Smart Freight Centre

Exploring Sustainability in Road Freight Electrification

A Comprehensive FAQ

February 2024

Exploring Sustainability in Road Freight Electrification

A Comprehensive FAQ

February 2024

Acknowledgements
This report was written by Gabriela Rubio Domingo, Priyansh Doshi, and Tharsis Teoh of Smart Freight Centre.

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.

Contact
Smart Freight Centre
Keizersgracht 560, 1017 EM, Amsterdam, Netherlands
P.O. Box 11772, 1001 GT, Amsterdam, Netherlands
Tel office: +31 6 4695 4405
www.smartfreightcentre.org
info@smartfreightcentre.org

Table of Contents

Table of Figures

Table of Tables

Table of Abbreviations

AVAS: Acoustic Vehicle Alerting Systems

CDP: Carbon Disclosure Project

CO2: Carbon Dioxide

EEA: European Environment Agency

EoL: End of Life

ESG: Environmental,Social & Corporate Governance

e-truck: Electric Truck (Battery Powered)

EU: European Union

EV: Electric Vehicle

GHG: Greenhouse Gas

GoO: Guarantees of Origin

GRI: Global Reporting Initiative

ICE: Internal Combustion Engine

kt: kilotonne

OEM: Original Equipment Manufacturer

PM: Particulate Matter

PV: Photovoltaic

RMI: Responsible Mineral Initiative

TWh: Trillion watt hours

UNECE: United Nations Economic Commission for Europe

1 Introduction

Road freight, predominantly powered by fossil fuel, contributes more than half of the carbon dioxide emissions produced in trade-related transport globally (ITF 2019). In Europe, road freight is accountable for over 19% of the greenhouse gas (GHG) emissions in the transport sector, and this figure is anticipated to grow by 8% by 2050 (ICCT 2022). Notably, a significant amount of these GHG emissions typically arise from the utilization of fossil fuels for propulsion (Scania 2020). Decarbonization efforts are advancing in the road freight transport sector globally to keep in line with the Paris Agreement Goals. For instance, the Dutch climate agreement plans to implement zero emission zones in city centers in the Netherlands from 2025 to reduce the logistics carbon footprint by a total yearly CO_2-reduction of 1 Mtonne in 2030 (Kin et al. 2021). Therefore, a fast transition to zero-emission freight vehicles is vital for decarbonization of the logistic sector and to keep in line with the emissions regulations placed globally. (ICCT 2022).

Electric trucks (e-trucks) represent a highly viable alternative for supply chain decarbonization.

The adoption of e-trucks by logistics sector can significantly decouple the reliance on fossil fuels especially in places with policies that support the reliance on greener electricity generation choices. According to ICCT (2023), transitioning to e-trucks would result in a drastic reduction of the lifecycle GHG emissions by up to 76% considering the average EU electricity mix. The reduction in GHG emissions can further improve along with the improvement in the energy mix consisting of a higher percentage of electricity generated from renewable sources.

Logistic actors need to have a broader understanding of impacts on overall sustainability arising from transitioning to e-trucks.

Despite these emissions benefits, e-trucks, like internal combustion engine (ICE) trucks, have associated environmental and social impacts across their lifecycle (Mowbray 2023). Therefore, to avoid impact shifting, it is crucial to ensure a transition that goes beyond just eliminating fossil fuel emissions but acknowledges the social, economic and environmental dimension as well. Furthermore, it's of utmost importance to track and mitigate the sustainability challenges across the entire lifecycle of the vehicles without having a carbon tunnel vision targeting only the operational phase of e-trucks.

It's vital to understand that both ICE trucks and e-trucks have sustainability impacts across different phases within the truck's lifecycle. Therefore, a broader understanding is required to identify and mitigate these sustainable challenges. For instance, concerning ICE trucks, the most substantial sustainability impacts occur downstream during the utilization phase, particularly from the combustion of fuels and upstream from the extraction, refining, and transportation of crude oil to produce liquid transportation fuel, as well as in the distribution of the refined fuel (CRS 2020). Long term dependency on the combustion of fossil fuel to power these ICE trucks have led to significant environmental, human and geopolitical consequences (Transport & Environment 2021, CRS 2020, O'Rourke & Connolly 2003). Conversely, the most crucial yet mitigable sustainability challenges are associated with the manufacturing and final life (End-of-Life) stage of an e-truck. For instance, the energy-intensive extraction of essential materials and the manufacturing of batteries to power the e-truck powertrain pose various sustainability risks. Additionally, during the final life cycle phase of the e-truck, the disposal and treatment of batteries present unique environmental challenges. While adopting a circularity approach for handling spent e-truck batteries is considered the most suitable strategy, it comes with significant economic and technical challenges.

This sustainability guidance report takes a triple-bottom line approach to highlight the mitigable sustainability challenges categorized under environmental, social and economic aspects that can be associated throughout the lifecycle of e-trucks, including electricity generation. Furthermore, it explores key strategies that can be implemented to mitigate these sustainability challenges.

Implementing strategies to mitigate associated challenges is the key to an overall sustainable transition within the road freight transport sector.

Several practices within the manufacturing, operational and end of life (EoL) phase of e-trucks can be adopted to mitigate the environmental, social and economic challenges associated with e-trucks. For instance, implementing circularity within the value chain aids in addressing the sustainability issues arising from extraction of new raw materials. Circularity allows the minimization of issues related to disposal of batteries and reduces the need for raw materials, thereby mitigating the associated social, environmental and supply risks.

The use of alternative sources for energy generation is key to further reducing the sustainability impacts from manufacturing and the operational phase of e-trucks. Technological advancement and optimization of fleet and battery use, further contribute to reducing impacts arising from all the three phases of e-trucks.

Additionally, adhering to the legislative measures in place such as the European Union (EU) regulations and supply chain due diligence standards is another way to mitigate these broader sustainability challenges arising from the material sourcing of the required raw materials. Logistic actors should request for supply chain due diligence reports from the manufacturers to ensure the e-trucks procured comply to the sustainability standards. This will subsequently also give a signal to the market and stakeholders in the supply chain to progressively adhere to adequate sustainability standards and take action to mitigate issues arising from the up- and downstream activities in the e-truck materials supply chain.

Logistic actors can maximize the sustainability benefits of e-trucks by prioritizing adoption in urban operations. A sustainable transition roadmap should prioritize specific regions for e-truck deployment where the energy mix comprises of a greater share from renewable sources to gain maximum benefits from the transition.

What can you expect from this document?

The report explores mitigable sustainability challenges and solutions categorized under environmental, social and economic aspects that can be associated throughout the lifecycle of e-trucks including electricity generation. In the section on environmental sustainability, the report thoroughly examines challenges and mitigation strategies at key stages such as raw material extraction, processing, component and e-truck production, vehicle use (considering energy infrastructure and production impacts), and the end-of-life phase. Subsequently, the section on social sustainability identifies potential social risks associated within the entire battery supply chain and suggests mitigation measures to eliminate these risks. In the final section of the report on economic sustainability, the focus is on strategies to tackle economic sustainability challenges and ways in which economic transformation can contribute to achieving environmental and social sustainability goals within the e-truck industry.

The report adopts a cradle-to-grave perspective to highlight sustainability challenges and present mitigation strategies individually for both the vehicle and the fuel lifecycle as it allows for the evaluation of the total environmental impact, including emissions, energy efficiency, and use of resource use, associated with different modes of transportation and energy sources. The vehicle lifecycle refers to the various stages a vehicle goes through from its initial design and manufacturing to its eventual disposal or recycling, including raw material extraction, manufacturing, use and end-of-life, as depicted in Figure 1.

On the other hand, fuel lifecycle includes the complete life of a fuel source, from extraction or production to its eventual consumption and (if relevant) disposal. This includes the extraction or production, refinement and processing, distribution, storage and handling, consumption and end-of-life or disposal. It also involves the construction, operation and dismantling of any relevant infrastructure. In the case of electricity consumption for e-trucks, fuel lifecycle refers to all aspects related to the generation, distribution of electricity and the construction, operation and dismantling of electricity generation and distribution related facilities.

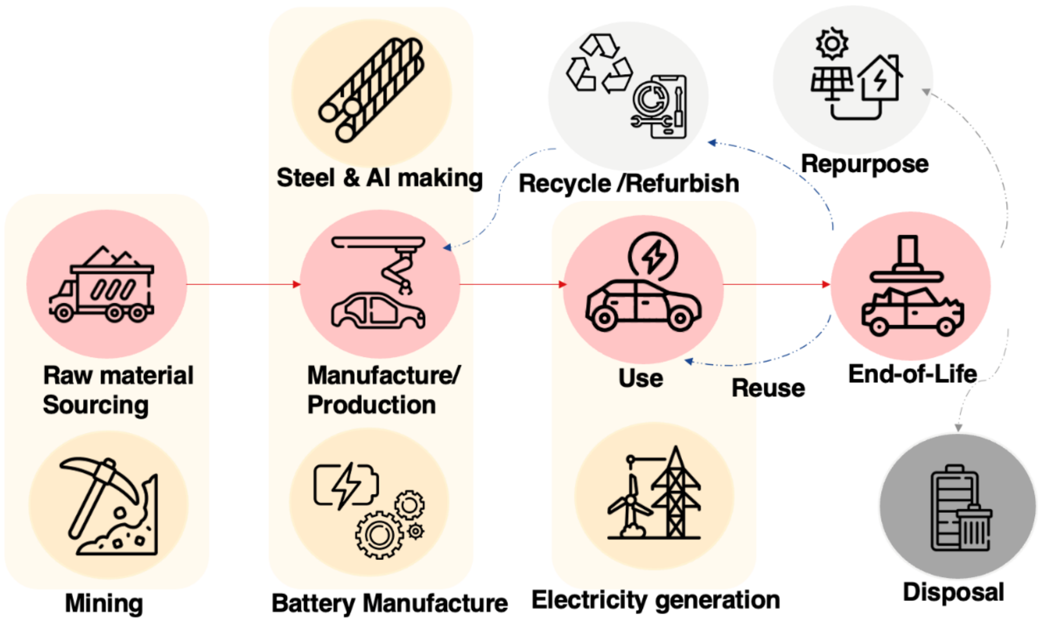

Figure 1: E-trucks lifecycle and key stages involving sustainability issues.

The document is designed in the form of an FAQ as to offer concrete guidance to key questions and concerns about sustainability in e-trucks from the different sustainability perspectives, as well as comparing them with ICE trucks where relevant.

2 Environmental Sustainability

This section aims to provide an objective examination of the environmental impacts associated with the lifecycle of e-trucks. It comprehensively covers key lifecycle stages, including raw material extraction, processing, component and e-truck production, vehicle use (considering energy infrastructure and production impacts), and the end-of-life phase. The discussion also highlights potential solutions to mitigate environmental risks associated with e-trucks and electricity production. Adopting a cradle-to-grave perspective ensures a thorough and genuinely environmentally sustainable transition to e-trucks, avoiding the perpetuation of issues, or creating new ones upstream or downstream.

Overview

2.1 What are the most energy-intensive stages of e-trucks lifecycle?

The lifecycle stages of a e-truck include the production phase, comprising extraction of raw materials, manufacturing and any transportation or distribution; the use phase which includes electricity generation and distribution as well as charging of the vehicle and operations; and the end-of-life stage which comprises of all processes related to the decommissioning of the vehicle, such as re-selling, reuse, recycling and any waste management activities.

A report by Transport & Environment (2021), analyses the energy requirements for the different lifecycle stages of an e-truck and establishes a comparison on the material requirements for diesel and e-trucks. As per the findings, the production of electricity for e-truck operation stands out as the most energy-intensive stage throughout its life cycle, comprising 60% of the overall energy consumption, as illustrated in Figure 2. Therefore, decarbonizing the electricity grid to which e-trucks connect is crucial. Nevertheless, the emissions pales in comparison to the contribution of GHG emissions in the fuel production and consumption for a diesel truck.

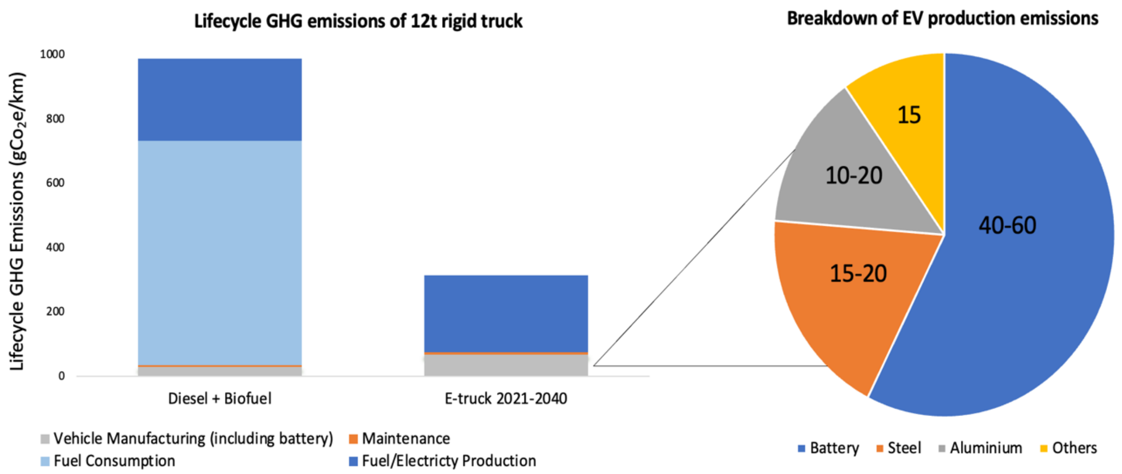

Figure 2: Breakdown of GHG Emissions for e-trucks & ICE trucks (Adapted from ICCT 2023, McKinsey 2023b)

Notably, battery manufacturing ranks as the second most carbon-intensive stage, accounting for over 25% of total life cycle energy consumption. This highlights the importance of addressing battery manufacturing to enhance energy efficiency and source energy from clean channels. The vehicle production phase, particularly steel and aluminium manufacturing, is also energy-intensive, representing 11% of total life cycle energy consumption. Note that the amount of emissions in this category would be similar in the diesel truck.

2.2 How does the lifecycle carbon footprint of e- trucks compare to that of traditional ICE trucks?

A comprehensive cradle-to-grave analysis of GHG emissions is imperative to facilitate a fair comparison of the lifecycle GHG emissions of ICE and e-trucks. This analysis encompasses emissions from all three stages of the truck's lifecycle, namely upstream emissions from vehicle manufacturing and energy production, emissions from the vehicle use phase, and the eventual recovery of vehicles. The sustainability of e-trucks in each region is significantly influenced by the type of energy mix prevalent in that specific geography (ICCT 2023; Scania 2020).

According to an analysis by ICCT (2023), transitioning from diesel to electric powertrains yields substantial reductions in GHG emissions, even when considering the EU average electricity mix. Throughout their lifecycle, e-trucks currently in production exhibit a 63% to 76% reduction in life cycle GHG emissions compared to the present best-in-class diesel trucks. The decarbonization and enhancement of the electricity grid can further augment the GHG emission reduction of e-trucks to a range of 84-92% (100% renewable energy scenario). These reductions stem from the heightened energy efficiency of e-trucks and the decreased carbon intensity of the average electricity mix in contrast to diesel.

Despite the overall emissions advantage of e-trucks, it is essential to acknowledge that they may incur a production debt in terms of GHG emissions relative to ICE trucks as shown in figure 2. This arises from the energy-intensive nature of battery production. However, e-trucks demonstrate the potential to outperform ICE trucks in terms of GHG emissions as the GHG break-even point is typically reached within one or two years of operation (considering electricity mix of EU 2020 & EU 2030). (Scania 2020)

Mining and extraction of key minerals and metals

2.3 What are the main environmental issues associated with mining and extraction of key minerals in e-trucks?

Mining is a key activity in the lifecycle of e-trucks, as various minerals and metals are required for their production. These are essential for the manufacturing of batteries, electric motors and other components. Some of the significant minerals and metals used in e-trucks include lithium, cobalt, nickel and manganese, which are used in the manufacturing of the batteries; rare elements and copper for the electric motor; and steel and aluminum for manufacturing of the e-truck body.

The mining and extraction processes of raw materials used in e-trucks give rise to several environmental concerns such as local pollution of air, water & soil, the depletion of vital resources like water, biodiversity loss, and the generation of hazardous waste (Zimmermann 2023; GBA and WEF 2019; McKinsey 2023a).

Moreover, specific raw materials used in e-truck production introduce additional environmental challenges. For instance, manganese mining involves extensive land utilization and the emission of airborne contaminants (GBA and WEF 2019). In the case of nickel, its extraction entails the management of acid in leaching processes, which poses a distinct risk.

Due to the scarcity of certain minerals and metals, there is an anticipation that mining activities may extend beyond terrestrial operations in the future. As suggested by GBA and WEF (2019), deep seabed mining is expected to become a more widespread practice in the coming decade. While this could potentially mitigate some of the challenges associated with terrestrial mining, it also raises concerns about its impact on the ocean's ability to sequester CO_2, in addition to other potential, yet undiscovered issues.

2.4 What are the most critical sustainability issues associated with key materials required for e-trucks?

The most critical sustainability issues for cobalt, lithium, nickel and manganese, which are all key components for the manufacture of e-trucks, are summarized in Table 1. The list is not exhaustive and intends to point out the issues that are hardest to address particular to each material.

Lithium and nickel, due to their geographical concentration, present supply chain risks that can potentially result in disruptions or high prices. Cobalt mining is also related to important social and governance issues in Congo, where most of world resources are to be found and where precarious mining sites and informal working conditions affect local populations (European Commission 2023b; GBA and WEF 2019).

This section of the report covers the related environmental issues while the economic and social issues, also reflected in the table, are addressed in detail in later sections of the FAQ.

Table 1: Summary of sustainability issues for key metals in e-trucks (Goldman Sachs 2022)

	Economic / Supply Chain	Environmental	Social & Governance
Cobalt			▪ Important social & governance issues (health, working conditions, child labour, corruption)
Lithium	▪ Tight market (supply barely covers demand)	▪ Carbon intensive raw material supply ▪ High energy requirement ▪ Impact in water scarce areas	
Nickel	▪ High geographical mine concentration,which can lead to supply risks	▪ Risk in management of acid in leaching processes	
Manganese		▪ Intensive land use and release of airborne contaminants	

2.5 Is mining more impactful for ICE trucks or e-trucks?

The mining and processing stages differ significantly for ICE and e-trucks. In the case of ICE trucks, the mining phase is primarily focused on extracting the fuel needed for vehicle operation. Conversely, e-trucks necessitate the extraction of specific materials essential for battery manufacturing, with the potential for recycling or repurposing these materials as raw inputs for new vehicles.

Presently, e-trucks exhibit greater environmental impacts during the mining phase compared to ICE trucks. This is due to the well-established nature of the fossil fuel industry, which has optimized fuel extraction processes. Even though ICE trucks involve the extraction of more substantial quantities of materials through mining, e-trucks tend to have higher lifecycle impacts related to acidification, human toxicity, particulate matter emissions, and resource depletion (Del Pero, Delogu, and Pierini 2018).

Despite of this, ongoing research anticipates a shift in this dynamic over time. As mining activities related to e-truck production become more streamlined and efficient, and recycling practices for e-trucks components get to be more widespread and effective, it is expected that material demand will gradually diminish. This transition is expected to contribute to a reduction in the overall environmental impact of e-trucks in the long term.

2.6 What are solutions to identify and minimize environmental impacts of mining and extraction?

Solutions to the issues mentioned in this chapter include identifying and minimizing environmental impacts, following a consistent approach and adhering to international standards. An illustrative example is the Environmental, Social & Corporate Governance (ESG) Standard for Minerals Supply Chains (Responsible Minerals Initiative 2021). This framework proposes a set of measures to prevent or minimize these concerns such as:

- providing relevant training for workers and managers
- the establishment of corrective and preventive action protocols
- the sourcing of materials exclusively from mines independently evaluated against global standards.
- the implementation of tailored measures for specific issues like water and soil pollution
- and the enhancement of waste management practices on mining sites.

Furthermore, an additional approach to tackle environmental issues linked to mining is to reduce mining activities by adopting circularity principles (GBA and WEF 2019). This can be achieved by enhancing the traceability of materials, for instance, implementing mechanisms like battery passports, and by creating appropriate market incentives and regulatory frameworks to promote and implement recycling practices.

Processing and Manufacturing

2.7 What are emissions levels from steel and aluminum manufacturing, and what viable decarbonization solutions are being explored within these industries?

Steel and aluminum exert a notable influence on the GHG emissions throughout the vehicle life cycle, in the context of both diesel and e-trucks. In diesel trucks, steel production is the primary contributor to emissions arising from vehicle manufacturing. Conversely, in e-trucks, materials associated with lithium-ion batteries (including cathode, anode, aluminum, and battery assembly) exhibit the highest GHG emissions accounting for upto 35% to 50% of the material carbon footprint of an e-truck. (Iyer et al. 2023, Billy & Müller 2023)

A study by Iyer et al. (2023), illustrates that aluminum accounts for an outsized share of impact on the vehicle cycle emissions compared to steel because of its highly energy- and GHG-intensive production. Consequently, OEMs must carefully evaluate the consequential increase in GHG emissions resulting from the substitution of steel with aluminum, a practice aimed at manufacturing lightweight and fuel-efficient medium and heavy-duty vehicles. Furthermore, truck manufacturers can optimize vehicle design to necessitate less material, thereby diminishing the demand for steel and aluminum manufacturing. (Iyer et al. 2023; WEF 2020c; 2020a)

Manufacturers of steel and aluminum can contribute to emission mitigation efforts by either enhancing the proportion of recycled content in their materials or by adopting more energy-efficient production methods, possibly through redesigning fuel systems. Another avenue for emission reduction involves the implementation of Carbon Capture and Storage coupled with low-carbon biomass and replacement of coking coal with hydrogen or green electricity. Additionally, technical solutions, such as substituting carbon anode with inert anode in aluminum production, hold promise for diminishing emissions stemming from aluminum manufacturing. (WEF 2020c; 2020a)

Lastly, a study by Iyer et al. (2023) concludes the impact of frequent battery replacement on e-truck's vehicle-cycle impacts. Advancements in battery technology and the adoption of optimal operational strategies for e-trucks can substantially reduce the frequency of battery replacements required during the e-truck's lifecycle thereby enhancing the overall environmental outcomes in the vehicle life cycle.

2.8 What are measures to reduce emissions related to battery manufacturing?

Electricity produces half of emissions related to battery manufacturing, as the electrode production and cell assembly processes are very energy intensive. Thus, it becomes critical to decarbonize the grid to achieve improvements. With the prospective development of renewable energy generation, emissions for battery manufacturing are expected to be 17% lower by 2030 according to (ICCT 2018).

Alternative measures to mitigate the environmental impacts of batteries also include (EEA 2018; WEF 2020c):

- Using battery capacity that is appropriate for the expected driving range (as larger batteries involve greater impacts). This will be facilitated by an increasingly denser charging infrastructure.
- Enhancing battery technology and opting for battery types that offer higher energy densities and longer life cycle expectancy.
- Manufacturing for energy efficiency by making use of economies of scale in battery production.

Electricity Production & Use

2.9 What are the environmental issues related to energy infrastructure and electricity production?

Similar to environmental issues within the ICE trucks in terms of oil exploration, refining and distribution, there are a range of relevant issues within the e-truck ecosystem linked to energy infrastructure and electricity production, from a life-cycle perspective. Most relevant issues for the different sources of energy comprise:

- **Mining/raw materials/fuel production**: There are important issues linked to the materials needed to build energy infrastructure. Examples would be the use of rare earth materials in motors and of cobalt in wind turbines (Zimmermann 2023). These would be similar to the issues for the mining of materials for electric batteries mentioned earlier. For fossil-fuel based energy production, there are issues linked to crude oil, such as mining and risks of spilling. When burning biofuels, potential issues could include land use change, resource depletion, soil and ecosystem degradation, or labor issues.
- **Construction of power generation infrastructure** may have impacts on natural habitats and biodiversity, such as loss of habitats (hydropower), modification or fragmentation (wind, solar farms). (UNDP Serbia 2010; EERE 2023)
- **Power generation**: There can be associated GHG emissions and air pollution from fuel combustion, in the case of fossil-based generation technologies – for example, the smog from coal power plants. Power generation in many cases also has a water footprint, for example, in steam generation or cooling systems that are common to many energy sources.
- **Decommissioning**: The main environmental concerns associated with the decommissioning of power plants, regardless of their type, include managing residual pollutants from the operational phase, legacy pollution from the operational phase, managing hazardous waste materials, preventing water and soil contamination, minimizing land disturbance and habitat disruption, and controlling emissions during dismantling.

2.10 How does additional demand created by charging e-trucks affect the carbon content of the grid (marginal emissions)?

The term marginal emissions refers to the amount of additional GHG emissions or other pollutants produced as a result of a specific change in energy or resource consumption. These emissions represent the incremental environmental impact associated with increasing or decreasing a particular activity, such as using an additional unit of electricity or fuel or producing an extra unit of goods or services.

It is important to consider that the composition of the electricity mix on the grid is intimately tied to its demand patterns. When introducing the charging of e-trucks into this equation, it can either escalate or diminish emissions stemming from electricity generation, depending on if the charging happens in periods of low or high demand. For instance, if e-truck charging predominantly occurs during periods of low electricity demand, it can absorb surplus capacity generated by renewable sources. This results in an overall greener grid mix because it maximizes the use of clean energy sources. Conversely, if e-truck charging aligns with high-demand periods, it can exacerbate demand peaks, leading to increased reliance on natural gas power units and subsequent carbon emissions. Consequently, the concept of marginal emissions becomes particularly significant in situations where e-truck charging practices either align with or counteract prevailing demand dynamics.

To address these challenges and optimize the environmental benefits of e-truck adoption, it's imperative to promote flexible charging practices. This approach allows us to harness low-carbon electricity when it's abundant and prevents the creation or worsening of demand peaks. This aligns with the recommendations of the European Environment Agency (EEA) in 2018.

Furthermore, there are additional strategies to consider that would increase the sustainability of power generation and transmission. These encompass enhancing grid infrastructure, including enhancing the grid energy storage capacity and achieving better grid integration. Additionally, implementing practices like battery swapping allows for charging that is disconnected from vehicle usage, and optimizing battery capacity to match actual travel needs—avoiding unnecessary over-sizing—further enhances the sustainable use of the vehicles.

2.11 Which energy source options for electricity production are more sustainable from a broader sustainability perspective? How can this be measured?

To standardize the way different environmental impacts affect electricity production, the United Nations Economic Commission for Europe (UNECE) proposes 16 categories of impacts with corresponding units of measurement and guidance for their calculation (UNECE 2022). These impact categories include use of minerals and metals, water use, particular matter, human toxicity, among others.

Figure 3 presents a summary of the normalized environmental impacts corresponding to 1 TWh of electricity for the different categories, enabling a comparison of the main electricity generation options.

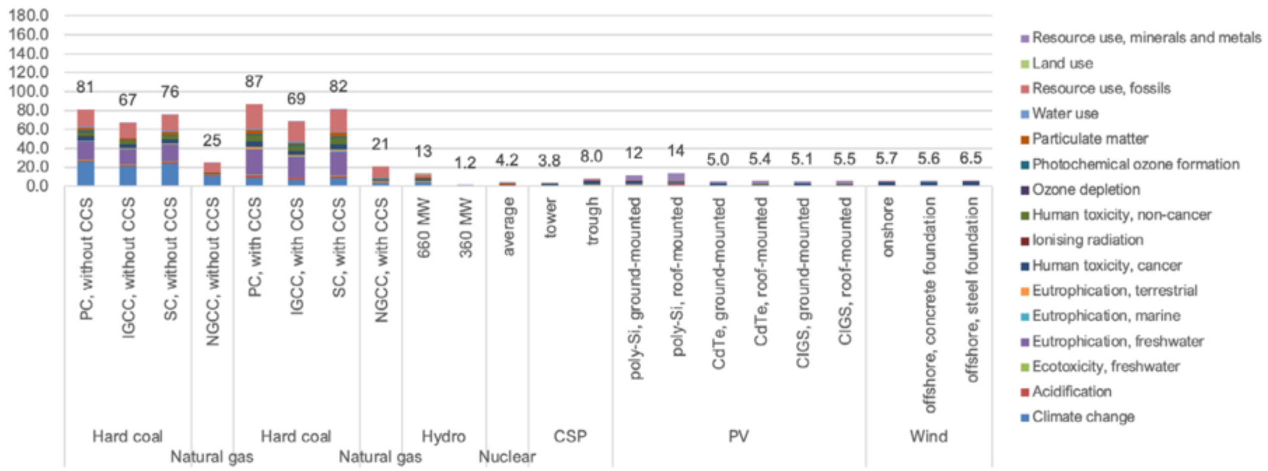

Figure 3: Normalized, weighted, environmental impacts of the generation of 1 TWh of electricity (UNECE 2022)
Note: Consider this figure for illustrative purposes only.

Based on the analysis, it can be concluded that fossil fuels have the highest environmental impact, even when considering broader impacts beyond just GHG emissions. In contrast, low carbon and renewable energy sources display an overall reduced environmental impact.

Among the options with lower environmental impacts are nuclear energy, photovoltaic (PV) solar, and wind power. This suggests that these sources are more appropriate for ensuring sustainable electricity production. However, it's important to note that each of these sources has its own unique challenges:

- Nuclear Energy: While nuclear energy offers low environmental impact, it faces constraints such as high initial costs, lengthy construction timelines, security concerns, public perception issues, and regulatory complexities.
- PV Solar and Wind Power: These sources are generally more accessible and environmentally friendly. However, they do encounter challenges related to intermittency, which may necessitate additional power generation, the integration of technologies with more consistent output, or advancements in energy storage solutions to ensure a reliable energy supply.

In summary, while low carbon and renewable energy sources like nuclear, PV solar, and wind show promise for sustainable electricity production, each has its unique set of obstacles that must be addressed for their effective and widespread adoption.

2.12 What mechanisms can be used to evaluate the sustainability attributes of the electricity purchased and what do they include?

The Global Reporting Initiative (GRI) Electric Utilities Sector Disclosures offers a framework for power generation, transmission, distribution, and retail entities to assess economic, environmental, and social sustainability facets of electricity generation. Additionally, the Carbon Disclosure Project (CDP) reports provide a means to evaluate a company's environmental performance and its social impacts across a spectrum of topics, including the adoption and effects of e-trucks in their operations.

Beyond the documentation on the sustainability attributes of the electricity purchased, companies can directly invest in and procure renewable electricity generation. According to Smart Freight Centre (2024), the primary approaches for doing so include on-site or “behind-the-meter” generation, power purchase agreements, green tariffs and green power products, as well as other energy attribute certificates.

Finally, Guarantees of Origin (GoOs) or Renewable Energy Certificates serve as tools to enhance the environmental sustainability of purchased electricity. They allow to sell low emission attributes separate from the electricity delivered from the grid and are used to directly finance investment in renewable electricity production. GoOs typically provide details about the specific renewable energy source, the location of the generating facility, and the amount of electricity produced. However, they don´t provide information on broader sustainability issues.

2.13 How can the use of e-trucks impact noise, air pollution and safety?

E-trucks offer significant advantages over ICE trucks, including reduced noise levels that enhance driver well-being and contribute to lower noise pollution. Moreover, e-trucks demonstrate benefits in local pollution within urban areas by producing no exhaust emissions. Additionally, their superior energy efficiency, attributed to higher efficiency of electric powertrain comparatively and regenerative braking, sets them apart from ICE trucks (Ricardo 2021).

However, these advantages come with certain drawbacks. While low noise levels are advantageous at lower speeds, the friction between the e-trucks and the road generates noise pollution at higher speeds that is comparable to that of ICE vehicles. In urban settings, the minimal noise levels can pose a safety risk for pedestrians accustomed to the audible cues of traditional vehicle engines.

Furthermore, the increased weight of e-trucks, primarily due to the weight of the battery (14% to 29% higher than ICE vehicles), contributes to elevated emissions from tire-road friction, partially offsetting the air pollution benefits. This increase is particularly notable in particulate matter (PM) emissions and the resuspension of road dust. (EEA 2018)

Addressing the safety concerns related to noise involves the implementation of "Acoustic Vehicle Alerting Systems" (AVAS) to mitigate potential risks for pedestrians in urban areas, as outlined by the EEA (EEA 2018). EU legislation, specifically EU Regulation 2017/1576, mandates the incorporation of AVAS as a requirement for electric and hybrid vehicles in the EU (European Commission 2019).

To reduce tire emissions, potential solutions include opting for low rolling resistance tires, implementing weight reductions through advancements in battery technology, and favoring lightweight vehicle design. These measures aim to mitigate the challenges posed by noise and emissions in the transition to e-trucks.

Environmental Sustainability: End of Life

2.14 What are EoL options for batteries of e-trucks? Which EoL option should be preferred under what circumstances?

According to Börner et al. (2022), there are four possibilities for the EoL batteries from a circularity perspective. These are summarized in Table 2: End of Life Options for electric batteries from a circularity perspective (Börner et al. 2022).

Table 2: End of Life Options for electric batteries from a circularity perspective (Börner et al. 2022)

EoL Option	Definition	Conditions under which EoL option is most suitable
Reuse	Reuse without additional works in the original application	If the battery still retains a significant portion of its original capacity and functionality, it can be reused

		in another vehicle. This option is best when the battery's degradation is minimal.
Remanufacturing	Remanufacturing for batteries is a process in which used or worn-out batteries are restored to a like-new condition, allowing them to be reused instead of being discarded.	This option is the most suitable when only certain components of the battery are damaged.
Repurpose	Refurbishment of the battery and use in a new type of application. Second-life applications can include stationary energy storage for renewable energy systems, backup power, or grid stabilization.	If the battery retains some of its original capacity and functionality, repurposing it in a less demanding second-life application can be an environmentally and economically favorable option.
Recycling	The recycling process involves recovering and processing valuable materials like lithium, cobalt, nickel, and other metals.	It is a good EoL option for batteries that have significantly degraded and can no longer be used effectively in EVs or second-life applications.

From a circularity perspective, it can be observed that in the reuse, remanufacturing and repurpose options the battery re-enters the use loop. At the same time, for recycling the battery does not come back to a second use phase, but just the materials are recovered.

In addition to the four EoL possibilities mentioned, a fifth EoL option would be the disposal of batteries. This is a highly unrecommended option, presenting important risks due to the highly polluting substances that landfilled batteries may release. Additionally, disposal of batteries will lead to loss of valuable materials requiring new mining activities to take place to obtain the required minerals for battery production. Existing regulations, such as Regulation (EU) 2023/1542 of the European Parliament pertaining to batteries and waste batteries sets minimum rates of recycling of materials and explicitly prohibit the disposal of batteries (European Commission 2023b).

2.15 What are main EoL challenges from a circularity perspective (assuming batteries are not to be disposed of)?

The major EoL challenges from a circularity perspective are summarized in Table 3: Main EoL challenges for batteries from a circularity perspective (GBA and WEF 2019; Börner et al. 2022)

Table 3: Main EoL challenges for batteries from a circularity perspective (GBA and WEF 2019; Börner et al. 2022)

EoL Option	Challenges
Reuse / Repurpose /Refurbish	Lack of information on battery health. User data would be needed for evaluation, with the restriction that details of battery design, BMS hard- and software are confidential. This hinders the reincorporation of the battery to a second life purpose, (either it is reuse, repurpose or remanufacturing).
Reuse	• <u>High transaction costs</u> to be equalized by low prices of new batteries. • <u>Thermal events and diminished performance</u> are more subject to occur to reused batteries. • <u>Same requirements expected</u> as in first life in terms of safety and liability, with lack of adapted homologation test for second use. • <u>Technical complexity</u>: electrical, thermal, mechanical, ageing. All are linked and need to be addressed to ensure quality standards are met.

Recycling	• Economic viability. Recycling is capital intensive, and costs could be higher than the value of recovered materials. • Lack of infrastructure: Establishing the necessary infrastructure and facilities for recycling demands substantial investments in specialized resources. Collection and logistics infrastructure are also complex and need to be addressed. • Complex battery composition that needs to be effectively separated and processed. This process is complex and costly. • Environmental and safety concerns: Battery recycling involves handling hazardous materials, including toxic chemicals and flammable substances. Ensuring proper safety measures, complying with environmental regulations, and managing potential risks associated with the recycling process are critical but can pose barriers due to the complexity and costs involved.

2.16 What are the solutions that address environmental challenges arising from batteries reaching its EoL? How can logistic actors aid in mitigating these challenges?

a. Operational Measures

Planning and scheduling of e-truck operations, in a way that optimizes battery cycles can significantly contribute to mitigating environmental sustainability challenges. Additionally, strategic operational measures by logistic actors, that result in optimal battery life and optimal utilization of power, can further aid in mitigating environmental risks. This is due to the reduction in the number of batteries and power required over the e-truck's lifetime comparatively, that results in a reduction in the GHG emissions of e-trucks arising from additional battery manufacturing, vehicle utilization and EoL phase. These measures include the selection of appropriate battery technology, optimal battery capacity, awareness of factors influencing battery life, and route optimization.

b. Legislations & Initiatives

The Battery Passport initiative introduced by the Global Battery Alliance ensures transparency throughout the battery lifecycle, encompassing critical information pertaining to the state of health of batteries used in e-trucks (GBA and WEF 2019). In tandem with this initiative, the Regulation (EU) 2023/1542 of the European Parliament pertaining to batteries and waste batteries, mandates the implementation of a battery passport for all EVs. These regulatory measures and collaborative initiatives facilitate effective EoL decision-making processes for retired batteries, ensuring their judicious utilization in second-life applications and preventing unwarranted disposal. Furthermore, the regulation explicitly prohibits the disposal of waste batteries, thereby promoting environmental sustainability within the electric vehicle (EV) sector. Additionally, the regulation sets recycling and recovery targets, alongside stipulating minimum quantities of recycled materials for integration into the manufacturing of new batteries. (European Commission 2023b) The adhesion to this framework would ensure a certain degree of circularity within the ecosystem, effectively addressing environmental sustainability challenges arising from retired e-truck batteries.

2.17 How should one report lifecycle GHG emissions for e-trucks according to the GHG Protocol?

Companies reporting the lifecycle GHG emissions of e-truck-based operations must differentiate between the GHG emissions produced in the vehicle cycle (including the charging equipment) and the emissions from the energy cycle. The emission categories are divided into Scope 2 and different subcategories under Scope 3. Generally, Scope 2 emissions fall under mandatory reporting, while Scope 3 emissions are optional. Figure 4 summarizes the stages of e-trucks life cycle where emissions should be reported, together with the scopes this should be reported under for truck owners and purchasers of logistics services.

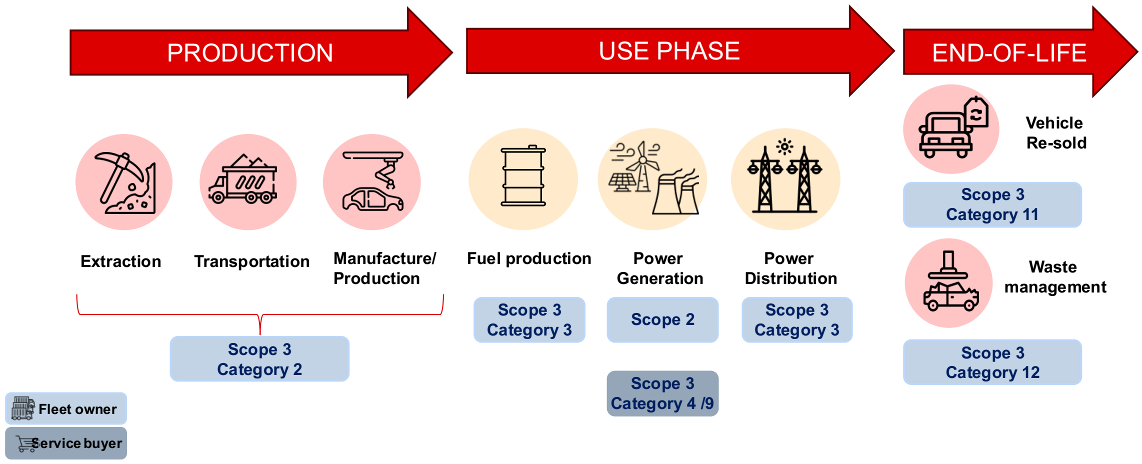

Figure 4: GHG emissions in the life cycle of e-trucks

It is not common practice for fleet owners to disclose the emissions related to the production and end-of-life stages of the vehicle lifecycle, hence the following describes the interpretation of the written Scope 3 standards.

- Asset production: Scope 3 Category 2 “Capital Goods” includes all extraction, production and transportation activities within the vehicle and charging equipment product lifecycle.
- Asset end-of-life: Scope 3 Category 11 “Use of sold products” includes “direct use-phase emissions of sold products over their expected lifetime” of vehicles resold in the secondhand market. Scope 3 Category 12 “End-of-life treatment of sold products” would comprise emissions from end-of-life treatments by waste management companies in case the vehicle or parts of them are recycled or disposed of.

The emissions from the electricity lifecycle are disclosed by the Electric Vehicle (EV) operator and buyer of EV services according to Table 4 (Smart Freight Centre 2024).

Table 4: 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 the 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, wind and hydropower is zero.
EV operator	Scope 3 Category 3 from ▪ Fuel production, i.e., emissions from the extraction, production, and transportation of fuel. ▪ Transmission and distribution losses, i.e., the Scope 2 emissions allocated to the electricity lost in transmission and distribution

Note that the ISO 14083 “Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations” despite being aligned with the GHG Protocol differs in several aspects, such as the definition of electricity lifecycle and the reporting obligations. These are discussed in detail in the whitepaper providing guidance on how to apply the ISO 14083 to EVs (Smart Freight Centre 2024).

3 Social Sustainability

To ensure a holistic transition, it is crucial to go beyond addressing only the environmental sustainability aspect and recognize the social dimension. This helps prevent the shift of impact where trade-offs disadvantaging communities are made on behalf of the environment. Much like their traditional counterparts, e-trucks are associated with social sustainability risks that can be mitigated. Yet e-trucks also contribute significantly to fostering a positive impact on the job market which's assessed in a study undertaken by Transport & Environment (2023). Subsequently, the section illuminates various solutions and practices that logistics stakeholders can adopt to address these risks, ensuring a sustainable transition within the road freight transport sector. These mitigation solutions encompass the entire e-truck battery supply chain to promote social sustainability throughout the e-truck lifecycle.

3.1 What are the anticipated changes in the demand for specific materials crucial for EVs and renewable electricity production, and what is done to address sustainable sourcing shortages?

Due to the fast development of the EVs and renewable electricity production markets, whose technologies require specific minerals for the construction of electronic components, there has been a scale up of raw material sourcing for certain minerals. The upward trend in production is anticipated to persist in the coming years, projecting an increase in demand for lithium sourcing up to 36kt, cobalt sourcing up to 21kt and nickel up to 276kt by the year 2030. (Transport & Environment 2021).

Due to the concentration of production of some of these minerals in certain regions, there is a risk of disruption and projected imbalances which make it difficult to address the increased demand sustainably. Some countries or regions envision taking measures to address these demand shortages and secure sourcing of raw materials. For example, under the Critical Raw Materials Act, Europe is considering opening new mining sites and lowering environmental and ecosystem restrictions for mining, as it is expected that the environmental benefits from clean energy would compensate for those sustainability issues. (European Commission 2023a)

3.2 What are the social sustainability issues associated with sourcing of raw material?

Various social sustainability issues significantly impact the sourcing of raw materials, with a particular emphasis on the cobalt supply chain. These issues include child labour, forced labour and unsafe working conditions (European Commission 2023b). The lack of safe working conditions not only exposes workers to fine dust and particulates but also poses risks of DNA-damaging toxicity and, in cases of poorly secured tunnels, even fatalities. Additionally, violations of indigenous rights and labor laws may occur, giving rise to governance issues such as corruption, bribery, funding of armed conflicts, and tax evasion (McKinsey 2023a). These issues are exacerbated by the conditions of extreme poverty and vulnerability of local populations.

3.3 What initiatives and frameworks are in place to address social sustainability challenges in the e-truck value chain, and how can logistic actors take advantage of them?

Many initiatives, both public and private, are in place to address and alleviate social sustainability challenges within the e-truck value chain. This section discusses a few of them and highlights ways in which logistic actors can align with these initiatives.

Noteworthy among these are both local and international regulatory frameworks and standards, exemplified by the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (OECD 2016) and Regulation (EU) 2023/1542 of the European Parliament pertaining to batteries and waste batteries. These directives are strategically oriented towards the responsible sourcing of raw materials, imposing a set of obligations on Original Equipment Manufacturers (OEMs). These obligations include the establishment of robust company management systems, identification of supply chain risks, formulation and implementation of risk mitigation strategies, independent third-party audits of supply chain due diligence from suppliers, and comprehensive reporting on supply chain due diligence (OECD 2016). Furthermore, these regulations will mandate traceability within the value chain and articulate recycling and recovery targets within the upcoming years which would reduce social sustainability challenges arising from new mining activities (European Commission 2023b)

In parallel, various private sector initiatives and consortiums actively engage in mitigating social sustainability concerns emanating from raw material sourcing in the e-truck domain. These include the Initiative for Responsible Mining Assurance, Responsible Minerals Initiative (RMI), Responsible Minerals Assurance Process, Responsible Cobalt Initiative, Drive Sustainability & European Commission Partnership, and the Global Battery Alliance's Battery Passport. These initiatives lay standards aligned with international benchmarks for the responsible sourcing of materials, conduct independent or third-party audits, provide digital tools for self-assessment of mining activities, and promote transparency within the battery value chain.

Logistic actors are well-advised to procure their e-truck fleets exclusively from OEMs that adhere to the supply chain due diligence regulations and standards stipulated by the aforementioned public sector initiatives, which are expressly designed to address and mitigate social sustainability issues within the e-truck battery value chain. Furthermore, logistic actors may find it prudent to consider procuring their fleets exclusively from e-truck manufacturers that have contractual agreements with battery suppliers mandating the procurement of raw materials solely from sources audited by the aforementioned private sector initiatives.

3.4 Which stakeholders in the supply chain should hold responsibility for issues related to raw material sourcing?

As depicted in Figure 5, the assurance standards landscape by RMI covers the entire supply chain, from mining companies to final user companies. This emphasizes the fact that all stakeholders in the supply chain should hold responsibility for issues incurred in the sourcing of raw materials and request appropriate action from their suppliers.

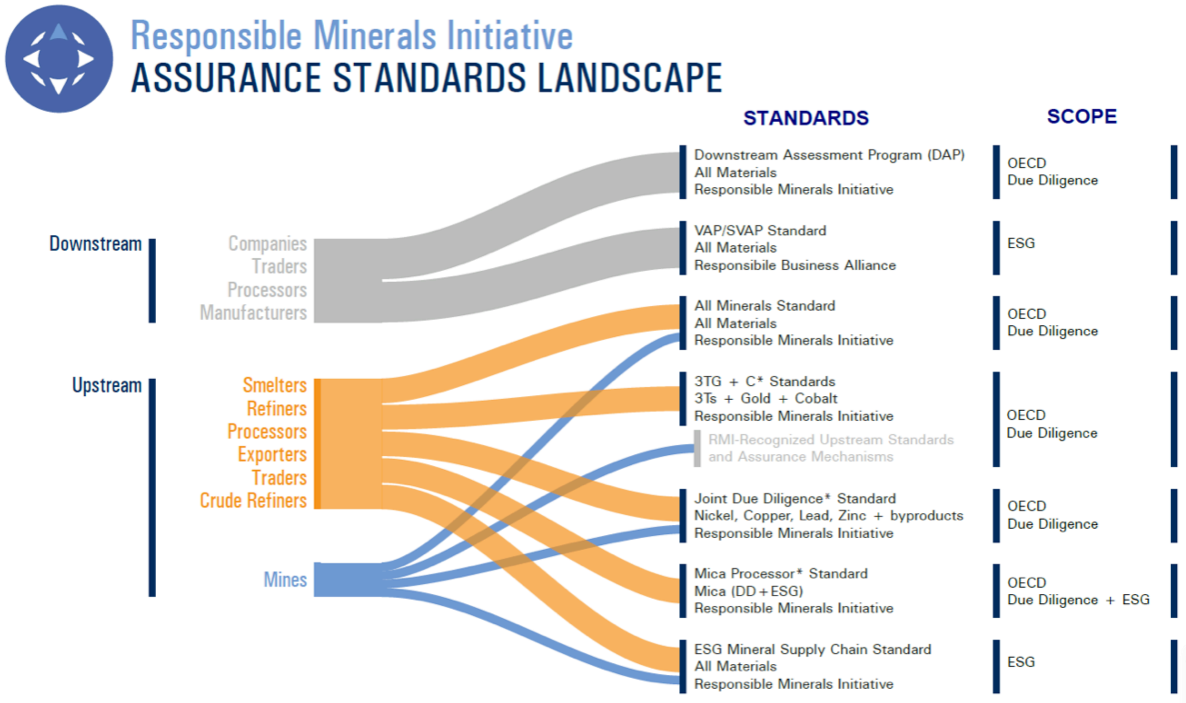

Figure 5: Responsible Minerals Initiative -Assurance Standards Landscape for the Minerals Supply Chain (Responsible Minerals Initiative n.d.)

4 Economic Sustainability

The future trajectory of e-trucks is significantly influenced by economic sustainability, necessitating wise decisions and advancements for market viability. This section delves into the economic challenges that needs to be addressed in the e-truck industry, to accelerate the transition from conventional to e-trucks. Additionally, it underscores strategies to address these economic sustainability challenges and ways in which economic transformation can aid in attainment of environmental and social sustainability goals within the e-truck industry.

4.1 What are the major economic sustainability challenges that affect e-trucks from the OEM's perspective?

The major economic sustainability challenges that affect e-trucks from the OEM's perspective are summarized in Table 5.

Table 5: Economic sustainability challenges that affect e-trucks from the OEMs perspective. (GBA and WEF 2019; McKinsey 2023a).

Lack of charging infrastructure and low utilization of existing infrastructure	The "chicken-egg" situation, also mentioned as part of the OEMs challenges, affects the macro-economics of the BE market. The necessary infrastructure is not in place for a stronger e-truck market to develop while at the same time, the under-utilization of existing infrastructure hinders further investment in infrastructure.
Limited customer acceptance	E-trucks are not completely accepted in the market because of several reasons, including limitations in range and charging infrastructure, lower payload capacity, higher upfront costs and limited model availability.
Supply chain risks	There are important risks of disruption for some of the raw materials that are key to the production of batteries. This is the case of Lithium, Cobalt, rare earth elements and Nickel.
Unclear business case for circularity	Recycling of batteries, which will be mandated by the regulation in the upcoming year, is an expensive process and there is no clear business case for the re-incorporation of batteries in their 2nd life, especially in competition with newer upgraded battery technologies.
Volatility of energy and materials price	The difficult prevision of prices for raw materials and energy creates a situation of uncertainty that makes decision-making and investment in e-truck manufacturing difficult if no appropriate regulatory measures in place.
Large scale investment and economies of scale needed	The e-truck market and technology are still at a developing stage. Large scale investments would be key to reach the required economies of scale.
Changing national regulations & lack of incentives	Changing national regulations and a diversified picture in terms of government support to the development of a market for e-trucks create an uneven playing field for stakeholders in different regions. Lack of sufficient incentives and subsidies for the development of a still relatively costly technology

4.2 What are the main solutions to existing economic and supply chain challenges that affect e-trucks?

From the OEM's perspective there is a range of solutions to the aforementioned problems, which include vertical supply-chain integration and long-term contracts, greater collaboration among stakeholders, innovation in productivity, and cost optimization. Simultaneously, flexibility in requirements and clear signals about long-term demand from the purchaser's side would greatly facilitate planning and cost optimization efforts for the OEMs.

From the macro-economic viewpoint, open dialogue and communication between stakeholders to support the battery industry would be important to overcome many of the existing market uncertainties. At the same time, innovation in battery technologies and the harmonization of international standards would level the playing field and contribute to lowering current high costs of the technology. (McKinsey 2023a)

4.3 What economic transformation is necessary to ensure environmental and social sustainability?

Environmental and social issues can be addressed through economic transformation, which can be summarized in three aspects: demand reduction, circularity and decarbonization of energy inputs (WEF 2020b), with the corresponding adhesion to standards and legislation that serve to prove efforts to avoid and mitigate sustainability issues.

Demand reduction refers to the reduction of materials inputs, which can take place through technological advancement, optimization of fleet and battery use (e.g., extending the life of the battery) (WEF 2020c). Circularity would allow the minimization of issues related to disposal of batteries and would contribute to minimizing the supply needs for raw materials. And finally, decarbonization of energy inputs refers to the energy use for production of materials and battery manufacture, and the electricity mix of the grid used to charge the vehicles.

Following these three strategies, the optimization of material and energy resources and economies of scale, which add to economic sustainability of the e-truck market, would support environmental and social sustainability.

Glossary

Battery Degradation: Battery degradation refers to a phenomenon in which the health of batteries is adversely affected by its operating and storage conditions, with deterioration occurring during charging/discharging and during storage. It leads to loss in the battey's original energy capacity.

Battery Passport: A Battery Passport functions as a digital record for individual batteries, documenting their entire lifecycle, from the initial sourcing of raw materials throughout refurbishment and recycling. It contains information about the battery's composition, manufacturing, performance, and environmental impact.

Carbon Capture and Storage: CCUS involves the capture of CO_2, generally from large point sources like power generation or industrial facilities that use either fossil fuels or biomass as fuel. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications or injected into deep geological formations such as depleted oil and gas reservoirs or saline aquifers.

Circularity: Circularity in electric vehicle industry is a practice in which the main components are intentionally designed to be upgraded, reused, repurposed, refurbished, remanufactured or recycled to have precious/recoverable materials easily extracted from them post its end of life.

Cradle-to-grave: Cradle-to-grave assessment considers impacts at each stage of a product's life cycle, from the time natural resources are extracted from the ground and processed through each subsequent stage of manufacturing, transportation, product use, and ultimately, disposal.

End of Life: End of Life of e-truck batteries is the end of battery's life in the automotive sector beyond which the battery has lost a significant proportion of its original energy capacity and therefore doesn't perform efficiently comparatively.

Marginal Emissions: The term marginal emissions refer to the amount of additional GHG emissions or other pollutants produced as a result of a specific change in energy or resource consumption. The marginal emissions factor refers to rate at which emissions would change with a small change to electricity load.

Retired/Spent e-truck Batteries: This refers to batteries that are no longer useful in e-truck application and can enter reuse/recycling phase.

Second Life of Batteries: The second life of e-truck batteries refer to batteries that have reached its end of first life in e-truck application, but still have enough capacity to be be reused, repurposed, refurbished, remanufactured to be used for second life application including stationary application.

State of Health: State of health refers to the health of e-truck batteries which is represented in percentage of remaining capacity of the battery.

Upstream and Downstream: Upstream operations refer to identifying, extracting and producing materials for e-trucks batteries and components whereas downstream operations include the production and manufacturing of these components and e-trucks bringing products to consumers.

Bibliography

Billy, R. G., & Müller, D. B. (2023). Aluminium use in passenger cars poses systemic challenges for recycling and GHG emissions. Resources, Conservation and Recycling, 190, 106827. https://doi.org/10.1016/j.resconrec.2022.106827

Börner, Martin F., Moritz H. Frieges, Benedikt Späth, Kathrin Spütz, Heiner H. Heimes, Dirk Uwe Sauer, and Weihan Li. (2022). "Challenges of Second-Life Concepts for Retired Electric Vehicle Batteries." Cell Reports Physical Science 3 (10): 101095. https://doi.org/10.1016/j.xcrp.2022.101095

CGEP, Columbia I. (2021). "Low-Carbon Production of Iron & Steel: Technology Options, Economic Assessment, and Policy." Center on Global Energy Policy at Columbia University SIPA I CGEP. March 8, 2021. https://www.energypolicy.columbia.edu/publications/low-carbon-production-iron-steel-technology-options-economic-assessment-and-policy/.

CRS (2020). Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles. https://sgp.fas.org/crs/misc/R46420.pdf

Del Pero, Francesco, Massimo Delogu, and Marco Pierini. (2018). "Life Cycle Assessment in the Automotive Sector: A Comparative Case Study of Internal Combustion Enginge (ICE) and Electric Car."

EEA. 2018. "Electric Vehicles from Life Cycle and Circular Economy Perspectives."

EERE. 2023. "Environmental Impacts and Siting of Wind Projects." Energy.Gov. 2023. https://www.energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects.

European Commission. (2019). Electric and hybrid cars: New rules on noise emitting to protect vulnerable road users - European Commission. https://single-market-economy.ec.europa.eu/news/electric-and-hybrid-cars-new-rules-noise-emitting-protect-vulnerable-road-users-2019-07-03_en

European Commission. (2023a). "European Critical Raw Materials Act." Text. European Commission - European Commission. 2023. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661.

———. (2023b). Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (Text with EEA relevance) https://eur-lex.europa.eu/eli/reg/2023/1542/oj

GBA and WEF. 2019. "A Vision for a Sustainable Battery Value Chain in 2030." https://www.globalbattery.org/media/publications/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf.

Goldman Sachs. (2022) Green Metals Battery Metals Watch the end of the beginning https://www.goldmansachs.com/intelligence/pages/gs-research/battery-metals-watch-the-end-of-the-beginning/report.pdf

Hawkins, Troy, Guillaume Majeau-Bettez, Bhawna Singh, and Anders Stroemman. 2013. "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles."
ICCT. 2018. "Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions."

ICCT. 2022. "Road freight decarbonization in Europe: Readiness of the European fleets for zero-emission trucking." https://theicct.org/wp-content/uploads/2022/09/road-freight-decarbonization-europe-sep22.pdf

ICCT. 2023. "A COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF EUROPEAN HEAVY-DUTY VEHICLES AND FUELS." https://theicct.org/publication/lca-ghg-emissions-hdv-fuels-europe-feb23/

ISO. 2023. "ISO 14083 Greenhouse Gases - Quantification and Reporting of Greenhouse Gas Emissions Arising from Transport Chain Operations." 2023.

ITF (2019), ITF Transport Outlook 2019, OECD Publishing, Paris, https://doi.org/10.1787/transp_outlook-en-2019-en.

Iyer, R. K., Kelly, J. C., & Elgowainy, A. (2023). Vehicle-cycle and life-cycle analysis of medium-duty and heavy-duty trucks in the United States. Science of The Total Environment, 891, 164093. https://doi.org/10.1016/j.scitotenv.2023.164093

McKinsey. 2023a. "Battery 2030: Resilient, Sustainable, and Circular." 2023. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular.

———. 2023b. The race to decarbonize electric-vehicle batteries, McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

Mowbray, S. (2023) Internal Combustion vs. evs: Learning from the past to boost sustainability, Mongabay Environmental News. Available at: https://news.mongabay.com/2023/08/internal-combustion-vs-evs-learning-from-the-past-to-boost-sustainability/

OECD. 2016. OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition. OECD. https://doi.org/10.1787/9789264252479-en.

O'Rourke, D., & Connolly, S. (2003). Just Oil? The Distribution of Environmental and Social Impacts of Oil Production and Consumption. Annual Review of Environment and Resources, 28(1), 587–617. https://doi.org/10.1146/annurev.energy.28.050302.105617

Responsible Minerals Initiative. 2021. "RESPONSIBLE MINERALS ASSURANCE PROCESS and STANDARDS." https://www.responsiblemineralsinitiative.org/minerals-due-diligence/standards/

Ricardo. 2021. "Lifecycle Analysis of UK Road Vehicles." Final Report, no. 4.

Scania. 2020 Life cycle assessment of distribution vehicles 'battery electric vs diesel driven'. https://www.scania.com/content/dam/group/press-and-media/press-releases/documents/Scania-Life-cycle-assessment-of-distribution-vehicles.pdf.

Smart Freight Centre. 2024. "Measuring and Reporting the Carbon Footprint of Electric Freight Vehicle Operations."

Transport & Environment. 2021. "From Dirty Oil to Clean Batteries. Batteries vs. Oil: A Systematic Comparison of Material Requirements."

Transport & Environment. (2023). Impact assessment of the transition to zero-emission trucks in Europe. Transport & Environment. https://www.transportenvironment.org/discover/impact-assessment-of-the-transition-to-zero-emission-trucks-in-europe/

UNDP Serbia. 2010. "Guidelines on the Environmental Impact Assessment for Wind Farms."

UNECE. 2022. "Life Cycle Assessment of Electricity Generation Options." 2022. https://unece.org/sed/documents/2021/10/reports/life-cycle-assessment-electricity-generation-options.

Verma, Shrey, Puneet Verma, and Gaurav Dwivedi. 2021. "Life Cycle Assessment of Electric Vehicles in Comparison to Combustion Engine Vehicles: A Review."

WEF. 2020a. "Aluminum for Climate: Exploring Pathways to Decarbonize the Aluminium Industry."

———. 2020b. "Forging Ahead: A Materials Roadmap for the Zero-Carbon Car."

———. 2020c. "The Road Ahead: A Policy Research Agenda for Automotive Circularity."
WRI and WBCSD. (2011) Corporate Value Chain (Scope 3) Accounting and Reporting Standard, World Business Council for Sustainable Development (WBCSD). https://www.wbcsd.org/girhj

WEF and McKinsey. (2021). Road Freight Zero: Pathways to faster adoption of zero-emission trucks.https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/road%20freight%20global%20pathways%20report/pathways-to-faster-adoption-of-zero-emission-trucks-2021.pdf

WRI, and WBCSD. 2013. "Greenhouse Gas Protocol - Technical Guidance for Calculating Scope 3 Emissions."

Zimmermann, Antonia. 2023. "Europe's Green Dilemma: Mining Key Minerals without Destroying Nature." POLITICO (blog). March 15, 2023. https://www.politico.eu/article/europes-green-dilemma-mining-key-minerals-without-destroying-nature/

Join our journey towards efficient and zero-emission global freight and logistics

Contact

Smart Freight Centre

Keizersgracht 560, 1017 EM

Amsterdam, Netherlands

P.O. Box 11772, 1001 GT

Amsterdam, Netherlands

Tel. office: +31 6 4695 4405

www.smartfreightcentre.org

info@smartfreightcentre.org