It must be noted that these descriptive overview is intended to familiarize the reader about the basics of an EVSE not explicitly linked to any specific PEP/EPDs analyzed in this report. For a more detailed discussion about the same, interested readers are encouraged to refer to major EVSE manufacturers (Ensto, 2021), engineering and design service providers (FESTO, 2021), 3rd party testing and certification organizations (UL, 2022) or city/local/regional EVSE procurement guidelines (vattenfall, 2022) .

### 4.1.1 Generalized Description

Single Household Charger

A 7 kW home EV smart charger (Wall box -WALL) is a type of electric vehicle charger designed for residential use. It typically features smart technology that enables remote management and monitoring of the charging process. A conventional 7 kW home EV smart charger consists of:

- Power input: This is the point where the charger is connected to the power grid. Depending on the model, this can be a standard 120/240-volt AC input, more likely single phase.
- Charging port: This is the point where the EV is connected to the charger. It typically consists of a plug that fits into the EV's charging port (Type 2 Mennekes)
- Charging controller: This component regulates the charging process and communicates with the EV to determine the optimal charging rate and handle any safety features, such as detecting faults or overloads. A communication controller maybe embedded within the charging controller which facilitates user access via smart phone connectivity for remote monitoring, charging session scheduling as well as receiving any notifications.
- Voltage regulator: This component takes the AC power from the power input and regulates to ensure the incoming voltage and current ratings are within the OBC capabilities.
- Built-in safety measures: Depending on the manufacturer, trim, feature selection (basic or add-on), certain safety features could be integrated inside the charger. Examples include ground fault protection, temperature sensors, lock and cable release mechanisms, and any regional, building, or utility electrical code compliance.

All these are enclosed in a lightweight cabinet or housing, typically made of plastics. In principle, an outdoor floor standing EVSE (FLST) also consists of the same components but housed in a metal cabinet, usually aluminium or steel alloy capable of withstanding harsher outdoor weather, dust and other ambient conditions.

Multi-household Residential, Workplace or Commercial Facilities Parking Chargers

A workplace charger such as the pedestal mounted, outdoor parking lot EVSE is designed to provide at least 22 kW powered by three-phase AC, more ruggedly constructed, equipped with two connectors to safely and efficiently charge up to 2 EVs simultaneously. In general, since utdoor chargers are rated higher (up to 22 kW) and may need to be compatible with single phase and three phase AC supply, some of the internal components such as the regulator and select safety measures are included within the main EVSE by default.

### 4.1.2 Representative Parts, Specifications and Recommended Flow Mappings

#### *4.1.2.1 Wall box EVSE*

***Table 3 Specification, reference composition and ecoinvent flows: Wall box EVSE***

| | **Wall box -WALL (Ensto, 2022)** |
|---|---|
| *Part* | Ensto One Home EVH321B-HCR00 |
| *Description* | Wallbox running on alternating current (AC). Installation type: wall installation: garages, roofed sheds or exterior parking areas in collective residential buildings or buildings used as offices, car parks, or the public highway. Charging type: Normal. Number of charging points: 1 joined cable (length 5 m) rated up to 32A. Charging mode: Mode 3. Presence of connected sockets: 0 domestic sockets. Reference power: 32 A - 230V - 7 kW single phase. |
| *Weight [kg]* | 6.0<br>*7.7 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Steel* | 19.2% | steel, low-alloyed | sheet rolling, metal working, average for steel product manufacturing | 1.16E+00 |
| *Copper* | 5.6% | copper, cathode | Wire drawing, metal working, average for copper product manufacturing | 3.39E-01 |
| *Other metals* | 0.4% | aluminium, wrought alloy | Sheet rolling/extrusion, average for aluminium product manufacturing | 2.31E-02 |
| *PC* | 28.1% | polycarbonate | injection molding | 1.69E+00 |
| *PA* | 8.1% | glass fiber reinforced plastic, polyamide, injection molded | " " | 4.86E-01 |
| *PET* | 1.0% | polyethylene terephthalate, granulate, amorphous | " " | 6.17E-02 |
| *PBT* | 0.9% | polyethylene terephthalate, granulate, amorphous | " " | 5.40E-02 |
| *PP* | 0.8% | polypropylene, granulate | " " | 4.63E-02 |
| *Other plastics* | 4.5% | polypropylene, granulate | " " | 2.70E-01 |
| *PE* | 0.3% | polyethylene, low density, granulate | " " | 1.54E-02 |
| *Electric cables/wires* | 26.5% | electric connector, peripheral component interconnect buss | - | 1.60E+00 |
| *Electronic cards* | 3.7% | printed wiring board, surface mounted, unspecified, Pb free | - | 2.24E-01 |
| *Other electronic components* | 0.8% | printed wiring board, surface mounted, unspecified, Pb free | - | 4.63E-02 |
| | **100%** | | | **6.01E+00** |
| *Excluded Packaging* | | | | |
| *Paper* | | *corrugated board box* | | *1.10E+00* |
| *Wood* | | *Plywood* | | *6.02E-01* |
| *Other packaging plastics* | | *LDPE* | | *7.71E-03* |
| | | | | *1.77E+00* |
| **For assembly input, refer section 4.3** | | | | |

### 4.1.2.2 Floor standing EVSE

***Table 4 Specification, reference composition and ecoinvent flows : Floor standing EVSE***

| | **Floor standing -FLST (legrand, 2022)** |
|---|---|
| *Part* | Wiremould- XCSAL2GUU-BZ; XCSPP2GUU-BK |
| *Description* | Outdoor charging station with accent light to enable device charging during the day and after dark. Accent light ensures the station stands out from standard boll For charging all electric vehicles (equipped with single-phase and three-phase chargers) and plug-in hybrids in Mode 2 or Mode 3 in complete safety. Compliant with standards IEC 61851-1 and 61851-22.ards and clearly indicates charging. Station includes one duplex GFCI Receptacle and one 4-Port USB Outlet. |
| *Weight [kg]* | 13.6<br>*21.5 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Aluminium* | 76.0% | aluminium, wrought alloy | Sheet rolling/extrusion, metal working average for aluminium product | 1.03E+01 |
| *Steel* | 13.8% | steel, low-alloyed | Sheet rolling, metal working average for steel product | 1.87E+00 |
| *Copper alloys* | 0.7% | brass | Brass casting | 9.66E-02 |
| *PC* | 4.5% | polycarbonate | Injection molding | 6.12E-01 |
| *PA* | 0.5% | glass fiber reinforced plastic, polyamide, injection molded | " " | 6.44E-02 |
| *Other plastics* | 0.6% | polyurethane, flexible foam | | 8.59E-02 |
| *PVC* | 0.5% | polyvinylchloride, bulk polymerized | | 6.44E-02 |
| *PP* | 0.1% | polypropylene, granulate | | 1.07E-02 |
| *PET* | 0.1% | polyethylene terephthalate, granulate, amorphous | | 1.07E-02 |
| *PE* | 2.4% | polyethylene, low density, granulate | " " | 3.22E-01 |
| *Electronic components* | 0.6% | printed wiring board, surface mounted, unspecified, Pb free | - | 8.59E-02 |
| *Printed Circuit Board* | 0.2% | printed wiring board, surface mounted, unspecified, Pb free | - | 3.22E-02 |
| *LED* | 0.2% | light emitting diode | - | 2.15E-02 |
| | **100%** | | | **13.6E+00** |
| *Excluded Packaging* | | | | |
| *Paper* | | | | *4.9E+00* |
| *Wood* | | | | *1.9E+00* |
| | | | | *7.87E+00* |
| **For assembly input, refer section 4.3** | | | | |

#### 4.1.2.3 Parking lot EVSE

***Table 5 Specification, Reference composition and ecoinvent flows : Parking lot EVSE***

| | **Parking lot EVSE -PRKG (SE, 2021)** |
|---|---|
| *Part* | EVF2S22P44R |
| *Description* | The EVlink Parking charging station product is designed to charge the electric vehicle and meet the requirements of secure parking lots (closed, with filtered access, or under surveillance):Parking lots for vehicle fleets; Paid-access car parts; Shopping mall parking lots. It includes a dedicated connection to the power supply capable of charging up to 22 kW (charging mode 3). |
| *Weight [kg]* | 36.9<br>*50.7 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Brass* | 0.3% | brass | Brass casting | 1.07E-01 |
| *Zinc* | 0.3% | zinc | - | 1.07E-01 |
| *Ferrite* | 0.4% | ferrite | - | 1.61E-01 |
| *Copper* | 3.5% | copper, cathode | Wire drawing, metal working average for copper product | 1.29E+00 |
| *Steel* | 32.4% | steel, low-alloyed | Sheet rolling, metal working average for steel product | 1.20E+01 |
| *PCBA* | 1.3% | Printed wiring board, surface mounted, unspecified, Pb free | - | 1.07E-01 |
| *Epoxy Resin* | 0.3% | epoxy resin, liquid | | 1.61E-01 |
| *PA resin* | 0.4% | phenolic resin | | 3.76E-01 |
| *EPDM* | 1.0% | synthetic rubber | | 7.52E-01 |
| *PA Resin* | 2.0% | phenolic resin | | 9.14E-01 |
| *GFRP* | 2.5% | glass fiber reinforced plastic, polyamide, injection molded | Injection molding | 1.95E+01 |
| *PC* | 52.7% | polycarbonate | " " | 2.15E-01 |
| *PVC* | 0.6% | polyvinylchloride, bulk polymerized | " " | 4.84E-01 |
| | | | | 6.99E-01 |
| *Glass fiber* | 1.9% | glass fiber | " " | 1.07E-01 |
| | **100%** | | | **36.9E+00** |
| *Excluded Packaging* | | | | |
| *Paper* | | | | *6.9E-01* |
| *Wood* | | | | *13.2E+00* |
| | | | | *13.9E+00* |
| **For assembly input, refer section 4.3** | | | | |

## 4.2 INSTALLATION, GRID INTERFACE AND PERIPHERALS

**Generalized Description-Circuit Protection Devices**

In the context of EV charging, circuit protection devices encompass a wide range of functions aimed at ensuring safe, reliable, and secure charging as well as protect the vehicle, equipment, and personnel from any electrical, mechanical, thermal, and weather-related faults. In this report, five such devices are included in the inventory and depending on the type of charger one or more such devices are required for the complete charging infrastructure installation. Commonly occurring faults include leakage current, grounding faults, or when current and voltages are outside the safe operating limits.

A combination of electrical, magnetic, mechanical, and electronic components constitutes such devices. Internally these are represented by contacts made of mostly metal , a trip or triggering mechanism that responds to abnormal conditions (voltage, current, temperature, lightning, transient spikes, grounding etc), sensing mechanism that continuously compares the reference with the actual parameter (peak currents and voltages for example), a reset or recoil mechanism to restore the device back to its initial condition (normally open or close) once the operating conditions are back to normal.

### 4.2.1 Residual Current Detection (RCD)

#### *4.2.1.1 Typical Functions*

A residual current detection system for electric vehicle charging, also known as an earth leakage protection system or ground fault circuit interrupter (GFCI), is a safety mechanism that protects against electric shocks and electrocution during the charging process. An RCD device is an important safety feature. It works by constantly monitoring the electric current flowing through the charging cable and detecting any imbalances in the flow of electricity. If there is an imbalance, it indicates that some of the current is leaking out of the charging cable and into the surrounding environment, potentially posing a safety risk. In response to this imbalance, the residual current detection system will automatically shut off the power supply to the charging cable, preventing any further electrical flow until the issue is resolved. This helps ensure the safety of the user, equipment, vehicle as well as any bystanders who may be in the vicinity. An RCD typically contains a current transformer for sensing current, differential amplifier for current comparison, solenoid which is activated upon detecting an imbalance housed in an enclosure.

Type A and Type B are the main types of RCDs used in electrical installations differing principally based on the type of residual current they are designed to detect:

- Type A RCDs are designed to detect and trip in the presence of alternating residual currents, which are typically caused by AC voltage sources. They are typically used in residential and workplace charging to protect against electrical shock hazards caused by faults in appliances and equipment. Direct residual currents are typically caused by

DC voltage sources, which are becoming increasingly common in renewable energy systems and electric vehicles.

- Type B RCDs are designed to detect and trip in the presence of both alternating and direct residual currents. Type B RCDs also have a higher sensitivity compared to Type A RCDs, and they can detect smaller current imbalances. Type B RCDs are used in these applications to provide additional protection against electrical shock hazards caused by DC faults. This also makes them more suitable for applications where very low current leakage must be detected as is the case with slow AC charging.

#### *4.2.1.2 Representative Part, Specifications and Recommended Flow Mappings*

***Table 6 Specification, reference composition and ecoinvent flows: RCD***

| | **Residual Current Detector (RCD) (SE, 2020a)** |
|---|---|
| *Part* | Acti9 iID, 4P, 40A, B-EV (Electric Vehicle) type, 30mA, double terminal. Acti9 iID B-SI RCCB - A9Z65463 |
| *Description* | This Acti9 iID is a modular and reliable residual current circuit breaker (RCCB) for electrical vehicle. It is a 4P circuit breaker with In rated current of 40A, B-EV type protection class and a 30mA earth leakage sensitivity. This product protects against electrical shock by direct or indirect contact and fire hazards. It performs the function of disconnection of electrical circuits in case of earth fault. |
| *Weight [kg]* | 0.388<br>*0.463 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Steel* | 23.5% | steel, low-alloyed | sheet rolling, metal working, average for steel product manufacturing | 9.13E-02 |
| *Stainless steel* | 1.9% | steel, chromium steel 18/8 | sheet rolling, metal working, average for chromium product manufacturing | 7.22E-03 |
| *Copper* | 23.5% | copper, cathode | wire drawing, metal working, average for chromium product manufacturing | 9.13E-02 |
| *POM polyacetal* | 0.2% | nylon 6 | injection molding | 8.49E-04 |
| *PET* | 1.1% | polyethylene terephthalate, granulate, amorphous | " " | 4.25E-03 |
| *PC* | 1.4% | polycarbonate | " " | 5.52E-03 |
| *PBT* | 2.9% | polyethylene terephthalate, granulate, amorphous | " " | 1.15E-02 |
| *PPS* | 3.5% | polyphenylene sulfide | " " | 1.36E-02 |
| *PA* | 37.6% | glass fiber reinforced plastic, polyamide, injection molded | " " | 1.46E-01 |
| *Others* | 0.1% | polyurethane, flexible foam | " " | 4.25E-04 |
| *Electronic components* | 4.1% | printed wiring board, surface mounted, unspecified, Pb free | - | 1.61E-02 |
| *Silver* | 0.1% | silver | - | 4.25E-04 |
| | **100%** | | | **3.89E-01** |
| *Excluded Packaging* | | | | |
| *Paper* | | *corrugated board box* | | *9.3E-03* |
| **For assembly input, refer section 4.3** | | | | |

## 4.2.2 Overcurrent Circuit Breaker (OCCB)

### *4.2.2.1 Typical Functions*

Over current protection helps prevent damage to the charging equipment, the vehicle's battery, and other electrical components in case of a fault or malfunction by limiting the current flowing through the charging system caused by short circuit, over loading or ground fault. Overcurrent circuit breakers are also useful for controlling and limiting the amount of power that is supplied to the EV as charging occurs within safe operable voltage and current levels. Options for overcurrent protection include but not limited to:

- Fuses: A wire or filament that melts when current exceeds the threshold. They are simple and cost-effective but must be replaced after they blow.
- Circuit breakers: Circuit breakers are like fuses, but they can be reset after they trip. They use an electromechanical, magnetic or electronic mechanism to disconnect the circuit when the current exceeds a certain level.
- Electronic trip units: Electronic trip units are used in more advanced over current protection systems. They use electronic sensors to measure current and can be programmed to provide more precise protection based on specific current thresholds.
- Ground fault circuit interrupters (GFCIs): GFCIs are designed to protect against ground faults, which occur when current flows from an electrical circuit to the ground. They work by detecting imbalances in the current flow between the hot and neutral conductors and interrupting the circuit if a ground fault is detected.
- Overcurrent relays: Overcurrent relays are another type of advanced protection system that use current transformers and electronic sensors to detect overcurrent conditions. They can be used to protect against sudden inrush, short-circuit and overload conditions.

### *4.2.2.2 Representative Part, Specifications and Recommended Flow Mappings*

***Table 7 Specification, reference composition and ecoinvent flows: OCCB***

| | **Over Current Circuit Breaker (OCCB) (ABB, 2022)** |
|---:|---|
| *Part* | Low voltage circuit breaker SACE Tmax XT. TmaxXT2 with electronic release |
| *Description* | SACE Tmax XT range can be found in the three-pole and four-pole, fixed, plug-in and withdrawable versions, fitted with the very latest generation thermo-magnetic and electronic trip units, with the possibility of interchangeability. |
| *Weight [kg]* | 1.25<br>*1.45 (including packaging)* |

| *EPD Information* | | *Recommended market activity, GLO or RER* | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Steel* | 25.90% | steel, low-alloyed | Sheet rolling, metal working, average steel product | 3.87E-01 |
| *Epoxy Resin* | 41.70% | epoxy resin, liquid | - | 6.24E-01 |
| *PA* | 5.6% | glass fiber reinforced plastic, polyamide, injection molded | Injection molding | 7.03E-02 |
| *ABS* | 0.4% | acrylonitrile-butadiene-styrene copolymer | " " | 4.49E-03 |
| *PCB* | 2.0% | printed wiring board, surface mounted, unspecified, Pb free | - | 2.54E-02 |
| *Brass* | 2.8% | brass | Brass casting | 3.44E-02 |
| *Copper alloys* | 2.8% | brass | " " | 3.44E-02 |
| *Copper* | 17.1% | copper, cathode | Wire drawing, metal working, average copper product | 2.14E-01 |
| *Stainless steel* | 1.1% | steel, chromium steel 18/8 | Sheet rolling, metal working, average chromium steel product | 1.35E-02 |
| *Precious metal* | 0.8% | silver | - | 1.05E-02 |
| | **100%** | | | 1.25E00 |
| *Excluded packaging* | | | | |
| *Paper* | | *corrugated board box* | | *1.3E-01* |
| *Cardboard* | | *corrugated board box* | | *6E-02* |
| *Plastic* | | *HDPE* | | *1.5E-02* |
| | | | | *2.05E-01* |
| **For assembly input, refer section 4.3** | | | | |

### 4.2.3 Undervoltage Lockout Auxiliary (UVLO)

#### *4.2.3.1 Typical Functions*

Under voltage lockout (UVLO) is a safety feature that is commonly used in electric vehicle charging systems to protect against voltage levels that are too low. UVLO is designed to prevent the charging system from operating if the input voltage falls below a certain threshold. UVLO works by monitoring the input voltage by using a voltage detector or a comparator circuit that compares the input voltage to a reference voltage. If the input voltage falls below the reference voltage, the UVLO circuit will disable the charging system until the voltage returns to an acceptable level. UVLO is an important safety feature in electric vehicle charging systems because it helps prevent damage to the charging system and the vehicle's battery. A few EV charging specific UVLO protection could be realized by:

Commonly implemented UVLO protection mechanisms include but not limited to:

- DC-DC converters: DC-DC converters are used to convert the voltage from the charging system to a level that is suitable for charging the EV's battery. They help to ensure that the voltage is delivered at the correct level and prevent overcharging or undercharging of the battery.
- Control circuits: Control circuits are used to monitor the operation of the charging system and trigger UVLO protection if any anomalies are detected. They help to ensure safe operation of the charging system and prevent damage to the EV or the charging infrastructure. Control circuits and DC-DC converters are essential components of electrified propulsion systems and in practice they are integrated within the on-board charging mechanism.

- Fuses and circuit breakers: Fuses and circuit breakers are used to protect the charging system and the EV from overcurrent and short circuits. They help to prevent damage to electrical components and ensure safe operation of the charging system.
- Voltage sensors: Voltage sensors are used to monitor the voltage levels in the charging system and trigger UVLO protection if the voltage drops below a certain threshold. They help to prevent damage to the charging system and ensure safe charging of the EV.

#### *4.2.3.2 Representative Part, Specifications, and Recommended Flow Mappings*

***Table Specification, reference composition and ecoinvent flows : UVLO***

| | **Voltage release auxiliaries-adjustable threshold (SE, 2020d)** |
|---|---|
| *Part* | Auxiliaries iMSU - A9A2650 |
| *Description* | It provides a protection of equipment against overvoltage on the electrical network (neutral conductor break) and voltage monitoring between phase and neutral conductors.<br>the phase/neutral voltage is exceed |
| *Weight [kg]* | 0.077<br>*0.095 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Electronic components* | 15.0% | printed wiring board, surface mounted, unspecified, Pb free | - | 1.16E-02 |
| *Silver* | 0.1% | silver | - | 9.50E-05 |
| *Stainless steel* | 0.7% | steel, chromium steel 18/8 | sheet rolling; metal working, average chromium steel product | 5.70E-04 |
| *Brass* | 5.0% | brass | Brass casting | 3.90E-03 |
| *Steel* | 5.8% | steel, low-alloyed | sheet rolling; metal working, average steel product | 4.47E-03 |
| *Ferrous alloys* | 7.7% | steel, low-alloyed | sheet rolling; metal working, average steel product | 5.99E-03 |
| *Copper* | 17.2% | copper, cathode | wire drawing; metal working, average copper product | 1.33E-02 |
| *PPS* | 1.8% | polyphenylene sulfide | injection molding | 1.43E-03 |
| *PBT* | 3.3% | polyethylene terephthalate, granulate, amorphous | " " | 2.57E-03 |
| *PC* | 3.7% | polycarbonate | " " | 2.85E-03 |
| *PA* | 39.3% | glass fiber reinforced plastic, polyamide, injection molded | " " | 3.04E-02 |
| | **100%** | | | **7.71E-02** |
| *Excluded packaging* | | | | |
| *Paper* | | *Corrugated board box* | | *6.65E-04* |
| *Cardboard* | | “ “ | | *1.71E-02* |
| | | | | *1.78E-02* |
| **For assembly input, refer section 4.3** | | | | |

### 4.2.4 Surge Protection Device (SPD)

#### *4.2.4.1 Typical Functions*

Surge protection devices help to protect the charging infrastructure, including the charging station and associated electrical components, from damage caused by voltage surges and transient spikes. Many jurisdictional standards and regulations mandate their inclusion within EV charging installations. These devices help to extend the lifespan of the charging infrastructure, reduce maintenance costs, ensure the safe and reliable operation of the EV, avoid costly non-compliance fines, and facilitate safe and efficient EV charging. Like other circuit protection devices, there are several variants and SPD options such as:

- Type 1 SPD: Type 1 SPDs are designed to protect against direct lightning strikes and other high-energy surges that can occur in outdoor environments. They are typically installed on the incoming power line to the charging station and provide high-level protection against transient surges.
- Type 2 SPD: Type 2 SPDs are designed to protect against lower-level surges that may occur in indoor or outdoor environments. They are typically installed at the service entrance or subpanel and provide intermediate-level protection against transient surges.
- Type 3 SPD: Type 3 SPDs are designed to protect against low-level surges that may occur within the charging station or in other electrical equipment connected to the charging system. They are typically installed at the device level and provide low-level protection against transient surges.
- Combination SPD: Combination SPDs combine two or more types of SPDs (e.g. Type 1 and Type 2) in a single device. They provide multiple levels of protection against transient surges and are often used in locations where high levels of surge protection are required.
- Modular SPD: Modular SPDs are designed to be installed in a modular fashion, allowing for easy expansion and modification of the surge protection system. They are often used in larger charging stations or in locations where the electrical system is subject to frequent changes.
- Active SPD: Active SPDs use electronic components to actively monitor the electrical system and provide surge protection as needed. They are often used in high-tech charging systems or in locations where advanced surge protection capabilities are required.

## 4.2.5 Contactor Relay (MCR)

### *4.2.5.1 Typical Functions*

Also known as mini contactor relays (MCR), these devices protect the charging station and the EV by controlling the flow of electrical power from the charging station to the EV's battery. Contactor relays are used to switch the power supply on and off to the EV charging station; connect and disconnect the EV from the charging station; regulate and control the charging rates; and interrupt the charging station in the event of an electrical fault and or overloads.

- AC and DC contactors: As the name implies, they are used in AC and DC charging stations respectively, with the latter being more suited for higher voltage and current ratings.
- Pre-charge contactors are used to gradually charge the EV's capacitors before the main contactor engages. This helps to protect the contactor from damage due to high inrush currents and ensure reliable operation.
- Load-sharing contactors are used in multi-port charging stations to distribute the electrical load between multiple ports. They help to ensure that the load is evenly distributed between the charging ports and prevent overloading of the electrical system.
- Auxiliary contactors are used to control other electrical components in the charging system, such as fans or lights. They are typically used in larger charging stations or in locations where additional electrical components are required.
- Solid-state contactors use semiconductor technology to switch the electrical load on and off. They are often used in high-tech charging systems or in locations where advanced control capabilities are required such as smart or flexible charging.

### *4.2.5.2 Representative Part, Specifications and Recommended Flow Mappings*

In this report, the modeled inventory uses the EPD/PEP of an MCR with an integrated SPD (MCR-SPD) (ABB, 2020b). To account for the use case specific part number , the EPD/PEP weight (0.27 kg) is scaled by a factor of 2.05 based on the equivalent and recommended part number's weight of 0.556 kg (Siemens, 2022)

**Table 8 Specification, reference composition and ecoinvent flows: MCR integrated SPD**

| | **MCR integrated SPD (ABB, 2020b; Siemens, 2022)** |
|---|---|
| *Part* | NF22E-11 |
| *Description* | NF contactor relays are used for switching auxiliary and control circuit. Thanks to the AF technology, contactors and contactor relays accept a wide control voltage range (24...500 V 50/60 Hz and 20...500 V DC) with only 4 coils managing large control voltage variations, reducing panel energy consumptions and ensuring distinct operations in unstable networks. Furthermore, surge protection is built-in, offering a compact solution. |
| *Weight [kg]* | 0.556<br>*0.012 (including packaging)* |

| *EPD Information* | | *Recommended market activity, GLO or RER* | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Steel* | 40.0% | steel, low-alloyed | sheet rolling; metal working, average steel product | 2.22E-01 |
| *Copper and copper alloys* | 19.3% | brass | Brass casting | 1.07E-01 |
| *Stainless steel* | 0.9% | steel, chromium steel 18/8 | sheet rolling; metal working, average chromium steel product | 5.11E-03 |
| *Precious metal* | 0.6% | silver | - | 3.34E-03 |
| *PA* | 36.6% | glass fiber reinforced plastic, polyamide, injection molded | | 2.03E-01 |
| *PCBA* | 2.5% | printed wiring board, surface mounted, unspecified, Pb free | | 1.39E-02 |
| *Other* | 0.1% | polyethylene, low density, granulate | injection molding | 5.68E-04 |
| | **100%** | | | **5.56E-01** |
| *Excluded Packaging* | | | | |
| Paper | | *corrugated board box* | | *6.65E-04* |
| Cardboard | | *corrugated board box* | | *1.71E-02* |
| | | | | *1.78E-02* |
| **For assembly input, refer section 4.3** | | | | |

## 4.2.6 EV Charging Controller (EVCC)

### *4.2.6.1 Typical Functions*

Functionalities of an EVCC is synonymous with EV charging or load management systems that help manage the flow of electricity to the vehicle, monitor the battery charge level, and provide data on energy usage and costs. is responsible for communicating with the vehicle to determine the optimal charging rate and to ensure that the battery is not overcharged or damaged. Electricity grids are designed to supply power to meet the peak demand during the day, which typically occurs in the late afternoon or early evening when people return home from work and turn on their appliances. If many EVs were to start charging during this peak period, it could put a strain on the grid and potentially cause blackouts or brownouts. An effective charging load management via the EVCC helps to avoid this problem by distributing the charging load more evenly throughout the day. It can do this by scheduling EV charging during off-peak periods when demand for electricity is lower, or by adjusting the charging rate in real-time to match the available capacity on the grid.

By using an EV charging load management system, utilities can better manage their grid infrastructure, reduce the need for costly grid upgrades, and avoid overloading the grid during peak periods. At the same time, EV drivers can avail reliable and efficient charging, whilst potentially benefiting from lower electricity rates during off-peak periods. These instances highlight the collective benefits of EVCC for not just the charging station and or the EV user but also for the utility grid and distribution system operators (DSOs). Some charging controllers or management systems can also provide features such as remote monitoring and control, billing and payment processing, and integration with renewable energy sources for net metering and feed-in tariff.

Now a days, EVCCs are by default included within charging station installation plans especially for public charging facilities for charging multiple EVs simultaneously for price based demand response programs such as the time-of-use (ToU), real-time pricing (RTP), critical peak pricing (CPP), fleet EV charging management, ensure seamless payment and billing. An EVCC is necessary when the EVSE and the infrastructure is designed to charge multiple EVs, though for a single residential wall box charger such as the one discussed in section 4.1.2.1, an EVCC is not required whereas for a floor standing EVSE in section 4.1.2.2 provided it is designed to charge more than 2 EVs, an EVCC is optional though highly recommended.

#### 4.2.6.2 *Representative Part, Specifications and Recommended Flow Mappings*

***Table 9 Specification, reference composition and ecoinvent flows: EVCC***

| | **EV Charging Controller (SE, 2020c)** |
|---|---|
| *Part* | Harmony Industrial PC - HMIBSCEA53D1L0T |
| *Description* | Harmony iPCs (formerly known as Magelis iPC) and Edge Box run at the Edge Control level of Ecostruxure, the Schneider Electric IIoT architecture. They enable secured communication from shop floor to IT, improving profitability and offering new business opportunities through enhanced asset performance for more efficient operation and maintenance of capital assets. They offer smart application design and engineering to leverage asset performance, with end-to-end cybersecurity |
| *Weight [kg]* | 0.947<br>*1.21 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *Steel* | 57.6% | steel, low-alloyed | sheet rolling; metal working, average steel product | 5.46E-01 |
| *Electronic components* | 18.0% | printed wiring board, surface mounted, unspecified, Pb free | - | 1.70E-01 |
| *PC* | 0.3% | polycarbonate | injection molding | 3.31E-03 |
| *PS* | 7.0% | polystyrene, general purpose | "" | 6.61E-02 |
| *PE* | 0.5% | polyethylene, low density, granulate | "" | 4.41E-03 |
| *Aluminium* | 16.5% | aluminium, wrought alloy | sheet rolling/extrusion; metal working, average aluminium product | 1.57E-01 |
| *Battery* | 0.13% | battery cell, Li-ion | - | 1.20E-03 |
| | **100%** | | | **9.47E-01** |
| *Excluded Packaging* | | | | |
| PS | | *Polystyrene (general purpose)* | | *1.89E-01* |
| Cardboard | | *corrugated board box* | | *7.36E-02* |
| | | | | *2.63E-01* |
| **For assembly input, refer section 4.3** | | | | |

### 4.2.7 Smart Energy Meter (METR)

#### 4.2.7.1 *Typical Functions*

A separate EV meter may be desirable under certain circumstances for billing, load management, utility incentives and installation readiness reasons. For example, a new EV owner interested in installing a dedicated home charging station may opt for a separate EV meter for billing validation, familiarize with the technology and adjusting his/her charging behavior. A separate EV meter is also suited for cases where the existing electrical wiring system must be upgraded and retrofitted to install the home charging station. Lastly utilities could also use the separate EV meter installation status as an eligibility criteria for enrolling in their EV incentive programs. Installing an EV-use meter and an EVCC provides Cascading benefits and broader functional capabilities can be achieved by installing the EVCC together with an EV-use meter.

#### *4.2.7.2 Representative Part, Specifications and Recommended Flow Mappings*

***Table 10 Specification, reference composition and ecoinvent flows: METR***

| | **Three Phase Energy Meter (SE, 2020b)** |
|---|---|
| *Part* | Acti9 iEM3000 series Energy Meter |
| *Description* | The Acti 9 iEM3000 Series Energy Meter is a cost-attractive, competitive range of DIN rail-mounted meters ideal for sub-billing and cost allocation applications, which provides direct measurement up to 63A in 3-phase circuits,or is designed for measurement with 1A/5A inputs (CTs) in 3-phase circuits. |
| *Weight [kg]* | 0.37<br>*0.432 (including packaging)* |

| ***EPD Information*** | | ***Recommended market activity, GLO or RER*** | | |
|---|---|---|---|---|
| ***Material*** | **Weight [%]** | **Recommended _material_flows_e3.91** | **Recommended _transformation_flows_e3.91** | **Amount [kg]** |
| *PC* | 35.5% | polycarbonate | injection molding | 1.31E-01 |
| *PA* | 0.1% | glass fiber reinforced plastic, polyamide, injection molded | " " | 4.32E-04 |
| *Steel* | 10.7% | steel, low-alloyed | sheet rolling; metal working, average steel product | 3.97E-02 |
| *Copper* | 10.8% | copper, cathode | wire drawing; metal working, average copper product | 4.02E-02 |
| *LCD Screen* | 2.2% | glass, for liquid crystal display | liquid crystal display, minor components, auxilliaries and assembly effort | 8.21E-03 |
| *Electronic cards* | 19.0% | printed wiring board, surface mounted, unspecified, Pb free | | 7.04E-02 |
| *Elastomer* | 0.7% | styrene-acrylonitrile copolymer | - | 2.59E-03 |
| *PUR* | 0.1% | polyurethane, flexible foam | injection molding | 4.32E-04 |
| *PET* | 20.6% | polyethylene terephthalate, granulate, amorphous | " " | 7.65E-02 |
| | **100%** | | | **3.70E-01** |
| *Excluded Packaging* | | | | |
| Cardboard | | *corrugated board box* | | *6.22E-02* |
| | | | | *6.22E-02* |
| **For assembly input, refer section 4.3** | | | | |

## 4.2.8 Charging Cable (CABL)

#### *4.2.8.1 Typical Functions*

The purpose of an electric vehicle (EV) charging cable is to connect the electric vehicle to a charging station, allowing the vehicle's battery to be charged with electricity. The cable must be capable of transmitting the required amount of electrical power to charge the battery, which can range from a few kilowatts for a home charging station to several hundred kilowatts for a fast charging station. Charging cables are designed with safety in mind, to protect against electric shock, short circuits, and other hazards. The cables typically include features like insulation, grounding, shielding, and jacketing, which improve their durability to withstand the rigors of daily use such as weather, temperature changes, and overall stressors—physical, electrical, mechanical

Electric vehicle (EV) charging cables are typically manufactured using a combination of materials and processes to ensure their durability, reliability, and safety. Here is an overview of the general steps involved in the manufacturing of EV charging cables:

- Conductor Stranding: The first step in the manufacturing process is to strand the copper or aluminum conductors that will transmit the electric power to the vehicle. This process involves twisting multiple thin wires together to form a single, thicker conductor.
- Insulation Extrusion: Once the conductors are stranded, they are coated with insulation material. The most common insulation materials for EV charging cables are thermoplastic elastomers (TPE) or cross-linked polyethylene (XLPE). These materials are extruded onto the conductor using a process called insulation extrusion, which involves melting the insulation material and then extruding it over the conductor.
- Shielding: After the insulation has been applied, a layer of shielding is often added to protect the cable from electromagnetic interference (EMI). The shielding can be made of materials like copper or aluminum foil, or it can be braided with fine wires.
- Jacketing: The final step in the manufacturing process is to add a protective jacket over the cable. The jacket is typically made of a durable, weather-resistant material like PVC or TPE. It protects the cable from environmental factors like heat, cold, moisture, and sunlight.

#### *4.2.8.2 Representative Part, Specifications and Recommended Flow Mappings*

Given the lack of 1-1 or comparable mapping possibilities between a generalized charging cable manufacturing and the ecoinvent dataset, *cable, three-conductor cable* is used to model the charging cable. A few additional parametrization rationale for selecting the standard reference part within ecoinvent for modeling the charging cable are:

- the copper intensity (kg/m or Cu % of total cable) in the simplified representation (50%) and commercial product (between 50–65% Cu) might be of concern in the case of only DC charging, since there are over dozen configurations of the cable assembly by number of cores, diameter (IEC, 2017b).
- Copper intensity of *cable, three conductor* reference part in ecoinvent is 60 g/m and in its commercial equivalent—Helupower® Charge, copper content varies between 48–82 g/m for AC charging (Helukabel, 2021b).
- Ecoinvent flow representation captures all the key steps discussed in section 4.2.8.1

For the purposes of this report, the standard ecoinvent reference part sufficiently represents its commercially available equivalent. A standard charging cable is 7-8 m or roughly 25 feet (Leoni, 2018). A scaling factor of 1.25 is adopted based on commercially available EV charging cable specifications as a reasonable approximation allowing the extra length for outdoor charging. The effective length of charging cable is therefore assumed 10 m.

## 4.3 Electrical Equipment Production

In sections 4.1-4.2, composition data and the intermediate material transformations were discussed and tabulated. These transformed materials may have to undergo one or more of further transformations and then be assembled, packaged and made ready for shipment to the installation site as a finished part or product subsequently assembled as a finished part or product, packaged and ready to be shipped to the installation site. As discussed earlier in the ecoinvent flow mapping assumptions, the absence of a detailed manufacturer provided bill of materials, primary and secondary supplier activities, nature, type and number of transformations stages raw materials have to undergo up to and including the final assembly stage, a few additional assumptions have been made in order to complete the inventory modeling.

For this purpose, publicly available environmental report of a company that manufactures the type and range of parts covered in this report for residential EV charging infrastructure installations is utilized as proxy indicators of assembly and processing inputs. Mitsubishi Electric Corporation (MELCO)—a global manufacturer of electrical and electronic products for home, building, energy, automotive, rolling stock and information and communication systems (ICT) was chosen (MELCO, 2023). It's most recent sustainability report (MELCO, 2022) provides aggregate estimates of a variety of material balance, energy, emissions, waste and water indicators assessed in accordance with the Global Reporting Initiative (GRI) standards (GRI, 2018). Three-year average (2019-2021) estimates is then normalized and reported on a per kg of product basis.

The following assumptions, observations and inferences support the above strategy for tackling the assembly and finished product stage data gaps.

- All raw materials required are brought together and assembled in the same factory
    - The EPD/PEPs analyzed in this report are from global electrical and electronic equipment manufacturers whose major assembly lines and factories as well as headquarters are EU-based. Their assembly lines and their parent companies are strongly committed to carbon neutrality[a], electrification and a dominant supplier of low voltage products and systems, which covers all parts and products inventoried in this report. Apart from adopting lean-manufacturing, one-piece continuous flow assembly line and smart factory[b], different components, sub-assemblies and semi-finished parts produced by suppliers for low voltage distribution system applications[c] like EV charging infrastructure, are routinely assembled on the same manufacturing line and in the same site by taking advantage of the commonality among different products—raw materials, functionality and use-case.
- Reconciling geographical differences between specific low voltage product and system factory location, proxied assembly line data and the eventual installation and use-case
    - ABB's Vaasa in Finland and or Dalmine in Italy is assumed to be the ideal location where the core manufacturing of all components, sub-assemblies, semi-finished parts and subsequent transformation occurs including and up

[a] https://new.abb.com/news/detail/90095/italian-factory-sets-the-benchmark-for-carbon-reductions
[b] https://www.bta.bg/en/news/economy/374295-factory-of-the-year-2022-title-goes-to-schneider-electric-s-smart-factory-in-plo
[c] Less than 1 kV, ~240-600 VAC

to the final finished product that is assembled, packaged and ready to be transported. For the purposes of completion, the complete charging infrastructure is assumed to be installed and operated in Sweden.

- The impact of product portfolio mix on material, energy, emission and waste indicators is critical determinant of whether the data collected from MELCO is a reasonable proxy for the desired EU site. Background system variations can be accommodated in a full LCA model through sensitivity studies and scenario analysis and as such out of scope of this LCI report. MELCO manufacturers low voltage product systems in part or whole essential for the complete charging infrastructure. For the selective indicators most pertinent to this report, the collected assembly line data is an acceptable proxy, notwithstanding MELCO's environmental data possibly reported from manufacturing and assembly lines predominantly situated in Asia (mainly Japan).

Table 11, Table 12 and Table 13 summarizes select input, output and water use indicators respectively, reported by MELCO (MELCO, 2022)

***Table 11 Manufacturing Input Indicators***

| *Category* | *Base Unit* | *2021* | *2020* | *2019* | *Average* |
|---|---|---|---|---|---|
| ***Manufacturing (Input)*** | | | | | |
| ■ ***Manufacturing*** | | | | | |
| *Materials (Weight of all products sold + Weight of packaging materials + Waste emissions)* | *kt* | 2420 | 2660 | 2820 | 2.63E+03 |
| ***Total energy input*** | ***10,000GJ*** | **1866** | **1957** | **2035** | **1.95E+03** |
| *Electricity* | *GWh* | 1733 | 1810 | 1874 | 1.81E+03 |
| *Traditional electric power* | *GWh* | 1708 | 1788 | 1852 | 1.78E+03 |
| *Electric power from renewable energy sources* | *GWh* | 25 | 22 | 22 | 2.30E+01 |
| *City gas* | *$m^3$* | 34890000 | 37180000 | 39910000 | 3.73E+07 |
| *LPG* | *t* | 3725 | 3617 | 3674 | 3.67E+03 |
| *Oil (crude oil equivalent)* | *kl* | 2813 | 3806 | 3917 | 3.51E+03 |
| *Other greenhouse gases* | *t* | 6720 | 7611 | 8237 | 7.52E+03 |
| *Water usage* | *$m^3$* | 14890000 | 15710000 | 15410000 | 1.53E+07 |
| *Intake* | *$m^3$* | 10350000 | 11060000 | 10900000 | 1.08E+07 |
| *Reuse* | *$m^3$* | 4550000 | 4650000 | 4500000 | 4.57E+06 |
| *Chemical substances* | | | | | |
| *Controlled chemical substances (amounts handled)* | *t* | 3727 | 3731 | 4231 | 3896 |
| *Volatile organic compounds* | *t* | 2408 | 2664 | 2777 | 2616 |
| *Average reduction rates of resource inputs* | | 43% | 42% | 42% | 42% |

*Table 12 Manufacturing Output, Emissions and Waste Indicators*

| Category | Base Unit | 2021 | 2020 | 2019 | Average |
|---|---|---|---|---|---|
| ***Manufacturing (Output)*** | | | | | |
| ***■ Products*** | | | | | |
| *Weight of all products sold*5* | *kt* | 2111.00 | 2303.00 | 2390.00 | 2.27E+03 |
| *Weight of packaging materials* | *kt* | 124.00 | 149.00 | 210.00 | 1.61E+02 |
| *Japan* | *kt* | 56.00 | 62.00 | 63.00 | 6.03E+01 |
| *Overseas* | *kt* | 68.00 | 87.00 | 150.00 | 1.02E+02 |
| | ***kt*** | **2235.00** | **2452.00** | **2600.00** | **2.43E+03** |
| ***■ Emissions (from manufacturing)*** | | | | | |
| *Emissions into the atmosphere* | | | | | |
| *Greenhouse gas emissions (CO2-equivalent)* | *kt-CO2* | 1160.00 | 1236.00 | 1290.00 | 1.23E+03 |
| *CO2* | *kt-CO2* | 1039.00 | 1086.00 | 1130.00 | 1.09E+03 |
| *Other greenhouse gases* | *kt-CO2* | 121.00 | 150.00 | 160.00 | 1.44E+02 |
| *Chemical substances* | | | | | |
| *Controlled chemical substances* | *t* | 814.00 | 791.00 | 881.00 | 8.29E+02 |
| *Volatile organic compounds* | *t* | 792.00 | 946.00 | 999.00 | 9.12E+02 |
| *NOx* | *t* | 25.00 | 83.00 | 141.00 | 8.30E+01 |
| *SOx* | *t* | 1.00 | 1.00 | 1.00 | 1.00E+00 |
| *Discharge into water* | | | | | |
| *Water* | *m³* | 8160000.00 | 8640000.00 | 8580000.00 | 8.46E+06 |
| *Chemical substances* | | | | | |
| *Controlled chemical substances* | *t* | 8.00 | 8.00 | 8.00 | 8.00E+00 |
| *BOD* | *t* | 101.00 | 98.00 | 95.00 | 9.80E+01 |
| *COD* | *t* | 109.00 | 131.00 | 153.00 | 1.31E+02 |
| ***■ Waste*** | | | | | |
| *Emissions* | *t* | 187137.00 | 210168.00 | 212752.00 | 2.03E+05 |
| *Non-hazardous waste* | *t* | 181689.00 | 197560.00 | 205530.00 | 1.95E+05 |
| *Hazardous waste* | *t* | 5448.00 | 12607.00 | 7222.00 | 8.43E+03 |
| *Waste treatment subcontracted out* | *t* | 101605.00 | 110954.00 | 112196.00 | 1.08E+05 |
| *In-house weight reduction* | *t* | 757.00 | 550.00 | 457.00 | 5.88E+02 |
| *Amount recycled* | *t* | 147258.00 | 159340.00 | 172767.00 | 1.60E+05 |
| *Final disposal* | *t* | 121.00 | 311.00 | 404.00 | 2.79E+02 |
| *Japan* | *t* | 28.00 | 16.00 | 4.80 | 1.63E+01 |
| *Overseas* | *t* | 93.00 | 295.00 | 399.00 | 2.62E+02 |
| *Final waste disposal ratio (Japan)* | | 0.00 | 0.00 | 0.00 | 0 |
| *Final waste disposal ratio (Overseas)* | | 0.00 | 0.00 | 0.01 | 0 |

*Table 13 Water intake, discharge, and net use indicators*

| Category | Base Unit | 2021 | 2020 | 2019 | Average |
|---|---|---|---|---|---|
| ***Amount of Water Intake/Drainage/Reuse*** | | | | | |
| ***Water usage (water intake plus reuse)*** | *10000m3* | 0.00 | 0.00 | 0.00 | 1534 |
| *Intake* | | 1035.00 | 1106.00 | 1090.00 | 1077 |
| *Surface water* | | 300.00 | 330.00 | 355.00 | 328 |
| *Groundwater* | | 519.00 | 536.00 | 495.00 | 517 |
| *Seawater* | | 0.00 | 0.00 | 0.00 | 0 |
| *Water discharged during development/mining processes* | | 0.00 | 0.00 | 0.00 | 0 |
| *Water purchased from third parties* | | 216.00 | 240.00 | 240.00 | 232 |
| *Drainage volume* | | 816.00 | 864.00 | 858.00 | 846 |
| *Surface water* | | 398.00 | 407.00 | 383.00 | 396 |
| *Groundwater* | | 4.30 | 3.30 | 1.40 | 3 |
| *Seawater* | | 0.00 | 0.00 | 0.00 | 0 |
| *Water discharged into third-party drainage facilities* | | 413.00 | 453.00 | 474.00 | 447 |
| *Water reused* | | 455.00 | 465.00 | 450.00 | 457 |
| *Water consumption (water intake minus drainage volume)* | | 219.00 | 242.00 | 232.00 | 231 |
| *Reuse ratio (reused/used) (%)* | | 31% | 30% | 29% | 30% |
| *Water usage per unit of sales (Water usage/sales) (m³/million yen)* | *10000m3* | 3.55 | 3.52 | 3.41 | 3 |

Table 14 presents the per kg of product normalized indicators estimated homogenously applied for proxying the assembly process and all self-contained efforts.

*Table 14 TBD final AN calc*

# 5 DISCUSSION

## 5.1 STUDY LIMITATIONS AND FUTURE WORK

Data Quality and Uncertainty

Representativeness

— Technology Representativeness

— Geographical Representativeness

— Temporal Representativeness

Completeness

## 5.2 FUTURE WORK

This report presented an approach to systematically develop a life cycle inventory of residential EV charging infrastructure. The developed LCI serves as a reliable foundation for exploring future research questions including but not limited to:

- Assessing the environmental impacts associated with the production, use, and disposal of a home charger for electric vehicles.
- Identifying the key materials and components used in the production of a home charger for electric vehicles and evaluate their environmental impacts throughout the life cycle.
- Quantify the energy consumption and greenhouse gas emissions associated with the production, use, and disposal of a home charger for electric vehicles.
- Compare the environmental impacts of different types of home chargers for electric vehicles by incorporating spatiotemporal aspects of charging.
- Provide recommendations for reducing the environmental impacts of home chargers for electric vehicles, such as improving the efficiency of the charging process or using more sustainable materials in production.
- Better inform policymakers, manufacturers, and consumers about the environmental implications of home chargers for electric vehicles and support the development of more sustainable and eco-friendly solutions for charging electric vehicles at home.

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# APPENDIX A: SUPPLEMENTAL INFORMATION