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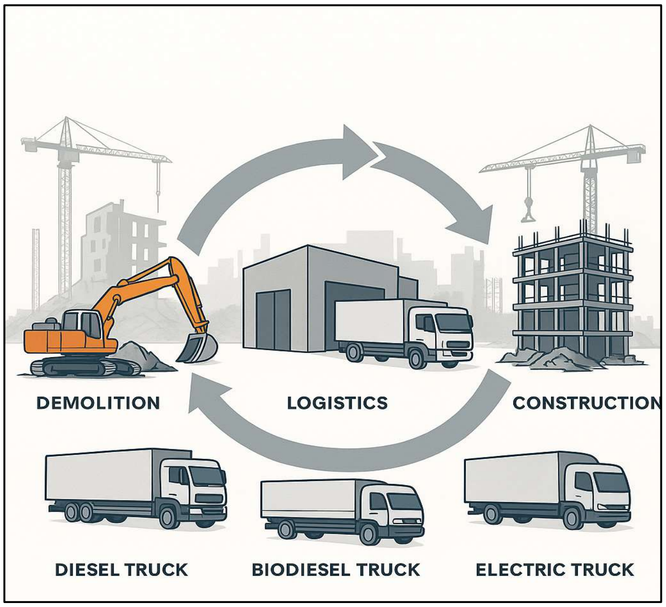

# Development of a Parametric Life Cycle Assessment (LCA) method for Construction Logistics in a Circular Economy

Master's thesis in the Master Programme Industrial Ecology and the Master Programme in Design & Construction Project Management

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MASTER’S THESIS ACEX30

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Cover: Illustration of circular construction logistics with diesel, biodiesel, and electric trucks (created by the authors using OpenAI DALL·E, 2025)

Department of Architecture and Civil Engineering
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## ABSTRACT

This thesis presents a parametric Life Cycle Assessment (LCA) model for evaluating the environmental impacts of construction logistics in circular economy contexts. The focus lies on quantifying the greenhouse gas emissions associated with transporting five categories of recovered construction material such as steel reinforcement bars, glass partitions, wooden doors, wooden flooring, and mineral wool in Sweden.Using openLCA 2.1 and the ecoinvent 3.8 database, logistics scenarios are modeled for diesel, biodiesel, and electric heavy goods vehicles. The analysis includes both single-load and co-loaded transport configurations. Results show that electric trucks, despite lower payload capacities, yield the lowest emissions due to the low-carbon Swedish electricity mix. Co-loading strategies also prove effective in reducing the total number of trips and overall emissions.Break-even distances are calculated to determine the threshold at which transporting reused materials becomes environmentally beneficial, with distances varying significantly by material and transport mode. An uncertainty analysis was performed to evaluate the sensitivity of break-even distances under different transport and loading conditions. The proposed model demonstrates the significance of logistics choices in circular construction planning. It offers practical insights for stakeholders aiming to reduce transport emissions and supports improved integration of logistics parameters into LCA frameworks.

**Keywords**: Construction logistics, circular economy, Life Cycle Assessment, greenhouse gas emissions, parametric modeling, transport strategies, breakeven distance, uncertainty analysis

# Preface

This master's thesis was carried out at the Division of Building Technology, Department of Architecture and Civil Engineering, Chalmers University of Technology, in collaboration with ongoing initiatives on circular construction logistics.

We would like to thank our supervisor, Maud Lanau, for her constructive guidance, continuous support, and detailed feedback throughout the course of this work. We are also grateful to our examiner, Alexander Hollberg, for his insights and thoughtful evaluation.

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Finally, we appreciate the support from our families and peers during the writing process.

Göteborg, May 2025
Sreelaj Athamkavil
Mahesh Mohan

# List of Acronyms

BIM – Building Information Modelling

CCC – Construction Consolidation Centre

CE – Circular Economy

CLI – Circular Logistics Integration

CLS – Construction Logistics Setup

CLC – Construction Logistics Centre

$CO_2$ – Carbon Dioxide

$CO_2$-eq – Carbon Dioxide Equivalent

$CH_4$ – Methane

EEA – European Environment Agency

EPD – Environmental Product Declaration

FL – Forward Logistics

GHG – Greenhouse Gas

GWP100 – Global Warming Potential over 100 years

HGV – Heavy Goods Vehicle

IPCC – Intergovernmental Panel on Climate Change

ISO – International Organization for Standardization

LCIA – Life Cycle Impact Assessment

LCI – Life Cycle Inventory

LCA – Life Cycle Assessment

LVL – Laminated Veneer Lumber

PEF – Product Environmental Footprint

RL – Reverse Logistics

# List Of Units

kg – kilogram

tonne – metric ton (1,000 kg)

km – kilometre

kWh – kilowatt-hour

kg $CO_2$-eq – kilogram carbon dioxide equivalent

tkm – tonne-kilometer

m3 – meter

% – percent

# Glossary of Technical Terms

**Biogenic Carbon**
It is the carbon that originates from living or recently living organisms (plants, trees, etc.), unlike fossil carbon which is from ancient organic matter now stored in fossil fuels.

**Break-even Distance**
The maximum transport distance at which the environmental benefit of using a reused material still outweighs the emissions caused by transporting it.

**Building Information Modelling (BIM)**
A digital process that allows for the planning, design, and management of construction projects using a 3D model enriched with data.

**Carbon Dioxide Equivalent ($CO_2$-eq)**
A standard unit for comparing the global warming potential of various greenhouse gases by converting their impacts into the equivalent amount of carbon dioxide.

**Circular Economy (CE)**
An economic model aimed at reducing waste and promoting the continual reuse of resources by closing material loops through reuse, recycling, and recovery.

**Circular Logistics Integration (CLI)**
An approach that combines forward and reverse logistics to enhance material recovery, coordination, and sustainability in construction projects.

**Construction Consolidation Centre (CCC)**
A logistics facility used to consolidate deliveries of materials before they reach the construction site, aiming to reduce the number of trips and associated emissions.

**Construction Logistics Setup (CLS)**
A planned system for organizing and controlling the delivery, movement, and storage of materials on and around construction sites to improve efficiency and reduce environmental impacts.

**Cradle-to-gate Embodied Carbon**
The total greenhouse gas emissions associated with producing material, including raw material extraction, manufacturing, and excluding the emissions from transportation to site, installation, operational and end of life processes.

**Ecoinvent Database**
A life cycle inventory database that provides consistent and transparent environmental data on materials, energy use, and transport processes for use in LCA models.

**Electricity Consumption (kWh)**
Measured in kilowatt-hours, it refers to the energy used by electric vehicles or equipment during operation. It is used to calculate emissions when linked to a national electricity grid.

**Environmental Product Declaration (EPD)**
A third-party verified document providing transparent and standardized information about a product's environmental impact based on life cycle assessment.

**European Environment Agency (EEA)**
A European Union agency that supplies independent environmental data, often referenced for emission factors and transport-related information.

**Functional Unit**
The quantified performance of a product system for use as a reference unit in a life cycle assessment study. (ISO 14044:2006, section 3.20). It expresses the function of the product. It is the reference flow to which all other flows are related (i.e. quantitative). It also forms a basis for product comparisons.

**Global Warming Potential (GWP100)**
A metric used to compare the impact of greenhouse gases on global warming over a 100-year period, with $CO_2$ used as the reference gas.

**Greenhouse Gas (GHG)**
Gases that trap heat in the atmosphere and contribute to global warming. Common examples include carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$).

**Heavy Goods Vehicle (HGV)**
A large freight truck used for transporting materials. This thesis includes different types of HGVs powered by diesel, biodiesel, and electricity.

**Life Cycle Assessment (LCA)**
A standardized method (ISO 14040/44) used to assess the environmental impacts associated with all stages of a product's life from cradle to grave.

**Life Cycle Impact Assessment (LCIA)**
A phase of LCA that evaluates the potential environmental impacts associated with the inventory data collected during life cycle inventory analysis.

**Life Cycle Inventory (LCI)**
A phase in LCA that involves data collection and calculation of all inputs and outputs of a system, such as materials, energy, and emissions.

**Laminated Veneer Lumber (LVL)**
An engineered wood product made from thin layers of wood bonded together, used as a recovered material in this thesis.

**OpenLCA**
An open-source software tool used to model life cycle assessments. It allows for customization of LCA models using databases like ecoinvent.

**Parametric LCA**
An LCA model that allows key variables to be adjusted (e.g., transport distance, fuel type), making it flexible for scenario analysis.

**Product Environmental Footprint (PEF)**
A methodology developed by the European Commission to measure the environmental performance of products based on life cycle thinking.

**Reverse Logistics (RL)**
The process of moving materials from their final destination back into the supply chain for reuse, recycling, or disposal.

**System Boundary**
The defined limits of what is included and excluded in an LCA study, such as material production, transport, energy use, and end-of-life scenarios.

**Tonne-Kilometre (tkm)**
A transport performance unit representing the movement of one tonne of goods over one kilometre. It is used to measure and compare freight transport emissions.

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# 1 Chapter - Introduction

The construction sector is a major source of greenhouse gas emissions and resource consumption (GlobalABC, 2021). As global attention shifts toward sustainability, the sector is under increasing pressure to transition from a linear model to a circular economy (CE), where materials are recovered, reused, and reintegrated into new projects rather than discarded as waste (Ellen MacArthur Foundation, 2019). This shift highlights the critical role of logistics, as the environmental benefits of material reuse heavily depend on how materials are transported.

Recent studies indicate that transport-related emissions from construction projects are substantial. In Sweden alone, emissions from construction transport were estimated at over 400,000 tonnes of $CO_2$ in a single year (Sezer & Fredriksson, 2020). This underscores the need for efficient transport strategies in CE-based construction. While reusing materials reduces the demand for new production, the carbon savings can be offset by emissions from transporting recovered materials (Dahlbo et al., 2015). Understanding these trade-offs is essential for sustainable decision-making.

Life Cycle Assessment (LCA) is the standard method for evaluating environmental impacts in construction (Hellweg & Milà i Canals, 2014). However, many LCA studies do not fully account for logistics variables such as vehicle type, load optimization, and transport distance, which can significantly influence emissions (Nordelöf et al., 2019). Additionally, there is limited research comparing how different transport options such as diesel versus electric trucks affect emissions when moving reused materials under real-world conditions.

This thesis addresses this gap by developing a parametric LCA model to assess greenhouse gas emissions from construction logistics in circular economy scenarios. The model focuses on five materials commonly recovered in demolition projects such as steel reinforcement bars, glass partitions, wooden doors, wooden flooring, and mineral wool. It evaluates how different transport configurations such as single-load versus co-loaded, diesel versus electric impact overall emissions and identifies break-even distances beyond which reuse may no longer be environmentally beneficial.

By providing a data-driven approach to compare logistics scenarios, this research supports better decision-making in circular construction. It also highlights the importance of transport planning in ensuring that material reuse strategies contribute effectively to climate goals.

## 1.1 Goal Statement

This study aims to respond to the identified research gaps by developing a parametric life cycle assessment (LCA) model tailored to construction logistics in circular economy settings. The proposed model will support the evaluation of environmental performance across different logistics strategies, including various transport modes and configurations. It will also incorporate key parameters such as routing, load capacity, and frequency of trips. By doing so, the model is expected to improve understanding of the trade-offs involved in logistics planning and provide practical support for decision-making in sustainable material recovery and reuse. This approach addresses both methodological limitations in current LCA applications and the absence of flexible assessment tools for circular construction logistics.

# 2 Chapter – Literature Review

This Literature review examines existing literature on construction logistics within the context of the circular economy (CE), using a thematic structure to identify key areas affecting environmental performance. The analysis is organized under five major themes. The first theme outlines the role of logistics in enabling the transition to CE in construction, with a focus on emissions related to material transport. The second theme explores how environmental certifications influence logistics planning and emission levels. The third section looks at the integration of forward and reverse logistics systems in circular construction and the importance of governance and coordination. The fourth theme evaluates how life cycle assessment (LCA) methods are applied to assess logistics strategies and identifies their current limitations. The fifth theme discusses the use of digital and parametric tools in improving logistics efficiency, especially in early project stages. Across these themes, the review identifies a consistent lack of parametric tools for evaluating complex transport scenarios within circular construction. These gaps underscore the need for improved assessment models tailored to the logistics challenges of CE-based building projects.

## 2.1 Circular Economy and the Role of Construction Logistics

To meet Sustainability goals, the construction industry is increasingly acknowledging that it should transform from a linear to circular economy (CE) model. This transition is heavily dependent on Construction logistics where the transportation of recovered and recyclable materials plays an important role. Among the logistics components, material and waste transport has a noticeable impact on greenhouse gas (GHG) emissions. According to Sezer and Fredriksson (2020), construction transport accounts for approximately 6–8% of GHG emissions in construction projects. In 2017 alone, emissions from construction-related transport in Sweden were estimated at 422,800 tonnes of $CO_2$, resulting from the construction of over 141,200 flats, averaging 31 transports per flat across 12 projects.

Successful logistics measures like enhanced planning and implementation of construction logistics setups (CLSs) have shown the potential to reduce not only the number of transports but also emissions. A study of 40 Swedish construction projects demonstrated the average transport frequency to be 0.49 per square meter. The projects which employed a terminal and checkpoint combination had reported the lower average transport per square meter numbers. For example, residential projects using a checkpoint and terminal setup recorded an average of 0.42 transports/$m^2$ as compared to 0.84 transports/$m^2$ in projects that used only checkpoints, and 0.46 transports/$m^2$ in projects that used only terminals (Sezer & Fredriksson, 2021, Table 4).

Despite these findings, a significant research gap remains in the environmental evaluation of logistics solutions under circular economy conditions. While Sezer and Fredriksson (2020, 2021) provide useful statistics on transportation frequency and emissions, there is insufficient comparative research of the environmental impacts of certain logistics techniques, such as co-loading, backhauling, or the usage of consolidation centres. A shortage of parametric tools capable of simulating various transport configurations in circular construction restricts the development of evidence-based emission reduction strategies.

## 2.2 Environmental Certification and Its Influence on Transport Emissions

In the study by Sezer & Fredriksson, 2021, the projects were categorized based on the Swedish system of environmental certification Miljöbyggnad, consisting of three categories: bronze, silver, and gold. Projects certified as gold exhibit the most significant environmental performance. Gold-certified projects should quantify the impact of transport on the climate and at least demonstrate a 10% lower emissions level compared to silver-certified projects. By average, the gold-certified projects emitted 15.2 kg of $CO_2$ per square meter. Silver-certified projects, whose emissions calculations are also mandated to be performed by transport mode and distance, averaged slightly higher at 17 kg $CO_2/m^2$. Non-certified projects, without any mandatory guidelines to inform their transport emissions averaged the highest at 17.6 kg $CO_2/m^2$.

The emissions differed differently in these groups as well. Non-certified projects had the largest standard deviation (0.50) in emissions per square meter, which indicates non-uniformity and lower level of control over transport logistics. Certified projects, both gold and silver showed more uniform and lower emissions than non-certified projects. The results suggest that environmental certification especially at the gold level, is associated with better planning and execution of logistics. This confirms the importance of structured logistics arrangements such as Construction Logistics Setups (CLSs), in reducing environmental impact and achieving circular economy objectives in construction.

However, the existing literature does not adequately clarify the mechanisms by which certification standards influence logistics practices and environmental outcomes**.** While Sezer and Fredriksson (2021) show statistical associations between certification and emission levels, they do not identify the specific transport planning methods or management systems that lead to these differences. As a result, there is limited understanding of how certification can be operationalized as a tool to improve logistics performance in circular construction.

## 2.3 Integrated Construction Logistics: Forward, Reverse, and Circular Logistics

Forward logistics (FL), involving material delivery to construction sites and reverse logistics (RL), involving material take-back for reuse or recycling are crucial to circular economic efforts. (Ding et al., 2023) stress the importance of integrating FL and RL to achieve success in material loop closure. Fragmented logistics management is dominant in current practice, they note, based on their systematic review, advocating for a more comprehensive integration approach known as circular logistics integration (CLI). Integration involves incorporating communication channels, inventory management, and network coordination to make the resource recovery processes more streamlined.
(Janné & Fredriksson, 2019) discuss the governance mechanisms needed to properly adopt construction logistics centers (CLCs). They mention the significance of resolving conflicting interests of various stakeholders through defined duties, responsibilities, and sound communication plans to coordinate more easily and achieve gains in efficiency.

Against this backdrop, (Sundquist et al., 2018) call for the re-grouping of construction logistics where off-site logistics and site logistics would be combined with great inter-stakeholder collaboration and inter-share of information. (Muerza & Guerlain, 2021) also advocate for Construction Consolidation Centres (CCC) as being part of enhancing efficiency in logistics, traffic flow congestion, and environment pressure within metropolitan cities. Their approach assesses the technical and standards-based sustainability and feasibility of CCC implementation and offers policy application suggestions.

(Dubois et al., 2019) recognize coordination between construction sites and supply chains as the most significant factor for better logistics performance and lower costs. They report from their study that a more integrated, holistic strategy across various supply chains and project locations plays a much stronger role in performance.

Despite these contributions, existing studies do not sufficiently explore the environmental impacts of integrated logistics systems in circular construction. The emphasis has largely been on operational efficiency, stakeholder coordination, and cost outcomes, with limited empirical assessment of how these integration mechanisms affect environmental performance. There is a lack of analytical models or case studies that evaluate how CLI, CLCs, or CCCs contribute to emissions reduction, resource optimization, or overall sustainability outcomes.

## 2.4 Environmental Assessment in Circular Construction: LCA

Life Cycle Assessment (LCA) is one of the most applied tools for the evaluation of environmental impacts of CE strategies in the built environment. Its application has its shortcomings, however. According to Andersen et al. (2022), there is not yet a standard LCA procedure for CE strategies in the building sector. This leads to bias between assumptions, system boundaries, and allocation procedures, with dramatic consequences for LCA results.

One of the critical issues is how to allocate environmental impacts across different life cycles in the case of recycling or recovery of materials or parts. Eberhardt et al. (2020) acknowledge this issue and the necessity to make a choice between appropriate allocation methods. They include the Circular Footprint Formula which was created under the European Commission's Product Environmental Footprint (PEF) project because of the complexity of circular systems. The CFF encompasses both recycled content use and end-of-life recyclability. It adjusts environmental burden based on material quality and reuse quantities. For reuse scenarios, it distributes impacts proportionally across multiple life cycles by dividing the component's burden by the number of intended uses.

This method is more balanced than traditional allocation methods like the cut-off or 100:0 method. By accounting for both the upstream and downstream effects of recycling and reuse, the CFF provides a more representative figure for environmental effect in CE systems. Accordingly, as Eberhardt et al. argue, the choice of method like the CFF has direct consequences for the understanding of environmental gain and decision-making in circular construction practice.

(Rigamonti & Mancini, 2021) outline circularity indicators and LCA as supplementary roles. According to them, although circularity indicators do offer valuable information to the stakeholders towards circularity attainment, they should be placed within detailed LCA methodologies to help practically enable sustainable decision-making.

Nonetheless, current LCA methodologies do not sufficiently capture the complexity of logistics operations in circular construction. Many assessments rely on linear assumptions and do not incorporate multi-use transport cycles, reverse flows, or real-time logistics parameters. Also, allocation methods like the CFF have not been widely applied to logistics evaluation. This limits the capacity of LCA tools to support the environmental assessment of transport systems specific to circular construction logistics.

## 2.5 Enhancing Logistics Efficiency through Digital and Integrated Approaches

(Brusselaers et al., 2022) propose a systems sustainability assessment method that integrates life cycle assessment (LCA) with external costs estimation for both on-site and off-site building logistics. They highlight the greenhouse gas abatement potential through logistics optimization while also noting data availability and data management issues.

Development in digital technology, more so Building Information Modelling (BIM), brings fresh promises for applications of LCA in construction logistics. (Ge et al., 2024) build a BIM-supported LCA system to minimize embodied carbon in prefabricated buildings with significant efficiency gain in initial design stages. Therefore, (Säwén et al., 2022) propose parametric building LCA tools as they highlight the ability to investigate and optimize the environmental impacts in a limited duration in the early design phase by utilizing parametric design approaches.

Despite these advancements, there is still a significant gap in the use of digital tools for transport-specific logistics evaluation inside CE frameworks. Existing models lack the flexibility to examine how changes in transport mode, load capacity, routing, and trip frequency affect environmental effects. Most tools are built for broad material flows and lack the ability to simulate complex logistical scenarios involving salvaged or reused construction materials. This restricts their usefulness in facilitating evidence-based planning for sustainable building logistics.

# 3 Chapter - Methodology

This chapter presents the methodological steps taken to assess greenhouse gas (GHG) emissions from the transport of reclaimed construction materials in a circular economy context. The study applies a parametric Life Cycle Assessment (LCA) approach, consistent with the principles outlined in ISO 14040 and ISO 14044. The methodology combines secondary data collection, transport scenario development, and life cycle modeling using specialized software tools.

The first step involved selecting five representative construction materials namely steel, glass, wooden doors, wooden flooring, and mineral wool. The construction materials were selected based on the versatility of their physical properties, including factors such as high density (steel), high fragility (glass), and high volume-to-weight ratio (mineral wool and wooden elements). These characteristics influence transport requirements and emissions, making them suitable for comparative assessment in this study.

Following material selection, data were collected from multiple sources. Environmental Product Declarations (EPDs) were used to obtain material-specific environmental data, especially cradle-to-gate embodied carbon values. The ecoinvent 3.8 database served as the core background dataset for modeling. In addition, scientific literature and commercial product catalogues were used to supplement assumptions regarding vehicle configurations and payload characteristics. For electric truck emissions, data were based on a published Life Cycle Assessment study by Scania (Algesten, Ritzman, & Nilzén, 2024), which provides relevant life-cycle data for battery-electric freight vehicles.

Payload configuration was addressed by defining two distinct transport types, single material loaded trips and co-loaded material trips. These configurations reflect typical practices in construction logistics, where materials may be transported separately or together depending on project requirements and truck capacity.

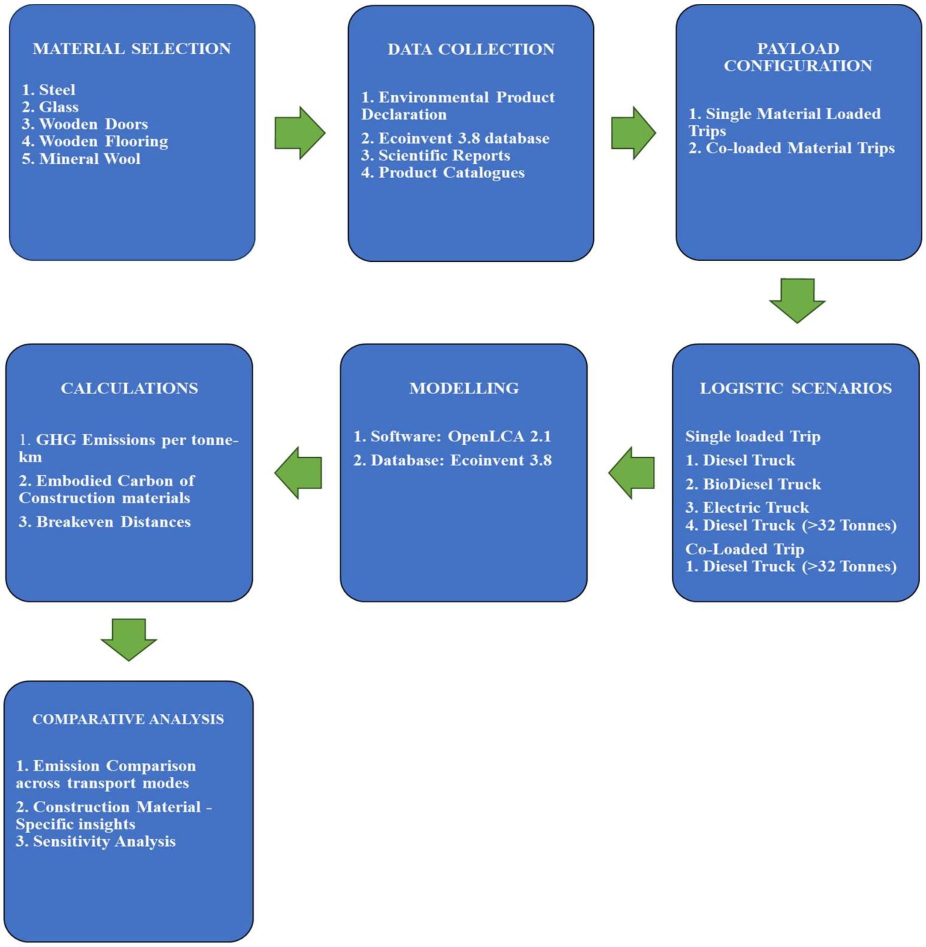
Based on these payload types, five logistics scenarios were developed. These included diesel truck (single-load), biodiesel truck (single-load), electric truck (single-load), and diesel truck (for both single and co-loaded trips) with a gross vehicle weight above 32 tonnes. These scenarios represent a range of conventional and low-emission transport options relevant to current industry practices.

Modeling of these scenarios was carried out using openLCA version 2.1, with ecoinvent 3.8 used as the underlying life cycle inventory database. Each transport mode was modeled in combination with each construction material to build a parametric dataset that allows emission performance to be compared across cases.

The next stage involved calculating GHG emissions per ton-kilometer for each material-transport combination. The cradle-to-gate embodied carbon values of the materials were used to estimate breakeven distances, defined as the transport distance at which emissions equal the product's cradle-to-gate embodied carbon. These calculations were completed using Microsoft Excel, where data from the LCA modeling was integrated with material-specific emission values.

The results were then analyzed to compare GHG emissions across transport modes and materials. A comparative analysis was carried out to identify which transport configurations result in lower environmental impacts. In addition, material-specific patterns were examined, and a sensitivity analysis was included to evaluate the effect of varying key parameter such as loading capacity.

The full methodological workflow is illustrated in *Figure 3.1*, which presents the sequential steps from material selection through data collection, modeling, calculations, and comparative analysis.



**MATERIAL SELECTION**

1. Steel
2. Glass
3. Wooden Doors
4. Wooden Flooring
5. Mineral Wool

**DATA COLLECTION**

1. Environmental Product Declaration
2. Ecoinvent 3.8 database
3. Scientific Reports
4. Product Catalogues

**PAYLOAD CONFIGURATION**

1. Single Material Loaded Trips
2. Co-loaded Material Trips

**LOGISTIC SCENARIOS**

Single loaded Trip
1. Diesel Truck
2. BioDiesel Truck
3. Electric Truck
4. Diesel Truck (>32 Tonnes)

Co-Loaded Trip
1. Diesel Truck (>32 Tonnes)

**MODELLING**

1. Software: OpenLCA 2.1
2. Database: Ecoinvent 3.8

**CALCULATIONS**

1. GHG Emissions per tonne-km
2. Embodied Carbon of Construction materials
3. Breakeven Distances

**COMPARATIVE ANALYSIS**

1. Emission Comparison across transport modes
2. Construction Material - Specific insights
3. Sensitivity Analysis

*Figure 3.1 Workflow Methodology for parametric LCA on Construction Logistics (Created by authors)*

# 4 Chapter - Goal & Scope Definition

## 4.1 Goal Definition

### 4.1.1 Goal of the Study

The goal of this Life Cycle Assessment (LCA) is to assess greenhouse gas emissions, specifically Global Warming Potential (GWP-100) associated with different construction logistics strategies for transporting recovered construction materials in a circular economy context in Sweden. This assessment corresponds to Module C2 (transport) in the life cycle of the construction materials.

### 4.1.2 Aim of the Study

The aim of this study is to develop a parametric LCA model that evaluates how key logistics-related parameters (e.g., distance, fuel type, and vehicle class) influence GHG emissions from the transport of recovered construction materials. The model will support data-driven logistics planning and contribute to lower-carbon practices in circular construction.

### 4.1.3 Objectives of the Study

- To evaluate the relative emissions of transport strategies to quantify greenhouse gas emissions ($CO_2$, $CH_4$, and $N_2O$) using the GWP100 impact category across various logistics scenarios in Module C2 (transportation) and to identify and compare important parameters like transport distance, vehicle type, fuel mix and Single versus co-loaded transport strategies.
- To evaluate the carbon balance between the emissions avoided during the production stage and transport-related emissions for reused materials.
- To offer practical guidance to stakeholders for optimizing transport logistics in circular construction.

## 4.2 Scope Definition

### 4.2.1 Functional Unit

The functional unit of an LCA serves as the foundation for comparing environmental impacts. In this study, the unit is defined as:

> "Transportation of 1 kg of recovered construction material from demolition site to new construction site."

Four important considerations from peer-reviewed literature and technical standards support this choice.

First, based on ISO 14040 principles, the mass-functional unit (Module C2) of building life cycle assessment targets transport-related impacts in a direct manner (British Standards Institution, 2006). This is aligned with set techniques used in material flow analysis (European Commission, 2010) and facilitates comparison on an equivalent basis between logistical conditions (Spielmann et al., 2005).

Secondly, the unit well responds to the needs of the circular economy. Recent studies indicate that the overall environmental value of material reuse is heavily influenced by transport emissions (Pomponi & Moncaster, 2017). This critical balance between transport emissions and avoided production effects is particularly measured by using indicators such as emissions per unit mass transported, e.g., kg $CO_2$-eq/kg (Hossain & Ng, 2018).

Thirdly, this unit facilitates parametric modeling by allowing integration of key transport variables:

- Transport distance
- Vehicle fuel efficiency (Allacker, 2010)
- Emission factors (European Environment Agency, 2019)

Finally, the functional unit supports practical applications at the industry level. These include comparative route analysis, planning of fleet composition, and evaluating the sustainability of logistics operations. Its compatibility with established ISO standards ensures both methodological consistency and usability for stakeholders in construction and demolition logistics (British Standards Institution, 2006; Swedish Standards Institute, 2006).

## 4.2.2 System Boundaries for Scope Definition

### 4.2.2.1 Product System Boundary

The system boundaries in this study are defined to support a consistent and transparent life cycle assessment of both construction materials and freight transport activities. The assessment is conducted using openLCA version 2.1, with datasets from the ecoinvent 3.8 database, as well as Environmental Product Declarations (EPDs) for selected construction materials.

For diesel and biodiesel freight trucks, the system boundary includes the full life cycle of the transport service. This includes the manufacturing, operation, maintenance, and end-of-life treatment of the vehicle, in addition to the construction, operation, and maintenance of road infrastructure. Fuel production, combustion-related emissions, and non-exhaust emissions such as tyre and brake wear are also included. These datasets reflect average European and swiss operating conditions and are expressed per tonne-kilometre of freight transport (Spielmann et al., 2007; Keller et al., 2010; Ntziachristos et al., 2013; De Ceuster et al., 2009; Knörr et al., 2011).

The electric truck model also includes full life cycle processes, including battery and vehicle manufacturing, electricity consumption during operation, and end-of-life disposal. Emissions during use phase are modeled using the Swedish national electricity carbon intensity factor (Statista, 2024), based on Scania's LCA data (Algesten, Ritzman, & Nilzén, 2024).

The transport modeling accounts for emissions from both the loaded trip and the return empty trip, assuming that the truck travels the same distance in both directions. Additional tools and attachments required for loading and securing specific materials are also included in the modeling. These include steel skips for steel, glass frame structures for flat glass, and truck body supports for wood products & wool. These components are not considered part of the vehicle's kerb weight but are included in the payload. Their mass is accounted for in the transport emissions calculation.

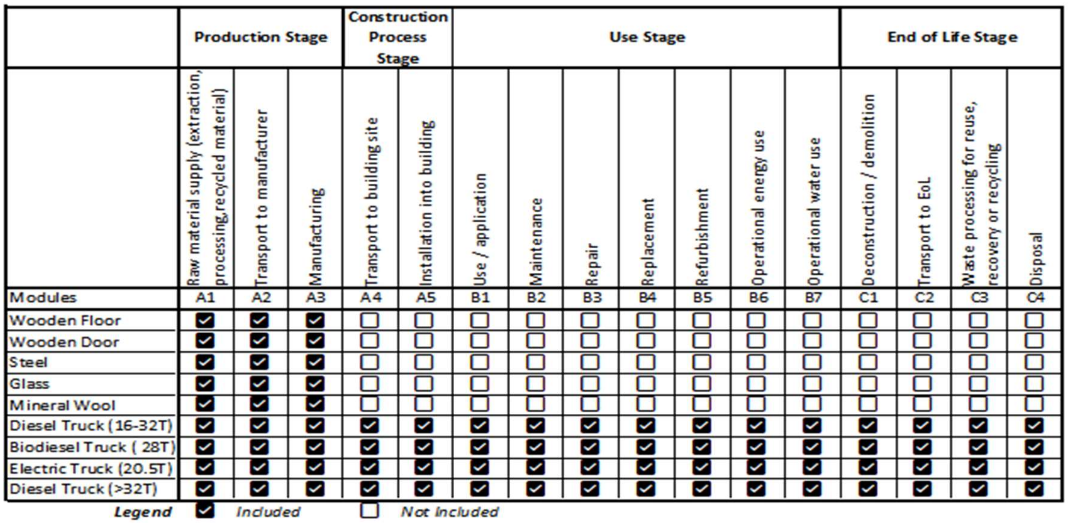
Regarding construction materials, the following boundaries are applied based on data availability and relevance to the study's objectives:

- Wooden flooring: Only production stages A1–A3 are included, based on an EPD (Wood Manners, 2022). Transport to site, use, and end-of-life stages are excluded.

- Wooden doors (Kerto LVL): The model includes A1–A3, based on cradle-to-gate data from a verified EPD (Metsä Wood, 2022). No downstream modules are considered.

- Steel reinforcement bars, flat glass, and stone wool: These materials are modeled from cradle to gate, including stages A1 to A3. Downstream stages (A4–C4) are not considered in the current system boundary (Remus et al., 2013; World Steel Association, 2010; ecoinvent, 2021a, 2021b).

The system boundary inclusion across all modules is summarized in *Figure 4.1*, which illustrates the lifecycle stages considered for each material and freight mode.



| | Production Stage | | | Construction Process Stage | | Use Stage | | | | | | | End of Life Stage | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw material supply (extraction, processing,recycled material) | Transport to manufacturer | Manufacturing | Transport to building site | Installation into building | Use / application | Maintenance | Repair | Replacement | Refurbishment | Operational energy use | Operational water use | Deconstruction / demolition | Transport to EoL | Waste processing for reuse, recovery or recycling | Disposal |
| Modules | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 |
| Wooden Floor | ☑ | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wooden Door | ☑ | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Steel | ☑ | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Glass | ☑ | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mineral Wool | ☑ | ☑ | ☑ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Diesel Truck (16-32T) | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |
| Biodiesel Truck ( 28T) | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |
| Electric Truck (20.5T) | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |
| Diesel Truck (>32T) | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ |

*Legend* ☑ *Included* ☐ *Not Included*

*Figure 4.1* *Life Cycle Module Coverage of Construction Materials and Freight Transport Modes*

Certain processes were excluded from the system boundaries to keep the assessment focused on the main transport and material production stages. Emissions from cranes, forklifts, and other machinery used for loading and unloading materials were not included. Likewise, energy use for compressing mineral wool into bales was omitted. The model also assumes flat terrain, so it does not account for increased or reduced energy needs due to uphill or downhill transport. The cradle-to-gate emissions for wood-based materials exclude biogenic carbon storage effects, hence any short -term carbon sequestration from wood was not considered. Finally, the reuse scenario only covers transport emissions. Minor activities such as inspections or small repairs before reuse were excluded. These omissions may lead to a slight underestimation of total greenhouse gas emissions but are not expected to change the comparative conclusions of this study.

#### 4.2.2.2 Geographical Scope

The geographical scope of this study is Sweden, with a focus on reflecting national conditions in the assessment of construction logistics and material-related environmental impacts. This includes considerations such as:

- The national road transport system and logistics structure
- Regulations governing heavy goods vehicle (HGV) operations and emissions
- Sweden's fuel supply composition, including fossil diesel and biodiesel
- The national electricity generation mix used for estimating emissions from electric vehicles
- Context-specific aspects such as seasonal weather variations and urban traffic characteristics

While Sweden serves as the primary geographic focus, high-quality Sweden-specific life cycle inventory (LCI) data were not available for all processes. In such cases, datasets from European countries were used as substitutes. Transport datasets for diesel and biodiesel trucks are sourced from ecoinvent 3.8 and represent average European or Swiss conditions. Likewise, Environmental Product Declarations (EPDs) for construction materials such as wood-based components are based on data from the European market.

For the battery-electric truck, electricity consumption values are derived from test drive data provided by Scania's prototype long-haul electric truck (Algesten, Ritzman, & Nilzén, 2024). Operational emissions are calculated using Sweden's national electricity carbon intensity (Statista, 2024). Apart from this case, no further adjustments were made to align foreign datasets with Swedish-specific conditions.

This approach allows the study to maintain a geographically consistent framework while relying on regionally relevant secondary data when Sweden-specific data are not available.

#### 4.2.2.3 Temporal Boundaries

The time horizon of the assessment is 100 years, as per globally agreed-upon LCA practice, e.g., as outlined by the IPCC and ISO 14040/14044 standards. The Global Warming Potential for 100 years (GWP100) indicator is applied to quantify the long-term climate impact of transport activities leading to greenhouse gas emissions. A 100-year time frame is selected to enable comparison with other LCA studies and global climate change impacts assessments.

#### 4.2.2.4 Impact Category

The key environmental impact category covered in this LCA is the 100-year Global Warming Potential (GWP100). This category examines the climate change effects of the greenhouse gases, carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) as kilograms of $CO_2$-equivalents (kg $CO_2$-eq).

The selection of Impact category GWP100 was done due to its:

- General applicability by LCA practices and policy measures (e.g., IPCC guidelines)
- Direct relevance to transport emissions attributable to construction logistics
- Alignment with circular construction goals that aim to reduce carbon footprint within material recycling cycles

The primary emphasis remains on GWP100; however the study may also investigate additional environmental impact categories (e.g., particulate matter formation, fossil resource depletion) dependent upon data availability, stakeholder demands, or inclusion in a broader sustainability assessment.

# 5 Chapter – Inventory Analysis

## 5.1 Inventory Modelling

The inventory comprised data and assumptions on material quantities, truck specs, cargo capacity, and site limitations. The material inventory of the selected construction material was assumed from the Kromet project, a demolition analysis which is tabulated in *Table 5.1* (White arkitekter AB, 2023).

*Table 5.1 Summary of the Construction Material Inventory*

| S.No | Material Description | Weight (Tons) |
|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 |
| 2 | Glass Partition | 103 |
| 3 | Mineral Wool | 38 |
| 4 | Wooden Flooring Boards | 37.6 |
| 5 | Doors- Wooden | 131.6 |

Material densities have been taken from research papers and relevant Environmental Product Declarations (EPDs). For sources of input for density please refer to *Appendix 11.1*

*Table 5.2 Densities of the Construction Materials*

| S.No | Material Description | Density (kg/m3) |
|---|---|---|
| 1 | Reinforcement Steel Rebar | 8000 |
| 2 | Glass Partition | 2580 |
| 3 | Mineral Wool | 385 |
| 4 | Wooden Flooring Boards | 678 |
| 5 | Doors- Wooden | 462 |

Based on the technical data sheet (Volvo Trucks, 2025), this study selected the Volvo FMX 5600 model with an 8x4 chassis configuration for transport operations under the vehicle class of 28 and 32 tonnes. This truck provides a suitable combination of loading capacity and operational flexibility. The loading area measures 8.78 meters in length, 2.50 meters in width, and allows a maximum loading height of 2.50 meters. It supports a gross vehicle weight of 28.35 tonnes and has a kerb weight of 9.60 tonnes. To ensure consistent comparison across transport scenarios, the same truck model was used for both diesel and biodiesel variants, since the manufacturer data sheet confirms compatibility with both fuel types. This approach strengthens the reliability of data inputs used in the life cycle analysis.

For the electric vehicle class, the study used a battery electric truck with a gross vehicle weight of 20.5 tonnes and a kerb weight of 10.2 tonnes. The loading area dimensions were kept the same as those of the Volvo FMX 5600 model, with a length of 8.78 meters, a width of 2.50 meters, and a maximum loading height of 2.50 meters, to ensure comparability across scenarios. The data for the electric truck configuration and its environmental performance were based on Scania's comprehensive life cycle assessment, which examined the climate impacts and other environmental indicators of long-haul battery electric trucks in comparison to conventional diesel trucks (Algesten, Ritzman, & Nilzén, 2024).

For the vehicle class above 32 tonnes, the study selected a diesel truck-trailer combination with a gross vehicle weight of 39 tonnes and a kerb weight of 6.91 tonnes, providing a payload capacity of 32.09 tonnes. The loading area of this vehicle measures 13.6 meters in length and 2.48 meters in width. The configuration uses P390 Huckepack trailers, which are designed for intermodal transport on both rail and road. These trailers meet the EN 12642 Code XL standard and feature a sliding roof, aluminium-reinforced side curtains, solid rear doors, and stanchion post restraints, making them well-suited for versatile logistics operations (P&O Ferrymasters, n.d.).

The four categories of trucks which were derived from technical sources and the ecoinvent database are tabulated below in *Table 5.3.*

*Table 5.3 Vehicle classes with Payload Capacity & Fuel Type*

| **Vehicle Class** | **Payload Capacity (tonnes)** | **Fuel Type** |
|---|---|---|
| 32 Tonnes | 18.76 | Diesel |
| 28 Tonnes | 18.76 | Biodiesel |
| 20.5 Tonnes | 10.3 | Electric |
| >32 Tonnes | 32.09 | Diesel |

The loading strategies and configurations used for transporting various construction materials in the study. It outlines the specific dimensions, weights, and packing methods applied to deformed steel rebars, glass partitions, mineral wool bales, wooden doors, and wooden flooring. Each material is loaded using appropriate handling systems such as steel skips, A-type frames, bale systems, and wooden pallets to ensure compliance with payload limits, stability during transport, and adherence to safety standards. Figures included illustrate both the loading and transit conditions for each material category, supporting the evaluation of logistics efficiency in the transport scenarios.

The deformed steel rebar is transported in heavy-duty steel skips with a nominal capacity of 25 m³. Each skip measures approximately 6 m in length, 2.45 m in width, and 1.8 m in height, conforming to commercial standards for hooklift skips (TEGUI CONTENEDORES, n.d.). Due to the irregular shape of the rebars, a load factor of 0.8 is applied to account for voids and stacking inefficienciesThis leads to an average skip payload of 13.02 tonnes per load. *Figure 5.1* illustrates a truck loaded with deformed steel rebars in an open steel skip during stationary loading, while Figure 5.2 shows the same configuration secured with a metallic skip cover for safe transit. This arrangement ensures compliance with safety and volume utilization criteria during the transportation of steel construction waste.

*Figure 5.1 Truck with Deformed Steel loaded in Steel Skip without Skip cover- Loaded View (created by the authors using OpenAI DALL·E, 2025)*

*Figure 5.2 Truck with Deformed Steel loaded in Steel Skip with metallic skip cover - Transit View (created by the authors using OpenAI DALL·E, 2025)*

The glass partitions are loaded on A-type frames designed to safely transport flat glass panels. Each glass partition measures 1 m in width, 0.01 m in thickness, and 2.7 m in length, with a density of 2580 kg/m³, resulting in an approximate weight of 69.66 kg per unit. The A-frame used has dimensions of 2.3 m length, 1.21 m width, and 1.9 m height, providing two shelves each capable of holding 10 glass partitions, summing to a total of 20 partitions per frame. The total weight of the glass partitions in one frame reaches approximately 1.39 tonnes, which remains within the frame's maximum capacity of 1.5 tonnes (GGR Group, 2021). *Figure 5.3* shows the truck loaded with the A-type frames carrying the glass partitions, while *Figure 5.4* illustrates the truck during transit. The secure configuration ensures stability and protection of the glass throughout transportation.

*Figure 5.3 Truck with Glass Partition loaded in A type Frame- Loaded View (created by the authors using OpenAI DALL·E, 2025)*

*Figure 5.4 Truck with Glass Partition loaded in A type Frame- Transit View (created by the authors using OpenAI DALL·E, 2025)*

*Figures 5.5 and 5.6* show the diesel truck loaded with mineral wool bales prepared for transport. Each bale is cylindrical with a diameter of 1.5 m and a height of 1.4 m, giving an approximate volume of 2.47 m³. The bales are packed using specialized bale packing systems (WTE International, n.d.), ensuring stable shape retention during handling and transport. Due to a compression factor of 10%, considered by accounting for the compressive strength properties of mineral wool (Buška, 2007), the density increases from 350 kg/m³ to 385 kg/m³ and resulting in a single bale weight of about 0.95 tonnes. These bales are loaded directly onto the truck bed in a configuration that maximizes the use of available space and aligns with the truck's volume and payload capacity, maintaining both stability and transport efficiency.

*Figure 5.5 Truck with Mineral Wool Bales – Loaded View (created by the authors using OpenAI DALL·E, 2025)*

*Figure 5.6 Truck with Mineral Wool Bales -Transit View (created by the authors using OpenAI DALL·E, 2025)*

*Figures 5.7 and 5.8* illustrate the loading and transit conditions of a diesel truck transporting wooden doors stacked on wooden pallets. Each pallet, measuring 2.04 m in length and 0.826 m in width, contains 30 doors with a total weight of approximately 0.93 tonnes. Based on the truck's loading area, internal volume, and maximum allowable payload, these pallets are systematically arranged to utilize the truck bed length and width while respecting height constraints. The arrangement ensures the truck carries a full load both by volume and by weight capacity. This method optimizes transport efficiency by balancing spatial occupancy with the payload limit, maintaining stability and compliance with road transport regulations.

*Figure 5.7 Truck with Wooden Doors loaded in wooden Pallet- Loaded View(created by the authors using OpenAI DALL·E, 2025)*

*Figure 5.8 Truck with Wooden Doors loaded in wooden Pallet- Transit View(created by the authors using OpenAI DALL·E, 2025)*

The loading configuration for the wooden flooring involves stacking standardized wooden flooring measuring 0.125 m in width, 0.02 m in thickness, and 0.88 m in length (Grato, n.d.), each weighing approximately 1.49 kg due to a material density of 678 kg/m³. These planks are arranged on customized pallets with a footprint of 0.88 m by 0.8 m and a base height of 0.144 m. Each pallet accommodates around 240 flooring pieces stacked in roughly six layers, reaching a height of 0.944 m and totaling about 0.358 tonnes per pallet. Based on the loading area,volume of the truck and the payload capacity, the pallet are loaded in the truck accordingly which would be similar to loading view shown the *Figure 5.9* and transit view shown in the *Figure 5.10*.

*Figure 5.9* *Truck with Wooden Floorings loaded in wooden Pallet - Loaded View (created by the authors using OpenAI DALL·E, 2025)*

*Figure 5.10* *Truck with Wooden Floorings loaded in wooden Pallet -Transit View (created by the authors using OpenAI DALL·E, 2025)*

For each material, the maximum load per trip was determined by comparing:

- The net permissible payload (Weight limitation)
- The weight constrained by volume, computed as in *Equation 5.1*

$$Payload\ or\ Weight\ Limit\ (Tonnes) = \frac{Skip\ Volume\ (m^3) \times Density\ (kg/m^3)}{1000} \qquad (5.1)$$

The total number of trips was computed as in *Equation 5.2*

$$Number\ of\ Trips = \frac{Total\ Material\ Weigh\ \ (tonnes)}{Effective\ Load\ per\ Trip\ (tonnes)} \qquad (5.2)$$

Trip values were approximated to the nearest integer.

## 5.2 Co-loaded Transport Optimisation

To improve efficiency, a co-loading strategy was used. This allowed different materials to be transported together when volume, mass, and packaging constraints permitted.

Key principles included:

- Steel rebar was always transported in a steel skip.
- Remaining payload capacity was used for other materials, such as wooden flooring, doors, glass, or mineral wool, using suitable packaging (pallets, bales, or frames).
- Truck payload limits and space usage were respected.
- Combinations were calculated in Excel, and total shipment weights were kept within legal and operational limits.

Twelve unique co-loading combinations were developed and compatibility was ensured to avoid damage (e.g., not mixing glass with heavy items unless secured). The combinations are tabulated in *Table 5.4.*

*Table 5.4 Co-loading combination used in Diesel Truck.*

| S.No | Loading Combination |
|---|---|
| 1 | 1x Steel Skip + 44x Flooring Pallet |
| 2 | 1x Steel Skip + 15x Door Pallet |
| 3 | 1x Steel Skip + 5x Bale Wool+ 17x Flooring pallet |
| 4 | 1x Steel Skip + 5x Bale Wool + 6x Door Pallet |
| 5 | 1x Steel Skip + 4x Glass Frame + 1x Door Pallet |
| 6 | 1x Steel Skip + 4x Glass Frame |
| 7 | 1x Steel Skip + 5x Bale Wool |
| 8 | 1x Steel Skip + 2x Glass Frame +1x Bale Wool |
| 9 | 2x Steel Skip + 1x Bale Wool |
| 10 | 1x Steel Skip + 5x Bale Wool |
| 11 | 2x Steel Skip |
| 12 | 2x Steel Skip* (One skip with remaining partial load) |

## 5.3 Configuration of the Parametric Model

Each material, vehicle, fuel combination was modelled manually in Microsoft Excel using parameters derived from openLCA, technical data, and secondary sources. The key inputs were:

- Number of trips per material
- Payload per trip
- Round trip distance
- Fuel or energy use per kilometre

- Emission factors or direct emissions per kilometre
- Embodied emissions per material unit (kg $CO_2$-eq)

For diesel and biodiesel trucks, per-kilometre emissions were obtained from the ecoinvent "Transport, freight, lorry" datasets. These datasets included internal fuel combustion emissions.

For electric trucks, energy use per kilometre was based on the Scania LCA study (Algesten, Ritzman, & Nilzén, 2024). Emissions were calculated using the Swedish electricity mix (Statista, 2024). This method enabled the estimation of total transport emissions for each scenario.

## 5.4 Cradle-to-Gate Embodied Carbon Estimation

The cradle-to-gate embodied carbon of the recovered construction materials was assessed to determine environmental savings from reuse. The data sources are mentioned below and detailed in the *Table 5.5*

- openLCA 2.1 with ecoinvent 3.8 – for steel, glass, and mineral wool
- EPDs for wood products

Emissions were expressed as kg $CO_2$-eq per unit of material and were used with transport emissions to calculate breakeven distances by *Equation 5.3 & 5.4*

*Table 5.5 Construction materials inventory details.*

| Material | Ecoinvent Process/ EPD Code | Source | Unit |
|---|---|---|---|
| Glass Partition | Flat glass production, uncoated, cutoff, U - RER | Ecoinvent 3.8 | 1 kg |
| Mineral wool | Stone wool production, cutoff, U - CH | Ecoinvent 3.8 | 1 kg |
| Steel Rebars | Steel Production, low-alloyed, Cutoff, U- Europe without Switzerland and Austria | Ecoinvent 3.8 | 1 kg |
| Wooden Door | Laminated Veneer Lumber, EPD: S-P-02802 | www.environdec.com | 1 $m^3$ |
| Wooden Flooring | Grato Parquet, Multilayer wood flooring EPD: S-P-06088 | www.environdec.com | 1 $m^2$ |

## 5.5 Breakeven Distance Modelling

Breakeven distance was defined as the point where transport emissions equal embodied emissions. Modelling steps are as followed.

- A 1 km round trip with full payload and empty return was modelled.
- Impact assessment used IPCC 2013 GWP 100a.
- Relevant datasets were used:

  - Diesel/Biodiesel: “Transport, freight, lorry” ( Ecoinvent 3.8)
  - Electric truck: Custom process using Swedish electricity mix
- Total transport emissions per material were calculated using *Equation 5.3*

$$\begin{aligned} Total\ Emissions\ (Tonnes\ CO_2 - eq/km) \\ = (Emissions\ same\ load\ trip\ per\ km\ \times Number\ Of\ Trips) \\ + Emissions\ of\ Last\ trip\ load\ per\ km \end{aligned} \tag{5.3}$$

- Breakeven distance (km) was then calculated using *Equation 5.4*

$$Breakeven\ Distance\ (km) = \frac{Cradle - to - gate\ Embodied\ Carbon\ (\ Tonnes\ CO_2 - eq)}{Emissions\ \ (Tonnes\ CO_2 - eq/km)} \tag{5.4}$$

This calculation was done for the following scenarios :

- Diesel truck (32 tonnes)
- Diesel truck (above 32 tonnes)
- Biodiesel truck (28 tonnes)
- Electric truck (20.5 tonnes)

The results formed the basis for comparing the environmental impacts of circular logistics options will be discussed in the next chapter.

# 6 Chapter – Result

All quantitative results presented in this chapter are based on the detailed calculations compiled in *Appendix 2*, which include payload estimates, trip numbers, emissions per kilometre, and break-even computations for each scenario.

## 6.1 Climate Impact of Logistic Scenarios

The evaluation of the climate impact associated with the transportation of reused construction materials involved an analysis of the required number of trips and the cumulative greenhouse gas emissions per kilometre. *Figures 6.1 and 6.2* illustrate the primary findings for the four freight modes analysed.

Diesel trucks with a capacity of 32 tonnes and biodiesel trucks with a capacity of 28 tonnes each needed 106 trips to transport all construction materials. Diesel trucks exceeding a capacity of 32 tonnes accomplished the same transport in merely 65 trips, indicative of their enhanced payload capacity. Electric trucks with a capacity of 20.5 tonnes required 200 trips, the highest among all transportation modes, attributed to a reduced load volume per trip *(Figure 6.1).*

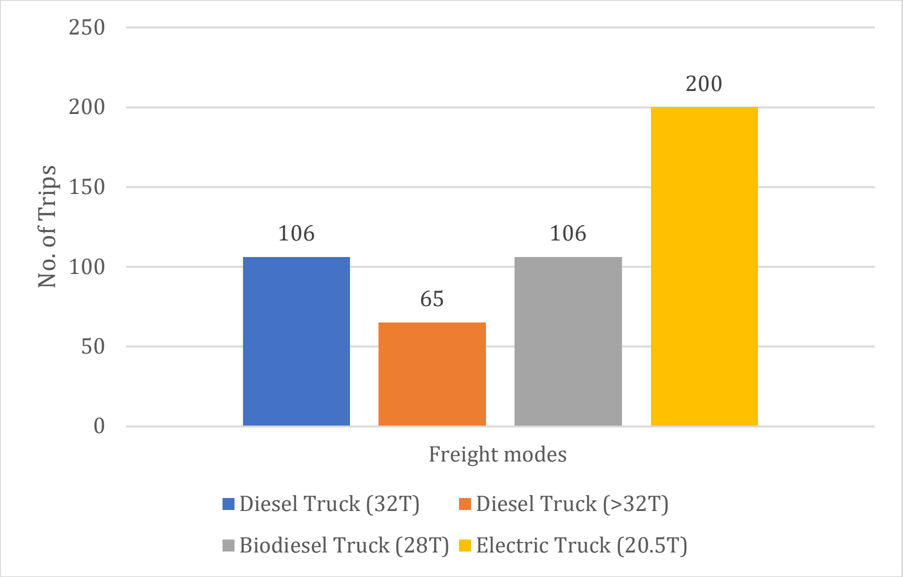


*Figure 6.1* *Number of Trips required to transport of construction materials (single material per trip) through different freight modes. (Created by authors)*

When considering the total emissions produced throughout the entire transportation, electric trucks demonstrated a notable climate benefit. *Figure 6.2* illustrates that the total cumulative emissions per kilometre for transporting all materials were lowest for electric trucks, recorded at 0.021 tonnes $CO_2$-eq/km. Diesel trucks (32T) exhibited the highest emission intensity at 0.294 tonnes $CO_2$-eq/km, while biodiesel trucks (28T) followed with an emission intensity of 0.227 tonnes $CO_2$-eq/km. Diesel trucks exceeding 32 tonnes in capacity exhibited reduced emissions compared to other combustion-based modes, recording 0.159 tonnes $CO_2$-eq/km.

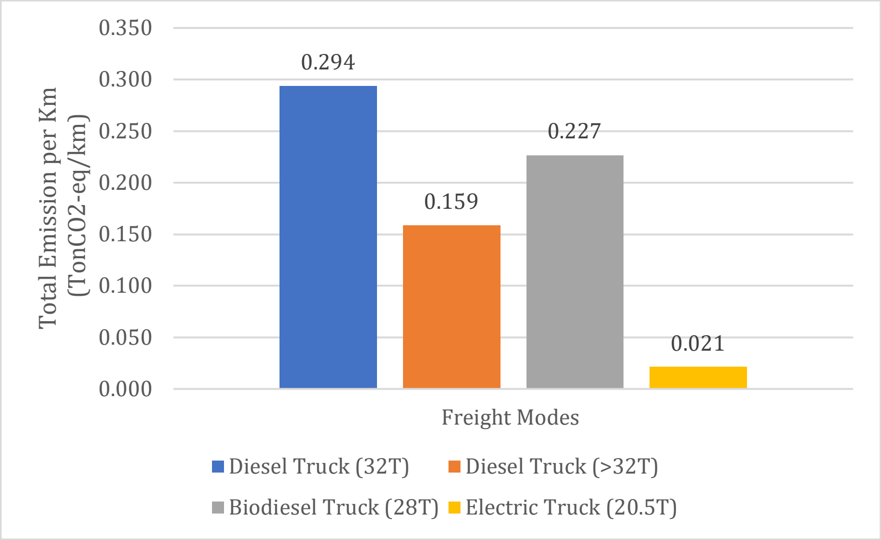


*Figure 6.2 Total Emission per Kilometer for transporting all construction materials through different freight modes (Created by authors)*

The outcomes indicate that, although resulting in additional trips, electric trucks generated the lowest total emissions per kilometer for the transportation of all evaluated construction materials. In comparison to standard diesel, biodiesel usage in combustion vehicles resulted in a moderate reduction of emissions, while larger diesel trucks enhanced efficiency by decreasing trip frequency.

In summary, electric trucks are identified as the most climate-efficient logistics alternative in this analysis. Their minimal operational emissions surpass the effects of increased trip frequency. In scenarios where electric alternatives are impractical, the use of biodiesel trucks or optimized high-capacity diesel trucks can lead to a reduction in emissions compared to traditional 32-tonne diesel transport.

## 6.2 Impact of Single vs Co-loaded Diesel Truck Trips

A comparison was carried out between single and co-loaded trips for Diesel Trucks (>32T). The total number of trips in the single-trip scenario was 65, whereas the co-loaded scenario required only 58 trips *(Figure 6.3)*. This indicates a reduction of approximately 10.8% in the total number of trips due to improved vehicle utilization.
This reduction in trips is directly associated with a proportional decrease in transport-related greenhouse gas emissions. Optimizing truck loading through co-transport strategies can enhance efficiency and reduce the environmental footprint, especially in urban construction logistics.
Due to data limitations in the ecoinvent database, a similar comparative analysis could not be conducted for biodiesel or electric trucks.

*Figure 6.3* *Number of trips by Diesel Truck- Single Material Vs Coloaded Trips Comparsion (Created by authors)*

## 6.3 Carbon Balances for Recovered Construction Materials

The cradle-to-gate embodied carbon of recovered materials was analyzed to assess the benefits of material reuse. The results show that the cradle-to-gate embodied carbon for steel rebar is 52.24 tonnes $CO_2$-eq, for glass partitions 99.18 tonnes $CO_2$-eq, for wooden doors 78.62 tonnes $CO_2$-eq, for wooden flooring 12.77 tonnes $CO_2$-eq, and for mineral wool 39.40 tonnes $CO_2$-eq *(Figure 6.4)*.

Integrating these values with transport emissions enables a carbon balance calculation, which helps determine whether reusing materials transported from demolition sites is preferable to sourcing new materials. The results indicate that reused materials with high cradle-to-gate embodied carbon, such as glass and steel, offer considerable emission savings even after accounting for transportation emissions.

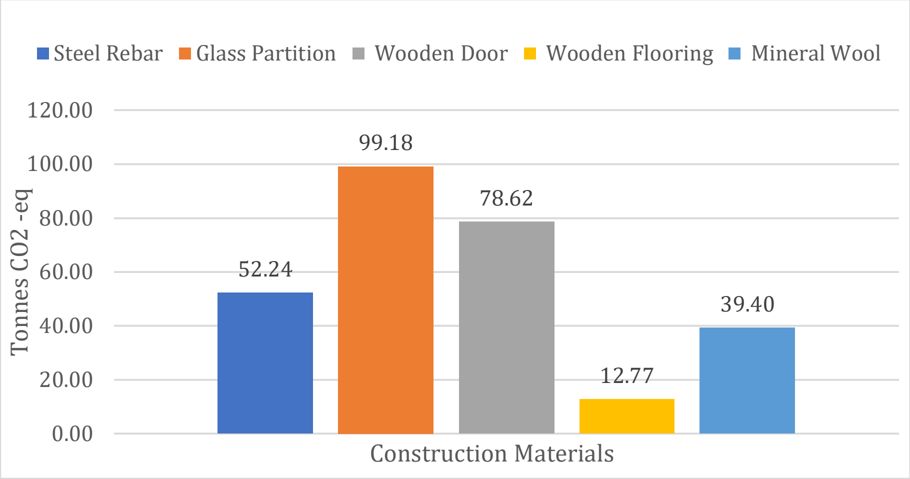


*Figure 6.4* *Cradle-to-Gate Embodied Carbon of Construction Materials (Created by authors)*

## 6.4 Break-even Distances for Reused Material Transport

Break-even distances were calculated to identify the maximum one-way transport distance within which the reuse of construction materials remains more climate-efficient than sourcing and producing new materials. These distances represent only the one-way trip from the demolition site to the new construction location. If return trips (e.g., empty backhauls) are considered, the actual roundtrip distances would be twice the values presented.

Electric trucks (20.5T) consistently achieved the longest break-even distances across all material categories as shown in Figure 5.5. For steel rebar, the one-way break-even distances were approximately 240 km for diesel trucks (32T), 434 km for biodiesel trucks (28T), 315 km for diesel trucks (>32T), and 3176 km for electric trucks. For glass, electric trucks allowed break-even transport up to 51822 km, compared to 3279 km for diesel trucks (32T), 4246 km for biodiesel trucks, and 6739 km for diesel trucks (>32T).

Similarly, wooden doors and wooden flooring showed break-even distances above 37000 km and 19000 km respectively for electric trucks. Other modes showed shorter distances: 2757–5636 km for doors, and 1503–2982 km for flooring. Mineral wool, with the highest total distance transported using electric trucks (56781 km), also demonstrated a significant break-even potential. Diesel and biodiesel trucks ranged between 3346 and 6711 km for the same material.

The results summarized in *Figure 6.5* indicate that the electric trucks support significantly longer transport distances while maintaining lower life cycle emissions. In contrast, conventional diesel modes offer shorter break-even ranges, limiting their suitability for long-distance reuse unless co-loading or route optimization is applied. This suggests that for high-impact materials such as glass and mineral wool, reuse remains viable across a broad geographic range when low-emission transport solutions are adopted.

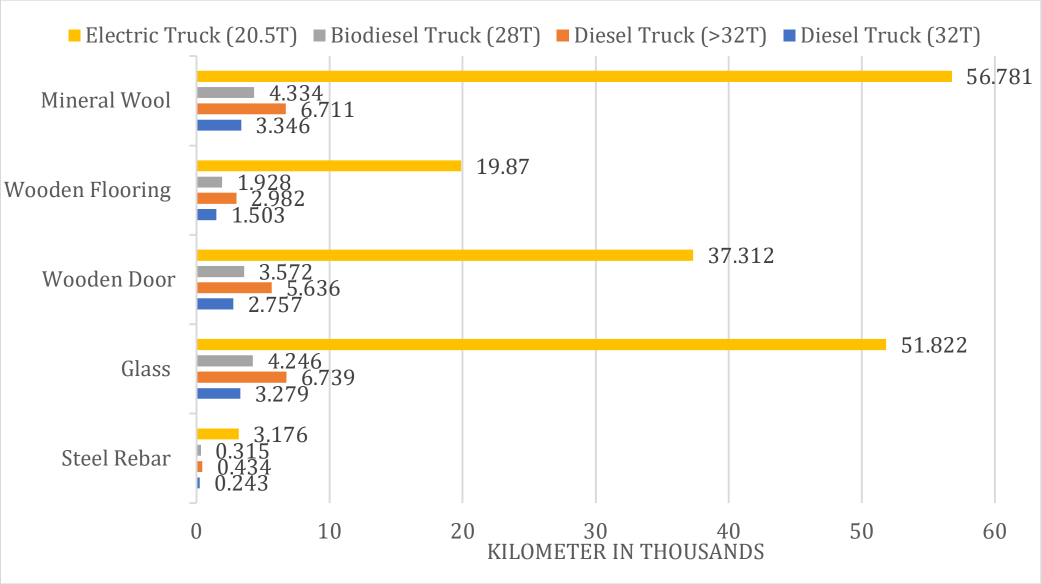


*Figure 6.5 Breakeven Distance of Construction Material (Created by authors)*

# 7 Chapter – Uncertainty Analysis

Uncertainty analysis is a methodological approach used to understand how variation in input assumptions affects the outcomes of a study. It helps to assess the credibility and reliability of the results by testing the influence of key variables. In the context of this thesis, which investigates the environmental performance of various truck types for transporting reused construction materials, uncertainty analysis is crucial. It ensures that the conclusions drawn about breakeven distances remain valid under realistic variations in logistics parameters. Sensitivity analysis was selected as the primary method for conducting uncertainty analysis, focusing on changes in truck payload, packaging density, and material handling efficiency.

The sensitivity analysis addressed three main uncertainties that could influence emissions and transport efficiency. First, reduced truck payload capacity was modeled to represent operational constraints such as partial loading at construction or demolition sites. Two payload scenarios were tested at 75% and 50%. At 75% loading, breakeven distances for steel rebar dropped modestly, from 3176 km to 2769 km for electric trucks, and from 240 km to 222 km for diesel trucks (32T). Similar trends were observed regarding wooden doors and flooring, although the reductions were relatively minor. When the payload was further reduced to 50%, breakeven distances decreased more sharply. For steel rebar, electric trucks dropped to 2200 km, while diesel trucks fell to 190 km. The pattern was similar for wooden flooring, where the breakeven distance fell to 1264 km for diesel trucks and 14,518 km for electric trucks. These results suggest that while electric trucks retain favorable environmental performance even under suboptimal loading, diesel and biodiesel trucks are more sensitive to payload inefficiencies.

The second parameter tested was the frame capacity utilization for glass, which has a high volume-to-weight ratio and requires careful handling. At 75% frame loading, the electric truck's breakeven distance decreased slightly, from 51,822 km to 50,248 km. Biodiesel and diesel trucks also showed reductions, with biodiesel falling from 4246 km to 3837 km. When frame loading was further reduced to 50%, the breakeven distance for electric trucks dropped to 39,069 km. Diesel and biodiesel trucks dropped to 2304 km and 2983 km, respectively. These findings indicate that glass transport is especially well-suited for electric trucks, which remain effective even with reduced capacity due to their low operational emissions.

The third uncertainty tested involved the packaging of mineral wool. Two scenarios were analyzed, one without bale compression and another with both no compression and one bale reduction per trip. Without compression, the electric truck's breakeven distance declined from 56,781 km to 53,152 km. Diesel (32T) dropped from 3346 km to 3132 km. In the second scenario, with one bale removed, the electric truck fell further to 49,959 km, while diesel (32T) dropped to 2646 km and biodiesel to 3816 km. This analysis confirmed that bale compression is a critical factor in maintaining high transport efficiency, especially for voluminous materials like mineral wool.

The results of all sensitivity scenarios are summarized in *Figures 7.1 -7.6*, which presents the breakeven distances across all materials and freight modes under different assumptions (S1 and S2) for each parameter tested. The calculations remain the same and is detailed in *Appendix 2*.

In conclusion, electric trucks consistently performed best across all sensitivity scenarios, maintaining high breakeven distances and demonstrating resilience to variations in payload and packaging. Diesel and biodiesel trucks were more affected by operational inefficiencies, leading to substantial reductions in breakeven distances. These results suggest that, for materials such as glass and mineral wool, maintaining optimal volume efficiency is essential to achieving climate benefits. The insights from this uncertainty analysis can support more robust planning of circular logistics systems tailored to different material flows.

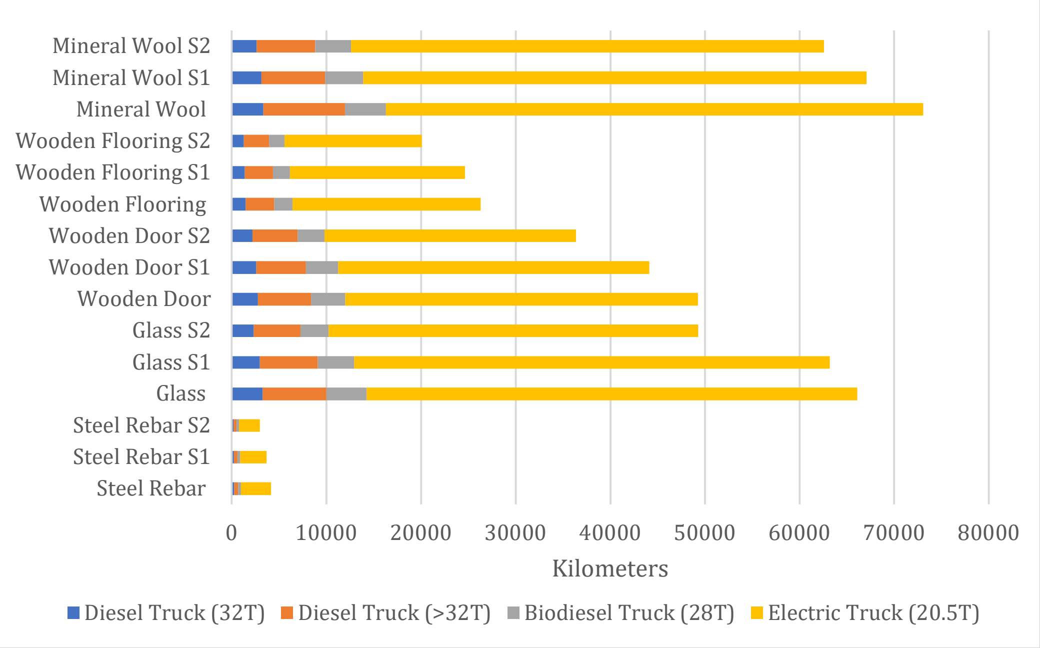


*Figure 7.1 Breakeven Distance of Construction Materials with different freight modes under different sensitivity scenarios (Created by authors).*

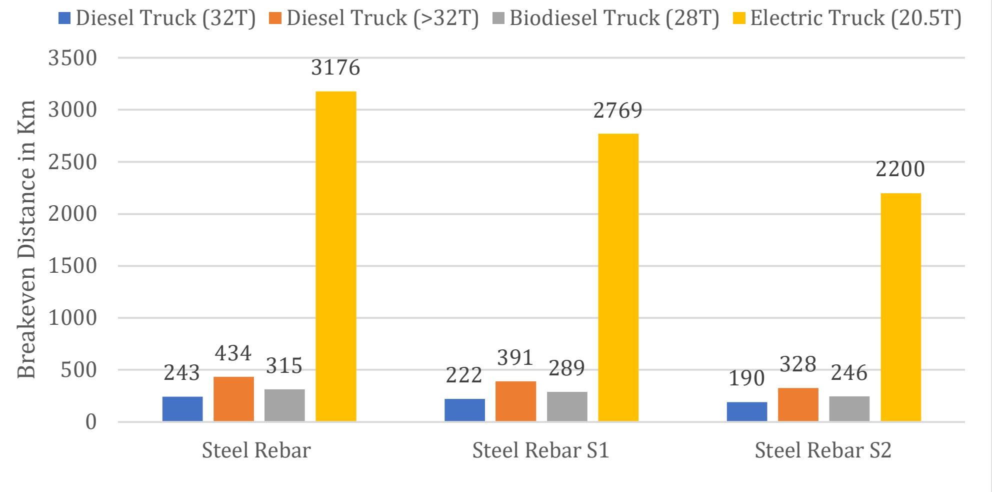


*Figure 7.2 Breakeven Distance of Steel Rebar with different freight modes under different sensitivity scenarios (Created by authors).*

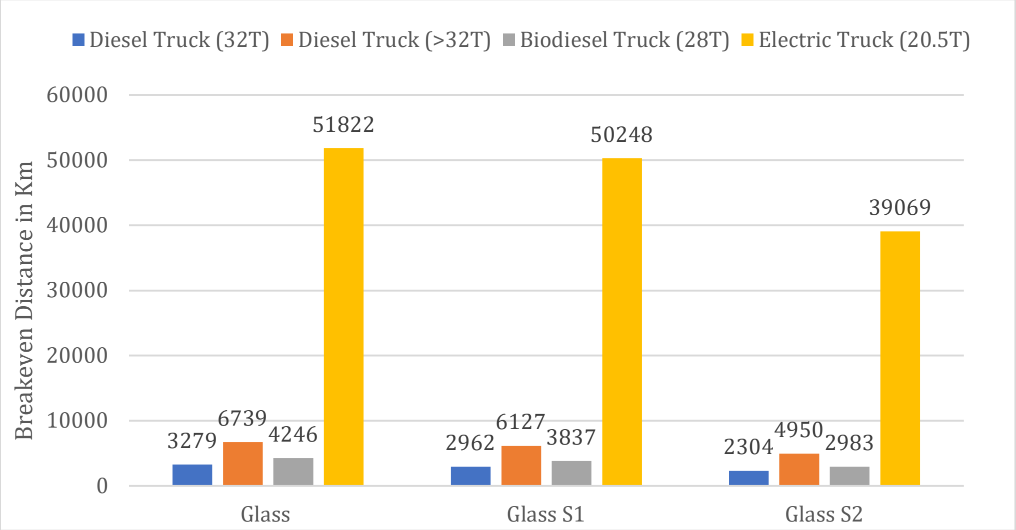


*Figure 7.3 Breakeven Distance of Glass Partitions with different freight modes under different sensitivity scenarios (Created by authors).*

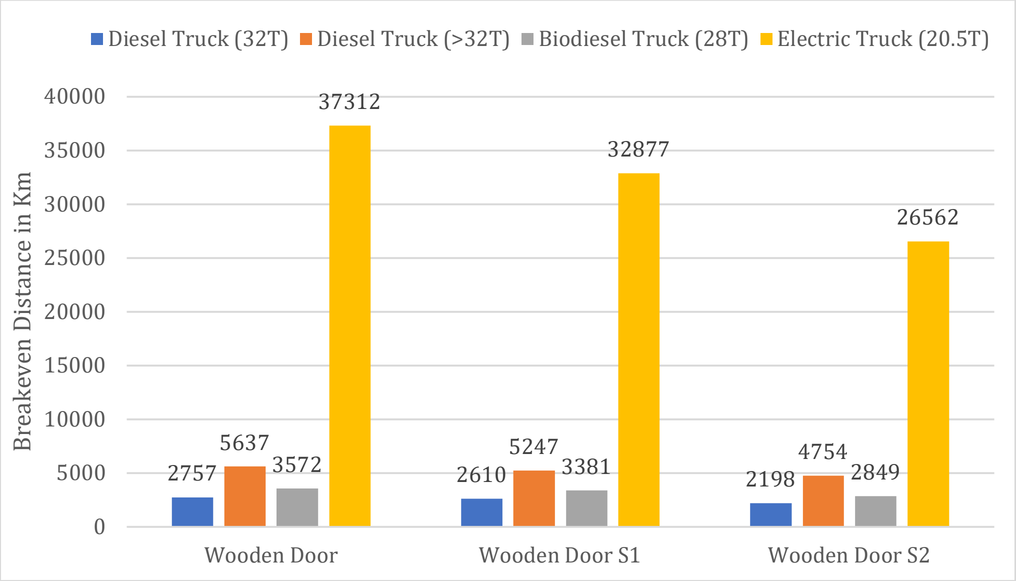


*Figure 7.4 Breakeven Distance of Wooden Door with different freight modes under different sensitivity scenarios (Created by authors).*

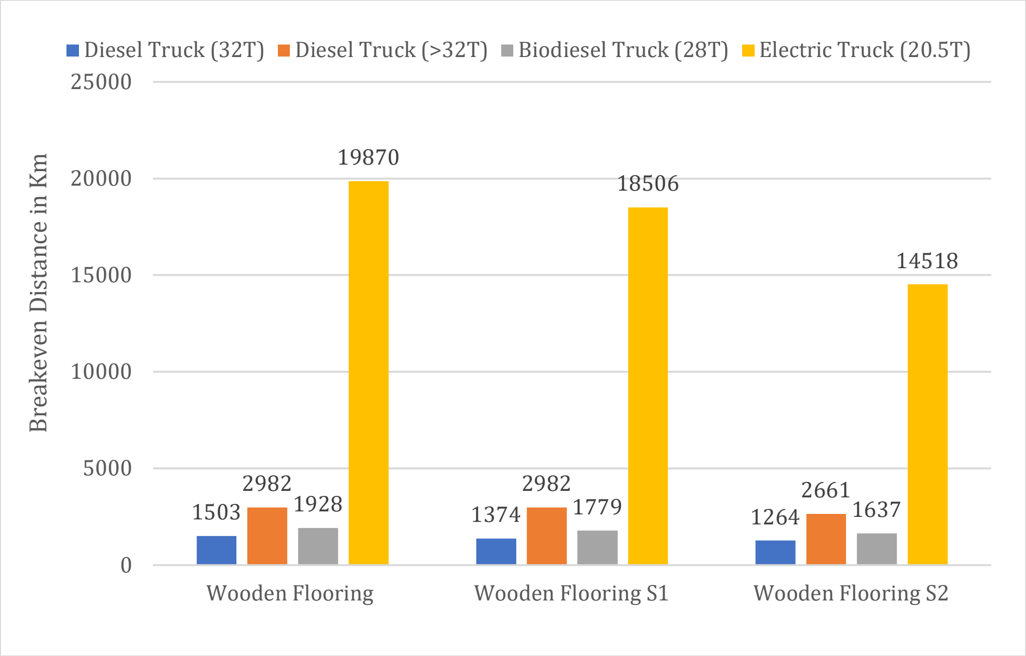


*Figure 7.5 Breakeven Distance of Wooden Flooring with different freight modes under different sensitivity scenarios (Created by authors).*

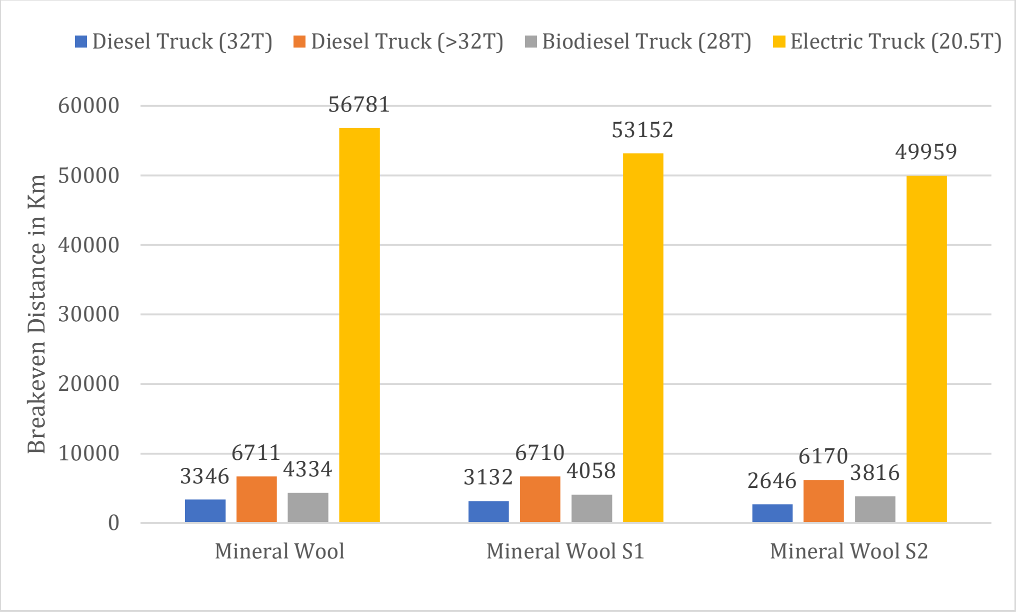


*Figure 7.6 Breakeven Distance of Mineral Wool with different freight modes under different sensitivity scenarios (Created by authors).*

# 8 Chapter – Discussion

The results of this parametric LCA highlight the central role of logistics strategies in determining the carbon footprint of circular construction. The choice of freight mode and loading configuration significantly influences greenhouse gas emissions from material transport (Sezer & Fredriksson, 2021). Electric trucks produced the lowest emissions despite requiring more trips due to limited payload capacity. This is largely due to Sweden's low-carbon electricity mix, which ensures minimal operational emissions for electric freight (Statista, 2024; Nordelöf et al., 2014). In contrast, conventional 32-tonne diesel trucks showed the highest emission intensity per kilometer (Keller et al., 2010; Spielmann et al., 2005). Replacing diesel with biodiesel offered moderate emission reductions, while using high-capacity diesel trucks reduced the number of trips and emissions per kilometer (Ntziachristos et al., 2013; Sezer & Fredriksson, 2020). These results emphasize that both vehicle type and utilization patterns directly affect the environmental performance of material reuse (Brusselaers et al., 2022).

## 8.1 Climate Impact of Freight Modes and Co-loading Strategies

This study confirms that optimizing load capacity and choosing low-emission transport modes can substantially reduce emissions (European Environment Agency, 2019). Co-loading mixed materials in a high-capacity diesel truck reduced trips by about 10.8%, from 65 to 58, which directly decreased fuel use and emissions (Dubois et al., 2019; Sundquist et al., 2018). These findings align with previous observations from construction projects that used consolidation centers to reduce transport frequency (Muerza & Guerlain, 2021). The analysis supports practical logistics solutions such as Construction Consolidation Centres (CCC) and coordinated deliveries (Janné & Fredriksson, 2019). By evaluating co-loading scenarios quantitatively, the study contributes to an area that remains underexplored in LCA literature (Andersen et al., 2022; Pomponi & Moncaster, 2017; Ding et al., 2023).

Electric trucks were the most climate-efficient option across all scenarios. Emissions per kilometer were approximately 0.021 tonnes $CO_2$-eq for electric transport, compared to 0.227 for biodiesel and 0.293 for standard diesel (ecoinvent, 2021a). This advantage is due to Sweden's clean electricity grid (Ellen MacArthur Foundation & Material Economics, 2019). Even though electric trucks require more trips due to lower capacity, the carbon savings per trip remain significant (Algesten et al., 2024). The results provide a rare empirical comparison of electric versus diesel transport in reused-material contexts, supporting calls for electric vehicle adoption in circular logistics (United Nations Environment Programme, 2021).

However, these findings assume ideal conditions. The sensitivity analysis showed that partial loading (e.g., 50% filled trucks) reduces the effectiveness of all transport modes, especially diesel. For example, with only half the payload, the break-even distance for reusing steel fell from 243 km to 190 km in diesel scenarios (Gontia et al., 2017). Electric trucks also saw reductions but retained a larger climate margin (Nordelöf et al., 2014). This suggests electric freight is more resilient to operational inefficiencies. For bulky materials like glass, under-loading halved the usable transport distance for diesel, while electric trucks still allowed significant range, over 39,000 km (ecoinvent, 2021b). These outcomes show the importance of maximizing load utilization to realize environmental gains, especially for fossil-fuelled vehicles (British Standards

Institution, 2006; Sezer & Fredriksson, 2020). Without proper logistics, reuse benefits may be lost due to inefficiencies (Dahlbo et al., 2015).

## 8.2 Cradle-to-Gate Embodied Carbon of Reused Materials and Break-even Distances

The carbon balance between material reuse and transport emissions depends on the cradle-to-gate embodied carbon of the material. The analysis showed wide variation in embodied emissions. Glass partitions had the highest (~99.2 tonnes $CO_2$-eq), followed by wooden doors (~78.6 tonnes), and steel rebar (~52.2 tonnes), while wooden flooring was much lower (~12.8 tonnes) (Metsä Wood, 2022; Remus et al., 2013; Wood Manners S.L., 2022). These figures frame the maximum distance a material can be transported while still offering a net climate benefit (Allacker, 2010; Rigamonti & Mancini, 2021).

High-carbon materials can be transported long distances and remain beneficial, especially with clean transport. For instance, using electric trucks, glass could be transported over 50,000 km one-way and still be climate-positive (ecoinvent, 2021a; Gontia et al., 2017). Even diesel trucks allowed for break-even distances of around 3,300 km, which exceeds typical distances in Sweden (Knörr et al., 2011; Sezer & Fredriksson, 2021). Similarly, wooden doors remained viable up to 5,000–6,000 km with diesel and over 37,000 km with electric freight. These results support the idea that long-distance reuse can be justifiable when paired with low-emission transport (European Commission – Joint Research Centre, 2010; Algesten et al., 2024).

Materials with lower cradle-to-gate embodied carbon, such as rebar and wooden flooring, had more limited transport thresholds. Rebar showed a short break-even distance of 243 km with diesel but extended to over 3,000 km using electric trucks (Gontia et al., 2017; Algesten et al., 2024). Wooden flooring required reuse within 1,500–3,000 km under diesel transport but could be shipped around 19,000 km with electric trucks. These findings emphasize that reuse decisions must consider both material type and logistics setup (Säwén et al., 2022; Sezer & Fredriksson, 2021).

## 8.3 Construction Material Selection

Five materials were assessed in this study such as steel reinforcement bars, glass partitions, wooden doors, wooden flooring, and mineral wool. Each material differs in cradle-to-gate embodied carbon, density, and packaging characteristics, which allowed for comparative analysis across diverse transport conditions.
However, the narrow material scope limits the relevance of the results. Common construction elements such as concrete components, gypsum boards, bricks, and composite waste were not included. Their exclusion reduces the applicability of the findings to more complex or mixed-material reuse projects. Furthermore, reuse assumptions were based on ideal conditions, without accounting for potential material degradation or compliance with building standards.

Data quality varied across materials. While Swedish-specific data were used where possible, European average values were applied when local data were unavailable. This introduces uncertainty into some of the cradle-to-gate embodied carbon estimates, especially for wood-based products and glass. A broader material scope and condition-based assessment would improve future evaluations

## 8.4 Comparison with Existing Literature

The results are consistent with prior research on sustainable logistics in construction. Reducing trips through co-loading and high-capacity transport aligns with documented strategies for emission reductions (Sezer & Fredriksson, 2020, 2021). Projects with logistics coordination, such as CCCs, have reported fewer deliveries and improved project efficiency (Muerza & Guerlain, 2021; Dubois et al., 2019; Janné & Fredriksson, 2019). This study adds value by quantifying those reductions (~10–11%) and demonstrating that combining load efficiency with low-emission technologies yields even greater savings (Algesten et al., 2024).

The findings also support observations from certification systems like Miljöbyggnad, where lower transport emissions are common in higher-rated projects. This study clarifies how such outcomes are achieved—through co-loading, consolidation, and the use of clean vehicles (Brusselaers et al., 2022). For example, a full-load electric truck dramatically reduces per-kilometer emissions compared to a half-empty diesel truck (Nordelöf et al., 2014).

Finally, the results contribute to the discussion on integrated logistics systems. Prior studies have proposed harmonizing material delivery and waste removal, using centralized hubs, and improving stakeholder coordination for circular economy outcomes (Pomponi & Moncaster, 2017; Ding et al., 2023). While much of this work has highlighted operational or cost benefits, this study offers a quantitative environmental dimension. Emission savings from backhauling and co-loading scenarios provide clear support for such integrated logistics approaches (Eberhardt et al., 2020; Sezer & Fredriksson, 2021).

## 8.5 Practical Implications for Construction Planning and Sustainability

The insights from this research carry several practical implications for stakeholders seeking to implement circular economy principles in construction:

- **Integrate Logistics Planning Early**
  The clear influence of transport mode and loading efficiency on emissions suggests that logistics should be a core consideration at the project planning stage (Ge et al., 2024; Janné & Fredriksson, 2019). Decisions about where to source reclaimed materials and how to transport them cannot be left as afterthoughts. Early integration of a circular logistics plan possibly using digital tools or BIM-based simulations can identify optimal routes, consolidation opportunities, and appropriate vehicle types to minimize carbon footprints (Brusselaers et al., 2022).

- **Maximize Load Utilization**
  Construction firms should strive to avoid half-empty trucks and unnecessary trips (European Environment Agency, 2019). Tactics like co-loading different materials destined for nearby sites, consolidating deliveries through logistics

centers, and planning backhauls can dramatically improve load factors (Dubois et al., 2019). The study showed that a modest improvement in utilization yielded an ~11% trip reduction for one scenario (Sezer & Fredriksson, 2021).

- **Adopt Low-Emission Freight Technologies**
  Transitioning to electric or other low-carbon fuel trucks for construction logistics can yield substantial emission savings (Algesten et al., 2024). Particularly in regions with clean electricity (like Sweden), electric heavy vehicles offer a chance to decouple transport activity from GHG emissions (Statista, 2024; Nordelöf et al., 2014). Projects aiming to be carbon-neutral should consider specifying electric transport in their logistics requirements (Ellen MacArthur Foundation & Material Economics, 2019; United Nations Environment Programme, 2021).

- **Consider Material Characteristics in Reuse Decisions**
  The break-even distance findings provide guidance on material selection for reuse (Dahlbo et al., 2015). Stakeholders should weigh the cradle-to-gate embodied carbon of a material against the distance it must travel. For high-impact materials (e.g., structural steel components, large glass elements), reusing them is beneficial only if they are be transported over long distances especially using low-emission transport (Remus et al., 2013; Gontia et al., 2017).

- **Enhance Packaging and Handling for Bulk Materials**
  The study's uncertainty analysis revealed that how materials are packaged and loaded (especially bulky, low-density materials like insulation) can impact emissions. Practical measures such as compressing materials (e.g., compacting mineral wool into dense bales) and using modular frames or skips to maximize each truck's payload capacity are important.

## 8.6 Limitations of the Study and Future Improvements

While the results offer useful insights, the study has several limitations:

- **Excluded impacts from secondary equipment**: Emissions from cranes, forklifts, and other machinery used for loading and unloading materials were not included. These operations consume fuel or electricity and may contribute significantly to emissions in projects involving heavy or high-volume materials.

- **Energy use for mineral wool baling omitted**: Compressing mineral wool into bales improves logistics efficiency but requires energy. The electricity or fuel used in this baling process was not accounted for, slightly underestimating total emissions for that material.

- **Terrain not considered**: The model assumes flat terrain. Real-world routes often involve elevation changes. Uphill routes increase fuel use; downhill routes may allow energy recovery in electric vehicles. Ignoring this may result in under- or overestimation of emissions, depending on topography.

- **Generic emission data**: Emission factors were based on average values from ecoinvent 3.8 and literature. In practice, fuel efficiency varies with driver behavior, road conditions, and vehicle maintenance. The results should be interpreted with caution and refined using case-specific data when possible.

- **Single impact category**: Only climate change (GWP100) was assessed. Other impacts (e.g., air pollution, noise) were excluded. Full environmental assessments should include multiple categories.

- **No refurbishment or minor processing considered**: Reuse emissions only included transport. In practice, reused materials may require inspection or minor repairs. These emissions are assumed negligible but may affect break-even calculations slightly.

- **Biogenic carbon storage excluded:** The EPD data for wooden doors and flooring considered only cradle-to-gate emissions without accounting for temporary carbon sequestration. As a result, potential climate benefits linked to the biogenic carbon cycle were not reflected in the results.

- **Limited vehicle and material scenarios**: Co-loading was modeled only for >32T diesel trucks. Results for electric and biodiesel co-loading were estimated by analogy. Material choices were limited to five commonly reused types in Sweden.

- **Swedish energy context**: The findings rely on Sweden's low-emission electricity grid. In other countries, the advantage of electric transport may be reduced.

**Recommendations for Future Research:**

- Extend co-loading analysis to electric and biodiesel trucks using more detailed volume-use modeling and real logistics case studies.
- Integrate reverse logistics data where materials are returned or redistributed.
- Develop a GIS-based extension of the model for route-specific emissions and congestion effects.
- Apply the model in different national contexts to evaluate its transferability.
- Including biogenic carbon accounting in future studies could provide a more complete picture of the comparative climate impacts of wood products.

# 9 Chapter – Conclusion

## 9.1 Research Objectives Revisited

This thesis aimed to develop a parametric Life Cycle Assessment (LCA) method for evaluating construction logistics within a circular economy framework. The main objectives were (1) to estimate the greenhouse gas emissions from transporting reused construction materials under different scenarios, (2) to determine carbon break-even distances by comparing transport emissions against the avoided emissions from using reclaimed instead of new materials, and (3) to provide scenario-based insights for improving environmental performance in circular construction logistics.

All three objectives were addressed in the study. A transport-focused LCA was conducted for five reclaimed materials like steel reinforcement bars, glass partitions, wooden flooring, and mineral wool. Various transport modes like diesel, biodiesel, and electric heavy goods vehicles (HGVs) were modelled under single-material and co-loading conditions. The study also calculated break-even distances to assess environmental viability. These results provide a data-driven basis for evaluating logistics decisions in material reuse.

## 9.2 Synthesis of Main Findings

The study demonstrates that logistics parameters such as vehicle type, fuel source, loading efficiency, and transport distance significantly influence the environmental benefits of reuse in construction.

Electric trucks consistently showed the lowest emissions across all scenarios. This result is mainly due to Sweden's low-carbon electricity mix. Diesel trucks had the highest emissions, while biodiesel trucks offered a moderate reduction. Co-loading materials improved environmental performance by reducing the number of required trips. In diesel truck scenarios, co-loading reduced the number of trips by approximately 11%, highlighting the benefit of optimizing vehicle utilization.

The break-even distance analysis revealed that reused materials with high cradle-to-gate embodied carbon, such as glass and wooden doors, remained environmentally beneficial even when transported over long distances. For instance, electric trucks allowed break-even distances of over 50,000 km for glass partitions. In contrast, low-impact materials like steel had shorter break-even thresholds, especially when transported by diesel trucks. However, the use of electric vehicles significantly increased these thresholds, making steel reuse viable over longer distances.

The study also confirmed that packaging density and payload efficiency affect total emissions. Mineral wool, due to its low density, showed reduced break-even distances despite baling. These results emphasize the need to consider material-specific properties in transport planning.

The parametric approach allowed scenario flexibility and demonstrated sensitivity to key assumptions. Overall, the model captured how logistics decisions can either enhance or negate the environmental gains of circular material reuse.

## 9.3 Implications for Practice and Policy

For construction practitioners, the study offers quantitative evidence for integrating logistics planning into circular economy strategies. Choosing low-emission freight options, especially electric trucks, can reduce the environmental burden of transporting reused materials. Implementing co-loading and ensuring full payload can further enhance performance.

For policymakers, the findings suggest the need to support clean logistics through incentives, infrastructure, and regulation. Expanding electric truck infrastructure, offering access or tax benefits for low-emission vehicles, and encouraging consolidation centers can improve the environmental outcomes of material reuse. Incorporating transport emissions into public procurement and sustainability assessments can ensure more accurate evaluations of circular practices.

The study reinforces that environmental benefits from reuse are not guaranteed but they depend on efficient and clean transport systems. Logistics decisions should therefore be included in early project planning and sustainability assessments.

## 9.4 Limitations and Recommendations for Future Research

This study used idealized assumptions to represent transport operations. It focused on road freight and excluded modes like rail or water. While truck scenarios incorporated full life cycle emissions for single material transit, real-world data for co-loading using electric or biodiesel trucks were limited and required assumptions. Simplified packaging densities and volume utilization estimates were used, although operational constraints may cause deviations in practice. Emissions from loading and unloading equipment and site-level energy use for processes like baling were not included. The effects of terrain or driving profile on fuel and electricity consumption were also not considered. These constraints suggest that site-specific analyses are necessary before applying the findings to specific projects or locations.

Future studies should expand the co-loading scenarios by including more diverse fuel types and real operational data. Reverse logistics, such as return trips and redistribution flows, could be modelled to reflect more complex circular transport systems. GIS-based methods could help assess route-specific emissions by incorporating elevation, road type, and traffic patterns. Applying the model in different countries would improve its broad applicability, especially in areas with different electricity profiles and transport infrastructure. Including emissions from packaging equipment and handling machinery would help assess transport impacts more comprehensively. Accounting for biogenic carbon in wood products could also improve estimates by capturing temporary carbon storage effects that were beyond the scope of this study. Together, these improvements can help refine environmental assessments and decision-making in circular construction logistics.

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# 11 Appendix

## 11.1 Appendix 1- Data Inventory

*Table 11.1 Data Inventory*

| S.NO | Description | Value | UOM | Source |
|---|---|---|---|---|
| 1 | Energy consumption of Electric Truck Scania 20.5 metric ton | 1.14 | KWh/km | Algesten et al., (2024) |
| 2 | Electric Truck Gross Vehicle Weight | 20.5 | Ton | Algesten et al., (2024) |
| 3 | Electric Truck Kerb Weight | 10.2 | Ton | Algesten et al., (2024) |
| 4 | Carbon intensity of the power sector in Sweden 2023 | 41 | gCO2/KWh | Statista, (2024) |
| 5 | Empty Weight of Hooklift Skip 25M3 | 2.485 | Tonnes | Tegui Contenedores, (2025) |
| 6 | Length of Hooklift Skip 25M3 | 6000 | mm | Tegui Contenedores, (2025) |
| 7 | Height of Hooklift Skip 25M3 | 1800 | mm | Tegui Contenedores, (2025) |
| 8 | Width of Hooklift Skip 25M3 | 2450 | mm | Tegui Contenedores, (2025) |
| 9 | Maximum Load Capacity of Hooklift Skip | 16 | Tonnes | Maxilead Metals,(2024) |
| 10 | Density of Steel | 8000 | kg/m3 | Gontia et al, (2017) |
| 11 | Density of glass | 2580 | kg/m3 | Gontia et al, (2017) |
| 12 | Mass of Wooden Flooring | 13.56 | kg/m2 | Wood Manners S.L. (2022) |
| 13 | Thickness of Wooden Flooring | 0.020 | m | Wood Manners S.L. (2022) |
| 14 | Density of Mineral Wool - Hard | 350 | kg/m3 | Gontia et al, (2017) |
| 15 | Compression Factor for Mineral Wool | 10 | Percentage | Buska, A , (2007) |
| 16 | Density of Doors ( Keto Beam) | 462 | kg/m3 | Gontia et al, (2017) |
| 17 | Length of Large Liftable Glass A Frame | 2300 | mm | GGR Group. (2021, February) |
| 18 | Width of Large liftable Glass A Frame | 1210 | mm | GGR Group. (2021, February) |
| 19 | Height of Large Liftable Glass A Frame | 1900 | mm | GGR Group. (2021, February) |
| 20 | Weight of Large Liftable Glass A Frame | 132 | kgs | GGR Group. (2021, February) |
| 21 | Maximum Load capacity of large Glass A frame | 1500 | kgs | GGR Group. (2021, February) |
| 22 | Wooden Floor Width | 125 | mm | Grato (n.d) |
| 23 | Wooden Floor Length | 880 | mm | Grato (n.d) |

| S.NO | Description | Value | UOM | Source |
|---|---|---|---|---|
| 24 | Wooden Door Length | 2040 | mm | Vibrant Doors. (n.d.) |
| 25 | Wooden Door Width | 826 | mm | Vibrant Doors. (n.d.) |
| 26 | Wooden Door Thickness | 40 | mm | Vibrant Doors. (n.d.) |
| 27 | Bale Packaging (Cylindrical) Diameter | 1.5 | m | WTE International. (n.d.) |
| 28 | Bale Packaging (Cylindrical) Height | 1.4 | m | WTE International. (n.d.) |
| 29 | Truck Gross Vehicle Weight (16-32 Tonnes) | 28.35 | Tonnes | Volvo Trucks |
| 30 | Diesel Truck Kerb Weight (16-32 Tonnes) | 9.595 | Tonnes | Volvo Trucks |
| 31 | Diesel Truck Loading Area Length (16-32 Tonnes) | 8.78 | m | Volvo Trucks |
| 32 | Diesel Truck Loading Area Width (16-32 Tonnes) | 2.5 | m | Volvo Trucks |
| 33 | Diesel Truck Trailer Gross Vehicle Weight ( >32 Tonnes) | 39 | Tonnes | P&O Ferrymasters |
| 34 | Diesel Truck Trailer Kerb Weight (>32 Tonnes) | 6.91 | Tonnes | P&O Ferrymasters |
| 35 | Diesel Truck Trailer Payload Capacity | 32.09 | Tonnes | P&O Ferrymasters |
| 36 | Diesel Truck Trailer Loading Area Length (>32 Tonnes) | 13.6 | m | P&O Ferrymasters |
| 37 | Diesel Truck Trailer Loading Area Width (>32 Tonnes) | 2.48 | m | P&O Ferrymasters |

## 11.2 Appendix 2 - Calculations

### 11.2.1 Payload Weight Limit

#### 11.2.1.1 For Diesel Truck & Bio-Diesel 16-32T

*Table 11.2* *Payload Weight Limit* for *Diesel Truck & Bio-Diesel 16-32T For Wooden Flooring*

| **Wooden Flooring** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.125 | |
| Thickness (m) | 0.02 | |
| Length (m) | 0.88 | |
| Density (kg/m3) | 678 | |
| Weight of 1 Flooring (kg) | 1.49 | |
| Customized Pallet | | |
| Length (m) | 0.88 | |
| Width (m) | 0.8 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet | | |
| Height of the layer | 0.944 | |
| No of Flooring layered in pallet (Nos) | 6.4 | 6 |
| Total Flooring in Pallet | 240.00 | |
| Weight/ Pallet (tonnes) | 0.35798 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.50 | |
| Max Loading Height (m) | 2.50 | |
| Gross Vehicle Weight (tonnes) | 28.35 | |
| Kerb Weight | 9.60 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity | 16.27 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 9.98 | 9 |
| Widthwise (Nos) | 3.13 | 3 |
| Height wise (Nos) | 2.65 | 2 |
| Additional Pallets loaded in remaining Vacant space | 1.08 | 1 |
| Total Pallet can be loaded (Nos) | 56.00 | 56 |
| Total Weight of all Pallets | 20.05 | |
| Reduced Pallet due to weight Limit (Nos) | 12 | |
| Actual Total Pallet can be loaded (Nos) | 44.45 | 44 |
| Total Weight of all 44 Pallets (tonnes) | 15.75 | |

*Table 11.3* *Payload Weight Limit* for *Diesel Truck & Bio-Diesel 16-32T For Wooden Door*

| **Wooden Door** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.826 | |
| Thickness (m) | 0.04 | |
| Length (m) | 2.04 | |
| Density (kg/m3) | 462 | |
| Weight of 1 Door (kg) | 31.14 | |
| Customized Pallet | | |
| Length (m) | 2.04 | |
| Width (m) | 0.826 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet | | |
| Height of the layer | 1.2 | |
| No of Doors layered in pallet | 1 | |
| Total Doors in Pallet | 30 | |
| Weight/ Pallet (tonnes) | 0.93 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Max Loading Height (m) | 2.50 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 28.35 | |
| Kerb Weight | 9.60 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity | 16.27 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 4.30 | 4 |
| Widthwise (Nos) | 3.027 | 3 |
| Heightwise (Nos) | 2.083 | 2 |
| Total Pallet can be loaded (Nos) | 24.00 | |
| Total Weight of all Pallets (tonnes) | 22.42 | |
| Reduce pallets due to weight limitation (Nos) | 7.00 | |
| Actual Total Pallet can be loaded (Nos) | 17.42 | 17 |
| Total Weight of all Pallets (tonnes) | 15.88 | |

*Table 11.4* *Payload Weight Limit* for *Diesel Truck & Bio-Diesel 16-32T For Mineral Wool*

| **Mineral Wool Bale** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Cylindrical Bale | | |
| Diameter (m) | 1.5 | |
| Height (m) | 1.4 | |
| Compression Ratio (10%) | 0.1 | |
| Volume (m3) | 2.47 | |
| Density before compression (kg/m3) | 350 | |
| Density after compression (kg/m3) | 385 | |
| Weight of 1 bale (tonnes) | 0.95 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Max Loading Height (m) | 2.50 | |
| Gross Vehicle Weight (tonnes) | 28.35 | |
| Kerb Weight | 9.60 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity | 16.27 | |
| Maximum Height Allowed | 2.50 | |
| Bales per Row (Width) | 1.67 | 1 |
| Bales per Row (Length) | 6.27 | 6 |
| Bales per Layer (Height) | 1.79 | 1 |
| Total Bales can be loaded (Nos) | 6.00 | |
| Total Weight of Bales Loaded (Tonnes) | 5.71 | |

*Table 11.5* *Payload Weight Limit* for *Diesel Truck & Bio-Diesel 16-32T For Glass Partition*

| **Glass Partition** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width(m) | 1 | |
| Thickness (m) | 0.01 | |
| Length(m) | 2.7 | |
| Density (kg/m3) | 2580 | |
| Weight of 1 glass partition (kg) | 69.66 | |
| Glass A Frame | | |
| Length (m) | 2.3 | |
| Width (m) | 1.21 | |
| Height (m) | 1.9 | |
| Shelf Width (m) | 0.39 | |
| Ground Clearance (m) | 0.2 | |
| Maximum Capacity of frame (tonnes) | 1.5 | |
| Weight of one frame (tonnes) | 0.132 | |
| Number of Glass loaded on shelf | 10 | |
| Number shelf in Frame | 2 | |
| Total Partition loaded in Frame | 20 | |
| Total Weight of Partitions in 1 frame (tonnes) | 1.39 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 28.35 | |
| Kerb Weight | 9.60 | |
| Additional Tools & body Support (tonnes) | 3.28 | |
| Payload Capacity | 15.48 | |
| Maximum Height Allowed | 2.50 | |
| Frame per Row (Width) | 2.07 | 2 |
| Frame per Row (Length) | 3.25 | 3 |
| Frame per Layer (Height) | 1.32 | 1 |
| Total Frames can be Loaded (Nos) | 6.00 | |
| Total weight of Partitions Loaded (tonnes) | 8.36 | |

*Table 11.6* *Payload Weight Limit* for *Diesel Truck & Bio-Diesel 16-32T For Steel Bar*

| **Steel Rebar** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Density of Steel Rebar (kg/m3) | 8000 | |
| Load Factor due to deformed shape | 0.8 | |
| Skip Width(m) | 2.45 | |
| Skip Height (m) | 1.8 | |
| Skip Length (m) | 6 | |
| Skip Capacity (m3) | 25 | |
| Skip Weight (tonnes) | 2.49 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 28.35 | |
| Kerb Weight | 9.60 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity (tonnes) | 16.27 | |
| Maximum Height Allowed | 2.40 | |
| Skip per Row (Width) | 1.02 | 1 |
| Skip Per Row (Length) | 1.5 | 1 |
| Skip Per Layer (Height) | 1.3 | 1 |
| Total Steel skip can Loaded (Nos) | 1.0 | |
| Total Weight of Steel Loaded (tonnes) | 13.02 | |

#### 11.2.1.2 For Diesel Truck >32T

*Table 11.7 Payload Weight Limit for Diesel Truck >32T for Wooden Flooring*

| Wooden Flooring | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.125 | |
| Thickness (m) | 0.02 | |
| Length (m) | 0.88 | |
| Density (kg/m3) | 678 | |
| Weight of 1 Flooring (kg) | 1.49 | |
| Customized Pallet Details | | |
| Length (m) | 0.88 | |
| Width (m) | 0.8 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet Arrangement Details | | |
| Height of the layer (m) | 0.944 | |
| No of Flooring layered in pallet (Nos) | 6.4 | 6 |
| Total Flooring in Pallet (Nos) | 240 | |
| Weight/ Pallet (tonnes) | 0.36 | |
| Loading Area of Truck | | |
| Length (m) | 13.6 | |
| Width (m) | 2.48 | |
| Gross Vehicle Weight (tonnes) | 39.00 | |
| Kerb Weight (tonnes) | 6.91 | |
| Additional Tools & body Support (tonnes) | 3.00 | |
| Payload Capacity (tonnes) | 29.09 | |
| Loading Height (m) | 2.7 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 15.45 | 15 |
| Widthwise (Nos) | 3.10 | 3 |
| Height wise (Nos) | 2.86 | 2 |
| Additional Pallets can be loaded in remaining Vacant space (Nos) | 0.50 | 0 |
| Total Pallet can be loaded (Nos) | 90.00 | |
| Total Weight of all Pallets (tonnes) | 32.22 | |
| Reduced 9 Pallet due to weight Limit (Nos) | 9.00 | |
| Actual Total Pallet can be loaded (Nos) | 81.27 | 81 |
| Total Weight of all Pallets (tonnes) | 29.00 | |

*Table 11.8 Payload Weight Limit for Diesel Truck >32T for Wooden Door*

| Wooden Door | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.825 | |
| Thickness (m) | 0.04 | |
| Length (m) | 2.04 | |
| Density (kg/m3) | 462 | |
| Weight of 1 Door (kg) | 31.10 | |
| Customized Pallet Detail | | |
| Length (m) | 2.04 | |
| Width (m) | 0.825 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet Arrangement Details | | |
| Height of the layer (m) | 1.2 | |
| No of Doors layered in pallet (Nos) | 1 | |
| Total Doors in Pallet | 30 | |
| Weight/ Pallet (tonnes) | 0.93 | |
| Loading Area of Truck | | |
| Length (m) | 13.6 | |
| Width (m) | 2.48 | |
| Gross Vehicle Weight (tonnes) | 39.00 | |
| Kerb Weight (tonnes) | 6.91 | |
| Additional Tools & body Support (tonnes) | 3.00 | |
| Payload Capacity | 29.09 | |
| Loading Height (m) | 2.7 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 6.67 | 6 |
| Widthwise (Nos) | 3.01 | 3 |
| Height Wise (Nos) | 2.25 | 2 |
| Total Pallet can be loaded (Nos) | 36 | |
| Total Weight of all Pallets (Tonnes) | 33.59 | |
| Reduced Pallet due to weight Limit (Nos) | 31.18 | 31 |
| Total Pallet can be loaded | 31 | |
| Total Weight of all Pallets | 28.92 | |

*Table 11.9 Payload Weight Limit for Diesel Truck >32T for Mineral Wool*

| Mineral Wool Bale | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Cylindrical | | |
| Diameter (m) | 1.5 | |
| Height (m) | 1.4 | |
| Compression Ratio (%) | 10 | |
| Volume (m3) | 2.47 | |
| Density before compression (kg/m3) | 350 | |
| Density after compression (kg/m3) | 385 | |
| Weight of 1 bale (tonnes) | 0.95 | |
| Loading Area of Truck | | |
| Length (m) | 13.6 | |
| Width (m) | 2.48 | |
| Gross Vehicle Weight (tonnes) | 39.00 | |
| Kerb Weight (tonnes) | 6.91 | |
| Additional Tools & body Support (tonnes) | 3.00 | |
| Payload Capacity (tonnes) | 29.09 | |
| Maximum Height Allowed (m) | 2.7 | |
| Bales per Row (Width) (Nos) | 1.65 | 1 |
| Bales per Row (Length) (Nos) | 9.71 | 9 |
| Bales per Layer (Height) (Nos) | 1.93 | 1 |
| Total Bales can be loaded (Nos) | 9 | |
| Total Weight of Bales Loaded (tonnes) | 8.57 | |

*Table 11.10 Payload Weight Limit for Diesel Truck >32T for Glass Partition*

| Glass Partition | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width(m) | 1 | |
| Thickness (m) | 0.01 | |
| Length(m) | 2.7 | |
| Density (kg/m3) | 2580 | |
| Weight of 1 partition (kg) | 69.66 | |
| Glass A Frame Arrangement Details | | |
| Length (m) | 2.3 | |
| Width (m) | 1.21 | |
| Height (m) | 1.9 | |
| Shelf Width (m) | 0.39 | |
| Weight of the A Frame (tonnes) | 0.132 | |
| Ground Clearance (m) | 0.2 | |
| Maximum Capacity of frame (tonnes) | 1.5 | |
| Number of Glasses loaded on shelf (Nos) | 10 | |
| Number shelf in Frame (nos) | 2 | |
| Total Partition loaded in Frame (Nos) | 20 | |
| Total Weight of Partitions in 1 frame (tonnes) | 1.39 | |
| Loading Area of Truck | | |
| Length (m) | 13.6 | |
| Width (m) | 2.48 | |
| Gross Vehicle Weight (tonnes) | 39.00 | |
| Kerb Weight (tonnes) | 6.91 | |
| Additional Tools & body Support (tonnes) | 4.32 | |
| Payload Capacity (tonnes) | 27.77 | |
| Maximum Height Allowed (m) | 2.7 | |
| Frame per Row (Width) (nos) | 2.05 | 2 |
| Frame per Row (Length) (nos) | 5.04 | 5 |
| Frame per Layer (Height) (nos) | 1.42 | 1 |
| Total Frames can be Loaded (nos) | 10 | |
| Total weight of Partitions Loaded (tonnes) | 13.93 | |

*Table 11.11 Payload Weight Limit for Diesel Truck >32T for Steel Bar*

| Steel Rebar | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Density of Steel Rebar (kg/m3) | 8000 | |
| Load Factor due to deformed shape | 0.8 | |
| Skip Width(m) | 2.45 | |
| Skip Height (m) | 1.8 | |
| Skip Length (m) | 6 | |
| Skip Capacity (m3) | 25 | |
| Skip Weight (tonnes) | 2.485 | |
| Loading Area of Truck | | |
| Length (m) | 13.6 | |
| Width (m) | 2.48 | |
| Gross Vehicle Weight (tonnes) | 39.00 | |
| Kerb Weight (tonnes) | 6.91 | |
| Additional Tools & Body Support (tonnes) | 4.97 | |
| Payload Capacity (tonnes) | 27.12 | |
| Maximum Height Allowed | 2.7 | |
| Skip per Row (Width) | 1.0 | 1 |
| Skip Per Row (Length) | 2.3 | 2 |
| Skip Per Layer (Height) | 1.5 | 1 |
| Total Steel skip can Loaded | 2 | |
| Total Weight of Steel Loaded | 21.70 | |

#### 11.2.1.3 For Electric Truck 20.5T

*Table 11.12 Payload Weight Limit for* Electric Truck 20.5T *for Wooden Flooring*

| Wooden Flooring | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.125 | |
| Thickness (m) | 0.02 | |
| Length (m) | 0.88 | |
| Density (kg/m3) | 678 | |
| volume (m3) | 0.00 | |
| Weight of 1 Flooring (kg) | 1.4916 | |
| Customized Pallet | | |
| Length (m) | 0.88 | |
| Width (m) | 0.8 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet | | |
| Height of the layer (m) | 0.944 | |
| No of Flooring layered in pallet (Nos) | 6.40 | 6 |
| Total Flooring in Pallet (Nos) | 240 | |
| Weight/ Pallet (tonnes) | 0.36 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.50 | |
| Maximum loading Height (m) | 2.50 | |
| Gross Vehicle Weight (tonnes) | 20.50 | |
| Kerb Weight (tonnes) | 10.20 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity (tonnes) | 7.82 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 9.98 | 9 |
| Widthwise (Nos) | 3.13 | 3 |
| Height Wise (Nos) | 2.65 | 2 |
| Additional Pallets loaded in remaining Vacant space (Nos) | 1.08 | 1 |
| Total Pallet can be loaded (Nos) | 54.00 | |
| Reduced Pallet due to weight Limitation (Nos) | 34.00 | |
| Actual Total Pallet can be loaded (Nos) | 20.83 | 20 |
| Total Weight of all Pallets (tonnes) | 7.16 | |

*Table 11.13 Payload Weight Limit for* Electric Truck 20.5T *for Wooden Door*

| **Wooden Door** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width (m) | 0.826 | |
| Thickness (m) | 0.04 | |
| Length (m) | 2.04 | |
| Density (kg/m3) | 462 | |
| Weight of 1 Door (kg) | 31.14 | |
| Customized Pallet | | |
| Length (m) | 2.04 | |
| Width (m) | 0.826 | |
| Height of the base (m) | 0.144 | |
| 1 Pallet | | |
| Height of the layer (m) | 1.2 | |
| No of Doors layered in pallet (Nos) | 1 | |
| Total Doors in Pallet (Nos) | 30 | |
| Weight/ Pallet (tonnes) | 0.93 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.50 | |
| Gross Vehicle Weight (tonnes) | 20.5 | |
| Kerb Weight (tonnes) | 12.69 | |
| Additional Tools & body Support (tonnes) | 2.485 | |
| Payload Capacity (tonnes) | 7.82 | |
| No of Pallets can be loaded | | |
| Lengthwise (Nos) | 4.30 | 4 |
| Widthwise (Nos) | 3.03 | 3 |
| Height wise (Nos) | 2.50 | 2 |
| Total Pallet can be loaded (Nos) | 24 | |
| Total Weight of all Pallets (tonnes) | 22.42 | |
| Reduce pallet due to weight limitation (Nos) | 16.00 | |
| Total Pallet can be loaded (Nos) | 8.37 | 8 |
| Total Weight of all Pallets (tonnes) | 7.47 | |

*Table 11.14 Payload Weight Limit for* Electric Truck 20.5T *for Mineral Wool*

| **Mineral Wool Bale** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Cylindrical | | |
| Diameter (m) | 1.5 | |
| Height (m) | 1.4 | |
| Compression Ratio (%) | 10 | |
| Volume (m3) after compression | 2.47 | |
| Density before compression (kg/m3) | 350 | |
| Density after compression (kg/m3) | 385 | |
| Weight of 1 bale (tonnes) | 0.95 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 20.50 | |
| Kerb Weight (tonnes) | 10.20 | |
| Additional Tools & body Support (tonnes) | 2.485 | |
| Payload Capacity (tonnes) | 7.82 | |
| Maximum Height Allowed (m) | 2.50 | |
| Bales per Row (Width) | 1.67 | 1 |
| Bales per Row (Length) | 6.27 | 6 |
| Bales per Layer (Height) | 1.79 | 1 |
| Total Bales can be loaded (Nos) | 6.00 | |
| Total Weight of Bales Loaded (tonnes) | 5.71 | |

*Table 11.15 Payload Weight Limit for* Electric Truck 20.5T *for Glass Partition*

| **Glass Partition** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Width(m) | 1 | |
| Thickness (m) | 0.01 | |
| Length(m) | 2.7 | |
| Density (kg/m3) | 2580 | |
| Weight of 1 glass partition (kg) | 69.66 | |
| Glass A Frame | | |
| Length (m) | 2.3 | |
| Width (m) | 1.21 | |
| Height (m) | 1.9 | |
| Shelf Width (m) | 0.39 | |
| Ground Clearance (m) | 0.2 | |
| Maximum Capacity of frame (tonnes) | 1.5 | |
| Weight of one frame (tonnes) | 0.132 | |
| Number of Glasses loaded on shelf (Nos) | 10 | |
| Number of shelves in Frame (Nos) | 2 | |
| Total Glass Partition loaded in Frame (Nos) | 20 | |
| Total Weight of Partitions in 1 frame (tonnes) | 1.39 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 20.5 | |
| Kerb Weight (tonnes) | 10.2 | |
| Additional Tools & body Support (tonnes) | 3.145 | |
| Payload Capacity (tonnes) | 7.16 | |
| Maximum Height Allowed (m) | 2.50 | |
| Frames per Row (Width) | 2.07 | 2 |
| Frames per Row (Length) | 3.25 | 3 |
| Frames per Layer (Height) | 1.32 | 1 |
| Total Frames can be Loaded (Nos) | 5.14 | 5 |
| Total weight of Partitions Loaded (tonnes) | 6.97 | |

*Table 11.16* *Payload Weight Limit for* Electric Truck 20.5T *for Steel Rebar*

| **Steel Rebar** | | |
|---|---|---|
| **Description** | **Value** | **Rounding off** |
| Density of Steel Rebar (kg/m3) | 8000 | |
| Load Factor due to deformed shape | 0.8 | |
| Skip Width(m) | 2.45 | |
| Skip Height (m) | 1.8 | |
| Skip Length (m) | 6 | |
| Skip Capacity (m3) | 25 | |
| Skip Weight (tonnes) | 2.49 | |
| Loading Area of Truck | | |
| Length (m) | 8.78 | |
| Width (m) | 2.5 | |
| Gross Vehicle Weight (tonnes) | 20.50 | |
| Kerb Weight (tonnes) | 10.20 | |
| Additional Tools & body Support (tonnes) | 2.49 | |
| Payload Capacity (tonnes) | 7.82 | |
| Maximum Height Allowed (m) | 2.50 | |
| Skip per Row (Width) | 1.02 | 1 |
| Skip Per Row (Length) | 1.463 | 1 |
| Skip Per Layer (Height) | 1.4 | 1 |
| Total Steel skip can Loaded (Nos) | 1.0 | |
| Total Weight of Steel Loaded (Tonnes) | 6.25 | |

### 11.2.2 Number of Trips- Single Transit and Co-loaded Transits

*Table 11.17 Diesel Truck 32T & Biodiesel Truck 28T– Single material Transit*

| S.No | Material Description | Weight (Tonnes) | Density (kg/m3) | Volume (m3) | Payload Capacity (Tonnes) | Total No of trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 13.02 | 73.73 | 74 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 8.36 | 12.32 | 13 |
| 3 | Mineral Wool | 38 | 385 | 98.701 | 5.71 | 6.65 | 7 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 15.75 | 2.39 | 3 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 15.88 | 8.29 | 9 |
| | | | | | | | 106.00 |

*Table 11.18 Diesel Truck >32T – Single material Transit*

| S.No | Material Description | Weight (Tonnes) | Density (kg/m3) | Volume (m3) | Payload Capacity (Tonnes) | Total No of trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 21.70 | 44.25 | 45 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 13.93 | 7.39 | 8 |
| 3 | Mineral Wool | 38 | 385 | 98.70 | 8.57 | 4.43 | 5 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 29 | 1.30 | 2 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 28.92 | 4.55 | 5 |
| | | | | | | | 65 |

*Table 11.19 Electric Truck 20.5T – Single material Transit*

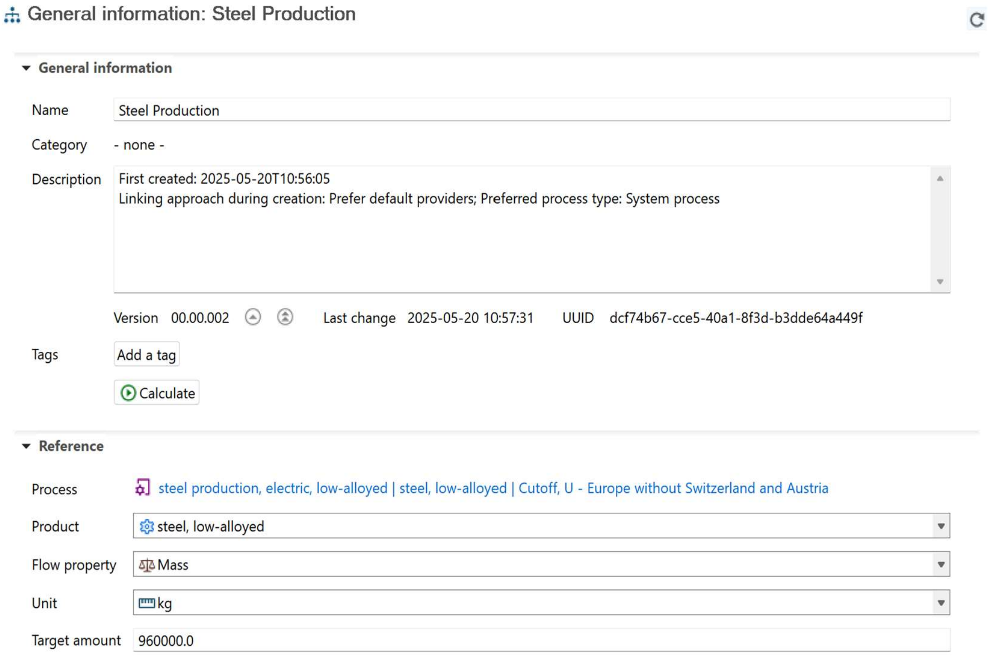
| S.No | Material Description | Weight (Tonnes) | Density (kg/m3) | Volume (m3) | Payload Capacity (Tonnes) | Total No of trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 6.25 | 153.55 | 154 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 6.97 | 14.78 | 15 |
| 3 | Mineral Wool | 38 | 385 | 98.70 | 5.71 | 6.65 | 7 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.46 | 7.20 | 5.25 | 6 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 7.47 | 17.62 | 18 |
| | | | | | | | 200 |

*Table 11.20 Diesel Truck >32T – Co-loaded Material Transit*

| S.No | Loading Combination | Weight of Material loaded (Tons) | | | | | Total Loaded Weight (Tons) | Payload Capacity (tons) | Total Trips |
|---|---|---|---|---|---|---|---|---|---|
| | | Steel | Flooring | Door | Glass | Wool | | | |
| 1 | 1x Steel Skip + 44x Flooring Pallet | 13.02 | 17.28 | 0 | 0 | 0 | 30.3 | 32.09 | 2 |
| 2 | 1x Steel Skip + 15x Door Pallet | 13.02 | 0 | 13.95 | 0 | 0 | 26.97 | 32.09 | 9 |
| 3 | 1x Steel Skip +5 x Bale Wool+ 17x Flooring pallet | 13.02 | 3.04 | 0 | 0 | 4.75 | 20.81 | 32.09 | 1 |
| 4 | 1x Steel Skip +5 x Bale Wool + 6x Door Pallet | 13.02 | 0 | 5.58 | 0 | 4.75 | 23.35 | 32.09 | 1 |
| 5 | 1x Steel Skip + 4x Glass Frame + 1x Door Pallet | 13.02 | 0 | 0.47 | 5.57 | 0 | 19.06 | 32.09 | 1 |
| 6 | 1x Steel Skip + 4x Glass Frame | 13.02 | 0 | 0 | 5.57 | 0 | 18.59 | 32.09 | 17 |
| 7 | 1x Steel Skip +5x Bale Wool | 13.02 | 0 | 0 | 0 | 4.75 | 17.77 | 32.09 | 1 |
| 8 | 1x Steel Skip + 2x Glass Frame +1x Bale Wool | 13.02 | 0 | 0 | 2.74 | 0.95 | 16.71 | 32.09 | 1 |
| 9 | 2x Steel Skip + 1x Bale Wool | 21.62 | 0 | 0 | 0 | 0.95 | 22.57 | 32.09 | 19 |
| 10 | 1x Steel Skip +5x Bale Wool | 13.02 | 0 | 0 | 0 | 4.75 | 17.77 | 32.09 | 1 |
| 11 | 2x Steel Skip | 21.62 | 0 | 0 | 0 | 0 | 21.62 | 32.09 | 4 |
| 12 | 2x Steel Skip* | 20.06 | 0 | 0 | 0 | 0 | 20.06 | 32.09 | 1 |
| Total Number of Trips Required | | | | | | | | | 58 |

## 11.2.3 Cradle-to-Gate Embodied Carbon Calculation

### 11.2.3.1 For Steel – Using openLCA & Ecoinvent 3.8



General information: Steel Production

General information

Name: Steel Production

Category: - none -

Description: First created: 2025-05-20T10:56:05
Linking approach during creation: Prefer default providers; Preferred process type: System process

Version 00.00.002 Last change 2025-05-20 10:57:31 UUID dcf74b67-cce5-40a1-8f3d-b3dde64a449f

Tags

Reference

Process: steel production, electric, low-alloyed | steel, low-alloyed | Cutoff, U - Europe without Switzerland and Austria

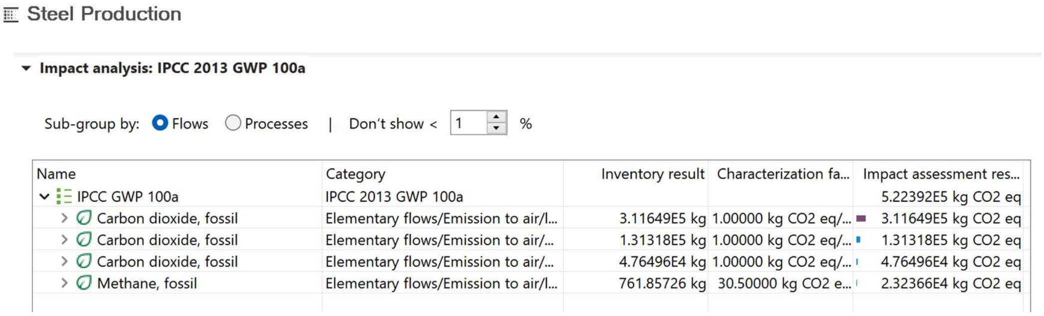
Product: steel, low-alloyed

Flow property: Mass

Unit: kg

Target amount: 960000.0

*Figure 11.1 General Information Steel Production*



Steel Production

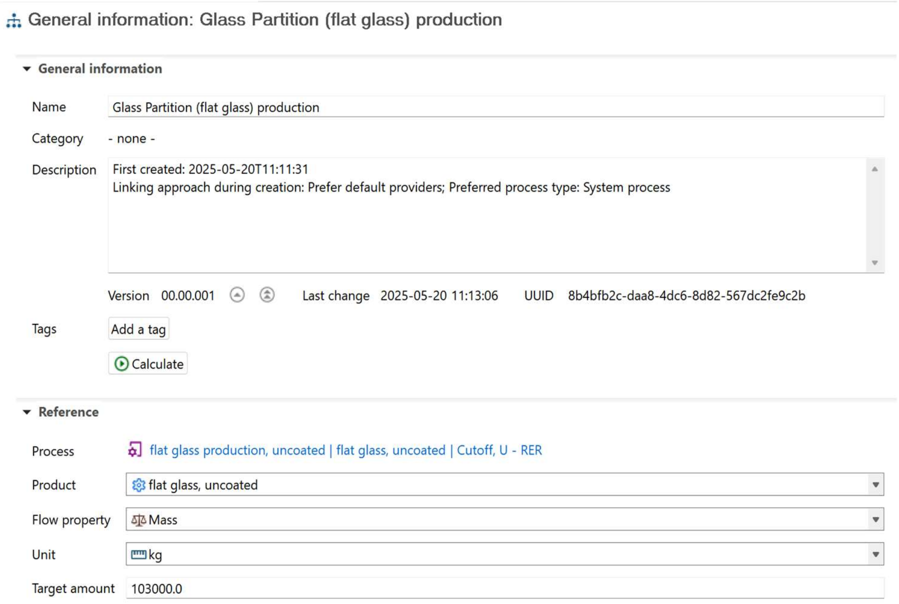
**Impact analysis: IPCC 2013 GWP 100a**

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment res... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 5.22392E5 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 3.11649E5 kg | 1.00000 kg CO2 eq/... | 3.11649E5 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 1.31318E5 kg | 1.00000 kg CO2 eq/... | 1.31318E5 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 4.76496E4 kg | 1.00000 kg CO2 eq/... | 4.76496E4 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 761.85726 kg | 30.50000 kg CO2 e... | 2.32366E4 kg CO2 eq |

*Figure 11.2 Impact Analysis Of Steel Production*

#### 11.2.3.2 For Glass – Using openLCA & Ecoinvent 3.8



General information: Glass Partition (flat glass) production

**General information**

Name: Glass Partition (flat glass) production

Category: - none -

Description: First created: 2025-05-20T11:11:31
Linking approach during creation: Prefer default providers; Preferred process type: System process

Version 00.00.001 Last change 2025-05-20 11:13:06 UUID 8b4bfb2c-daa8-4dc6-8d82-567dc2fe9c2b

Tags: Add a tag

Calculate

**Reference**

Process: flat glass production, uncoated | flat glass, uncoated | Cutoff, U - RER

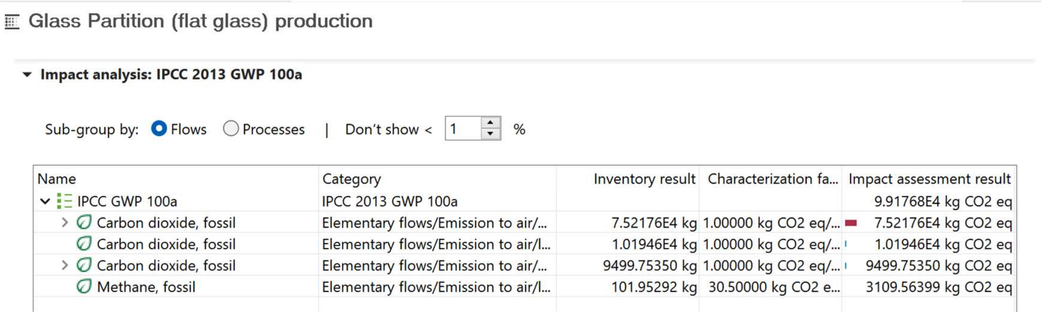
Product: flat glass, uncoated

Flow property: Mass

Unit: kg

Target amount: 103000.0

*Figure 11.3 General Information Glass Partition*



Glass Partition (flat glass) production

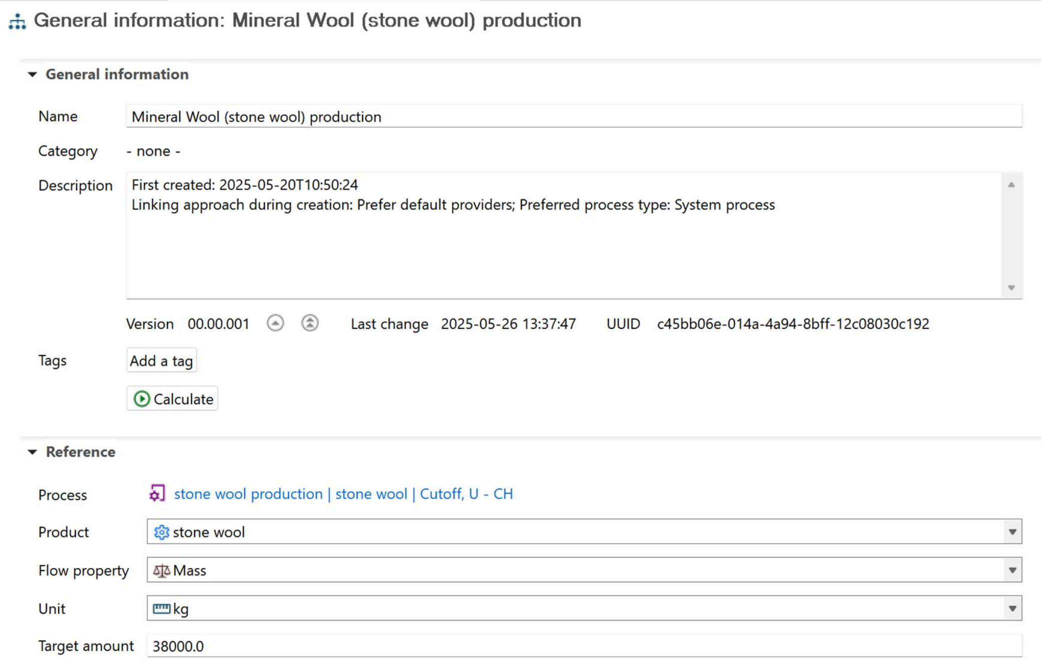
**Impact analysis: IPCC 2013 GWP 100a**

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment result |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 9.91768E4 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 7.52176E4 kg | 1.00000 kg CO2 eq/... | 7.52176E4 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 1.01946E4 kg | 1.00000 kg CO2 eq/... | 1.01946E4 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 9499.75350 kg | 1.00000 kg CO2 eq/... | 9499.75350 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 101.95292 kg | 30.50000 kg CO2 e... | 3109.56399 kg CO2 eq |

*Figure 11.4 Impact Analysis Glass Partition*

### 11.2.3.3 For Mineral Wool (Stone Wool) – Using openLCA & Ecoinvent 3.8



General information: Mineral Wool (stone wool) production

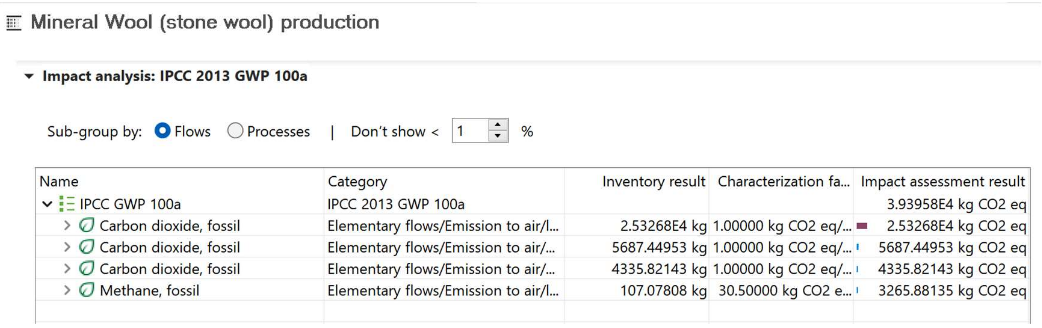
**General information**

Name: Mineral Wool (stone wool) production
Category: - none -
Description: First created: 2025-05-20T10:50:24
Linking approach during creation: Prefer default providers; Preferred process type: System process
Version 00.00.001 Last change 2025-05-26 13:37:47 UUID c45bb06e-014a-4a94-8bff-12c08030c192
Tags: Add a tag

**Reference**

Process: stone wool production | stone wool | Cutoff, U - CH
Product: stone wool
Flow property: Mass
Unit: kg
Target amount: 38000.0

*Figure 11.5 General Information Mineral Wool*



Mineral Wool (stone wool) production

**Impact analysis: IPCC 2013 GWP 100a**

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment result |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 3.93958E4 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 2.53268E4 kg | 1.00000 kg CO2 eq/... | 2.53268E4 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 5687.44953 kg | 1.00000 kg CO2 eq/... | 5687.44953 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 4335.82143 kg | 1.00000 kg CO2 eq/... | 4335.82143 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 107.07808 kg | 30.50000 kg CO2 e... | 3265.88135 kg CO2 eq |

*Figure 11.6 Impact Analysis Mineral Wool*

### 11.2.3.4 For Wooden Door – Using EPD Data Sheet

Commulative GWP For Module (A1-A3) in $KgCO_2$ eq/$m^3$ = 276 (excluding biogenic carbon)
Density of Wooden Door in Kg/$m^3$ = 462

$$Cradle\ to\ Gate\ Embodied\ Carbon\ per\ 1Kg\ Wooden\ Door\ in\ kg\ CO_2-eq = \frac{Commulative\ GWP}{Density\ of\ Wooden\ Door} \tag{11.1}$$

Cradle-to-Gate Embodied Carbon per 1 kg wooden Door in $KgCO_2$ eq = 0.597
Cradle-to-Gate Embodied Carbon per 131600 Kg Wooden Door in $KgCO_2eq$ = 78620
Cradle-to-Gate Embodied Carbon per 131600 Kg Wooden Door in $TonCO_2eq$ =78.62

#### 11.2.3.5 For Wooden Floor – Using EPD Data Sheet

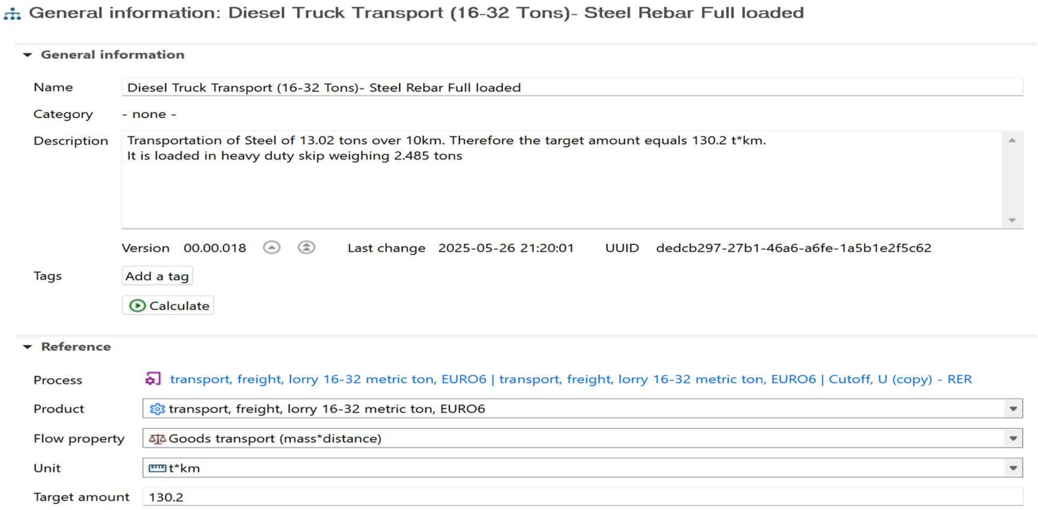
GWP For Module (A1-A3) in $KgCO_2\,eq/m^2$ = 4.605
Commulative GWP (A1-A3) in $KgCO_2\,eq/m^2$ = 4.605
Mass of the Wooden Flooring in $Kg/m^2$ = 13.56
Thickness of the Wooden Flooring in meter (m) = 0.020

$$Cradle\ to\ gate\ Embodied\ Carbon\ per\ 1Kg\ Wooden\ Floor\ in\ kg\ CO_2 - eq = \frac{Commulative\ GWP}{Mass\ of\ Wooden\ Floor} \tag{11.2}$$

Cradle-to-Gate Embodied Carbon per 1 kg wooden floor in $KgCO_2$ eq = 0.3396
Cradle-to-Gate Embodied Carbon per 37600Kg Wooden Door in $KgCO_2$eq=12769.03
Cradle-to-Gate Embodied Carbon per 37600Kg Wooden Door in $TonCO_2$eq = 12.77

### 11.2.4 Breakeven Distance Calculation

#### 11.2.4.1 For Steel Diesel truck 16-32T– Using openLCA 2.1 and Ecoinvent 3.8


General information: Diesel Truck Transport (16-32 Tons)- Steel Rebar Full loaded

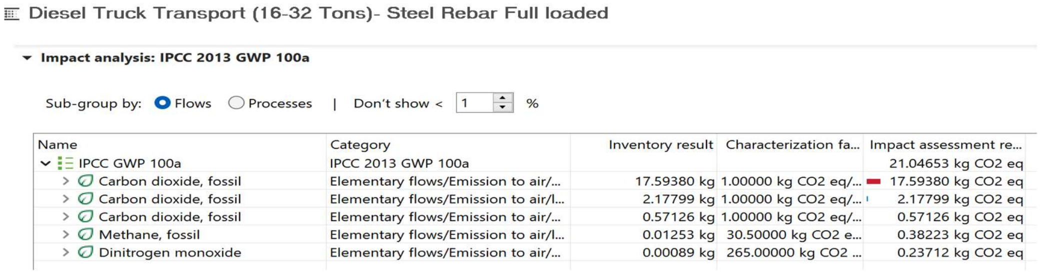
General information

Name: Diesel Truck Transport (16-32 Tons)- Steel Rebar Full loaded
Category: - none -
Description: Transportation of Steel of 13.02 tons over 10km. Therefore the target amount equals 130.2 t*km.
It is loaded in heavy duty skip weighing 2.485 tons
Version 00.00.018 Last change 2025-05-26 21:20:01 UUID dedcb297-27b1-46a6-a6fe-1a5b1e2f5c62
Tags: Add a tag

Reference

Process: transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6 | Cutoff, U (copy) - RER
Product: transport, freight, lorry 16-32 metric ton, EURO6
Flow property: Goods transport (mass*distance)
Unit: t*km
Target amount: 130.2

*Figure 11.7 General Information Diesel Truck Transport (16-32 tonnes)- Steel Rebar Full loaded*

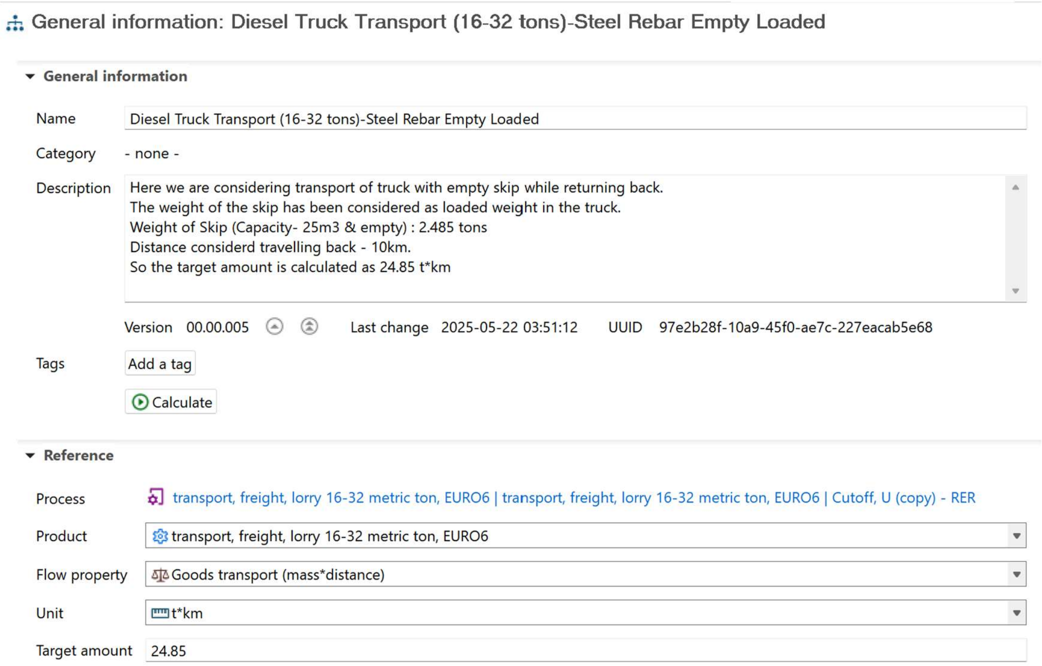

Diesel Truck Transport (16-32 Tons)- Steel Rebar Full loaded

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment re... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 21.04653 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 17.59380 kg | 1.00000 kg CO2 eq/... | 17.59380 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 2.17799 kg | 1.00000 kg CO2 eq/... | 2.17799 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.57126 kg | 1.00000 kg CO2 eq/... | 0.57126 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.01253 kg | 30.50000 kg CO2 e... | 0.38223 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00089 kg | 265.00000 kg CO2 ... | 0.23712 kg CO2 eq |

*Figure 11.8 Impact Analysis Diesel Truck Transport (16-32 tonnes)- Steel Rebar Full loaded*


General information: Diesel Truck Transport (16-32 tons)-Steel Rebar Empty Loaded

General information

Name: Diesel Truck Transport (16-32 tons)-Steel Rebar Empty Loaded

Category: - none -

Description:
Here we are considering transport of truck with empty skip while returning back.
The weight of the skip has been considered as loaded weight in the truck.
Weight of Skip (Capacity- 25m3 & empty) : 2.485 tons
Distance considerd travelling back - 10km.
So the target amount is calculated as 24.85 t*km

Version 00.00.005 Last change 2025-05-22 03:51:12 UUID 97e2b28f-10a9-45f0-ae7c-227eacab5e68

Tags: Add a tag

Reference

Process: transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6 | Cutoff, U (copy) - RER

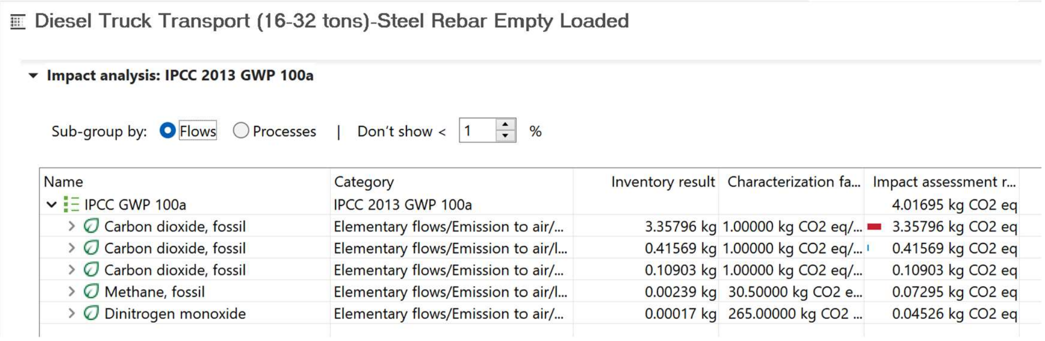
Product: transport, freight, lorry 16-32 metric ton, EURO6

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 24.85

*Figure 11.9 General Information Diesel Truck Transport (16-32 tonnes)- Steel Rebar Empty loaded*


Diesel Truck Transport (16-32 tons)-Steel Rebar Empty Loaded

Impact analysis: IPCC 2013 GWP 100a

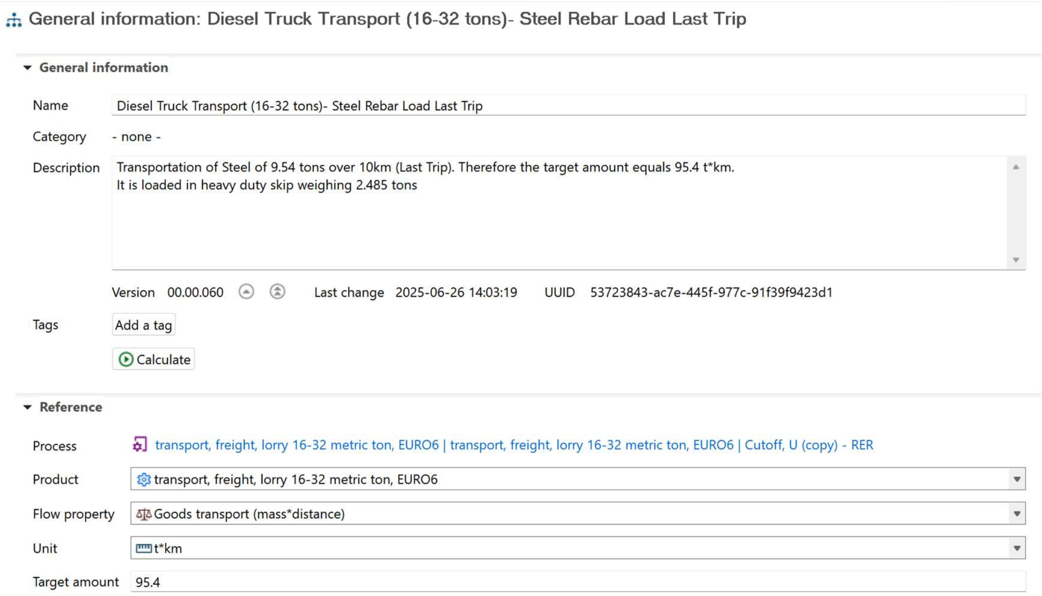
Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment r... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 4.01695 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 3.35796 kg | 1.00000 kg CO2 eq/... | 3.35796 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 0.41569 kg | 1.00000 kg CO2 eq/... | 0.41569 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.10903 kg | 1.00000 kg CO2 eq/... | 0.10903 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.00239 kg | 30.50000 kg CO2 e... | 0.07295 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00017 kg | 265.00000 kg CO2 ... | 0.04526 kg CO2 eq |

*Figure 11.10 Impact Analysis Diesel Truck Transport (16-32 tonnes)- Steel Rebar Empty loaded*

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (21.05+4.02)= 25.07
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 4.02
Total Emission per Same Loaded & Empty trip in Kg$CO_2$- eq = 29.09

No of Trip Required Steel Rebar Single Transit excluding last trip – 73



General information: Diesel Truck Transport (16-32 tons)- Steel Rebar Load Last Trip

General information

Name: Diesel Truck Transport (16-32 tons)- Steel Rebar Load Last Trip

Category: - none -

Description: Transportation of Steel of 9.54 tons over 10km (Last Trip). Therefore the target amount equals 95.4 t*km.
It is loaded in heavy duty skip weighing 2.485 tons

Version: 00.00.060 Last change: 2025-06-26 14:03:19 UUID: 53723843-ac7e-445f-977c-91f39f9423d1

Reference

Process: transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6 | Cutoff, U (copy) - RER

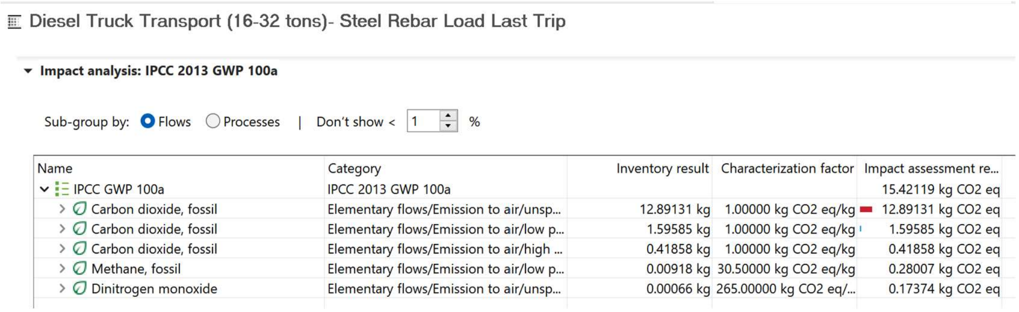
Product: transport, freight, lorry 16-32 metric ton, EURO6

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 95.4

*Figure 11.11 General Information Diesel Truck Transport (16-32 tonnes)- Steel Rebar loaded last Trip*



Diesel Truck Transport (16-32 tons)- Steel Rebar Load Last Trip

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization factor | Impact assessment re... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 15.42119 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/unsp... | 12.89131 kg | 1.00000 kg CO2 eq/kg | 12.89131 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/low p... | 1.59585 kg | 1.00000 kg CO2 eq/kg | 1.59585 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/high ... | 0.41858 kg | 1.00000 kg CO2 eq/kg | 0.41858 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/low p... | 0.00918 kg | 30.50000 kg CO2 eq/kg | 0.28007 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/unsp... | 0.00066 kg | 265.00000 kg CO2 eq/... | 0.17374 kg CO2 eq |

*Figure 11.12 Impact Analysis Diesel Truck Transport (16-32 tonnes)- Steel Rebar loaded last Trip*

For Last Trip
Emission for Last Loaded trip per 10km in KgCO$_2$- eq =(15.42+4.02) = 19.44
Emission for Last Empty trip per 10 km in KgCO$_2$- eq = 4.02
Total Emission per Last Loaded & Empty Trip in KgCO2-eq = 23.46

Total transport emissions per Steel Rebar is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton CO$_2$-eq/km) = 0.215

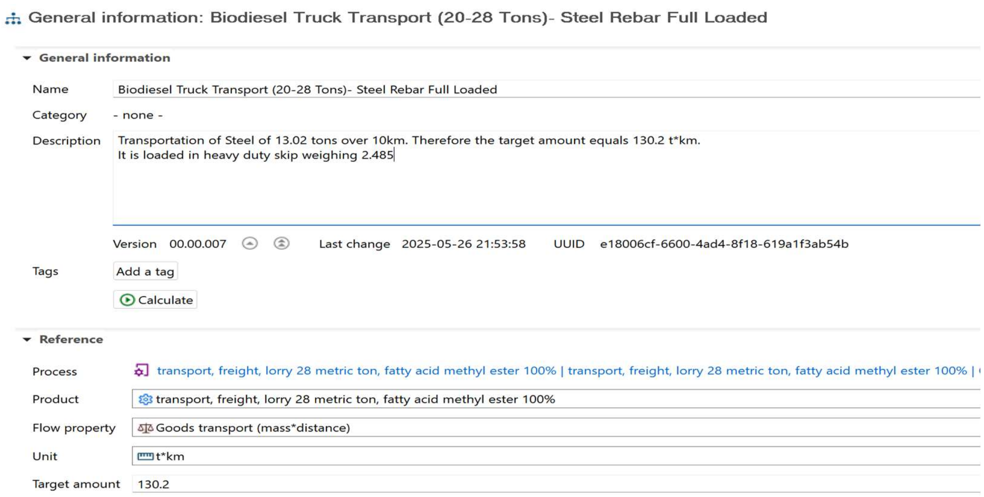
Breakeven distance (km) was then using

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 960000 kgs Steel in TonCO2-eq = 52.24

Breakeven Distance of Transporting Steel Rebar  32T Diesel truck in Km = 243

### 11.2.4.2 For Steel Bio-Diesel truck 20-28T– Using openLCA 2.1 and Ecoinvent 3.8



General information: Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Full Loaded

General information

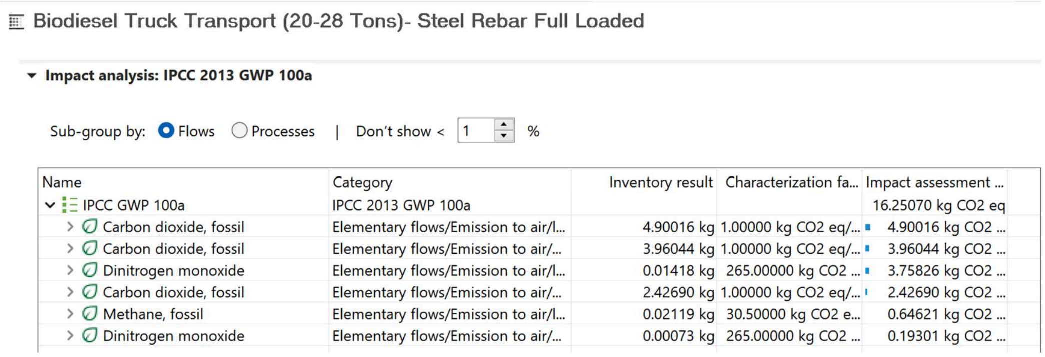
| | |
|---|---|
| Name | Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Full Loaded |
| Category | - none - |
| Description | Transportation of Steel of 13.02 tons over 10km. Therefore the target amount equals 130.2 t*km.<br>It is loaded in heavy duty skip weighing 2.485 |

Version 00.00.007 Last change 2025-05-26 21:53:58 UUID e18006cf-6600-4ad4-8f18-619a1f3ab54b

Reference

| | |
|---|---|
| Process | transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% \| transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% \| |
| Product | transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% |
| Flow property | Goods transport (mass*distance) |
| Unit | t*km |
| Target amount | 130.2 |

*Figure 11.13 General Information  Bio-Diesel Truck Transport (20-28 Tonnes)- Steel Rebar Fully  loaded*



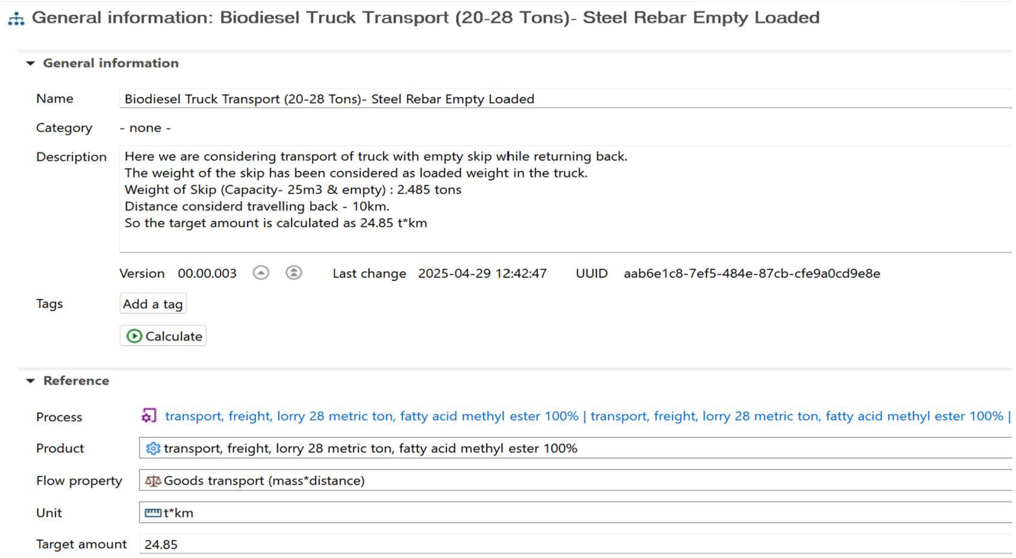
Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Full Loaded

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment ... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 16.25070 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 4.90016 kg | 1.00000 kg CO2 eq/... | 4.90016 kg CO2 ... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 3.96044 kg | 1.00000 kg CO2 eq/... | 3.96044 kg CO2 ... |
| Dinitrogen monoxide | Elementary flows/Emission to air/l... | 0.01418 kg | 265.00000 kg CO2 ... | 3.75826 kg CO2 ... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 2.42690 kg | 1.00000 kg CO2 eq/... | 2.42690 kg CO2 ... |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.02119 kg | 30.50000 kg CO2 e... | 0.64621 kg CO2 ... |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00073 kg | 265.00000 kg CO2 ... | 0.19301 kg CO2 ... |

*Figure 11.14 Impact Analysis Bio-Diesel Truck Transport (20-28 tonnes)- Steel Rebar Fully loaded*


General information: Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Empty Loaded

General information

Name: Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Empty Loaded

Category: - none -

Description: Here we are considering transport of truck with empty skip while returning back.
The weight of the skip has been considered as loaded weight in the truck.
Weight of Skip (Capacity- 25m3 & empty) : 2.485 tons
Distance considerd travelling back - 10km.
So the target amount is calculated as 24.85 t*km

Version 00.00.003 Last change 2025-04-29 12:42:47 UUID aab6e1c8-7ef5-484e-87cb-cfe9a0cd9e8e

Tags: Add a tag

Reference

Process: transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% | transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% |

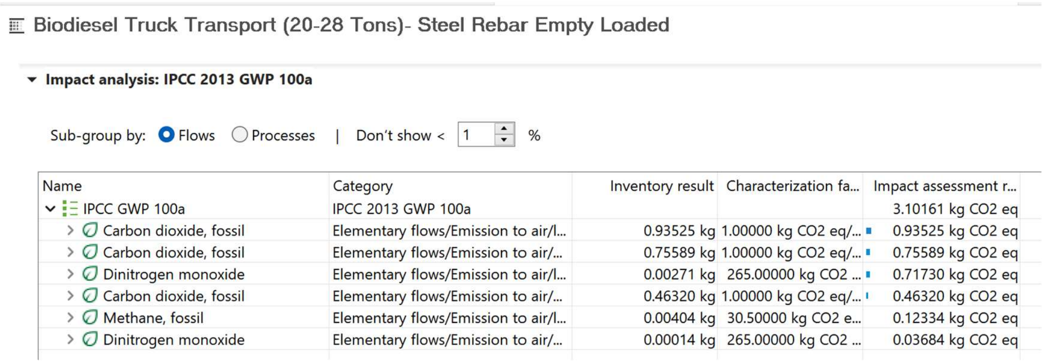
Product: transport, freight, lorry 28 metric ton, fatty acid methyl ester 100%

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 24.85

*Figure 11.15 General Information Bio-Diesel Truck Transport (20-28 Tonnes)- Steel Rebar Empty loaded*


Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Empty Loaded

Impact analysis: IPCC 2013 GWP 100a

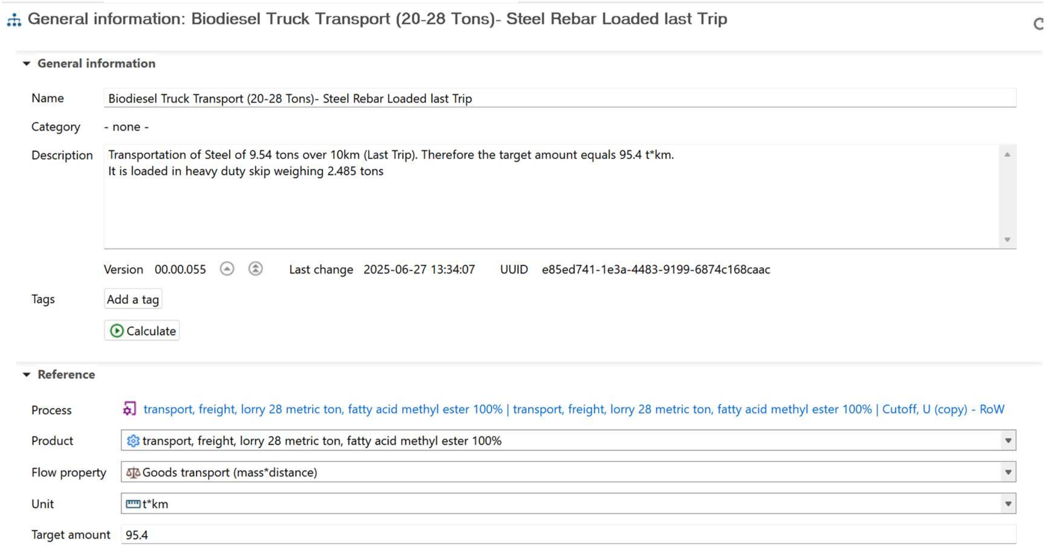
Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment r... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 3.10161 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 0.93525 kg | 1.00000 kg CO2 eq/... | 0.93525 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.75589 kg | 1.00000 kg CO2 eq/... | 0.75589 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/l... | 0.00271 kg | 265.00000 kg CO2 ... | 0.71730 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.46320 kg | 1.00000 kg CO2 eq/... | 0.46320 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.00404 kg | 30.50000 kg CO2 e... | 0.12334 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00014 kg | 265.00000 kg CO2 ... | 0.03684 kg CO2 eq |

*Figure 11.16 Impact Analysis Bio-Diesel Truck Transport (20-28 tonnes)- Steel Rebar Empty loaded*

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (16.251+3.102) = 19.353
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 3.102
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (19.353+3.102) = 22.46

No of Trip Required Single Transit excluding last trip – 73


General information: Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Loaded last Trip

General information

Name: Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Loaded last Trip

Category: - none -

Description: Transportation of Steel of 9.54 tons over 10km (Last Trip). Therefore the target amount equals 95.4 t*km.
It is loaded in heavy duty skip weighing 2.485 tons

Version 00.00.055 Last change 2025-06-27 13:34:07 UUID e85ed741-1e3a-4483-9199-6874c168caac

Tags: Add a tag

Reference

Process: transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% | transport, freight, lorry 28 metric ton, fatty acid methyl ester 100% | Cutoff, U (copy) - RoW

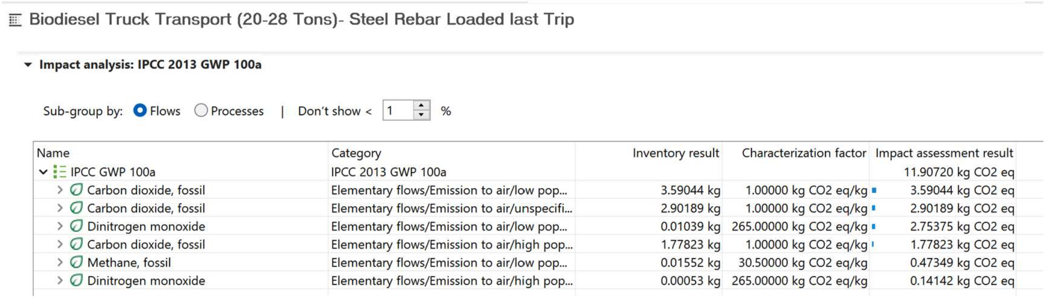
Product: transport, freight, lorry 28 metric ton, fatty acid methyl ester 100%

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 95.4

*Figure 11.17 General Information Bio-Diesel Truck Transport (20-28 Tonnes)-Steel Rebar loaded last trip.*


Biodiesel Truck Transport (20-28 Tons)- Steel Rebar Loaded last Trip

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization factor | Impact assessment result |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 11.90720 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/low pop... | 3.59044 kg | 1.00000 kg CO2 eq/kg | 3.59044 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/unspecifi... | 2.90189 kg | 1.00000 kg CO2 eq/kg | 2.90189 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/low pop... | 0.01039 kg | 265.00000 kg CO2 eq/kg | 2.75375 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/high pop... | 1.77823 kg | 1.00000 kg CO2 eq/kg | 1.77823 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/low pop... | 0.01552 kg | 30.50000 kg CO2 eq/kg | 0.47349 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/high pop... | 0.00053 kg | 265.00000 kg CO2 eq/kg | 0.14142 kg CO2 eq |

*Figure 11.18 Impact Analysis Bio-Diesel Truck Transport (20-28 tonnes)- Steel Rebar loaded last trip.*

For Last Trip
Emission for Last Loaded trip per 10km in KgCO$_2$- eq =(11.91+3.102) = 15.012
Emission for Last Empty trip per 10 km in KgCO$_2$- eq = 3.102
Total Emission per Last Loaded & Empty Trip in KgCO2-eq = 18.114

Total transport emissions per Steel Rebar is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ Trip\ per\ km \end{aligned}$$

Total Emissions in Ton CO$_2$-eq/km= 0.166

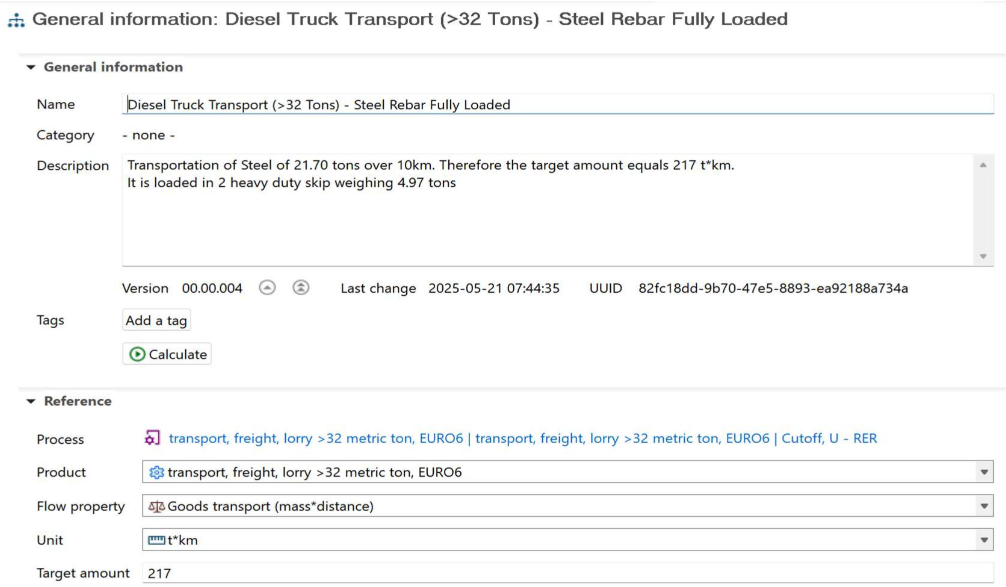
Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 960000 kgs Steel in TonCO2-eq = 52.24

Breakeven Distance of Transporting Steel Rebar 28T Diesel truck in Km = 315

### 11.2.4.3 For Steel, Diesel truck >32T– Using openLCA 2.1 and Ecoinvent 3.8



General information: Diesel Truck Transport (>32 Tons) - Steel Rebar Fully Loaded

General information

Name: Diesel Truck Transport (>32 Tons) - Steel Rebar Fully Loaded

Category: - none -

Description: Transportation of Steel of 21.70 tons over 10km. Therefore the target amount equals 217 t*km.
It is loaded in 2 heavy duty skip weighing 4.97 tons

Version 00.00.004 Last change 2025-05-21 07:44:35 UUID 82fc18dd-9b70-47e5-8893-ea92188a734a

Tags: Add a tag

Reference

Process: transport, freight, lorry >32 metric ton, EURO6 | transport, freight, lorry >32 metric ton, EURO6 | Cutoff, U - RER

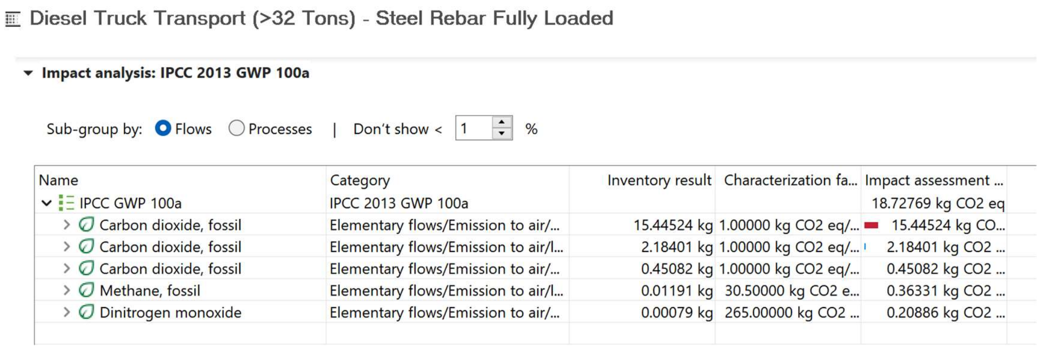
Product: transport, freight, lorry >32 metric ton, EURO6

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 217

*Figure 11.19 General Information Diesel Truck Transport (>32 Tonnes)- Steel Rebar Fully loaded*



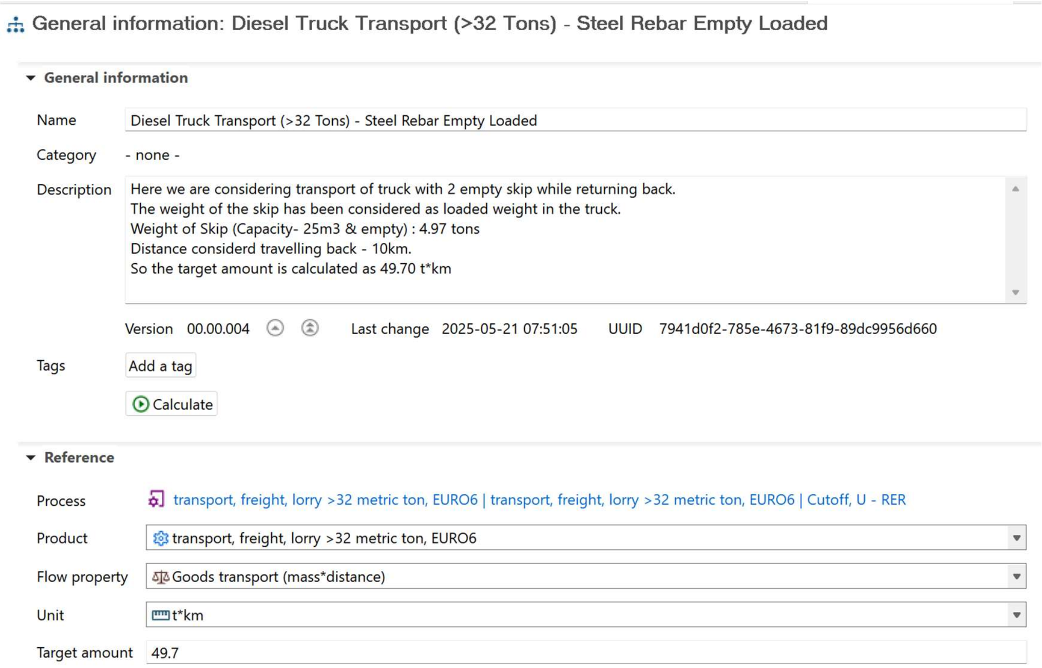
Diesel Truck Transport (>32 Tons) - Steel Rebar Fully Loaded

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment ... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 18.72769 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 15.44524 kg | 1.00000 kg CO2 eq/... | 15.44524 kg CO... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 2.18401 kg | 1.00000 kg CO2 eq/... | 2.18401 kg CO2 ... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.45082 kg | 1.00000 kg CO2 eq/... | 0.45082 kg CO2 ... |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.01191 kg | 30.50000 kg CO2 e... | 0.36331 kg CO2 ... |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00079 kg | 265.00000 kg CO2 ... | 0.20886 kg CO2 ... |

*Figure 11.20 Impact Analysis Diesel Truck Transport (>32 Tonnes)- Steel Rebar Fully loaded*



General information: Diesel Truck Transport (>32 Tons) - Steel Rebar Empty Loaded

General information

Name: Diesel Truck Transport (>32 Tons) - Steel Rebar Empty Loaded

Category: - none -

Description:
Here we are considering transport of truck with 2 empty skip while returning back.
The weight of the skip has been considered as loaded weight in the truck.
Weight of Skip (Capacity- 25m3 & empty) : 4.97 tons
Distance considerd travelling back - 10km.
So the target amount is calculated as 49.70 t*km

Version 00.00.004 Last change 2025-05-21 07:51:05 UUID 7941d0f2-785e-4673-81f9-89dc9956d660

Tags: Add a tag

Reference

Process: transport, freight, lorry >32 metric ton, EURO6 | transport, freight, lorry >32 metric ton, EURO6 | Cutoff, U - RER

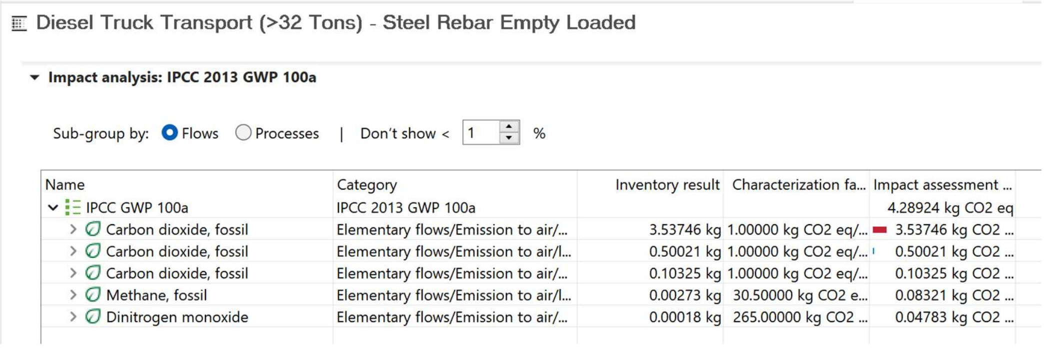
Product: transport, freight, lorry >32 metric ton, EURO6

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 49.7

*Figure 11.21 General Information Diesel Truck Transport (>32 Tonnes)- Steel Rebar Empty loaded*



Diesel Truck Transport (>32 Tons) - Steel Rebar Empty Loaded

Impact analysis: IPCC 2013 GWP 100a

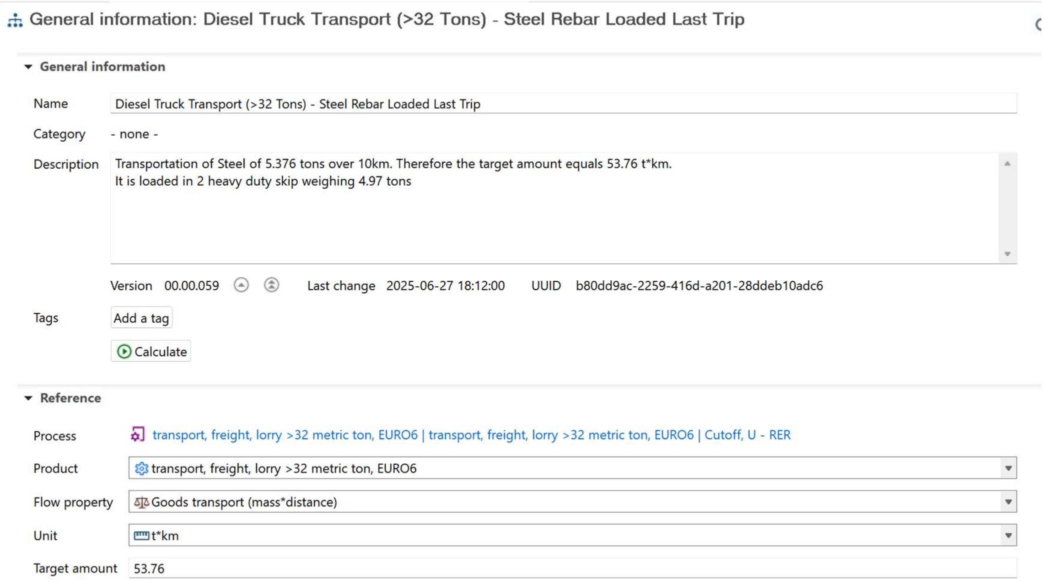
Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization fa... | Impact assessment ... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 4.28924 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 3.53746 kg | 1.00000 kg CO2 eq/... | 3.53746 kg CO2 ... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/l... | 0.50021 kg | 1.00000 kg CO2 eq/... | 0.50021 kg CO2 ... |
| Carbon dioxide, fossil | Elementary flows/Emission to air/... | 0.10325 kg | 1.00000 kg CO2 eq/... | 0.10325 kg CO2 ... |
| Methane, fossil | Elementary flows/Emission to air/l... | 0.00273 kg | 30.50000 kg CO2 e... | 0.08321 kg CO2 ... |
| Dinitrogen monoxide | Elementary flows/Emission to air/... | 0.00018 kg | 265.00000 kg CO2 ... | 0.04783 kg CO2 ... |

*Figure 11.22 Impact Analysis Diesel Truck Transport (>32 Tonnes)- Steel Rebar Empty loaded*

For Same trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (18.73+4.29) = 23.02
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 4.29
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (23.02+4.29) = 27.31

No of Trip Required Single Transit excluding last trip – 44



General information: Diesel Truck Transport (>32 Tons) - Steel Rebar Loaded Last Trip

General information

Name: Diesel Truck Transport (>32 Tons) - Steel Rebar Loaded Last Trip

Category: - none -

Description: Transportation of Steel of 5.376 tons over 10km. Therefore the target amount equals 53.76 t*km.
It is loaded in 2 heavy duty skip weighing 4.97 tons

Version 00.00.059 Last change 2025-06-27 18:12:00 UUID b80dd9ac-2259-416d-a201-28ddeb10adc6

Tags: Add a tag

Reference

Process: transport, freight, lorry >32 metric ton, EURO6 | transport, freight, lorry >32 metric ton, EURO6 | Cutoff, U - RER

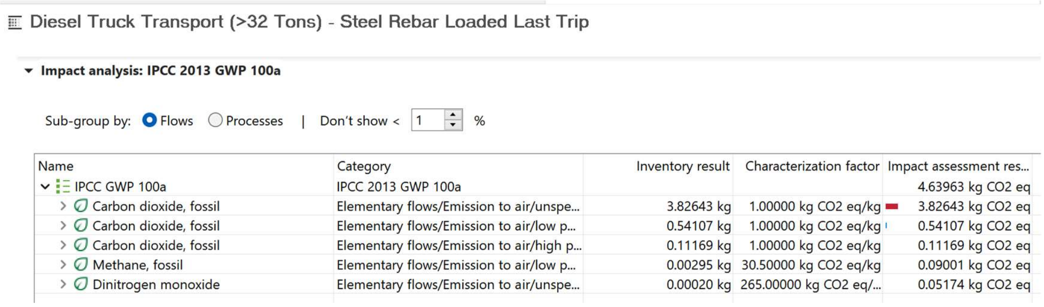
Product: transport, freight, lorry >32 metric ton, EURO6

Flow property: Goods transport (mass*distance)

Unit: t*km

Target amount: 53.76

*Figure 11.23 General Information Diesel Truck Transport (>32 Tonnes)- Steel Rebar loaded last trip*



Diesel Truck Transport (>32 Tons) - Steel Rebar Loaded Last Trip

Impact analysis: IPCC 2013 GWP 100a

Sub-group by: ● Flows ○ Processes | Don't show < 1 %

| Name | Category | Inventory result | Characterization factor | Impact assessment res... |
|---|---|---|---|---|
| IPCC GWP 100a | IPCC 2013 GWP 100a | | | 4.63963 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/unspe... | 3.82643 kg | 1.00000 kg CO2 eq/kg | 3.82643 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/low p... | 0.54107 kg | 1.00000 kg CO2 eq/kg | 0.54107 kg CO2 eq |
| Carbon dioxide, fossil | Elementary flows/Emission to air/high p... | 0.11169 kg | 1.00000 kg CO2 eq/kg | 0.11169 kg CO2 eq |
| Methane, fossil | Elementary flows/Emission to air/low p... | 0.00295 kg | 30.50000 kg CO2 eq/kg | 0.09001 kg CO2 eq |
| Dinitrogen monoxide | Elementary flows/Emission to air/unspe... | 0.00020 kg | 265.00000 kg CO2 eq/... | 0.05174 kg CO2 eq |

*Figure 11.24 Impact Analysis Diesel Truck Transport (>32 Tonnes)- Steel Rebar loaded last trip*

For Last Trip
Emission for Last Loaded trip per 10km in KgCO$_2$- eq =(4.64+4.29) = 8.93
Emission for Last Empty trip per 10 km in KgCO$_2$- eq = 4.29
Total Emission per Last Loaded & Empty Trip in KgCO2-eq = 13.22

Total transport emissions per Steel Rebar is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton CO$_2$-eq/km) = 0.120

Breakeven distance (km) was then:

$$\textit{Breakeven Distance (km)} = \frac{Embodied\ Carbon\ (\ Tonnes\ CO_2 - eq)}{Emissions\ \ (Tonnes\ CO_2 - eq/km)}$$

Embodied Carbon for 960000 kgs Steel in Ton$CO_2$-eq = 52.24

Breakeven Distance of Transporting Steel Rebar 32T Diesel truck in Km = 434

#### 11.2.4.4 For Steel, Electric truck 20.5T– Using LCA Study

**Emission Factor Calculation**

As per Scania LCA study,
Emission of Electric Truck - projected euro electricity mix (Tonnes$CO_2$-eq) = 301
Mean Payload of the Scania LCA study (Tonnes) =10.95
Total Driven Kilometer – vehicle life span(km) = 1300000
Energy Consumption of Electric Truck in Kwh/km = 1.14
Carbon intensity of the power sector – projected euro mix in Kg$CO_2$/Kwh = 0.141
Use Phase wheel to wheel (WTW) emissions in Tonnes$CO_2$-eq = 233.1
Other Emissions excluding WTW emissions in Tonnes$CO_2$-eq = 67.9

As per Statista 2023
Carbon Intensity of the Power sector in Sweden 2023 in Kg$CO_2$/Kwh =0.041

For Modelling,
Adjustment Factor for using Swedish electricity mix instead of projected euro mix

$$Adjustment\ factor = \frac{Carbon\ Intensity\ of\ the\ Swedish\ Power\ Sector}{Carbon\ Intensity\ of\ Projected\ Euro\ Mix\ Power\ Sector} \tag{11.3}$$

Adjustment Factor = 0.29

Emission for Complete Life Cycle of Electric after adjustment (i.e. using Swedish Electricity mix)

$$\begin{aligned} Total\ Emissions\ (Tonnes\ CO_2 - eq) \\ &= (Emissions\ from\ use\ phase\ WTW\ \times Adjustment\ factor) \\ &+ Emissions\ from\ other\ phase\ excluding\ WTW \end{aligned} \tag{11.4}$$

Total Emission in Tonnes$CO_2$-eq= 135.68
Emission Intensity for Electric Truck using Swedish Electricity mix

$$\begin{aligned} &Emission\ Intensity\ (Kg\ CO_2 - eq/tonnes\ km) \\ &= \frac{Total\ Emission\ in\ (Tonnes\ CO_2 - eq) \times 1000}{Mean\ Payload\ (Tonnes)\ \times Total\ Driven\ Kilometer\ vehicle\ lifespan\ (km)} \end{aligned} \tag{11.5}$$

Emission Intensity in KgCO2-Eq/Tonnes-km = 0.009531

For Same load Trip,
Maximum Weight of the Steel Rebars Loaded in Tonnes= 6.25
Weight of the empty Skip in Tonnes = 2.485

No of Trip Required for Single Transit excluding Last trip = 153

$$\begin{aligned} &Emission\ For\ Loaded\ Trip\ per\ 10km \\ &\quad = (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\quad \times Max\ Weight\ of\ Material\ loaded\ ) \\ &\quad + (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\quad \times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned} \tag{11.6}$$

Emission for Loaded Trip per 10km in $KgCO_2$-eq = 0.833

$$\begin{aligned} &Emission\ For\ Empty\ Trip\ per\ 10km \\ &\quad = Emission\ For\ ton\ per\ Km\ \times Weight\ of\ Empty\ Skip\ loaded \\ &\quad \times Distance\ Travelled \end{aligned} \tag{11.7}$$

Emission for Empty Trip per 10km in $KgCO_2$-eq = 0.237
Same Load Emission per 10 km in KgCO2-eq = (0.833+0.237) = 1.069

For Last Load Trip,

Last Trip Weight of the Steel Rebars Loaded in Tonnes= 3.75
Weight of the empty Skip in Tonnes = 2.485

$$\begin{aligned} &Emission\ For\ Last\ Loaded\ Trip\ per\ 10km \\ &\quad = (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\quad \times Last\ Trip\ Weight\ of\ Material\ loaded\ ) \\ &\quad + (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\quad \times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned} \tag{11.8}$$

Emission for Last Loaded Trip per 10km in $KgCO_2$-eq = 0.594
Emission for Empty Trip per 10km in $KgCO_2$-eq = 0.237
Last Trip Emission per 10 km in KgCO2-eq = (0.594+0.237) = 0.831

Total transport emissions per Steel Rebar is calculated as:

$$\begin{aligned} &Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &\quad = (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &\quad + Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.016

Breakeven distance (km) was then:

$$\text{Breakeven Distance (km)} = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 960000 kgs Steel in TonCO$_2$-eq = 52.24

Breakeven Distance of Transporting Steel Rebar 20.5T Electric truck in Km = 3176

#### 11.2.4.5 For Glass Diesel truck 16-32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Glass in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in KgCO$_2$ -eq = (13.51+5.30) = 18.81
Emission for Empty trip per 10 km in KgCO$_2$- eq = 5.30
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (18.81+5.30) = 24.10

For Last Load Trip
Emission for Last Loaded trip per 10 km in KgCO$_2$ -eq = (4.33+4.44) = 8.77
Emission for Empty trip per 10 km in KgCO$_2$- eq = 4.44
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (8.77+4.44) = 13.21

No of Trip Required for Single Transit excluding last trip – 12

Total transport emissions per Glass Partition is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton CO$_2$-eq/km) = 0.0302

Breakeven distance (km) was then:

$$\text{Breakeven Distance (km)} = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 103000kgs Glass Partition in TonCO$_2$-eq = 99.18

Breakeven Distance of Transporting Glass Partition 16-32T Diesel truck in Km =3279

### 11.2.4.6 For Glass Bio-Diesel truck 28T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Glass in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (10.43+4.09) = 14.52
Emission for Empty trip per 10 km in $KgCO_2$- eq = 4.09
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (14.52+4.09) = 18.61

For Last Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (3.35+3.43) = 6.78
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.43
Total Emission per last Loaded trip & Empty trip 10 km in KgCO2-eq = (6.78+3.43) = 10.21

No of Trip Required for Single Transit excluding last trip – 12

Total transport emissions per Glass Partition is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) &= (Emissions\ Same\ load\ trip\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0233

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 103000 kgs Glass Partition in Ton$CO_2$-eq = 99.18

Breakeven Distance of Transporting Glass Partition 28T Bio-Diesel truck in Km =4246

### 11.2.4.7 For Glass Diesel truck >32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Glass in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (12.02+3.73) = 15.75
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.73
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (15.75+3.73) = 19.48

For Last  Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (4.74+3.04) = 7.78
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.04
Total Emission per last Loaded trip & Empty trip 10 km in KgCO2-eq = (7.78+3.04) = 10.82

No of Trip Required for Single Transit excluding last trip – 7

Total transport emissions per Glass Partition is calculated as:

$$Total\ Emissions\ (Ton\ CO_2 - eq/km) = (Emissions\ Same\ load\ trip\ per\ km\ \times Number\ Of\ Trips) + Emissions\ Last\ load\ Trip\ per\ km$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0147

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Total\ Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 103000 kgs Glass Partition in $TonCO_2$-eq = 99.18

Breakeven Distance of Transporting Glass Partition >32T Diesel truck in Km =6739

#### 11.2.4.8 For Glass Electric truck 20.5 T– Using LCA study

Emission Intensity in KgCO2-Eq/Tonnes-km = 0.009531

For Same load Trip,
Maximum Weight of the Glass Partitions Loaded in Tonnes= 6.97
Weight of the A type glass frame stand in Tonnes = 0.132
Weight of the empty Skip with 6 glass frames in Tonnes = 2.485+(6x0.132) = 3.28

No of Trip Required for Single Transit excluding Last trip = 14

$$Emission\ For\ Loaded\ Trip\ per\ 10km = (Emission\ Intensity\ for\ tonnes\ per\ Km \times Max\ Weight\ of\ Material\ loaded\ ) + (Emission\ Intensity\ for\ tonnes\ per\ km \times Weight\ of\ the\ Empty\ Skip\ loaded$$

Emission for Loaded Trip per 10km in $KgCO_2$-eq = 0.833

$$Emission\ For\ Empty\ Trip\ per\ 10km = Emission\ For\ ton\ per\ Km\ \times Weight\ of\ Empty\ Skip\ loaded \times Distance\ Travelled$$

Emission for Empty Trip per 10km in Kg$CO_2$-eq = 0.31
Same Load Emission per 10 km in KgCO2-eq = (0.98+0.31) = 1.29

For Last Load Trip,

Last Trip Weight of the Glass Partitions Loaded in Tonnes= 5.42
Weight of the empty Skip with 4 glass stand in Tonnes = 2.485+(4*0.132) = 3.013

$$\begin{aligned} &Emission\ For\ Last\ Loaded\ Trip\ per\ 10km \\ &\quad = (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\quad \times Last\ Trip\ Weight\ of\ Material\ loaded\ ) \\ &\quad + (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\quad \times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned}$$

Emission for Last Loaded Trip per 10km in Kg$CO_2$-eq = 0.80
Emission for Empty Trip per 10km in Kg$CO_2$-eq = 0.29
Last Trip Emission per 10 km in KgCO2-eq = (0.80+0.29) = 1.09

Total transport emissions per Glass Partitions is calculated as:

$$\begin{aligned} &Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &\quad = (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &\quad + Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0019

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 103000 kgs Glass partition in Ton$CO_2$-eq = 99.18

Breakeven Distance of Transporting Glass Partition in Km = 51822

### 11.2.4.9 For Mineral Wool Diesel truck 16-32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (9.23+4.02) = 17.27
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (17.27+4.02) = 17.27

For Last Load Trip

Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (6.05+4.02) = 10.07
Emission for Empty trip per 10 km in $KgCO_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq =
(10.07+4.02) = 14.09

No of Trip Required for Single Transit excluding last trip – 6

Total transport emissions per Mineral Wool is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.012

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 38000 kgs Mineral Wool in Ton$CO_2$-eq = 39.40

Breakeven Distance of Transporting Mineral Wool 16-32T Diesel truck in Km =3346

### 11.2.4.10 For Mineral Wool Bio-Diesel truck 28T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (7.13+3.10) = 10.23
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq =
(10.23+3.10) = 13.33

For Last Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (4.67+3.10) = 7.77
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq =
(7.77+3.10) = 10.87

No of Trip Required for Single Transit excluding last trip – 6

Total transport emissions per Mineral Wool is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0091

Breakeven distance (km) was then:

$$\text{Breakeven Distance (km)} = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 38000 kgs Mineral Wool in Ton$CO_2$-eq = 39.40

Breakeven Distance of Transporting Mineral Wool 28T Bio-Diesel truck in Km =4334

#### 11.2.4.11 For Mineral Wool Diesel truck >32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (7.40+2.59) = 9.99
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (9.99+2.59) = 12.58

For Last Load Trip
Emission for Last Loaded trip per 10 km in Kg$CO_2$ -eq = (3.21+2.59) = 5.80
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (5.80+2.59) = 8.39

No of Trip Required for Single Transit excluding last trip – 4

Total transport emissions per Mineral Wool is calculated as:

$$\begin{aligned} &Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &\quad = (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &\quad + Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0059

Breakeven distance (km) was then:

$$\text{Breakeven Distance (km)} = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 38000 kgs Mineral Wool in Ton$CO_2$-eq = 39.40

Breakeven Distance of Transporting Mineral Wool >32T Diesel truck in Km =6711

#### 11.2.4.12 For Mineral Wool Electric truck 20.5 T– Using LCA Study

Emission Intensity in KgCO2-Eq/Tonnes-km = 0.009531

For Same load Trip,
Maximum Weight of the Mineral Wool Loaded in Tonnes= 5.71
Weight of the empty Skip in Tonnes = 2.485
No of Trip Required for Single Transit excluding Last trip = 6

$$\begin{aligned} Emission\ For\ Loaded\ Trip\ per\ 10km \\ &= (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\times Max\ Weight\ of\ Material\ loaded\ ) \\ &+ (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned}$$

Emission for Loaded Trip per 10km in KgCO$_2$-eq = 0.78

$$\begin{aligned} Emission\ For\ Empty\ Trip\ per\ 10km \\ &= Emission\ For\ ton\ per\ Km\ \times Weight\ of\ Empty\ Skip\ loaded \\ &\times Distance\ Travelled \end{aligned}$$

Emission for Empty Trip per 10km in KgCO$_2$-eq = 0.24
Same Load Emission per 10 km in KgCO2-eq = (0.78+0.24) = 1.02

For Last Load Trip,

Last Trip Weight of the Mineral Wool Loaded in Tonnes= 3.74
Weight of the empty Skip in Tonnes = 2.485

$$\begin{aligned} Emission\ For\ Last\ Loaded\ Trip\ per\ 10km \\ &= (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\times Last\ Trip\ Weight\ of\ Material\ loaded\ ) \\ &+ (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned}$$

Emission for Last Loaded Trip per 10km in KgCO$_2$-eq = 0.59
Emission for Empty Trip per 10km in KgCO$_2$-eq = 0.24
Last Trip Emission per 10 km in KgCO2-eq = (0.59+0.24) = 0.83

Total transport emissions per Mineral Wool is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton CO$_2$-eq/km) = 0.00069
Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 38000 kgs Mineral Wool in TonCO$_2$-eq = 39.40

Breakeven Distance of Transporting Mineral Wool 20.5T Electric truck in Km = 56781

### 11.2.4.13 For Wooden Door Diesel truck 16-32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in KgCO$_2$ -eq = (25.67+4.02) = 29.69
Emission for Empty trip per 10 km in KgCO$_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (29.69+4.02) = 33.71

For Last Load Trip
Emission for Last Loaded trip per 10 km in KgCO$_2$ -eq = (7.37+4.02) = 11.39
Emission for Empty trip per 10 km in KgCO$_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (11.39+4.02) = 15.41

No of Trip Required for Single Transit excluding last trip – 8

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton CO$_2$-eq/km) = 0.029

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 131600 kgs Wooden Doors in TonCO$_2$-eq = 78.62

Breakeven Distance of Transporting Wooden Doors 16-32T Diesel truck in Km =2757

### 11.2.4.14 For Wooden Door Bio-Diesel truck 28T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we must run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (19.82+3.10) = 22.92
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (22.92+3.10) = 26.02

For Last Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (5.69+3.10) = 8.79
Emission for Empty trip per 10 km in $KgCO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (8.79+3.10) = 11.89

No of Trip Required for Single Transit excluding last trip – 8

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.022

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Embodied Carbon for 131600 kgs Wooden Doors in $TonCO_2$-eq = 78.62

Breakeven Distance of Transporting Wooden Doors 28T Bio-Diesel truck in Km =3572

#### 11.2.4.15 For Wooden Door Diesel truck >32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we must run the calculation for Mineral Wool in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (24.96+2.59) = 27.55
Emission for Empty trip per 10 km in $KgCO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (27.55+2.59) = 30.14

For Last Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (13.74+2.59) = 16.33
Emission for Empty trip per 10 km in $KgCO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (16.33+2.59) = 18.92

No of Trip Required for Single Transit excluding last trip – 4

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.014

Breakeven distance (km) was then:

$$\textit{Breakeven Distance (km)} = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 131600 kgs Wooden Door in Ton$CO_2$-eq
= 78.62
Breakeven Distance of Transporting Wooden Doors >32T Diesel truck in Km =5636

### 11.2.4.16 For Wooden Door Electric truck 20.5T– Using LCA Study

Emission Intensity in KgCO2-Eq/Tonnes-km = 0.009531

For Same load Trip,
Maximum Weight of the Wooden Door Loaded in Tonnes= 7.47
Weight of the empty Skip in Tonnes = 2.485
No of Trip Required for Single Transit excluding Last trip = 17

$$\begin{aligned} Emission\ For\ Loaded\ Trip\ per\ 10km \\ &= (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\times Max\ Weight\ of\ Material\ loaded\ ) \\ &+ (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned}$$

Emission for Loaded Trip per 10km in Kg$CO_2$-eq = 0.95

$$\begin{aligned} Emission\ For\ Empty\ Trip\ per\ 10km \\ &= Emission\ For\ ton\ per\ Km\ \times Weight\ of\ Empty\ Skip\ loaded \\ &\times Distance\ Travelled \end{aligned}$$

Emission for Empty Trip per 10km in Kg$CO_2$-eq = 0.24
Same Load Emission per 10 km in KgCO2-eq = (0.95+0.24) = 1.19

For Last Load Trip,

Last Trip Weight of the Wooden Door Loaded in Tonnes= 4.61
Weight of the empty Skip in Tonnes = 2.485

$$\begin{aligned} Emission\ For\ Last\ Loaded\ Trip\ per\ 10km &= (Emission\ Intensity\ for\ tonnes\ per\ Km \\ &\times Last\ Trip\ Weight\ of\ Material\ loaded\ ) \\ &+ (Emission\ Intensity\ for\ tonnes\ per\ km \\ &\times Weight\ of\ the\ Empty\ Skip\ loaded \end{aligned}$$

Emission for Last Loaded Trip per 10km in $KgCO_2$-eq = 0.68
Emission for Empty Trip per 10km in $KgCO_2$-eq = 0.24
Last Trip Emission per 10 km in KgCO2-eq = (0.68+0.24) = 0.91

Total transport emissions per Wooden Door is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0021

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 131600 kgs Wooden Door in $TonCO_2$-eq = 78.62

Breakeven Distance of Transporting Wooden Door 20.5T Electric truck in Km = 37312

#### 11.2.4.17 For Wooden Floor Diesel truck 16-32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Wooden Floor in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in $KgCO_2$ -eq = (25.46+4.02) = 29.48
Emission for Empty trip per 10 km in $KgCO_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (29.48+4.02) = 33.50

For Last Load Trip
Emission for Last Loaded trip per 10 km in $KgCO_2$ -eq = (9.86+4.02) = 13.88
Emission for Empty trip per 10 km in $KgCO_2$- eq = 4.02
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (13.88+4.02) = 17.90

No of Trip Required for Single Transit excluding last trip – 2

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} &Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &\qquad = (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &\qquad + Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0085

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 37600 kgs Wooden Floor in Ton$CO_2$-eq
= 12.77
Breakeven Distance of Transporting Wooden Floor 16-32T Diesel truck in Km =1503

#### 11.2.4.18 For Wooden Floor Bio-Diesel truck 28T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we have to run the calculation for Wooden Floor in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (19.66+3.10) = 22.76
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq =
(22.76+3.10) = 25.86

For Last Load Trip
Emission for Last Loaded trip per 10 km in Kg$CO_2$ -eq = (7.61+3.10) = 10.71
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 3.10
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq =
(10.71+3.10) = 13.81

No of Trip Required for Single Transit excluding last trip – 2

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} &Total\ Emissions\ (Ton\ CO_2 - eq/km) \\ &\qquad = (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &\qquad + Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0066

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 37600 kgs Wooden Floor in Ton$CO_2$-eq = 12.64
Breakeven Distance of Transporting Wooden Floor 28T Bio-Diesel truck in Km = 1928

#### 11.2.4.19 For Wooden Floor Diesel truck >32T– Using openLCA 2.1 and Ecoinvent 3.8

Like Steel, we must run the calculation for Wooden Floor in OpenLCA and get the below results.

For Same Load trip,
Emission for Loaded trip per 10 km in Kg$CO_2$ -eq = (25.03+2.59) = 27.62
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (27.62+2.59) = 30.21

For Last Load Trip
Emission for Last Loaded trip per 10 km in Kg$CO_2$ -eq = (7.42+2.59) = 10.01
Emission for Empty trip per 10 km in Kg$CO_2$- eq = 2.59
Total Emission per Same Loaded trip & Empty trip 10 km in KgCO2-eq = (10.01+2.59) = 12.60

No of Trip Required for Single Transit excluding last trip – 1

Total transport emissions per Wooden Doors is calculated as:

$$\begin{aligned} Total\ Emissions\ (Ton\ CO_2 - eq/km) &= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) \\ &+ Emissions\ Last\ load\ Trip\ per\ km \end{aligned}$$

Total Emissions (Ton $CO_2$-eq/km) = 0.0043

Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 37600 kgs Wooden Floor in Ton$CO_2$-eq = 12.77
Breakeven Distance of Transporting Wooden Floor >32T Diesel truck in Km =2982

#### 11.2.4.20 For Wooden Floor Electric truck 20.5T– Using LCA Study

Emission Intensity in KgCO2-Eq/Tonnes-km = 0.009531

For Same load Trip,
Maximum Weight of the Wooden Floor Loaded in Tonnes= 7.20
Weight of the empty Skip in Tonnes = 2.485

No of Trip Required for Single Transit excluding Last trip = 5

$$Emission\ For\ Loaded\ Trip\ per\ 10km$$
$$= (Emission\ Intensity\ for\ tonnes\ per\ Km \times Max\ Weight\ of\ Material\ loaded\ ) + (Emission\ Intensity\ for\ tonnes\ per\ km \times Weight\ of\ the\ Empty\ Skip\ loaded$$

Emission for Loaded Trip per 10km in KgCO$_2$-eq = 0.92

$$Emission\ For\ Empty\ Trip\ per\ 10km$$
$$= Emission\ For\ ton\ per\ Km\ \times Weight\ of\ Empty\ Skip\ loaded \times Distance\ Travelled$$

Emission for Empty Trip per 10km in KgCO$_2$-eq = 0.24
Same Load Emission per 10 km in KgCO2-eq = (0.92+0.24) = 1.16

For Last Load Trip,

Last Trip Weight of the Wooden Door Loaded in Tonnes= 1.6
Weight of the empty Skip in Tonnes = 2.485

$$Emission\ For\ Last\ Loaded\ Trip\ per\ 10km$$
$$= (Emission\ Intensity\ for\ tonnes\ per\ Km \times Last\ Trip\ Weight\ of\ Material\ loaded\ ) + (Emission\ Intensity\ for\ tonnes\ per\ km \times Weight\ of\ the\ Empty\ Skip\ loaded$$

Emission for Last Loaded Trip per 10km in KgCO$_2$-eq = 0.39
Emission for Empty Trip per 10km in KgCO$_2$-eq = 0.24
Last Trip Emission per 10 km in KgCO2-eq = (0.39+0.24) = 0.63

Total transport emissions per Wooden Door is calculated as:

$$Total\ Emissions\ (Ton\ CO_2 - eq/km)$$
$$= (Emissions\ Same\ load\ per\ km\ \times Number\ Of\ Trips) + Emissions\ Last\ load\ Trip\ per\ km$$

Total Emissions (Ton CO$_2$-eq/km) = 0.00064
Breakeven distance (km) was then:

$$Breakeven\ Distance\ (km) = \frac{Cradle\ to\ Gate\ Embodied\ Carbon\ (\ Ton\ CO_2 - eq)}{Emissions\ \ (Ton\ CO_2 - eq/km)}$$

Cradle-to-Gate Embodied Carbon for 37600 kgs Wooden Floor in TonCO$_2$-eq = 12.77

Breakeven Distance of Transporting Wooden Floor 20.5T Electric truck in Km = 19870

### 11.2.5 Uncertainty analysis

Uncertainty Analysis Scenario -1
For Steel rebar, Wooden Floorings & Wooden Doors, the payload load capacity was downgraded to 75%.
For Glass partitions, the glass frame capacity was downgraded to 75%.
For Mineral Wool, the compression process was removed completely.
All the calculations remain the same as computed in *Appendix 2* for number of trips, payload limit and breakeven distance based on scenarios applied.

Uncertainty Analysis Scenario -2
For Steel rebar, Wooden Floorings & Wooden Doors, the payload load capacity was downgraded to 50%.
For Glass partitions, the glass frame capacity was downgraded to 50%.
For Mineral Wool, the compression process was removed completely and 1 bale less per trip.
All the calculations remain the same as computed in *Appendix 2* for number of trips, payload limit and breakeven distance based on scenarios applied.

#### 11.2.5.1 Number of Trips- Single Transit under Uncertainty analysis

*Table 11.21 Diesel Truck 32T & Biodiesel Truck 28T– Single material Transit Uncertainity analysis Scenario -1*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 9.76 | 98.36 | 99 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 6.69 | 15.40 | 16 |
| 3 | Mineral Wool | 38 | 376.25 | 101 | 5.19 | 7.32 | 8 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 12.17 | 3.09 | 4 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 12.14 | 10.84 | 11 |
| | | | | | | | 138.00 |

*Table 11.22 Diesel Truck >32T – Single material Transit Uncertainity analysis Scenario -1*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 16.27 | 59.00 | 59 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 11.14 | 9.25 | 10 |
| 3 | Mineral Wool | 38 | 376.25 | 101 | 7.79 | 4.88 | 5 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 21.48 | 1.75 | 2 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 21.46 | 6.13 | 7 |
|  |  |  |  |  |  |  | 83 |

*Table 11.23 Electric Truck 20.5T – Single material Transit Uncertainity Analysis Scenario -1*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 4.69 | 204.73 | 205 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 6.69 | 15.40 | 16 |
| 3 | Mineral Wool | 38 | 376.25 | 101.00 | 5.19 | 7.32 | 8 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.46 | 5.70 | 6.60 | 7 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 5.61 | 23.46 | 24 |
|  |  |  |  |  |  |  | 260 |

*Table 11.24 Diesel Truck 32T & Biodiesel Truck 28T– Single material Transit Uncertainity analysis Scenario -2*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 6.51 | 147.47 | 148 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 4.18 | 24.64 | 25 |
| 3 | Mineral Wool | 38 | 367.5 | 103.4 | 4.33 | 8.78 | 9 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 7.88 | 4.77 | 5 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 7.47 | 17.62 | 18 |
|  |  |  |  |  |  |  | 205 |

*Table 11.25 Diesel Truck >32T – Single material Transit Uncertainity analysis Scenario -2*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 10.85 | 88.48 | 89 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 6.97 | 14.78 | 15 |
| 3 | Mineral Wool | 38 | 367.5 | 103.4 | 6.92 | 5.49 | 6 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.457 | 14.32 | 2.63 | 3 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 14.00 | 9.40 | 10 |
|  |  |  |  |  |  |  | 123 |

*Table 11.26 Electric Truck 20.5T – Single material Transit Uncertainity Analysis Scenario -2*

| S.No | Material Description | Weight (Tons) | Density (kg/m3) | Volume (m3) | Max Skip Capacity (Tons) | Total No of Single trips Reqd | Total Trips Rounding off |
|---|---|---|---|---|---|---|---|
| 1 | Reinforcement Steel Rebar | 960 | 8000 | 120.00 | 3.13 | 307.10 | 308 |
| 2 | Glass Partition | 103 | 2580 | 39.92 | 4.18 | 24.64 | 25 |
| 3 | Mineral Wool | 38 | 367.5 | 103.40 | 4.33 | 8.78 | 9 |
| 4 | Wooden Flooring Boards | 37.6 | 678 | 55.46 | 3.60 | 10.44 | 11 |
| 5 | Doors- Wooden | 131.6 | 462 | 284.85 | 3.74 | 35.19 | 36 |
|  |  |  |  |  |  |  | 389 |

### 11.2.5.2 Breakeven Distances under uncertainty scenarios

*Table 11.27 Breakeven Distance of Construction Materials*

| Construction Materials | Diesel Truck (32T) | Diesel Truck (>32T) | Biodiesel Truck (28T) | Electric Truck (20.5T) |
|---|---|---|---|---|
|  | (km) | (km) | (km) | (km) |
| **Steel Rebar** | 243 | 434 | 315 | 3176 |
| **Glass** | 3279 | 6739 | 4246 | 51822 |
| **Wooden Door** | 2757 | 5636 | 3572 | 37312 |
| **Wooden Flooring** | 1503 | 2982 | 1928 | 19870 |
| **Mineral Wool** | 3346 | 6711 | 4334 | 56781 |

*Table 11.28 Breakeven Distance of Construction Materials- Uncertainity analysis Scenario- 1*

| Construction Materials | Diesel Truck (32T) | Diesel Truck (>32T) | Biodiesel Truck (28T) | Electric Truck (20.5T) |
|---|---|---|---|---|
|  | (km) | (km) | (km) | (km) |
| **Steel Rebar** | 222 | 391 | 289 | 2769 |
| **Glass** | 2962 | 6127 | 3837 | 50248 |
| **Wooden Door** | 2610 | 5247 | 3381 | 32877 |
| **Wooden Flooring** | 1374 | 2982 | 1779 | 18506 |
| **Mineral Wool** | 3132 | 6710 | 4058 | 53152 |

*Table 11.29 Breakeven Distance of Construction Materials- Uncertainity analysis Scenario- 2*

| **Construction Materials** | **Diesel Truck (32T)** | **Diesel Truck (>32T)** | **Biodiesel Truck (28T)** | **Electric Truck (20.5T)** |
|---|---|---|---|---|
| | **(km)** | **(km)** | **(km)** | **(km)** |
| **Steel Rebar** | 190 | 328 | 246 | 2200 |
| **Glass** | 2304 | 4950 | 2983 | 39069 |
| **Wooden Door** | 2198 | 4754 | 2849 | 26562 |
| **Wooden Flooring** | 1264 | 2661 | 1637 | 14518 |
| **Mineral Wool** | 2646 | 6170 | 3816 | 49959 |

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