Measuring and Reporting the Carbon Footprint of Electric Freight Vehicle Operations

Whitepaper

January 2024

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About Smart Freight Centre

Smart Freight Centre is an international non-profit organization focused on reducing greenhouse gas emissions from freight transportation. Smart Freight Centre's vision is an efficient and zero emission global logistics sector. Smart Freight Centre's mission is to collaborate with the organization's global partners to quantify impacts, identify solutions, and propagate logistics decarbonization strategies. Smart Freight Centre's goal is to guide the global logistics industry in tracking and reducing the industry's greenhouse gas emissions by one billion tonnes by 2030 and to reach zero emissions by 2050 or earlier, consistent with a 1.5°C future.

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Executive Summary

The 'Measuring and Reporting the Carbon Footprint of Electric Freight Vehicle Operations: Whitepaper' is part of Smart Freight Centre's series on road freight electrification, which addresses the practical challenges of designing, implementing, and assessing the impacts of an electrification roadmap.

This whitepaper provides supplementary guidance on calculating operational emissions from electric vehicles, in alignment with the requirements and guidelines provided by ISO 14083, the global standard for emission calculation in transport chains.

Electric vehicles play a vital role in significantly reducing greenhouse gas emissions from road freight, decoupling driving from energy production through innovative traction battery packs. With an anticipated emission intensity reduction of up to 85% in low-carbon electricity countries, EVs surpass traditional fuel alternatives, making them essential for achieving sustainable and low-emission logistics.

Accurate emission measurement is vital for integrating electric vehicles (EVs) into operations and embedding them in the wider logistics ecosystem, requiring precise reporting to meet industry standards. The whitepaper, aligned with ISO 14083 and GLEC Framework v3, focuses on guiding the measurement and reporting of operational emissions from electric freight vehicles within established greenhouse gas emission frameworks, assuming a foundational understanding of ISO 14083. Additional guidance is needed in the industry especially due to the complex nature of EV charging behavior and strategy, the technical challenge related to charging infrastructure, and the unique requirements for electricity emission factors in the ISO 14083.

The whitepaper covers the following topics:

- Overall reporting rules for logistics GHG emissions from EVs, based on GHG Protocol standards and ISO 14083.
- Considerations when selecting electricity GHG emission factors, including emission categories, market-based measures, and data sources.
- Steps to quantify GHG emissions from an EV fleet operation, encompassing electricity consumption, energy intensity factors, and aggregated emission factors, including charging infrastructure losses, based on ISO 14083.

The proposed approach in the whitepaper aims to address the influence of the following factors in complicating the identification and derivation of an energy provision emission factor. Explicitly, the influences on the energy provision emission factors are:

- the average grid electricity mixes of countries where charging activity takes place,
- average energy contribution by behind-the-meter power generation, such as the facility's solar panels, and
- the on-site electrical and charging infrastructure layout (see Figure below).

Potential data types:

Metered energy consumption

Charging activity data

Vehicle telematics data or energy intensity factor

On-site power generation

Own electricity

Own consumption Meter

Energy grid connection

Grid electricity

Building/facility Meter

Supply to charging station

Charging station

Supply to battery

Electric truck and fleet

Lifecycle stage of energy: Energy provision (Well-to-tank) | Operational (Tank -to-wheel)

Illustration of electrical pathway through the on-site electrical and charging infrastructure.

The whitepaper concludes by highlighting certain industry standardization challenges.

- Lack of clarity over the use of the market-based method (e.g., using the emission factor of renewable energy explicitly purchased through energy attribute certificates market) by freight buyers.

- The limited availability and accessibility of an electricity emission factor databases covering all ISO 14083-required emission categories and for all relevant locations.

- The omission of losses from on-site electrical and charging infrastructure, affecting both the energy intensity factor of the vehicle and the resulting emission intensity factor of electricity use in EV operations, in the ISO 14083 standard.

It emphasizes the need for collaboration, leveraging primary data and innovative approaches to achieve standardization and practical impact in energy lifecycle reporting for global transport emissions. The ongoing efforts by Smart Freight Centre to address challenges and provide a path for standardization are crucial, inviting organizations, trade associations, and governments to unite in driving significant improvements in emission performance within the logistics sector. Taking decisive action is essential for a sustainable and emission-conscious future.

1   Introduction

The 'Measuring and Reporting the Carbon Footprint of Electric Freight Vehicle Operations: Whitepaper' is part of Smart Freight Centre's series on road freight electrification, which addresses the practical challenges of designing, implementing, and assessing the impacts of an electrification roadmap.

Electric vehicles (EV) play a crucial role in reducing greenhouse gas emissions from the road freight sector. Unlike internal combustion engine trucks, EVs use a traction battery pack to store electricity, effectively separating driving activity from energy production. This not only eliminates tailpipe emissions but also provides a lower lifecycle emission factor based on a much higher primary energy efficiency and allowing for the widespread use of renewable energy. As Figure 1 illustrates, EVs could achieve an average emission intensity reduction in the EU of about 35% and up to 85% in countries with low-carbon electricity. There is similar emissions reduction potential in the US as well, with the reduction potential expected to increase year on year due to the regional increase in renewable energy. In comparison, HVO100, itself an excellent low-carbon fuel with a potential reduction of 71%, is only available in selected locations and limited quantities (Smart Freight Centre, 2022). In conclusion, EVs provide an excellent low emission transport service investment that will provide benefits in both the short and long term.

GHG emission reduction potential of major low-carbon fuels and powertrains
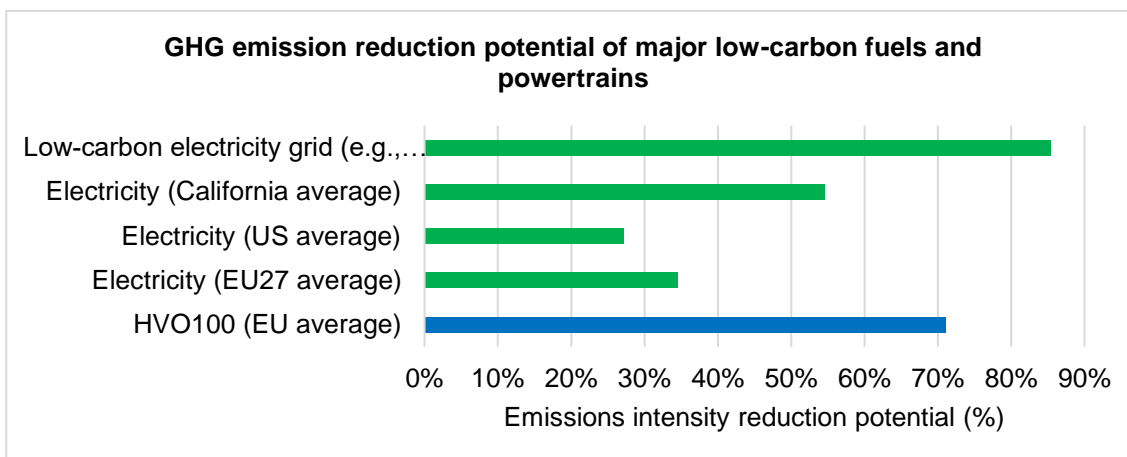
Figure 1 GHG emission reduction potential of different fuels and powertrains (Source: Own analysis based on Scarlat et al., 2022; Smart Freight Centre, 2023; US EPA, 2023)

Companies that have implemented EVs in their operations, whether directly or through subcontractors, need to understand, measure and report their emissions accurately. Electricity emissions can vary widely depending on how electricity is generated, and more confusingly, in the final representation mix of sources delivered to the end user. While emission from electricity have been used for a long time for logistics sites and rail transport, the charging behavior from EVs and electricity emission factors are expected to vary widely, as this paper will discuss. If EVs are to be used as an emission reduction solution, determining the correct emission factor is crucial. What constitutes a correct emission factor, however, is dependent on the purpose of the calculation and the reporting framework that is used.

In this pursuit, ISO 14083 "Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations" and guidance in the form of the GLEC Framework version 3, offer the general principles for the calculation and serve as a guide for the inclusion of emissions according to other reporting requirements, such as the GHG Protocol Scope 2 and Scope 3 standards. However, the use of EVs, the charging strategy, charging

electrical infrastructure, as well as the energy provision from grid or other distribution channels, introduces a new layer of complexity and variability that are not as established as the fuel energy provision.

1.1 Scope

This whitepaper aims to address how operational emissions from electric freight vehicles are to be measured and reported within the existing greenhouse gas emission disclosure frameworks, the GHG Protocol standards and ISO 14083. This document presents supplementary information to the GLEC Framework v3 and ISO 14083 specific to the calculation and reporting of GHG emissions from electric vehicles in logistics operations, and as such assumes that the reader has a general understanding of the approach used for emissions and emission intensity calculations according to ISO 14083. For guidance on how ISO 14083 is applied in the freight sector, the reader is directed to the GLEC Framework v3.

1.2 Document structure

This document provides guidance on how to report the greenhouse gas (GHG) emissions from electric vehicles (EVs) in logistics operations. It covers three main topics:

- The overall reporting rules of logistics GHG emissions from EVs, based on the GHG Protocol standards and ISO 14083.
- The general considerations when selecting electricity GHG emission factors, such as the electricity emission categories, the inclusion of market-based measures, and data sources.
- The step to quantifying the GHG emissions of an EV fleet operation, including the calculation of the electricity consumption and energy intensity factor, and the application of the aggregated emission factors including the losses from charging infrastructure.

2 Reporting rules of logistics GHG emissions from EVs

This section compares the reporting requirements that are relevant to EV operations in the GHG Protocol and the ISO 14083. The requirements present the framework and context in which emission reporting takes place. Both frameworks have similarities but as they have different aims and scopes there are important differences that need to be kept in mind.

2.1 Disclosure of GHG emissions according to the GHG Protocol Scope 2 guidance.

The GHG Protocol Corporate Standard classifies a company's GHG emissions into three scopes (Figure 2). The reporting of scope 1 emissions (i.e., emissions typically from the combustion of fuels from owned or controlled sources) and scope 2 emissions (i.e., indirect emissions from purchased energy consumed by the company) are required. Scope 3 emissions, which is a broad category that includes all other indirect emissions that occur in a company's value chain, is at this point optional, even if it offers the largest opportunities for GHG reductions.

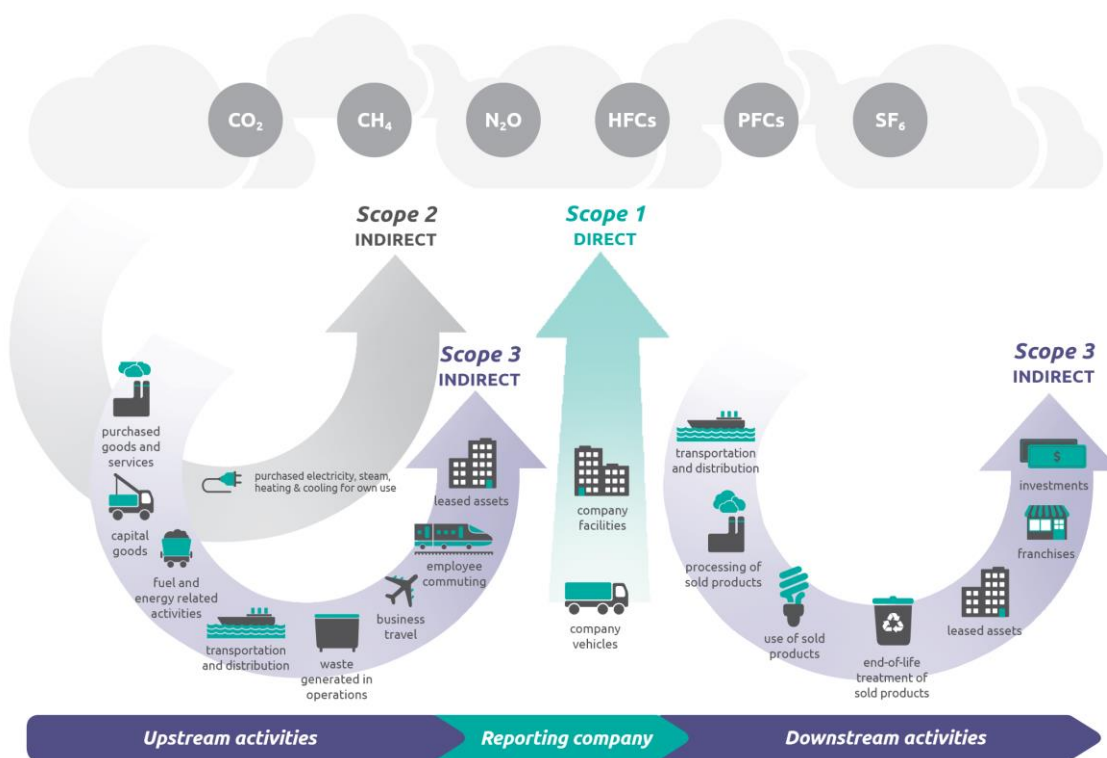**Figure 2 Overview of GHG Protocol scopes and emissions across the value chain (WRI & WBCSD, 2011)**

Emissions from EV operations are divided into different categories, depending on the electricity lifecycle emission categories, and the role of the reporting company. The electricity lifecycle categories included in the GHG Protocol are:

- "Power Generation", emission from the combustion of fuel to generate electricity.

- "Fuel production", emissions from upstream activities related to fuel production.
- Electricity "Transmission & Distribution" (T&D), emissions allocated to electricity losses due to the transmission and distribution of electricity, typically in the grid infrastructure.

EV operators are required to report emissions from "Power Generation" in scope 2, and may choose to report the emissions from "Fuel production" and T&D in scope 3 category 3 "Upstream fuel and energy-related activities".

Companies that have purchased the services of EV operators are only required to report the scope 2 emissions of their subcontractors in the scope 3 Category 4 "Upstream Transportation & Distribution" or Category 9 "Downstream Transportation & Distribution" (Smart Freight Centre & CDP, 2020). Strictly speaking, the scope 3 emissions only "include the scope 1 and scope 2 emissions of third-party transportation companies." (WRI & WBCSD, 2011, p. 44).

Table 1 provides a summary of the types of emissions related to EV operations that are accounted for under the different scopes.

Table 1 Emissions reporting for EV operations based on GHG Protocol

Reporting firm	Emission category
Buyer of EV services	Scope 3 Category 4 and 9 only includes amount of scope 2 emissions reported by carrier.
EV operator	Scope 2 for emission from power generation, that is emissions from fuel combustion at the power plant. For instance, the emission of solar power is zero.
EV operator	Scope 3 Category 3 from ▪ Fuel production, i.e., emissions from the extraction, production, and transportation of fuel. ▪ T&D, i.e., the Scope 2 emissions allocated to the electricity lost in transmission and distribution

The two **methods for calculating scope 2 emissions** according to the GHG Protocol Scope 2 Standard differ primarily in the type of electricity emission factor used.

- The **location-based method** uses a grid emission factor that reflects average emissions for energy consumption, based on generation as well as any net physical energy imports and exports, occurring within the time period and location of interest.
- In the **market-based method,** two types of emission factors are used. It allows for the use of a specific emission factor, associated contractually, to the purchase volume of low-carbon electricity or its attributes (e.g., renewable energy contract or guarantees of origin). The other electricity volume will be calculated using a **residual mix emission factor**, that represents the unclaimed power generation mix of that location. This would typically be close to a fossil fuel power generation emission factor (AIB, 2022) and higher than the location-based emission factor.

In both methods, **the scope 2 emissions are calculated** by multiplying the location-based or market-based emission factor by the metered electricity consumption in megawatt-hours (or kilowatt-hours).

The GHG Protocol requires reporting scope 2 emissions using the location-based method, and if relevant, using the market-based method under what they consider **dual or supplementary reporting**. In terms of purpose, the location-based method tracks the emissions of the energy sector within a geographic boundary (usually a country), whereas the market-based method tracks the purchasing choices of a single company. Another practical reason is to comply with different reporting programs, such as the RE100 (RE100, 2022).

Unfortunately, **disclosing Scope 3 based on Scope 2 using market-based reporting** is not explicitly discussed in any of the Scope 2 or Scope 3 standards. Hence, it is unclear whether a Scope 3 disclosure of an EV-based transport operation using, for instance renewable energy credits or even power purchase agreements, can be calculated based on the market-based emission factor. This issue is one of several that is being picked up in the current GHG Protocol round of consultation on Scope 2 and Scope 3 Standards and on market-based measures. Future versions may change how dual reporting is done.

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2.2   Reporting emissions according to ISO 14083

The ISO 14083:2023 is a **standard that provides a common methodology for the quantification and reporting of lifecycle GHG emissions arising from the operation of transport chains** of passengers and freight.

Emissions from vehicle operations in the ISO 14083 are divided into two major categories (ISO, 2023). The **vehicle operational GHG emissions** are released to atmosphere as a result of vehicle operations. The **vehicle energy provision GHG emissions** are released to atmosphere during the process of producing, storing, processing and distributing an energy carrier for vehicle operation.
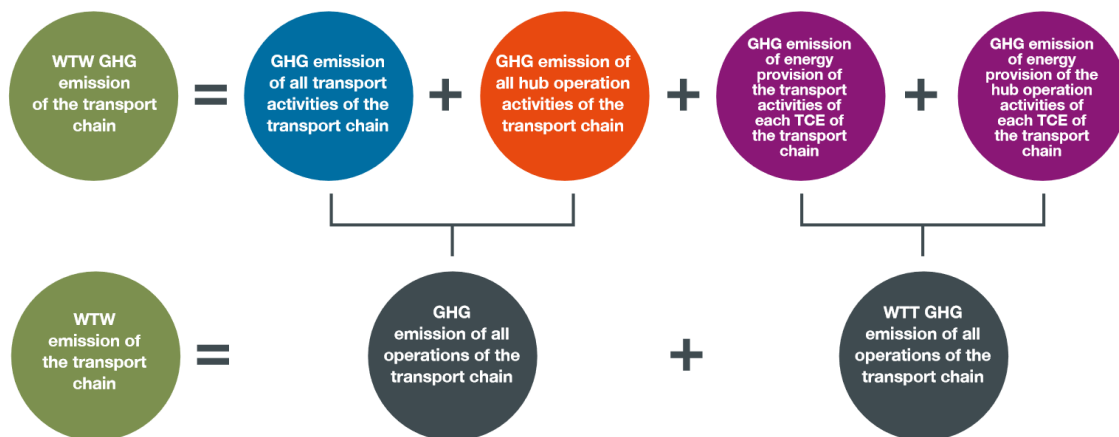
Figure 3 The ISO 14083 includes operational and energy provision emissions from all transport and hub operations (Smart Freight Centre, 2023a).

In the case of EV operations, the operational emissions are zero. Energy provision emissions, that is **emissions from provision of electricity**, includes all GHG emissions from "extraction, processing and transport of primary energy, power generation, power generation infrastructure, e.g., solar panel or wind turbine manufacture, grid losses associated with transmission and distribution of electricity." (ISO, 2023, p. 15) The emission from energy provision is reported together, with the exception of **emissions from power generation infrastructure, which may be reported separately**. Any methodological decision to omit an emission category must be clearly stated and justified in accordance with cut-off criteria outlined in the subclause 5.2.3 of ISO 14083.

ISO 14083 mandates that both transport service provider and transport service user **report the total emissions arising from both operational and energy provision activities**. Thus, both the fleet operator and the buyer of transport services must understand the type of electricity that was used in the operations to calculate the emissions.

ISO 14083 requires the location-based method (as introduced by the Scope 2 standard) to be used for calculating electricity energy provision emissions. In this method, the grid-average-emission factors should be based on the average consumption mix of the grid (i.e., the electricity generated taking into account net physical import and export of electricity).

The **optional market-based method can be used in dual-reporting**. While not explicitly stated, the ISO 14083 standard seems to allow for the emissions calculated using the market-based method to be reported by other entities besides the EV operator.

For example, if **the transport service operator** purchases a renewable energy certificate for the electricity used in the EV operation, the operator may **calculate two separate transport emissions and emission intensities**, corresponding to both the location and market-based methods. The **transport service user may then include both sets of emissions and emission intensities** in their ISO 14083 report.

2.3 Key differences between the standards

The ISO standard, which was built on the work done in the GLEC Framework, was designed to be aligned with the GHG Protocol. Hence, both reporting requirements hold common elements. However, there are several key differences between their reporting requirements emissions from EV operations.

These are briefly highlighted below.

- **Emission categories:**
  - ISO 14083 also includes the emissions from power generation infrastructure, albeit with the possibility of a separate reporting, or omissions, if justified. The implication is that non-fuel renewable energy sources (e.g., solar, wind and hydropower) also have emissions.
  - The GHG Protocol does not include this anywhere in the Scope 2 or Scope 3 standard.
- **Reporting responsibility and scopes:**
  - ISO 14083 mandates that both shipper and carrier are to include the total emissions from transport.
  - In contrast, the GHG Protocol Scope 2 is mandatory only for the electricity user/purchaser (e.g., fleet operator) and it only includes 'Power Generation' (i.e., Scope 1 of power generation companies). Other lifecycle emissions (i.e., upstream fuel and energy-related activities) are reported optionally as part of the Scope 3 disclosure.
- **The use of dual reporting by a buyer/user of a transport service:**
  - ISO 14083 allows for the possibility of dual-reporting (location-based and market-based methods) to be used by other companies besides the purchaser of electricity, i.e., outside scope 2.
  - GHG Protocol is not yet clear on the use of market-based method in the Scope 3 emissions. Further discussions with the community on their standard for reporting Scope 2, Scope 3 and Market-based Measures are being held.

3 Selecting electricity GHG emission factors according to ISO 14083

This section presents several considerations when it comes to selecting energy emission factors. The section begins with a general understanding of what is included in an electricity GHG emission factor, primarily based on what ISO 14083 requires to be included. Next, the section provides several trends based on the energy sector and policy that will change the current electricity landscape in the upcoming decade. The third sub-section presents several ways that companies may use to reduce their EV-based emissions, primarily based on market instruments. Finally, the section ends with a brief comparison of several notable emission factor sources.

3.1 Understanding GHG emissions from electricity

Figure 4 shows the different stages of electricity, as well as the upstream (fuel production) and combustion (power generation) emissions. As the figure shows, part of the electricity produced is used for own-use, load-balancing (e.g. by pumping) and for trade. The difference between the supplied and consumed electricity is due to transmission and distribution losses. It is important to understand the type of emission factor that is used and to apply a correction factor based on best available knowledge, or to disclose any deviations from the ISO 14083 requirement.
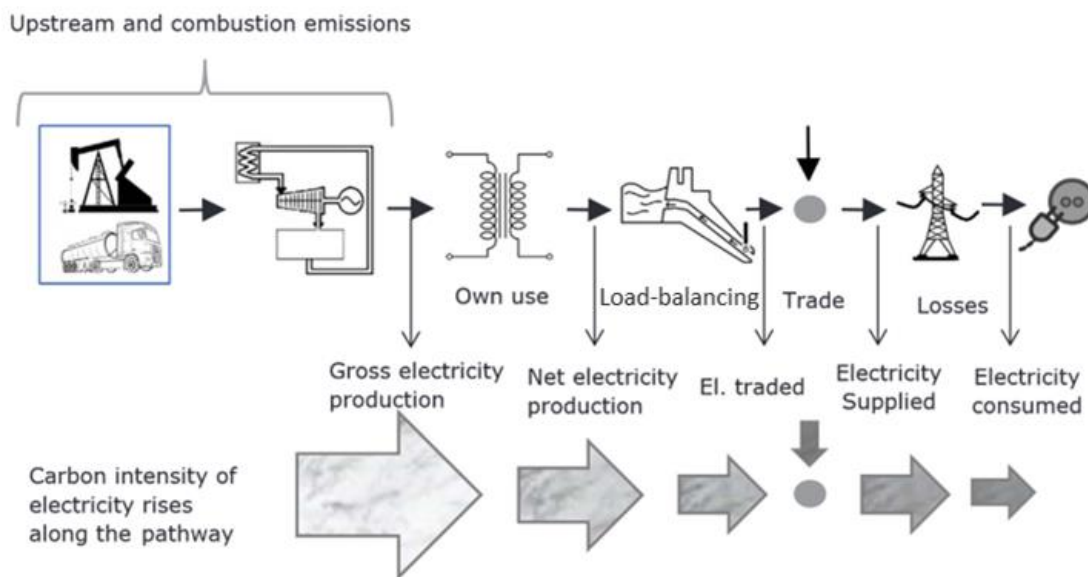
Figure 4 Carbon intensity from upstream activities to consumption (Moro & Lonza, 2018)

The **emissions from different types of energy sources** are presented in Figure 5. An electricity consumption mix that relies on fossil fuel-power generation will have a high emission factor. Renewables and nuclear are orders of magnitude lower than fossil-fuel power plants. The figure also shows why upstream emissions, which can be up to 100 gCO_2e/kWh for fossil fuels (or 10 to 20% of the total), should be included in the calculation.

On the other hand, **the emissions from renewable power generation infrastructure** range from 10 to 40 gCO_2e/kWh. The emissions only become a significant portion of the total when the share of renewable energy is high. To give an example of this significance, if the energy

consumption is based on half natural gas and half solar PV, the emissions from solar infrastructure would only constitute 9% of the total.
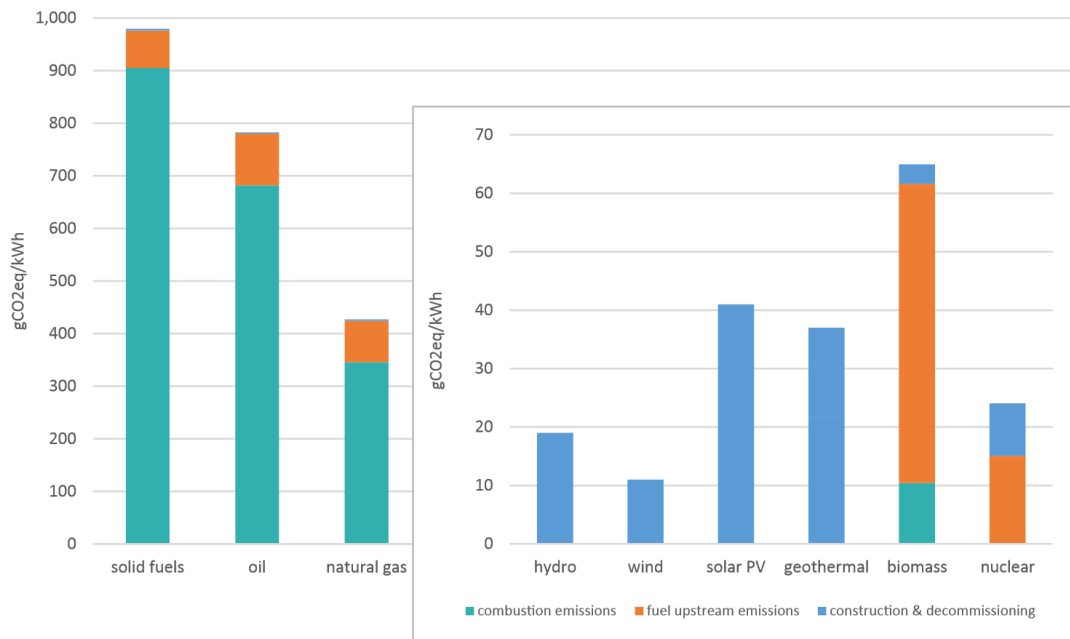
Figure 5 GHG emission factors from electricity producing facilities in EU27 (Scarlat et al., 2022)

The **trade of electricity** drastically changes the consumption emission factor, depending on the average power generation emission factor of the exporting and importing country. For instance, the electricity emission factor of Estonia in 2019 dropped by one third due to the import of predominantly low carbon electricity. The amount and type of energy traded can drastically change from year to year, such as when there is a shortage in natural gas.

Average transmission and distribution (T&D) losses are different depending on type of voltage distribution (i.e., low to high voltage grid connections). The final consumption at high and medium voltage sites are about 1 to 10% lower than at low voltage sites, which translates to about 1 to 78 g CO_2e per kWh of consumption. This is not an insignificant difference. The EU average is 3 to 4% and 15 to 19 g CO_2e per kWh of consumption. Nevertheless, most databases typically provide a national average for the T&D losses, which is suitable for emissions disclosure.

The final consumption emission factor provides the most appropriate basis to then compare the emissions intensity of an EV and diesel truck. Figure 6 provides a **country-level comparison for emissions from electricity consumption** in European countries in 2019 (Scarlat et al., 2022), as well as a comparison with the emission intensity of a diesel truck (Smart Freight Centre, 2019). The values include fuel production, power generation, infrastructure, trade, and transmission & distribution losses. The analysis shows that approximately half provide an electricity emission factor less than that of a diesel truck, and only 8 countries reduce emissions by at least 50%. An EV operating within the EU-27 would have an emission intensity reduction of 16%. In the US, based on eGRID subregion 2021, which do not include the effects of fuel production and infrastructure, only 3 out of 27 regions provide an emissions reduction of more than 25%.
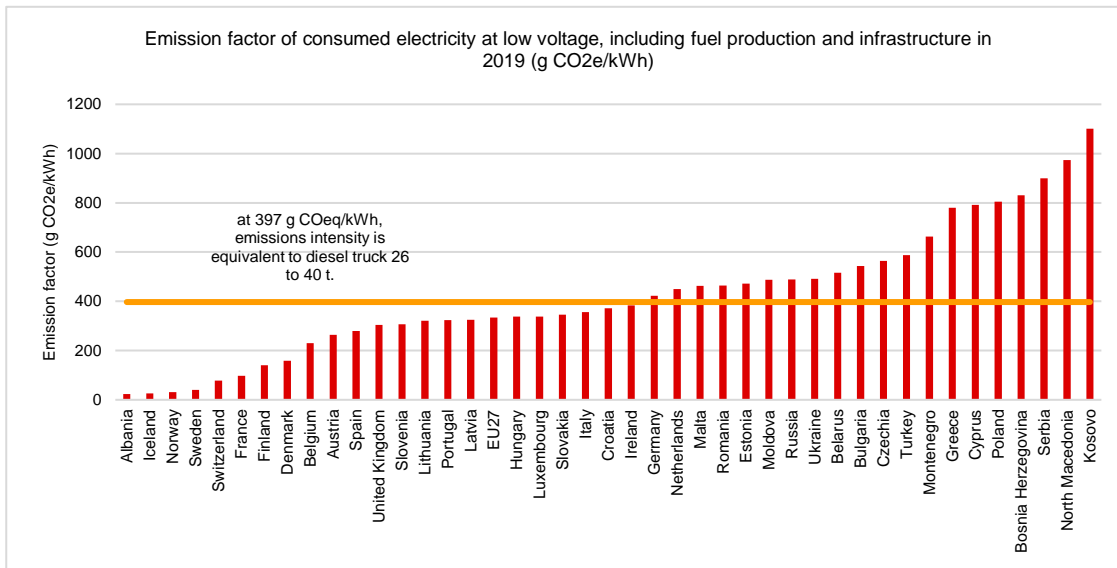
Figure 6 Full electricity emission factor for European countries in 2019 (Adapted data from Scarlat et al., 2022)

3.2   Grid electricity environmental performance trends

Globally, total emissions from the electricity sector have increased slightly in the past 3 years due to increased electricity generation, even as we see that emission intensity has reduced (IEA, 2023). In the US and European Union, emissions from the sector reduced slightly, driven by strong solar power performance. Nevertheless, these regions need to decrease much faster than before to meet its environmental commitments (https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1, accessed 24 August 2023).

One of the primary drivers in electricity decarbonization, which also has the sub-objective of reducing electricity prices, is policy. Different types of policies have been introduced to provide a long term, sustainable and stable pathway towards decarbonization. In the EU, the Renewable Energy Directive II has provided reduction targets for the energy sector of individual member states to achieve, as well as provided the basis for trading certificates (e.g., the Dutch Hernieuwbare Brandstof Eenheden) between suppliers to meet quotas (Schneider Electric, 2018). The proposed Renewable Energy Directive III (RED III) has the objective of RED III to increase the EU's binding renewable energy target for 2030 from 32% to 45%, in line with the European Green Deal and the goal of achieving climate neutrality by 2050[1]. Complementing the system is the EU's Emission Trading Scheme that provides a cap-and-trade mechanism for reducing emissions. In the US, the Inflation Reduction Act is expected to reduce the total emissions by more than 40% by 2030 (Roy et al., 2022), while demand is expected to increase.

In summary, it would appear that, at least in the EU and US, the electricity market looks set on moving in the right direction. However, for companies located in certain markets, it remains insufficient to make the short-term business and environmental case for electrification based on grid electricity emission factors.

3.3   Obtaining low-emission electricity or certificates

Several resources exist to support companies in making that transition, including the work conducted by RE100 (RE100, 2022). Four main approaches that companies can take to reduce electricity emissions compared to annual average grid emission factors are presented below,

based on IEA (2022) "Advancing Decarbonisation Through Clean Electricity Procurement". The purpose of listing them here is to illustrate the different options and to discuss their implications with respect to GHG emission disclosure. Companies should consider, together with specialist organizations, which approach should be taken, in alignment with their own goals and context.

On-site or "behind-the-meter" (BTM) generation: This is when companies invest in clean electricity generation to meet their own demand, such as installing solar panels on their rooftops or wind turbines on their premises. This option can reduce the company's reliance on the grid and lower their electricity bills, but it may also require additional investments in storage, backup, and grid connection. This reduces the energy demand from the grid and therefore reliance on the grid emission factor and would be considered under the 'location-based' method. Figure 7 illustrates how the GHG Protocol treats the additional power generation. In the ISO 14083, which disregards the scopes, an electricity emission factor for both the on-site generation and the grid must be applied for the volumes of electricity consumed respectively.
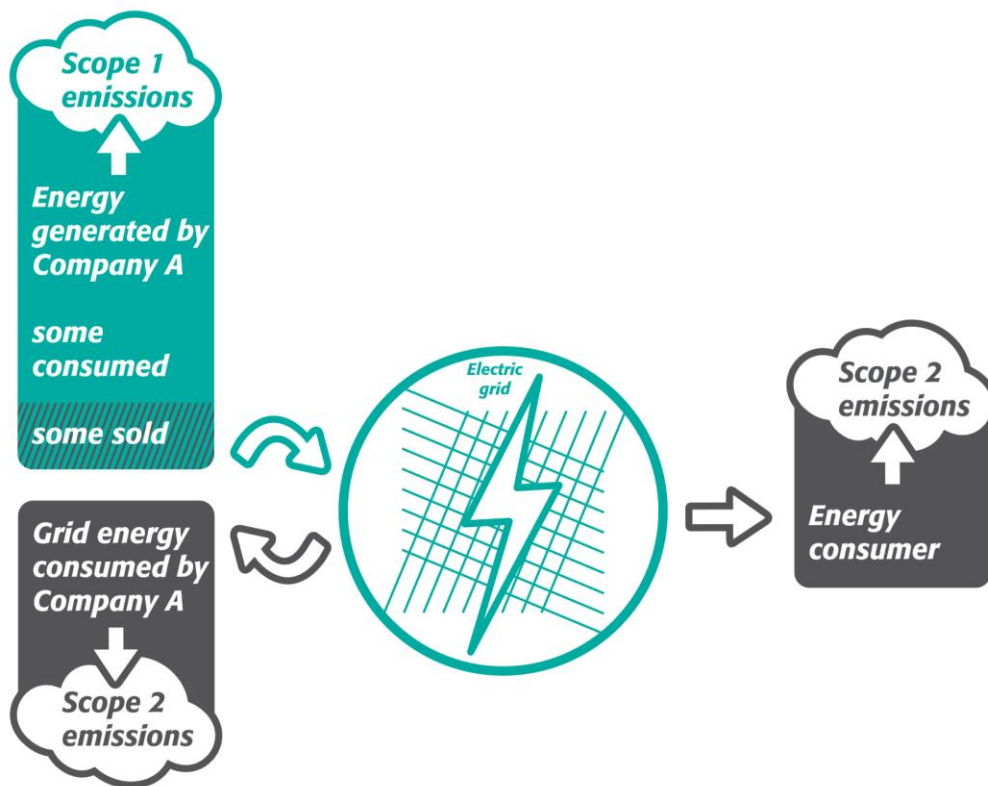
Figure 7 Facility consuming both energy generated on-site and purchased from the grid (Source: World Resources Institute, 2015)

Power purchase agreements (PPAs): These are long-term contracts between a consumer and an electricity producer, where the consumer agrees to buy a fixed amount of electricity at a fixed price for a fixed period. The producer can be either an existing or a new clean generator, and the contract can be either physical (where the electricity is delivered to the consumer) or virtual (where the electricity is sold to the grid and the consumer receives the price difference). While there may be a variety of different conditions, the physical PPA could be counted in the location-based method under the "Direct Line" category (WRI, 2015). The virtual approach, also called a finance PPA, would provide a renewable energy certificate and an associated emission factor eligible to be used in a market-based method. With the finance PPA, reporting using the location-based method will have to use the grid emission factor.

Green tariffs and green power products: These are short-term contracts for procurement of renewable electricity provided via the grid. The supplier-specific emission factors may be used in the market-based method, whereas reporting using the location-based method will have to use the grid emission factors.

Energy attribute certificates (EAC): These are tradeable credits that can include attributes such as type and time of generation. For example, a company can buy green electricity certificates (e.g. GOs in Europe or RECs in the US) to match its consumption with clean generation from existing plants. The emission factors associated with the EACs and the residual energy mix may only be used in the market-based approach. While these are typically used for annual matching, time-dependent EACs may be used for more granular matching of consumption and supply. This type of matching allows companies to adjust their charging activity to match periods of higher renewable energy availability (e.g., during the day, when solar PV is most effective). Note that the option to accept more granular time-dependent EACs is being considered in the current Scope 2 Guidance revision (WRI, 2023).

Energy procurement/generation	Method for reporting renewable energy attribute
On-site or BTM generation	Location-based
Power purchase agreements	Physical PPA: Location-based Financial PPA Market-based
Green tariffs and green power products	Market-based
Energy attribute certificates	Market-based

3.4   Emission factors and databases

Emission factors, used in both the location- and market-based methods, are subject to quality criteria stated in ISO 14083 "Annex J.3". However, obtaining the right emission factors, especially for the location-based method, is not simple. Table 2 compares several prominent databases. Regardless of the methodological selection, reporting entities are required to state clearly the emission factor source, why it was selected, what it includes, as well as provide reasons for any deviations from the requirements of ISO 14083.

The ISO 14083 standard recommends using the best available national GHG emission factors. For reporting entities with a global footprint, the IEA Emission Factor database, updated annually, would seem to be sufficiently practical. However, as the Table illustrates, it does not currently cover the full spectrum of emission categories. In our opinion its failure to include emissions from fuel production is its biggest deficiency. Another aspect to bear in mind that there is generally a 1 to 2 year lag in official data being published. This can become longer (easily 3 years) in documents like the IEA who need to wait for a country's data to be published before they include it in their own lengthy publication process.

Other national databases or emission factors, such as supplied by the Dutch, UK and US government, typically provide consumption emission factors, which includes power generation, trade effects, and transmission and distribution losses. The Dutch database, however, provides the fuel production emission factors, and as reference the emissions from infrastructure, based on the analysis CE Delft (2022).

EcoTransIT World (2023) provides emission factors at the country-level but does not adjust for trade. In other words, the electricity mix is based on generation, rather than consumption. EcoInvent, which actually serves as the underlying lifecycle analysis database for many of the different customer-facing databases, provides a consumption-level data and at different voltage levels (https://ecoinvent.org/the-ecoinvent-database/sectors/electricity/, accessed 25 August 2023). While detailed, one should note that application of the Ecoinvent database requires a high-level of LCA expertise.

Table 2 A comparison of selected emission factor sources

Emission factor source	Scope	Emission factor units	Fuel production	Power generation	Power generation infrastructure	Transmission and distribution losses	Trade included
IEA Emission Factors (annual)	Global scope, regional and country-level	gCO2e/kWh	No	Yes	No	Yes	Yes
Netherlands Government's CO$_2$ Emissiefactoren	Netherlands	gCO2e/kWh	Yes	Yes	Yes	Yes	Yes
UK Government's Greenhouse gas reporting: conversion factors 2023	UK	gCO2e/kWh	No	Yes	No	Yes	Yes
eGrid 2021	US, eGrid regions	Lb or kg CO$_2$e/MWh	No	Yes	No	Yes	Yes
EcoTransIT	Global scope, regional and country-level	gCO2e/kWh	Yes	Yes	Yes	Yes	No
Ecoinvent v3.9.1	Global scope, regional and country-level, division by low, medium and high voltage network	kgCO2e/kWh	Yes	Yes	Yes	Yes	Yes

If compromises are inevitable, for instance if the emission factor does not include all categories, the selection of database and emission factor should be dependent on the expected size of the impact. For instance, in Europe the impact of trade is significant and should be included. Construction emissions on the other hand do not make a significant difference in most European countries, except where renewable electricity makes up most of the consumption, such as Sweden and Iceland. The selection should be transparent and sufficient justification should be provided, as per the ISO 14083 cut-off criteria.

4 Quantifying the GHG emissions of an EV fleet operation

The steps to quantify the GHG emissions of a transport operation are described in the ISO 14083, as well as the GLEC Framework v3, in Section 1. The approach is bottom-up, where the calculation for a full transport chain is performed at subdivided parts, called the transport chain element (TCE). For a vehicle, the TCE is defined as "the part of transport chain where freight is carried by a single vehicle".

The general steps to calculate emissions of a vehicle-TCE are.

1. Calculate the transport activity, typically in tonne-kilometers (tkm), of the TCE.
2. Identify the applicable emission intensity of this TCE by establishing the relevant transport operation category (TOC).
3. Calculate the TCE's emissions by multiplying the transport activity by the emission intensity.

The use of EVs does not introduce any new complexity in Steps 1 and 3. However, there are additional considerations to be taken to perform Step 2, which is to identify the applicable emission intensity, correctly.

This section will focus on how to determine the emission intensity factor used for an EV operation. Readers are advised to refer to the GLEC Framework v3 to familiarize themselves with Steps 1 and 3.

The steps to calculate the TOC-level emission intensity factor are the following.

1. Calculate TOC-level energy intensity factor in kWh per tkm, whether based on primary or other data sources.
2. Calculate TOC-level emission intensity in g CO_2e per tkm, based on the electricity emission factors, and other losses to be accounted for.

This section discusses how to address some of the additional complexities in the steps above, when it comes to EVs.

4.1 TOC-level energy intensity factor

The estimation of the energy intensity factor of a vehicle operation should proceed based on primary data, if available. Figure 8 illustrates some of the primary data sources available along the electricity pathway from the grid meter to the vehicle.
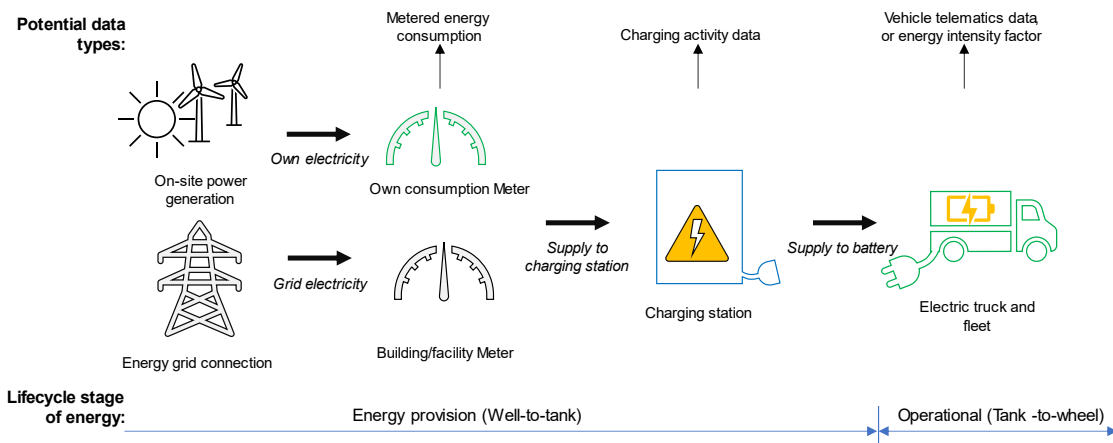
Figure 8 Illustration of electricity pathway from grid meter to vehicle and the various data sources available

As the TOC energy intensity factor is representative of the energy consumed at the vehicle, in calculating energy consumption based on either the metered data or charging activity data sources, a downward correction factor towards the vehicle should be applied (Table 3).

For example, a measurement of 100 kWh, based on metered data, could translate to only 90 kWh consumed by the vehicle. In this example, 10 kWh is lost due to charging losses for every 90 kWh charged by the vehicle.

Table 3 Sources of energy consumption data and need for correction factor

Type of data	Description	Correction factor towards the vehicle
Metered energy consumption	Metered energy consumption data represents the total electricity consumed at the charging facilities, i.e., all charge points at the same facility, whether from the grid or on-site power generators.	Yes
Charging activity data	Rich charging activity data can provide for each vehicle the time, duration, and amount of charging. In some cases, the charging losses may also be estimated by the system.	Yes
Vehicle telematics data	Vehicle telematics data and, more specifically, that related to the battery management system can provide charge activity data as well as granular data on energy consumption.	No
Default or modelled energy intensity factor	Default energy intensity factors are typically based on energy consumption at the vehicle, and do not include charging losses or any other. In this way, they try to replicate the energy intensity factor derived from vehicle telematics data.	No

The size of the correction factor should be determined based on the charging losses in a typical operating condition. This depends to a large extent on the electrical layout of the charging infrastructure (Apostolaki-Iosifidou et al., 2017). Some installations, in addition to the charging equipment (external and on-board), will require an on-site transformer or power converter. Charging efficiency for typical fast charging DC equipment is estimated by equipment manufacturers to be between 83 to 95% (Rajendran et al., 2021). However, operating conditions, such as hot weather, could also drastically affect efficiency.

For use in ISO 14083 reporting, it is not recommended to estimate energy intensity based on energy consumption or driving range values provided by manufacturers. They typically reflect a single use case, defined by a non-applicable driving and loading profile, which fulfills legislative requirements rather than reflecting real-world conditions. However, they may be helpful for planning purposes in the absence of better data.

4.2 TOC-level emission intensity

When calculating emissions for EV operations, it's crucial to consider both the electricity emission factor (outlined in Section 3.4) and potential losses at specific charging locations, as shown in Figure 8. As EV fleet operations often involve charging at various locations, especially in regional and long-haul scenarios, the emission factor calculation requires careful attention. For instance, in long-haul operations, carriers are expected to mainly charge at their truck depots overnight. However, additional charging to extend driving ranges may occur at destinations during loading or unloading or en-route at public or highway charging stations, potentially in different countries.

Explicitly, the influences on the energy provision emission factors for the TOC are:

- the average grid electricity mixes of countries where charging activity takes place,
- average energy contribution by behind-the-meter power generation (see Section 3.3), such as the facility's solar panels, and
- the on-site electrical and charging infrastructure layout (see Section 4.1).

To systematically take these factors into account, and also to account for the likely changes in grid emission factors, we propose that two additional variables are included.

Net electricity emission factor: This factor is specific to the charging location. It is the weighted average emission factor for all the sources of electricity used in the charging station: a location-specific grid emission factor and multiple emission factors from behind-the-meter (BTM) power generation. This aligns with the illustration in Figure 7.

$$Net\ emission\ factor = \frac{Energy_{grid} * Emission\ factor_{grid} + \sum Energy_{BTM} * Emission\ factor_{BTM}}{Energy_{grid} + \sum Energy_{BTM}}$$

Charging location energy correction factor: As discussed in Section 4.1 and illustrated in Figure 8, there may be charging losses from the on-site electrical and charging infrastructure, which will reduce the electricity delivered to the vehicle. This value represents the ratio between the amount of electricity in kWh transferred to the vehicle and the amount of electricity measured at the meter. There is insufficient empirical data to provide an industry-wide estimate, hence at this point, we recommend a conservative value of 1.11 to represent losses of 90% from meter to vehicle.

Multiplying both the net electricity emission factor and the charging location correction factor leads to a **corrected emission factor** associated to that charging location. The corrected emission factors for each charging location can be aggregated to a TOC-level emission intensity using the equation below, where i is the index representing a charging location. The aggregation proceeds based on amount of energy charged at a location, or more generally the percentage of charging activity carried out at each location.

$$Corrected\ emission\ factor = Net\ emission\ factor * Energy\ correction\ factor$$

$$TOC\ Emission\ Intensity = \frac{\sum_i (Energy_i * Corrected\ emission\ factor_i)}{tkm}$$
$$= Energy\ intensity\ factor * \sum_i Charging\ activity\ share_i * Corrected\ Emission\ factor_i$$

Example calculation

To illustrate this calculation, a small example is provided below. A TOC is composed of truck transport that crosses a national border. The annual charging activity share divided by locations

are presented in the table, including the net electricity emission factor and charging location energy correction factor.

Table 4 Example calculation for an aggregated emission factor

Charging location	Grid emission factor (g/kWh at meter)	Net emission factor (g/kWh at meter)	Charging correction factor (kWh at vehicle/ kWh at meter)	Corrected emission factor (g/kWh at vehicle)	Charging activity share (%)
Domestic A	100	84	1.11	93	40%
Domestic B	100	100	1.11	111	30%
International C	250	135	1.05	142	10%
International D	250	204	1.09	222	20%

Based on the corrected emission factor and charging activity share, an aggregated emission factor can be calculated. In the example above, it amounts to 129 g/kWh. If the energy intensity of the fleet is taken as 0.17 kWh/tkm (Smart Freight Centre, 2023a), the TOC emission intensity can be calculated as 22 g/tkm. In the normal methodology used by carriers or shippers, reporters can the TOC emission intensity and multiply it by that TOC's annual transport activity to calculate the annual emissions of the EV operations.

5   Conclusion

This whitepaper aims to clarify the measurement and reporting of operational emissions from electric freight vehicles within existing greenhouse gas emission frameworks, including GHG Protocol standards and ISO 14083. It begins with a high-level comparison of these standards and further explores considerations for selecting electricity GHG emission factors according to ISO 14083 requirements. The paper also adapts the ISO 14083 method to quantify operational emissions, considering the use of EVs, charging strategy, electrical infrastructure, and energy provision. While aligned with ISO 14083, certain industry standardization issues remain, summarized below for consideration.

One area of unclarity is **the use of TOC emission intensity factors using the market-based method**. While the Scope 2 standard and ISO 14083 allow for dual reporting by transport operators (or electricity users), the use of the resulting emission intensity factor by the user or buyer of the transport service, in Scope 3 reporting or as Transport Service User in ISO 14083, is not explicitly mentioned. Although ISO 14083 allows for the results based on the market-based method to be "used for a product carbon footprint in accordance with ISO14067" (ISO, 2023), it is unclear whether the transport service user may use emission intensities calculated using the market-based method. Further clarification is needed in the industry, as the publication of Smart Freight Centre's "Voluntary Market Based Measures Framework for Logistics Emissions Accounting and Reporting" (Smart Freight Centre, 2023b) suggests.

Another area of uncertainty is the **limited availability of comprehensive electricity emission factor databases covering all relevant locations**. As explained in Section 3.4, the widely used IEA database lacks coverage for all emission categories. From our survey (see Table 2), only two emission factor sources offer comprehensive coverage: one for a single country, the Netherlands, and one extensive database used for life cycle assessments, namely the Ecoinvent database. While sustainability reporters often resort to accessible databases like the IEA, which also offer broad coverage, their exclusion of emissions from fuel production and power generation infrastructure may necessitate an equally credible and widely applicable database encompassing all emission categories, including upstream emissions. The absence of such a database could limit the practical impact of achieving comprehensive energy lifecycle reporting in ISO 14083 for future global transport emission reporting.

Additionally, ISO 14083 overlooks **losses from on-site electrical and charging infrastructure, affecting both the energy intensity factor of the vehicle and the resulting emission intensity factor of electricity use in EV operations**. The evolving nature of the current charging landscape, especially for medium to heavy-duty vehicles, makes defining typical charging location correction factors premature. Nevertheless, it becomes essential to include this as an emission category, allowing users to calculate values based on primary data and taking a step towards standardizing EV emission calculations.

Looking ahead, it is crucial for the industry to unite, leveraging primary data and innovative approaches for standardization. This collaborative effort is vital to ensure the practical impact of energy lifecycle reporting and to establish a strong foundation for the future of global transport emission reporting. Smart Freight Centre's ongoing work in clarifying technological and sectoral challenges in logistics emission accounting, and in providing a clear path for standardization, is invaluable. We invite organizations, trade associations, and governments to actively join hands in addressing these challenges together. Taking decisive action on this initiative is essential for driving significant improvements in emission performance within the logistics sector.

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