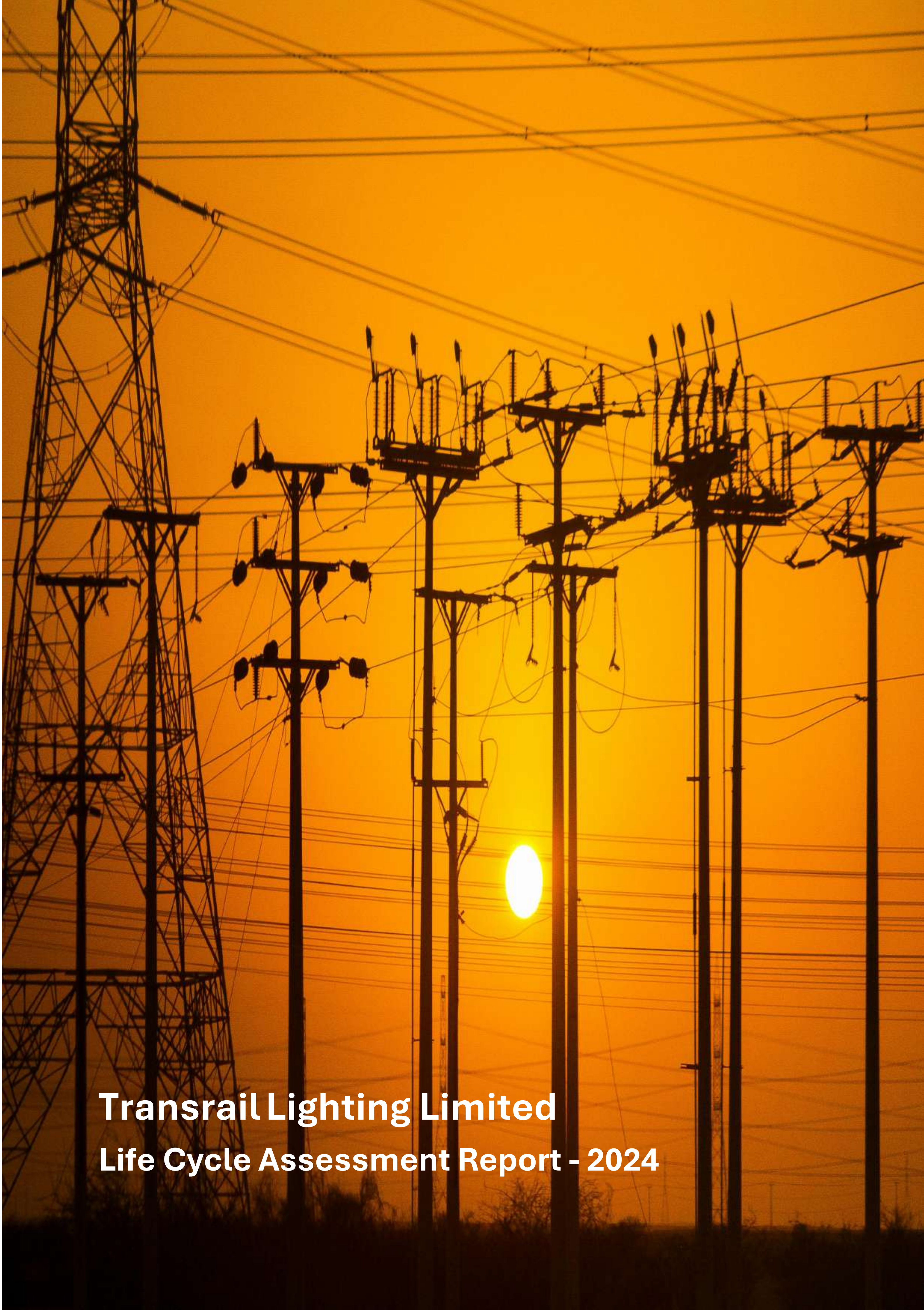

# Transrail Lighting Limited

## Life Cycle Assessment Report - 2024

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## Acronyms

| Acronym | Definition |
|---|---|
| ACSR | Aluminium Conductor Steel Reinforced |
| CEA | Central Electricity Authority |
| $CO_2$ | Carbon Dioxide |
| $CO_2e$ | Carbon Dioxide Equivalent |
| CFC | Chlorofluorocarbon |
| Cu | Copper |
| EPD | Environmental Product Declaration |
| ETP | Effluent Treatment Plant |
| ESG | Environment, Social, and Governance |
| FY | Financial Year |
| GHG | Greenhouse Gas(es) |
| GWP | Global Warming Potential |
| GJ | Gigajoule |
| H | Hierarchist perspective (ReCiPe methodology) |
| HCL | Hydrochloric Acid |
| HFCs | Hydrofluorocarbons |
| ISO | International Organization for Standardization |
| IS | Indian Standards |
| kBq | kiloBecquerel |
| kg | Kilogram |
| kL | Kilolitre |
| Km | Kilometre |
| kWh | Kilowatt-hour |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| LDO | Light Diesel Oil |
| m2a | Square meter-year |
| M3 | Cubic meter |
| N2O | Nitrous Oxide |
| NOx | Nitrogen Oxides |
| OpenLCA | Open Life Cycle Assessment Software |
| PM 2.5 | Particulate Matter ≤ 2.5 micrometres |
| PFCs | Perfluorocarbons |
| ReCiPe | Life Cycle Impact Assessment methodology |
| $SO_2$ | Sulphur Dioxide |

| | |
|---|---|
| SF6 | Sulphur Hexafluoride |
| t CO2-e | tonne of Carbon Dioxide equivalent |
| TLL | Transrail Lighting Limited |
| UN | United Nations |
| % | Percentage |

*Table 1: Acronyms*

## Glossary of Terms

| Term | Definition |
|---|---|
| Allocation | Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. |
| Background System | The part of the product system that includes processes not under direct control of the organization performing the LCA, typically represented using secondary databases such as ecoinvent. |
| Characterization | Calculation step in life cycle impact assessment where life cycle inventory results are converted into common units for each impact category using characterization factors. |
| Cradle-to-Gate | A system boundary that includes all life cycle stages from raw material extraction through manufacturing up to the factory gate, excluding use and end-of-life stages. |
| Cut-off Approach | An allocation approach where recycled materials entering a product system carry no environmental burden from previous life cycles, and scrap leaving the system is treated as waste without recycling credits. |
| Environmental Impact | Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products, or services. |
| Environmental Product Declaration (EPD) | A standardized document that communicates verified and comparable environmental information about the life cycle impacts of a product based on ISO 14025. |
| Functional Unit | A quantified description of the performance of a product system, used as a reference unit in an LCA study to ensure comparability of results. |
| Foreground System | The part of the product system that is under direct control of the organization conducting the LCA and for which primary data may be collected. |
| Global Warming Potential (GWP) | A measure of how much heat a greenhouse gas traps in the atmosphere relative to carbon dioxide, expressed as kg $CO_2$ equivalent. |
| Impact Category | A class representing environmental issues of concern to which life cycle inventory results may be assigned, such as climate change, acidification, or eutrophication. |
| Inventory Flow | An input or output of materials, energy, water, or emissions associated with a unit process or product system. |
| Life Cycle | Consecutive and interlinked stages of a product system, from raw material acquisition through production, use, and end-of-life treatment. |
| Life Cycle Assessment (LCA) | Compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. |
| Life Cycle Impact Assessment (LCIA) | Phase of LCA aimed at understanding and evaluating the magnitude and significance of potential environmental impacts based on life cycle inventory results. |
| Life Cycle Inventory (LCI) | Phase of LCA involving compilation and quantification of inputs and outputs for a product system throughout its life cycle. |
| Midpoint Indicator | An impact indicator located at an intermediate position in the cause–effect chain, representing potential environmental impacts before final damage occurs. |
| Normalization | Optional LCIA step in which impact category results are related to a reference value, such as total impacts in a region or per capita impacts. |
| Primary Data | Data collected directly from specific processes or activities within the foreground system of the LCA study. |
| Product System | A collection of unit processes connected by flows of intermediate products that perform one or more defined functions. |

| | |
|---|---|
| ReCiPe Method | A widely used life cycle impact assessment methodology that provides midpoint and endpoint indicators for environmental impact evaluation. |
| Sensitivity Analysis | A systematic procedure for estimating the effects of methodological choices or data variability on the results of an LCA study. |
| System Boundary | Definition of which unit processes are included within the LCA study, and which are excluded. |
| Unit Process | The smallest element considered in an LCA for which input and output data are quantified. |
| Uncertainty Analysis | Evaluation of the potential variation in LCA results due to data gaps, variability, and methodological assumptions. |
| Water Consumption | Water removed from a watershed and not returned to the same watershed due to evaporation, incorporation into products, or transfer to another watershed. |

*Table 2: Glossary of terms*

## Executive Summary

This Life Cycle Assessment (LCA) study evaluates the environmental performance of three key product lines manufactured by Transrail Lighting Limited (TLL) lattice transmission towers, steel poles, and aluminium conductors produced across the company's manufacturing facilities located in Deoli, Vadodara, and Silvassa in India. The assessment has been conducted in accordance with the latest international standards ISO 14040:2006 and ISO 14044:2006, following a Cradle-to-Gate system boundary and utilizing high-quality secondary data from the Ecoinvent database. All modelling was undertaken using the OpenLCA software platform.

The primary objective of this study is to quantify the life cycle environmental impacts associated with the manufacture of each product per one metric tonne of finished output, enabling TLL to benchmark performance, identify impact hotspots, guide future decarbonization strategies, and support disclosures under global sustainability expectations.

The scope covers all upstream and in-plant activities, including raw material extraction and processing, energy consumption, galvanizing operations (for towers and poles), chemical usage, internal utilities, packaging, and waste management. No co-products or by-products are generated in these processes; therefore, 100% of the associated environmental burdens have been allocated to the respective products.

Across all three product systems, the study identifies raw material production, particularly steel for towers and poles and aluminium for conductors, as the dominant contributor to overall environmental impacts including Global Warming Potential (GWP), resource depletion, and energy use. Steel production is globally recognized as one of the largest industrial emitters of greenhouse gases, and this trend is reflected in the study results. For conductors, the extraction and refining of aluminium significantly influence the total footprint due to its high electricity intensity.

At the manufacturing stage, the use of grid electricity, light diesel oil (LDO) for furnaces, and diesel for internal handling equipment represent the next major impact categories. For galvanized products, the consumption of zinc, hydrochloric acid, and fluxing agents also contributes to specific impact categories, although to a lesser extent compared to raw materials and energy.

The LCA highlights several opportunities for impact reduction, including using higher recycled-content steel and aluminium, transitioning to lower-carbon electricity sources, optimizing thermal efficiency in furnaces, and adopting advanced galvanizing process controls. These findings provide a technical foundation for TLL's broader sustainability roadmap, including emissions reduction planning, supplier engagement, and alignment with national and international ESG frameworks.

Overall, this LCA establishes robust and transparent environmental baselines for TLL's key product categories, enabling data-driven decision-making, improved disclosure quality, and strategic alignment with global best practices in sustainable manufacturing.

## Project Summary

| | |
|---|---|
| **Name of Product** | • Galvanized Steel Tower<br>• Galvanized Steel Pole<br>• Aluminum Conductor Steel Reinforced |
| **Client** | Transrail Lighting Limited |
| **Site Location** | • Deoli, Maharashtra, India<br>• Vadodara, Gujarat, India<br>• Silvassa, Dadra & Nagar Haveli, India |
| **Assessment type** | Product Life Cycle Assessment (LCA) |
| **Applied standards** | ISO 14040:2006 and ISO 14044:2006 |
| **Consolidated Approach** | Cradle to Gate (Raw material extraction to Factory Gate) including Packaging |
| **Reporting period** | 01st April 2024 – 31st March 2025 (period during which data for the study were collected along with logistics and procurement). Results will be valid for a period of 12 months following the study [March 2026] on the condition that NO changes are made to the product specifications, processes, or the product supply chain following the study. |
| **Base year** | 2025 LCA Assessment (1st April 2024– 31st March 2025 Reporting period) |
| **Intended user** | Management and Stakeholders of the company |
| **Report ID** | TLL/LCA/01 |
| **Client Contact** | Mr. Manish Shende |

*Table 3: Project summary*

## Key Findings

- Life Cycle Assessment of 1 MT of Galvanized Steel Tower.

| Impacts | Units | Characterized Impacts |
|---|---|---|
| Global warming | kg CO2 eq | 3,048 |
| Stratospheric ozone depletion | kg CFC11 eq | 1.2E-04 |
| Ionizing radiation | kBq Co-60 eq | 0.215 |
| Ozone formation, Human health | kg NOx eq | 1.84 |
| Fine particulate matter formation | kg PM2.5 eq | 1.26 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 1.97 |
| Terrestrial acidification | kg SO2 eq | 2.41 |
| Freshwater eutrophication | kg P eq | 0.018 |
| Marine eutrophication | kg N eq | 0.142 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 485 |
| Freshwater ecotoxicity | kg 1,4-DCB | 6.42 |
| Marine ecotoxicity | kg 1,4-DCB | 38.6 |
| Human carcinogenic toxicity | kg 1,4-DCB | 2.94 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 98.7 |
| Land use | m2a crop eq | 9.84 |
| Mineral resource scarcity | kg Cu eq | 1.21 |
| Fossil resource scarcity | kg oil eq | 865 |
| Water consumption | m3 | 4.28 |

*Table 4: LCA of Galvanized Steel Tower*

- Life Cycle Assessment of 1 MT of Galvanized Steel Pole.

| Impacts | Units | Characterized Impacts |
|---|---|---|
| Global warming | kg CO2 eq | 3,191 |
| Stratospheric ozone depletion | kg CFC11 eq | 1.4E-04 |

| | | |
|---|---|---|
| Ionizing radiation | kBq Co-60 eq | 0.228 |
| Ozone formation, Human health | kg NOx eq | 1.96 |
| Fine particulate matter formation | kg PM2.5 eq | 1.35 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 2.09 |
| Terrestrial acidification | kg SO2 eq | 2.56 |
| Freshwater eutrophication | kg P eq | 0.020 |
| Marine eutrophication | kg N eq | 0.158 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 512 |
| Freshwater ecotoxicity | kg 1,4-DCB | 6.88 |
| Marine ecotoxicity | kg 1,4-DCB | 41.2 |
| Human carcinogenic toxicity | kg 1,4-DCB | 3.12 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 105.4 |
| Land use | m2a crop eq | 10.4 |
| Mineral resource scarcity | kg Cu eq | 1.29 |
| Fossil resource scarcity | kg oil eq | 912 |
| Water consumption | m3 | 4.61 |

*Table 5: LCA of Galvanized Steel Pole*

- Life Cycle Assessment of 1 MT of Aluminium Conductor.

| **Impacts** | **Units** | **Characterized Impacts** |
|---|---|---|
| Global warming | kg CO2 eq | 16,680 |
| Stratospheric ozone depletion | kg CFC11 eq | 4.2E-04 |
| Ionizing radiation | kBq Co-60 eq | 0.612 |
| Ozone formation, Human health | kg NOx eq | 5.86 |
| Fine particulate matter formation | kg PM2.5 eq | 3.92 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 6.14 |
| Terrestrial acidification | kg SO2 eq | 7.35 |
| Freshwater eutrophication | kg P eq | 0.061 |

| | | |
|---|---|---|
| Marine eutrophication | kg N eq | 0.398 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 1,420 |
| Freshwater ecotoxicity | kg 1,4-DCB | 18.7 |
| Marine ecotoxicity | kg 1,4-DCB | 112 |
| Human carcinogenic toxicity | kg 1,4-DCB | 8.24 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 284 |
| Land use | m2a crop eq | 22.6 |
| Mineral resource scarcity | kg Cu eq | 6.42 |
| Fossil resource scarcity | kg oil eq | 2,940 |
| Water consumption | m3 | 18.9 |

*Table 6: LCA of Aluminium Conductor*

# 1. Introduction

## 1.1 Background

As the global energy landscape shifts toward renewable energy and low-carbon infrastructure, the environmental performance of transmission components has come under increasing scrutiny. In response to investor expectations, customer requirements, national climate commitments, and emerging regulatory frameworks, manufacturers are increasingly adopting science-based methods to quantify and manage the environmental footprint of their products.

Life Cycle Assessment (LCA) has become a key decision-support tool for understanding the upstream environmental burdens of industrial products, identifying improvement opportunities, and aligning with global sustainability standards. LCA is a crucial tool for evaluating environmental impacts across the entire lifecycle of a product. Given the rising concerns over carbon emissions, resource depletion, and industrial sustainability, it is imperative to assess the environmental footprint of energy-intensive products such as tower, pole, conductors, etc.

Given the growing demand for transparent environmental disclosure through frameworks such as ESG reporting, BRSR (India), GRI Standards, CDP, and sectoral Product Category Rules (PCRs) Transrail Lighting Limited has undertaken this comprehensive LCA study to establish credible, verifiable baselines for its major product categories. The study has been completed in accordance with ISO 14040 and ISO 14044 standards, employing robust datasets from the Ecoinvent database and modelling through OpenLCA, one of the world's most widely used LCA platforms. By conducting an LCA, this study aims to identify major impact contributors and propose sustainable improvement measures.

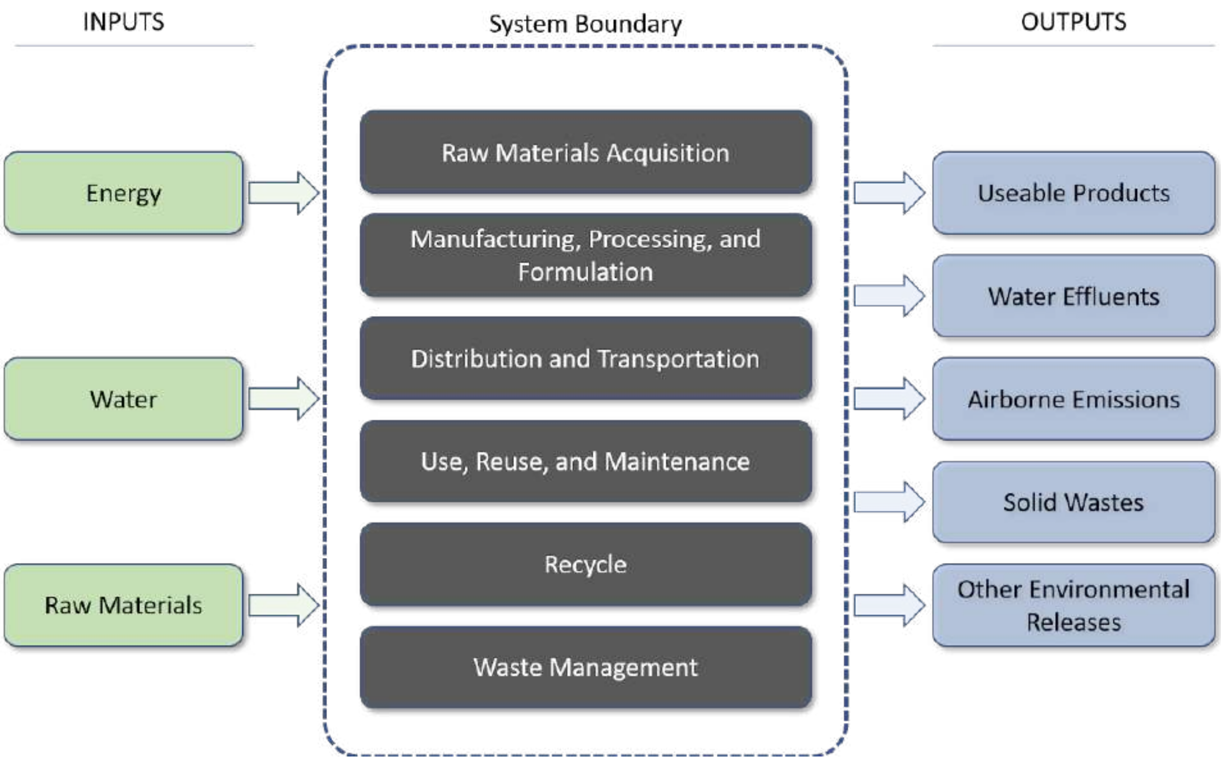


*Figure 1: Lifecycle Stages*

## 1.2 Purpose of the Study

The primary objective of this study is to perform an LCA of galvanized steel tower, pole, and aluminium conductor manufactured by Transrail Lighting Limited, across its facilities in India and provide environmental benchmarking. This assessment will help:

- Quantify environmental impacts of the selected products.
- Identify high-impact processes in terms of carbon emissions, energy consumption, and waste generation.
- Support decision-making for process optimization and sustainability improvements.
- Meet customer requirements for environmental performance evaluation.

This report follows the ISO 14040 & ISO 14044 framework and utilizes OpenLCA software for impact assessment.

## 1.3 About Transrail Lighting Limited

Transrail Lighting Limited is a prominent Indian engineering, procurement, and construction (EPC) company specializing in power transmission and distribution. Established in 2008, the company offers comprehensive turnkey solutions across various sectors, including transmission, distribution, rural electrification, and outdoor lighting.

**Key Services and Capabilities:**

- **Power Transmission & Distribution:** Transrail undertakes the design, manufacturing, testing, installation, and supply of galvanized steel structures and conductors for power transmission and distribution networks.
- **Railway Electrification:** The company provides services in overhead electrification, signalling and telecommunication, earthwork, track linking, and other composite works for railway infrastructure.
- **Civil Construction:** Transrail offers EPC services for infrastructure projects, including bridges, tunnels, elevated roads, and cooling towers.
- **Poles and Lighting:** The company manufactures pole structures for applications such as high masts, streetlights, solar streetlights, distribution monopoles, and stadium masts.

**Manufacturing Facilities:**
Transrail operates multiple manufacturing units across India:

- **Deoli Plant (Towers):** Located in Wardha, Maharashtra, this facility specializes in producing lattice towers.
- **Vadodara Plant (Towers):** Situated in Gujarat, this plant focuses on tower manufacturing.
- **Silvassa Plant (Conductors):** Based in Dadra and Nagar Haveli, this unit produces conductors.
- **Silvassa Plant (Poles):** Also located in Dadra and Nagar Haveli, this facility manufactures poles alongwith towers.

## 1.4 Scope of the Assessment

The scope of the study defines the system boundaries, functional unit, and key aspects considered in this LCA.

- Product Studied:
    - Galvanized Steel Tower
    - Galvanized Steel Pole
    - Aluminium Conductor Steel Reinforced

- Transmission Tower Manufacturing:
    - Deoli (Maharashtra)
    - Vadodara (Gujarat)
    - Silvassa (Dadra & Nagar Haveli)

- Steel Pole Manufacturing:
    - Silvassa (Dadra & Nagar Haveli)

- Conductor Manufacturing:
    - Silvassa (Dadra & Nagar Haveli)

Each facility has distinct operational characteristics, electricity consumption patterns, and process variations; however, the results have been harmonized to provide representative product-level environmental impacts.

- **Functional Unit:** 1 MT of finished product. The LCA Assessment for 3 products was carried out within the agreed boundary level of "Cradle to Factory Gate", and the Functional Unit for the assessment was 'One Metric Tonnes (1 MT) of each product manufactured'.
- **System Boundaries:** Cradle-to-Gate (from raw material extraction to finished product at the factory gate). The system boundary included all applicable material and resource use and emissions sources from "Cradle to Factory Gate", the extraction and process of the raw materials, their transportation to the production facility, manufacturing of 3 products and its packaging.
- **Temporal Coverage:** The geographical coverage of the study is India. Recent aggregated data from 2024-25 have been collected from the plant and its suppliers to model this LCA study.
- **Impact Assessment Methodology:** Life Cycle Impact Assessment (LCIA) per ISO 14040 & ISO 14044
- **Intended Audience:** This report is intended for internal sustainability management, external stakeholder communication, ESG and BRSR disclosures, and public environmental reporting. It may be shared with customers, investors, regulators, and other interested parties as part of TLL's commitment to transparency and sustainable manufacturing.

This LCA does not include the use phase and end-of-life disposal of the products studied, as the focus is strictly on the manufacturing phase.

## 1.5 System Boundaries

The Life Cycle Assessment (LCA) of Transrail Lighting Limited's transmission towers, poles, and conductors is performed under a Cradle-to-Gate framework. This boundary condition includes all upstream and core manufacturing processes from raw material extraction to the point where the finished products exit the respective facilities. Downstream activities including distribution to customer sites, installation, use, and end-of-life processing are excluded. The definition of system boundaries reflects strict adherence to ISO 14040 and ISO 14044 requirements on transparency, completeness, and consistency.

- **Cradle to Gate Approach**: The Cradle-to-Gate boundary encompasses:

    - Extraction and processing of raw materials
    - Manufacturing and processing activities within TLL facilities
    - Production and use of ancillary materials
    - Hot-dip galvanizing (for towers and poles)
    - All energy inputs from grid electricity, fuels, and utilities
    - Internal transportation and handling
    - Waste management and wastewater treatment
    - Packaging of finished goods prior to dispatch

- **Following things were excluded:**
    - Capital goods (machinery, buildings)
    - Employee commuting
    - Use phase and end-of-life (as per cradle-to-gate boundary)
    - Recycling credits (scrap treated as waste, cut-off approach)

This scope ensures that all environmental impacts associated with TLL's manufacturing processes are comprehensively assessed while excluding downstream product performance and end-of-life fate, which vary across client geographies and applications.

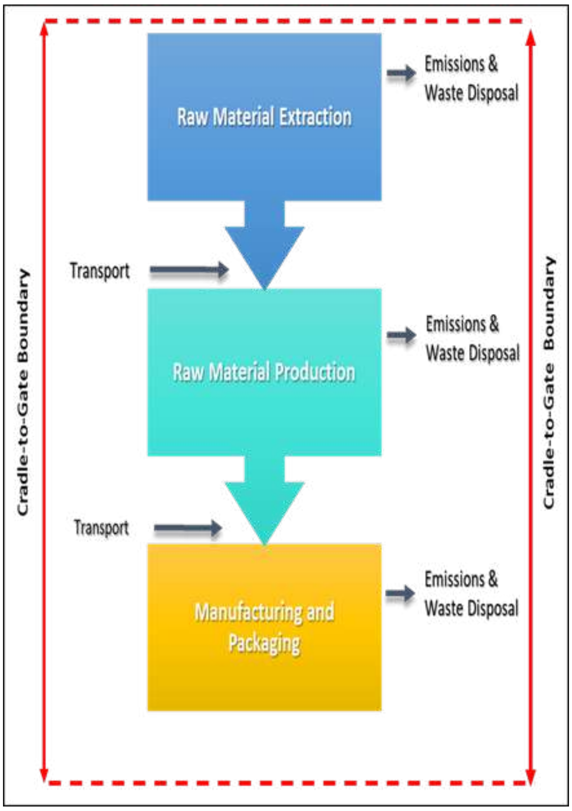


*Figure 2: System Boundary (Cradle to Gate)*

- **Life Cycle Stages Includes:** The following stages are explicitly included in the system boundary for all three products:

    - Raw material extraction and upstream production:

- Steel production for towers and poles (Mild Steel Angles, Plates, Pipes)
- Zinc production for the galvanization process
- Chemical production including Hydrochloric Acid (HCl), fluxing agents, ammonia (liquid/powder), degreasers, and other pre-treatment chemicals
- Aluminium and alloy production for conductors (e.g., AAC, ACSR, AAAC depending on product type)
- LDO, diesel, and other fuel production
- Electricity generation models based on Indian grid mix (from Ecoinvent regional datasets)
- Packaging material production, such as wooden pallets, steel straps, or plastic wraps

- Manufacturing stage (Gate to Gate)

A. Tower Manufacturing (Deoli, Vadodara, Silvassa)

- Steel angle cutting, notching, punching (electricity driven)
- Furnace-based bending (using LDO fuel)
- Surface cleaning, pickling, and pre-treatment
- Hot-dip galvanization (zinc consumption, HCl, flux, natural gas or fuel assistance if any)
- Cooling, inspection, and quality checks
- Internal movement using EOT cranes, forklifts, or diesel-based equipment
- Water usage for cooling, rinsing, and effluent treatment
- Wastewater treatment via in-house ETP
- Scrap generation and handling (sold to recyclers)

B. Pole Manufacturing (Silvassa)

- Mild steel sheet cutting and rolling
- Automatic/semiautomatic welding
- Surface treatment, pickling, and galvanization
- Machining and assembly
- Internal material handling
- Water and effluent treatment
- Packaging

C. Conductor Manufacturing (Silvassa)

- Aluminium melting (furnace), wire drawing, stranding, compacting, and closing
- Spool preparation
- Electricity-driven production
- Lubricant and grease usage (where applicable)
- Waste recovery (aluminium/steel scrap returned to recyclers)
- Packaging on drums or reels

- Utilities and internal services: All supporting processes are included within the system boundaries

- Electricity consumption from the regional grid
- Heating utilities, particularly LDO-fired furnaces
- Compressed air systems, if used
- Water supply and treatment, including effluent load

- Internal logistics, including forklifts, cranes, and inter-process handling equipment
- Maintenance materials (lubricants, oils) where significant

- Packaging and dispatch: Transportation to customer sites is excluded as per the Cradle-to-Gate scope.

    - Wooden pallets or drums
    - Steel or plastic straps
    - Plastic foil wrapping
    - Labels and protective coatings
    - Energy/fuel used in preparing goods for dispatch.

- Waste & scrap management

    - Collection and sale of metal scrap
    - Transport of waste to treatment or disposal units
    - ETP sludge handling and disposal
    - Zinc ash and dross treatment pathways (secondary zinc recovery using default Ecoinvent datasets)

- Exclusions: The following elements are excluded, with justification as per ISO 14044. These exclusions are consistent with standard Cradle-to-Gate LCA boundaries and do not materially affect study conclusions.

    - Construction of buildings and equipment, unless they have a measurable and significant contribution (expected negligible)
    - Downstream transportation, installation, use phase, and end-of-life scenarios
    - Human labour and occupational health impacts
    - Capital goods impacts (factory infrastructure, computers, offices)
    - General administrative activities
    - Transportation of employees

## 1.6 Key Modelling Assumptions

- Electricity mix: Indian national grid average (aligned with ecoinvent IN datasets)
- Galvanization: Heavy zinc coating (>900 g/m$^2$) as per IS 4759
- Scrap handling: No recycling allocation or credit applied
- Conductor configuration: ACSR conductor modelled as a representative composition of ~80% aluminium strands and ~20% galvanized steel core by mass (typical of standard ACSR conductor codes, e.g., Zebra/Moose, per IS 398). [Revised — see Revision Note]
- Impact assessment method: ReCiPe 2016 Midpoint (H) covering 18 environmental impact categories
- Allocation approach: Cut-off system model as per ecoinvent recommendation

## 1.7 Data Sources and Assumptions

Since primary data collection may not cover all aspects, this study relies on a mix of Ecoinvent database, industry literature, and process-specific estimates. Key assumptions include:

- Aluminium production data is derived from the ecoinvent database version 3.9.1 (cut-off system model), cross-checked against published India-specific primary aluminium GHG intensity disclosures from Hindalco Industries and Vedanta Aluminium, and sector estimates published by CEEW (2023). [Revised — see Revision Note]
- Electricity and fuel consumption values are referenced from general literature on aluminium processing.
- Diesel-based transportation emissions are calculated based on assumed average distances and vehicle efficiency.
- Emission factors are referenced from standard databases (e.g., IPCC, Ecoinvent).
- In the absence of required data for certain activities, data were derived based on assumptions, and all assumptions and exclusions are listed in Annex 1.

## 1.8 Intended Use of the Report

This report is intended for:

- Internal sustainability and energy management
- Supporting environmentally responsible decision-making and process optimisation
- Public environmental disclosure and corporate website reporting
- ESG reporting (BRSR, GRI Standards, CDP), investor disclosures, and stakeholder communication
- Customer and supply chain environmental performance evaluation
- Supporting future Environmental Product Declaration (EPD) development and third-party verification

## 2. Goal and Scope of the Study

This section defines the goal and scope of the LCA in accordance with ISO 14040:2006 Section 4.2 and ISO 14044:2006 Section 5.2, including the rationale for the study, the intended application and audience, the functional unit, the system boundary, and any comparative assertions.

### 2.1 Goal of the Study

The goal of this study is to quantify and document the cradle-to-gate environmental impacts of three transmission and distribution infrastructure products manufactured by Transrail Lighting Limited (TLL): galvanized steel lattice towers, galvanized steel poles, and ACSR aluminium conductors. The study is intended to establish a transparent, standards-aligned environmental baseline for each product, identify life cycle hotspots, and inform internal decarbonization and supplier-engagement strategies.

### 2.2 Intended Application and Audience

The results are intended for internal sustainability and energy management, ESG and BRSR/GRI/CDP disclosures, customer and supply-chain environmental performance evaluation, and public communication via TLL's corporate website. The study may also serve as a foundation for future third-party verified Environmental Product Declarations (EPDs). The intended audience includes TLL management, customers, investors, regulators, and the public.

### 2.3 Functional Unit

The functional unit for all three product systems is 1 metric tonne (1 MT) of finished product at the factory gate, ready for dispatch. This common mass-based functional unit enables direct comparability of environmental performance across the three product systems, consistent with standard practice in metal-product EPDs (e.g., Worldsteel and International Aluminum Institute methodologies).

### 2.4 System Boundary

The study applies a Cradle-to-Gate system boundary, covering raw material extraction and upstream processing, inbound transport, and all in-plant manufacturing, galvanizing, utility, and packaging activities up to the factory gate. The use phase, downstream transport, installation, and end-of-life stages are excluded. Full details of inclusions and exclusions are provided in Sections 1.4 and 1.5.

### 2.5 Comparative Assertions

This report presents environmental results for three distinct products with different material compositions, functions, and applications (lattice towers, poles, and conductors). The results are not intended to support comparative assertions of environmental superiority between these products, as they are not functionally equivalent or substitutable for one another. Comparisons in Section 5 are presented solely to aid interpretation of relative material and process contributions and should not be read as a claim that one product is environmentally “better” than another. Any future comparison of TLL's products against third-party products (e.g., competitor EPDs) would require alignment of Product Category Rules, system boundaries, and data quality in accordance with ISO 14025 and EN 15804, which has not been performed as part of this study.

## 2.6 Study Commissioner and Practitioner

This study was commissioned by Transrail Lighting Limited. The life cycle modelling was performed using openLCA (version 2.4.0) with background data from ecoinvent 3.9.1 (cut-off system model), based on primary operational data collected from TLL's Deoli, Vadodara, and Silvassa facilities for the reporting period 1 April 2024 to 31 March 2025, supplemented by secondary data and literature-based estimates as detailed in Section 1.7.

# 3. Methodology

## 3.1 Project Initiation, Understanding, and Scoping

A successful project begins with a clear understanding of the client's expectations, project boundaries, operational context, and applicable standards. During this stage, we establish the technical foundation and administrative structure required to deliver the assignment efficiently and accurately:

- Conduct an internal planning discussion to align project teams and experts.
- Hold a structured kick-off meeting with the client for clarification of:
  - Project objectives and anticipated outcomes
  - Operational constraints and logistical aspects
  - Required deliverables, timelines, and reporting expectations

## 3.2 Life-Cycle Assessment Framework

LCA assessment follows the ISO 14040 and ISO 14044 guidelines. An LCA study consists of four stages:

- **Stage 1:** Goal and scope aim to define how big a part of product life cycle will be taken in assessment and to what end will the assessment be serving. The criteria that will be used for system comparison and specific times are described in this step.
- **Stage 2:** In this step, inventory analysis describes material and energy flows within the product system and especially its interaction with the environment, consumed raw materials, and emissions to the environment. All-important processes and subsidiary energy and material flows are described later.
- **Stage 3:** Details from inventory analysis serve for impact assessment. The indicator results of all impact categories are detailed in this step; the importance of every impact category is assessed by normalization and eventually also by weighting.
- **Stage 4:** Interpretation of a life cycle involves critical review, determination of data sensitivity, and result presentation.

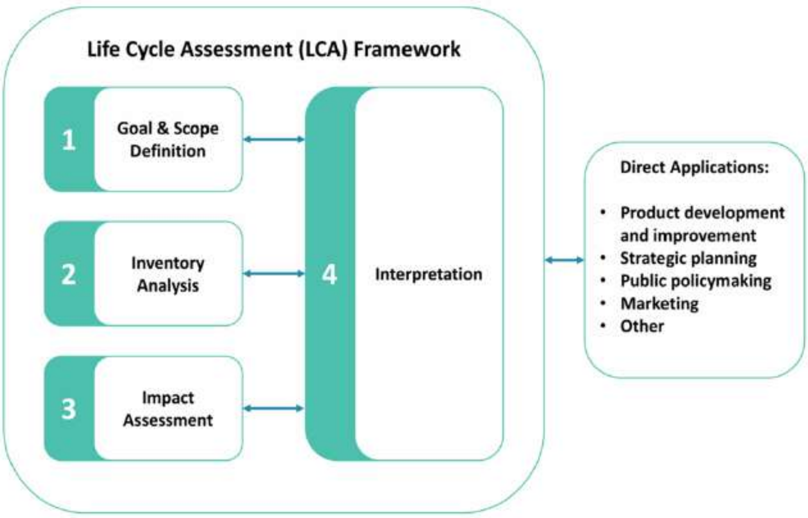


*Figure 3: LCA Study Framework*

## 3.3 Life-Cycle Inventory Analysis

### 3.3.1 Data Collection

The Life Cycle Inventory (LCI) Analysis is carried out to systematically compile and quantify all relevant inputs and outputs associated with a product system within the defined system boundaries. This phase involves the detailed collection of data related to mass and energy flows, including the consumption of raw materials, chemicals, fuels, and utilities, as well as the generation of emissions to air, water, and soil, and the production of solid and hazardous wastes.

### 3.3.2 Raw Material Extraction and Processing

This stage includes the environmental impacts of the processing of raw materials, packing materials, and other raw materials applicable to the products. Therefore, data related to the raw material and packing materials were analysed.

### 3.3.3 Upstream Transport

The environmental impacts from material transport from the supplier to the manufacturing facility were considered. Since all raw materials and packing materials were sourced locally, only land distances were considered.

### 3.3.4 Manufacturing Impacts

The environmental impacts associated with manufacturing the three selected products were assessed. This stage accounts for resource use during production, including electricity consumption and water usage, and models the impacts arising from overall manufacturing operations and energy requirements.

### 3.3.5 Packaging

The environmental impacts for packaging of finished products have been considered in the assessment.

### 3.3.6 Data Validation

A team of multi-disciplinary experts conducted a site visit of the manufacturing factory to identify the product manufacturing process, materials used, waste streams and emissions sources related to the manufacturing process, and to collect sample measurements where possible.

### 3.3.7 Allocation Procedures

Selected environmental impact factors are geographically relevant, pertaining to the specific location of the environmental impact-generating activity in question. In order of preference, environmental impact factors and secondary data were applied first from local, sub-national datasets; then from national datasets; and finally, from regional datasets. In the absence of required data from all these datasets, available global factors and data were applied.

This study did not use any allocation procedure as the manufacturing units manufacture a specific product only and all associated energy/material/process are used for a single product.

### 3.3.8 Assessment Tool

The life cycle modelling and calculations for this study were performed using openLCA, a globally recognized open-source software platform specifically designed for Life Cycle Assessment and environmental footprint studies. openLCA supports the full LCA framework in accordance with ISO 14040 and ISO 14044, enabling transparent definition of system boundaries, functional units, inventory modelling, impact assessment, and result interpretation. The software allows integration of high-quality life cycle inventory databases, including Ecoinvent, and facilitates detailed process-based modelling with full traceability of material, energy, and emission flows. openLCA was selected for this study due to its robustness, flexibility in handling complex industrial systems, compatibility with internationally accepted LCIA methodologies, and its widespread use by practitioners, researchers, and certification bodies for product-level environmental assessments.

#### *3.3.9 Cut-off Rules*

A minimum of 95% of the total mass, energy, and environmental relevance for the system has been considered. Processes contributing to less than 1% environmental impact have not been considered. But efforts have been made to include majority of input materials and their transportation. No known flows are deliberately excluded from this LCA assessment.

### 3.4 Life Cycle Assessment

The Life Cycle Assessment (LCA) was conducted in accordance with the principles and framework defined in ISO 14040:2006 and ISO 14044:2006, following internationally accepted best practices for product environmental footprint studies. The study adopts a cradle-to-gate approach, evaluating environmental impacts from raw material extraction through manufacturing and finishing processes up to the factory gate.

The assessment was modelled using openLCA version 2.4.0, with background life cycle inventory data sourced from the ecoinvent database version 3.9.1 (cut-off system model), which is widely accepted for Environmental Product Declarations (EPDs), BRSR disclosures, and third-party verified sustainability reporting.

### 3.5 Data Quality, Assumptions, and Limitations

The study is based on a combination of process-level operational information provided by Transrail Lighting Limited and secondary data from the database. In the absence of precise plant-specific measurements for electricity, fuel, and water consumption on a per-tonne basis, conservative and representative secondary datasets were applied in line with ISO 14044 guidance. Key assumptions include average operating efficiencies, standard galvanizing consumption rates, and representative Indian electricity mixes. The study assumes steady-state production conditions and does not account for short-term operational variability. Certain elements such as capital goods, employee commuting, and administrative activities were excluded due to their expected negligible contribution to overall impacts. While these assumptions may introduce some level of uncertainty, they do not materially affect the identification of environmental hotspots or the overall conclusions of the assessment. The results should therefore be interpreted as indicative and comparative, suitable for strategic decision-making and baseline establishment rather than precise footprint declarations.

# 4. Life Cycle Assessment Results

## 4.1 Overview

The Life Cycle Impact Assessment (LCIA) was conducted using the ReCiPe 2016 Midpoint (H) methodology to evaluate the potential environmental impacts associated with the cradle-to-gate production of galvanized steel transmission towers, galvanized steel poles, and ACSR conductors manufactured by Transrail Lighting Limited.

Results are presented per metric tonne of finished product at the factory gate and cover midpoint impact categories relevant to metal-intensive electrical infrastructure products. The assessment confirms that raw material production and energy consumption are the dominant contributors across all product systems, with variations driven by material composition, surface treatment requirements, and electricity intensity.

## 4.2 Global Warming Potential

### *4.2.1 Product Carbon Footprint*

Climate Change (GWP, 100 years) was identified as the most relevant impact category for comparative evaluation, given the energy- and material-intensive nature of the products.

| Product | Functional Unit | GWP (t $CO_2$ eq / tonne) |
|---|---|---|
| Galvanized Steel Tower | 01 tonne | 3.04 |
| Galvanized Steel Pole | 01 tonne | 3.19 |
| Aluminum Conductor | 01 tonne | 16.68 |

*Table 7: Product Carbon Footprint – Cradle to Gate*

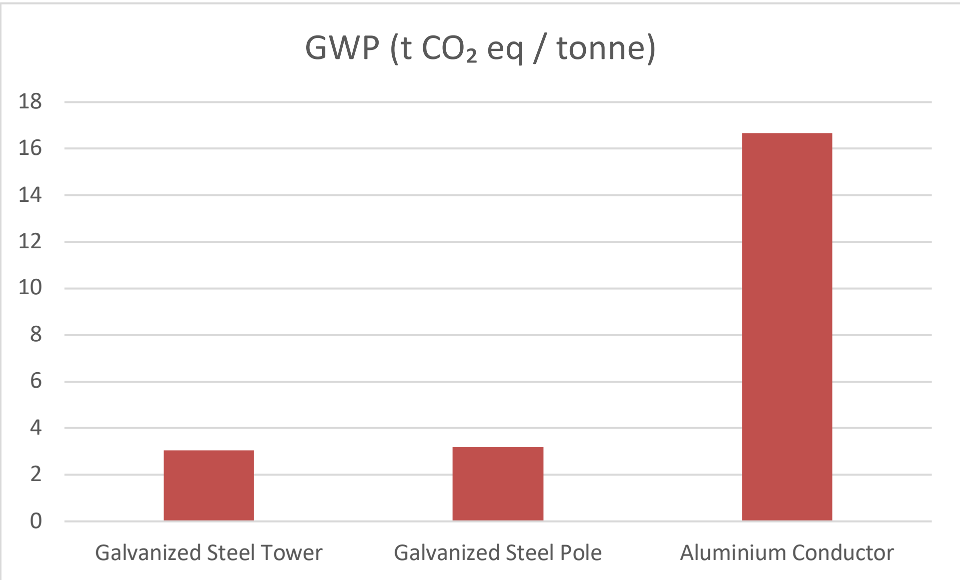


*Figure 4: LCA Study Framework*

## 4.3 Galvanized Steel Tower – 1 MT

### *4.3.1 Process Flow – Manufacturing*

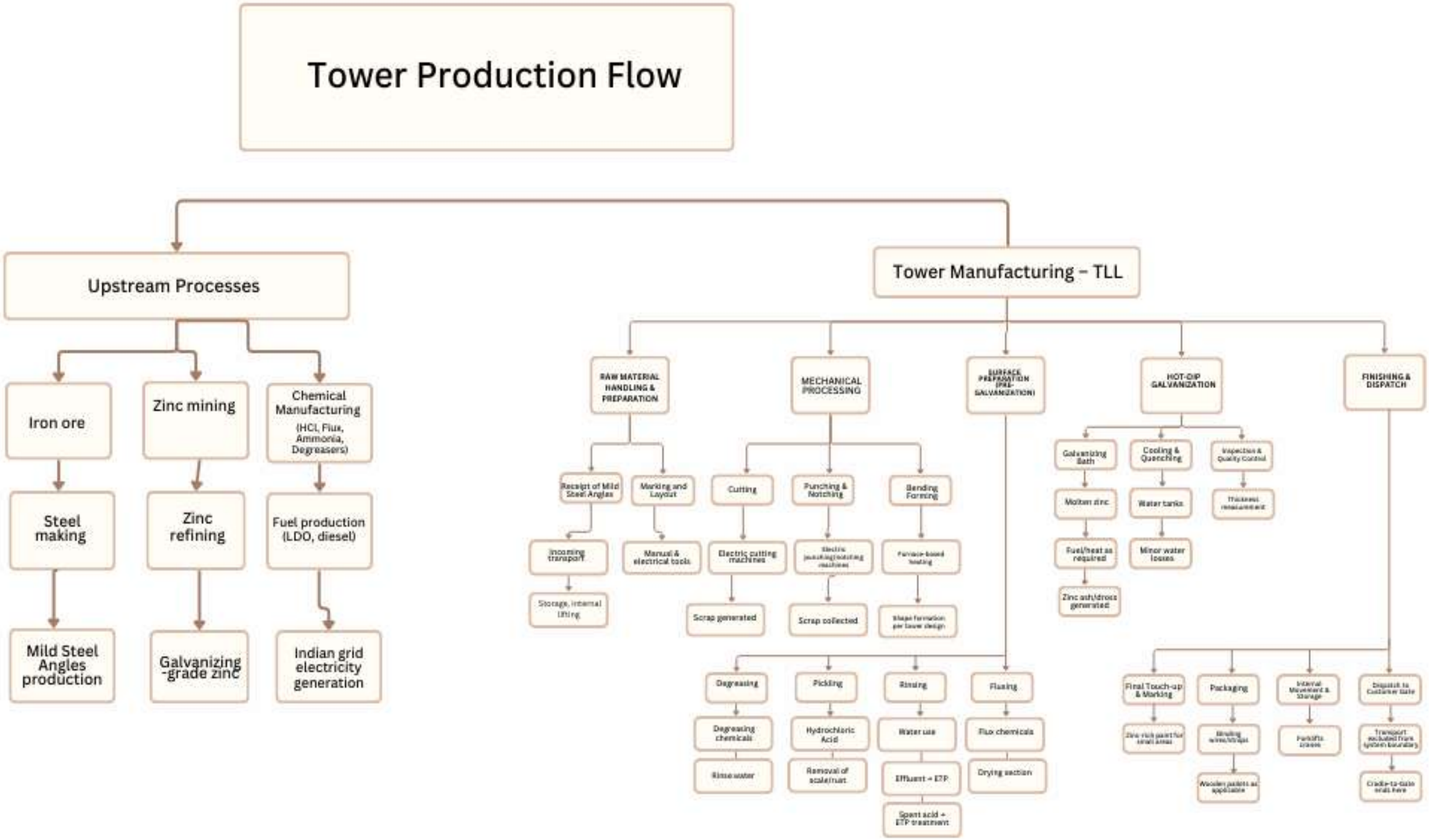


*Figure 5 -Manufacturing flow chart – Galvanized Steel Tower*

### *4.3.2 Environmental Impacts – Galvanized Steel Tower*

| Impacts | Units | Characterized Impacts |
|---|---|---|
| Global warming | kg CO2 eq | 3,048 |
| Stratospheric ozone depletion | kg CFC11 eq | 1.2E-04 |
| Ionizing radiation | kBq Co-60 eq | 0.215 |
| Ozone formation, Human health | kg NOx eq | 1.84 |
| Fine particulate matter formation | kg PM2.5 eq | 1.26 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 1.97 |
| Terrestrial acidification | kg SO2 eq | 2.41 |
| Freshwater eutrophication | kg P eq | 0.018 |
| Marine eutrophication | kg N eq | 0.142 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 485 |
| Freshwater ecotoxicity | kg 1,4-DCB | 6.42 |
| Marine ecotoxicity | kg 1,4-DCB | 38.6 |
| Human carcinogenic toxicity | kg 1,4-DCB | 2.94 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 98.7 |
| Land use | m2a crop eq | 9.84 |
| Mineral resource scarcity | kg Cu eq | 1.21 |
| Fossil resource scarcity | kg oil eq | 865 |
| Water consumption | m3 | 4.28 |

*Table 8: Environmental Impact – Galvanized Steel Tower (1MT)*

## 4.4 Galvanized Steel Pole – 1MT

### *4.4.1 Process Flow – Manufacturing*

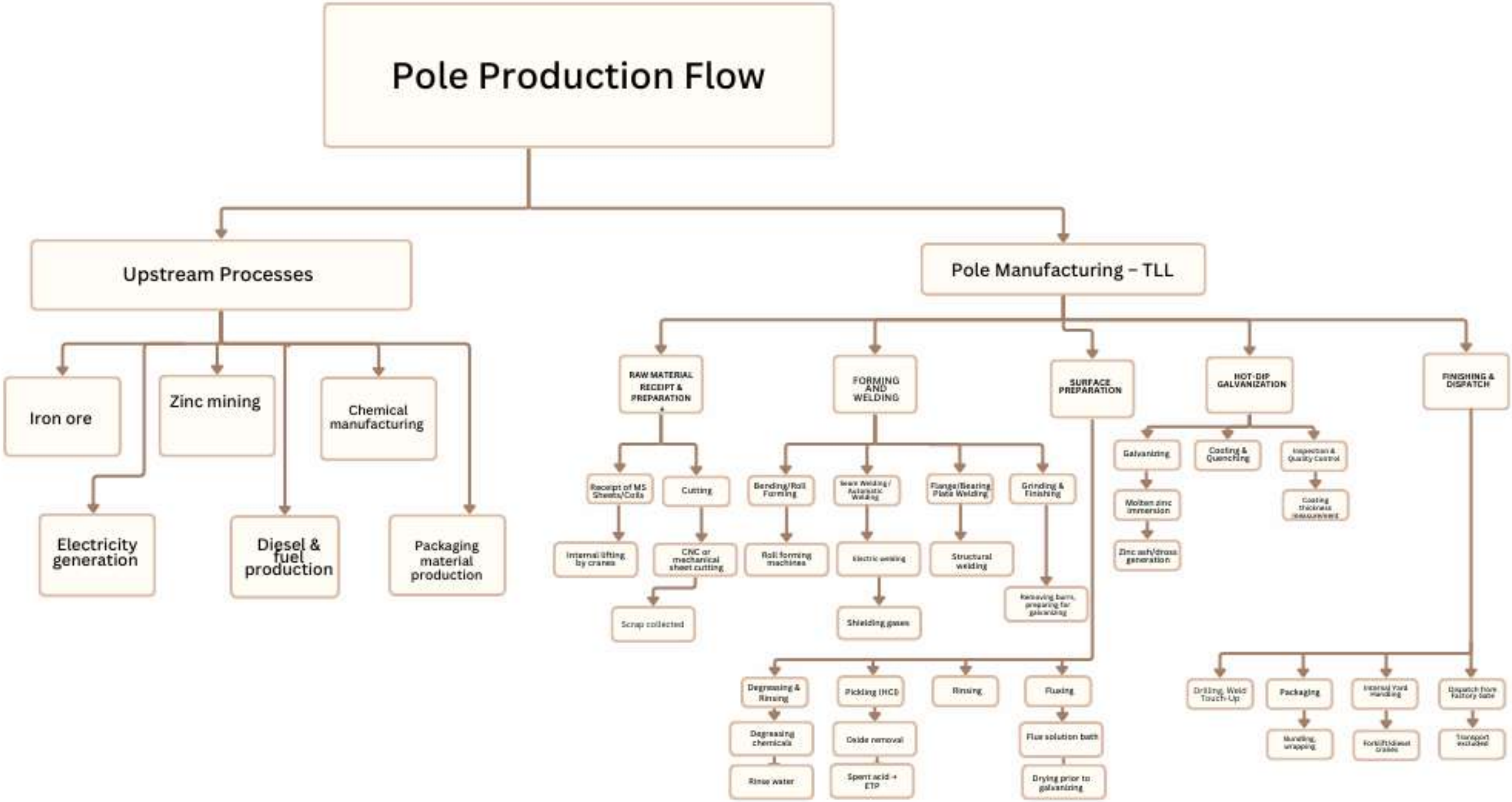


*Figure 6 -Manufacturing flow chart – Galvanized Steel Pole*

### 4.4.2 Environmental Impacts – Galvanized Steel Pole

| Impacts | Units | Characterized Impacts |
|---|---|---|
| Global warming | kg CO2 eq | 3,191 |
| Stratospheric ozone depletion | kg CFC11 eq | 1.4E-04 |
| Ionizing radiation | kBq Co-60 eq | 0.228 |
| Ozone formation, Human health | kg NOx eq | 1.96 |
| Fine particulate matter formation | kg PM2.5 eq | 1.35 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 2.09 |
| Terrestrial acidification | kg SO2 eq | 2.56 |
| Freshwater eutrophication | kg P eq | 0.020 |
| Marine eutrophication | kg N eq | 0.158 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 512 |
| Freshwater ecotoxicity | kg 1,4-DCB | 6.88 |
| Marine ecotoxicity | kg 1,4-DCB | 41.2 |
| Human carcinogenic toxicity | kg 1,4-DCB | 3.12 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 105.4 |
| Land use | m2a crop eq | 10.4 |
| Mineral resource scarcity | kg Cu eq | 1.29 |
| Fossil resource scarcity | kg oil eq | 912 |
| Water consumption | m3 | 4.61 |

*Table 9: Environmental Impact – Galvanized Steel Pole (1MT)*

## 4.5 ACSR Conductor – 1MT

### *4.5.1 Process Flow – Manufacturing*

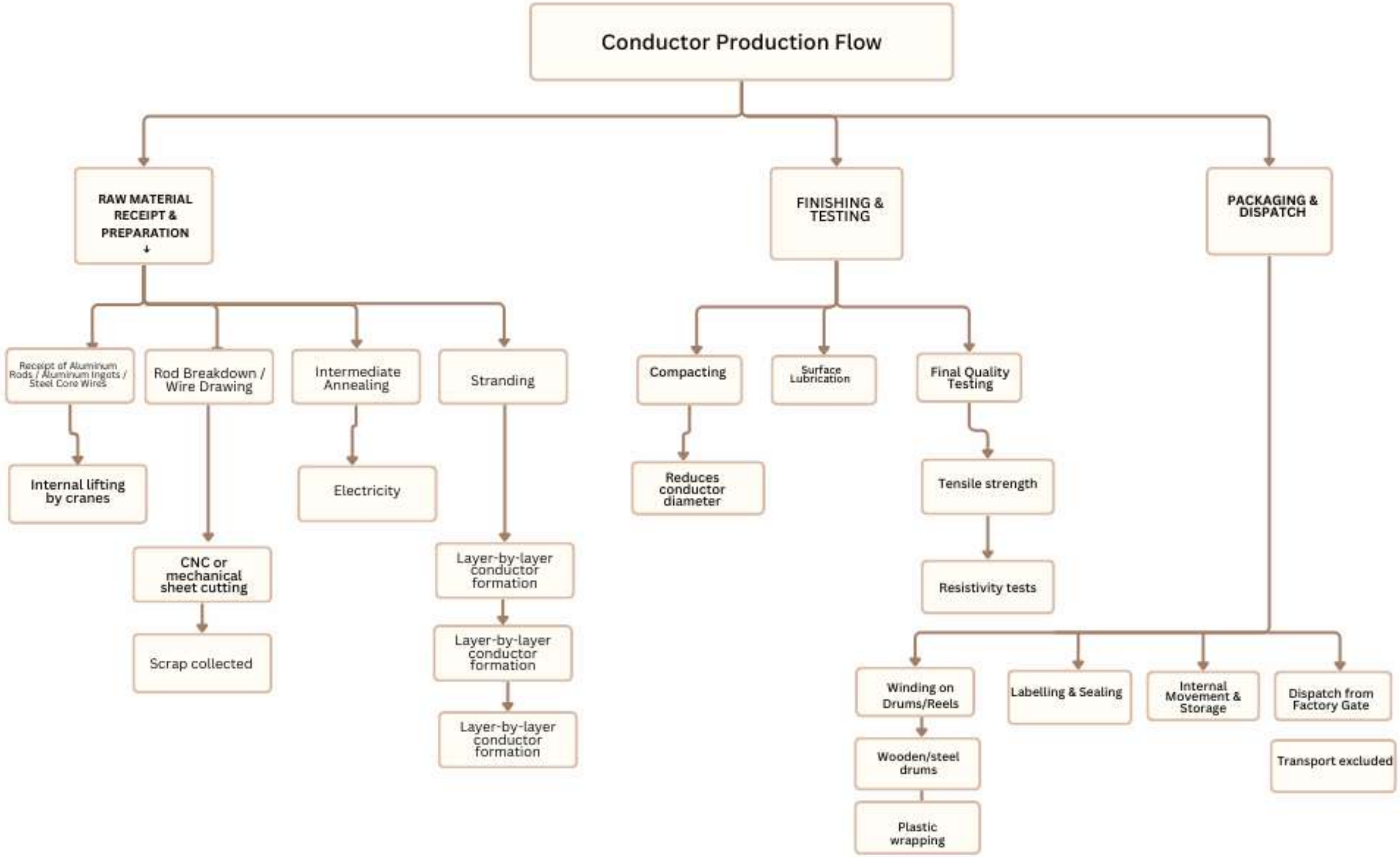


*Figure 7 -Manufacturing flow chart – ACSR Conductor*

### *4.5.2 Environmental Impacts – ACSR Conductor*

| Impacts | Units | Characterized Impacts |
|---|---|---|
| Global warming | kg CO2 eq | 16,680 |
| Stratospheric ozone depletion | kg CFC11 eq | 4.2E-04 |
| Ionizing radiation | kBq Co-60 eq | 0.612 |
| Ozone formation, Human health | kg NOx eq | 5.86 |
| Fine particulate matter formation | kg PM2.5 eq | 3.92 |
| Ozone formation, Terrestrial ecosystems | kg NOx eq | 6.14 |
| Terrestrial acidification | kg SO2 eq | 7.35 |
| Freshwater eutrophication | kg P eq | 0.061 |
| Marine eutrophication | kg N eq | 0.398 |
| Terrestrial ecotoxicity | kg 1,4-DCB | 1,420 |
| Freshwater ecotoxicity | kg 1,4-DCB | 18.7 |
| Marine ecotoxicity | kg 1,4-DCB | 112 |
| Human carcinogenic toxicity | kg 1,4-DCB | 8.24 |
| Human non-carcinogenic toxicity | kg 1,4-DCB | 284 |
| Land use | m2a crop eq | 22.6 |
| Mineral resource scarcity | kg Cu eq | 6.42 |
| Fossil resource scarcity | kg oil eq | 2,940 |
| Water consumption | m3 | 18.9 |

*Table 10: Environmental Impact – ACSR Conductor (1MT)*

### 4.6 Hotspot Analysis

| Product | Raw Materials | Processing & Galvanizing / Stranding | Electricity | Internal Transport |
|---|---|---|---|---|
| Tower | 75% (High) | 15% (Medium) | 7% (Low) | 3% (Low) |
| Pole | 70% (High) | 20% (Medium) | 7% (Low) | 3% (Low) |
| ACSR | 85% (High) | 6% (Medium) | 8% (Low) | 1% (Low) |

*Table 11: Hotspot Analysis*

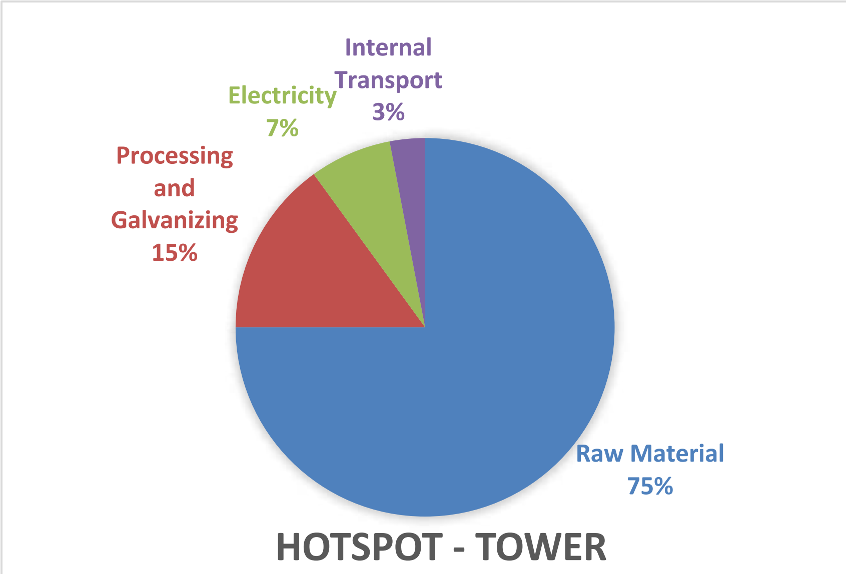


*Figure 8 -Hotspot Analysis – Galvanized Steel Tower*

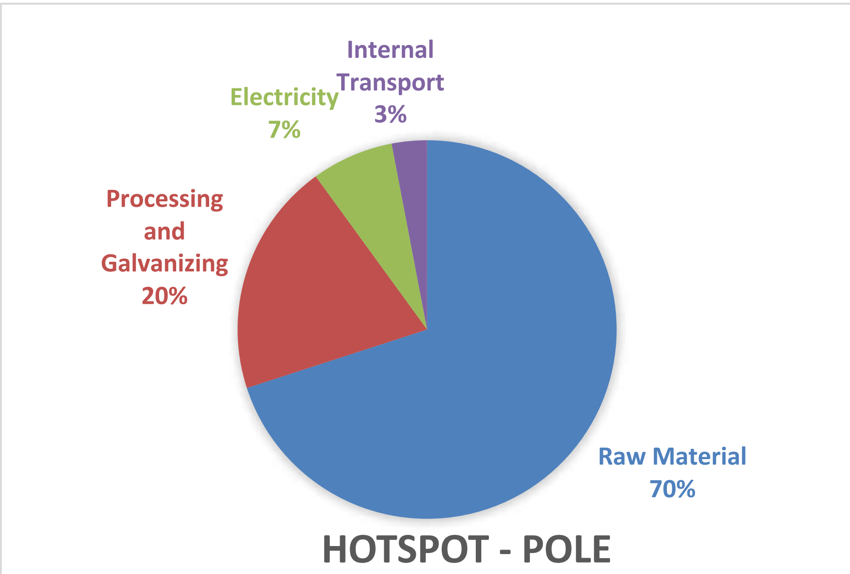


*Figure 9 -Hotspot Analysis – Galvanized Steel Pole*

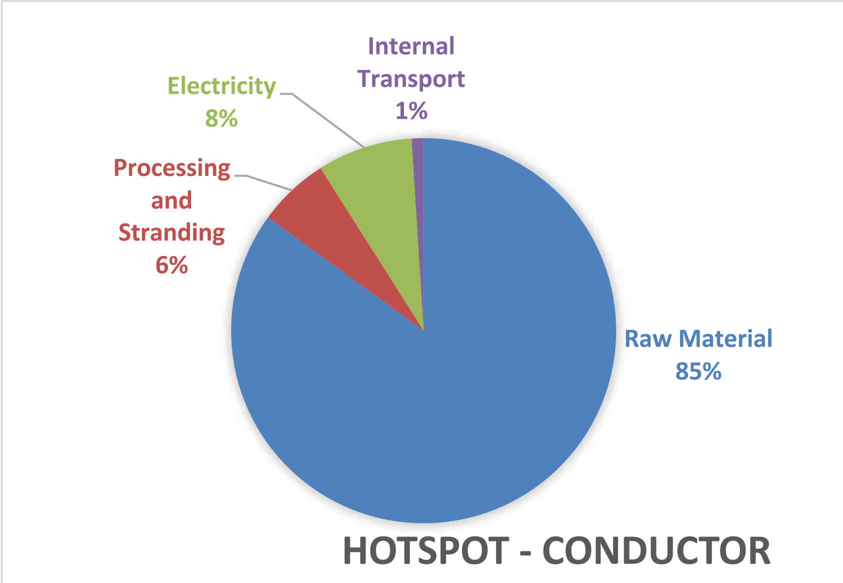


*Figure 10 -Hotspot Analysis – ACSR Conductor*

## 4.7 Benchmarking Against Published Industry Data

To support the credibility and external comparability of this study's results, TLL's reported cradle-to-gate Global Warming Potential figures are benchmarked below against published, third-party-verified or company-disclosed GHG intensity data for equivalent raw materials produced in India. This benchmarking is indicative only — differences in system boundary, data vintage, steelmaking route (Blast Furnace–Basic Oxygen Furnace vs. Electric Arc Furnace/Induction Furnace), recycled content, and background datasets mean that exact alignment is not expected.

A representative ACSR mass composition of 80% aluminium / 20% galvanized steel core, typical of standard ACSR conductor codes (e.g., Zebra, Moose) under IS 398. Primary aluminum GHG intensity of approximately 19.2 $tCO_2e$/tonne, averaged from three published India-specific disclosures: Vedanta Aluminium (17.01 $tCO_2e$/t, FY25), Hindalco Industries (19.66 $tCO_2e$/t, 2022), and CEEW's national sector average estimate (20.88 $tCO_2e$/t).

Steel core (galvanized) GHG intensity of approximately 2.8 $tCO_2e$/tonne, based on Tata Steel Limited's published cradle-to-gate EPDs for India-manufactured Hot Rolled Coil (2.86 $tCO_2e$/t, A1–A3) and Steel Rebar (2.73 $tCO_2e$/t, A1–A3).

### *4.7.1 Benchmarking Table*

| TLL Product / Material | TLL Reported GWP (kg CO2 eq / tonne, cradle-to-gate) | Published Reference Benchmark (kg CO2 eq / tonne) | Reference Source |
|---|---|---|---|
| Galvanized Steel Tower (steel input) | 3,048 | 2,730 – 2,860 (India BF-BOF route, before galvanizing) | Tata Steel Limited EPDs: Steel Rebar (S-P-05018); Hot Rolled Coil |
| Galvanized Steel Pole (steel input) | 3,191 | 2,730 – 2,860 (India BF-BOF route, before galvanizing) | Tata Steel Limited EPDs: Steel Rebar; Hot Rolled Coil |
| ACSR Conductor (revised) | 16,680 | 17,010 – 20,880 (100% primary aluminium, India) | Vedanta Aluminium (FY25); Hindalco Industries (2022); CEEW (2023) |

*Table 12: Benchmarking of TLL Reported GWP Against Published Indian Industry Data*

# 5. Conclusion

## 5.1 Overview

This section presents the interpretation of the Life Cycle Assessment (LCA) results for the three assessed products galvanized steel transmission towers, galvanized steel poles, and ACSR conductors manufactured by Transrail Lighting Limited. The interpretation follows the requirements of ISO 14044, focusing on identification of significant issues, evaluation of completeness and consistency, sensitivity of key assumptions, and derivation of conclusions and improvement opportunities.

The results are interpreted on a cradle-to-gate basis, using a common functional unit of 1 metric tonne of finished product at factory gate, ensuring direct comparability across products.

## 5.2 Comparative Environmental Performance

The LCA results indicate clear differentiation in environmental performance across the three products, driven primarily by differences in material composition and upstream material production pathways.

- ACSR conductors exhibit the highest environmental impacts across all assessed categories, including global warming potential, fossil resource scarcity, mineral resource scarcity, and water consumption. This outcome is primarily attributable to the resource- and energy-intensive nature of primary aluminium production in India, which dominates the life cycle profile despite relatively lower downstream fabrication impacts.
- Galvanized steel poles has the highest global warming potential and demonstrate moderately higher impacts than galvanized steel towers across most categories. This difference is mainly due to higher galvanization intensity and material thickness typically associated with pole manufacturing, resulting in increased zinc consumption and thermal energy demand during hot-dip galvanizing.
- Galvanized steel towers show the lowest overall environmental impacts among the three products. The modular and lattice-type design of towers results in relatively lower material intensity per tonne of finished product compared to poles, despite similar fabrication and galvanizing processes.

## 5.3 5.3 Environmental Hotspot Analysis

The hotspot analysis clearly indicates that raw material production is the dominant contributor across all three products:

- for galvanized steel towers and poles, primary steel production accounts for approximately 70–75% of the total global warming potential, followed by zinc production and galvanizing operations, contributing an additional 15–20%.
- For ACSR conductors, primary aluminium production alone contributes approximately 80–85% of total climate change impacts, with the steel core contributing a further 8–10%.

Manufacturing operations such as stranding and internal transport represent a comparatively minor share of the total impact.

Electricity consumption during fabrication and internal diesel-based material handling (~500 m) contribute marginally (typically below 10%) across all impact categories, indicating that upstream material choices are significantly more influential than on-site operational efficiencies.

## 5.4 Impact-Category Specific Interpretation

- **Climate Change (Global Warming Potential):** Strongly driven by fossil energy use in steel and aluminium production. ACSR conductors show substantially higher GWP per tonne than steel-based products, primarily due to the high electricity intensity of primary aluminium smelting under India's coal-dominated grid mix.
- **Resource Depletion (Fossil and Mineral):** ACSR conductors show the highest mineral resource scarcity due to aluminium and steel extraction. Zinc use significantly influences mineral scarcity in galvanized products.
- **Toxicity and Ecotoxicity Categories:** Elevated terrestrial and aquatic ecotoxicity impacts are observed for all products, mainly due to metal extraction and processing emissions. ACSR conductors again exhibit higher toxicity indicators due to aluminium refining and associated upstream emissions.
- **Water Consumption:** Water use is highest for ACSR conductors, reflecting the water-intensive nature of aluminium refining. Steel-based products show relatively lower but still material water consumption.

## 5.5 5.5 Improvement Opportunities

Based on the interpretation of results, the following improvement opportunities are identified:

- Material-level interventions such as increased use of secondary steel or aluminium offer the highest potential for impact reduction.
- Optimisation of zinc coating thickness within technical standards could reduce resource and toxicity impacts for towers and poles.
- Renewable electricity sourcing for fabrication processes can further reduce climate change and air pollution impacts, although benefits are secondary compared to material sourcing.
- Supplier engagement and low-carbon material procurement represent the most effective strategy for long-term environmental performance improvement.

The interpretation confirms that the environmental impacts of transmission infrastructure products are predominantly driven by upstream material production rather than manufacturing operations. Among the assessed products, ACSR conductors exhibit the highest environmental footprint, followed by galvanized steel poles and galvanized steel towers.

## 6. Limitations and Uncertainty

This Life Cycle Assessment (LCA) was conducted in accordance with ISO 14040 and ISO 14044, following best available data and internationally accepted modelling practices. However, as with all LCA studies, the results are subject to certain limitations and inherent uncertainties arising from data availability, modelling assumptions, and methodological choices. These limitations do not invalidate the conclusions but should be considered when interpreting and applying the results.

### 6.1 Data Related Limitations

- The assessment relies primarily on secondary life cycle inventory data sourced from ecoinvent version 3.9.1 (cut-off system model) for upstream processes such as steel, aluminium, zinc production, fuel combustion, and electricity generation. While ecoinvent is a peer-reviewed and widely accepted database, the datasets represent industry averages and may not fully reflect the specific technologies or efficiencies of individual suppliers in the Indian context.
- The Indian national grid electricity mix was modelled using CEA-aligned proxy datasets available in ecoinvent. Temporal variations in grid composition, regional differences, and future decarbonisation pathways are not captured in this static representation.
- In the absence of product-specific measured data for electricity, fuel, and water consumption per metric tonne, representative industry datasets were used. This may lead to deviations between modelled results and actual operational performance.

### 6.2 Modelling Assumptions and Simplifications

- The ecoinvent cut-off approach was applied, under which scrap generated during manufacturing is treated as waste and no recycling credits are assigned. While this is conservative and aligned with EPD and BRSR practices, it may overestimate impacts compared to approaches that allocate recycling benefits.
- Capital equipment such as machinery, buildings, and infrastructure were excluded, consistent with common cradle-to-gate LCA practice. Inclusion of these elements would marginally increase impacts but is unlikely to affect comparative conclusions.
- Internal transport within manufacturing facilities was modelled as an average 500 m diesel-based material handling activity using generic forklift and hydra datasets. Actual distances, vehicle efficiencies, and load factors may vary slightly across plants.
- Zinc coating thickness was assumed based on IS 4759 heavy galvanization requirements (>900 $g/m^2$). Variations in coating thickness within acceptable specification limits may influence zinc consumption and associated impacts.

### 6.3 Impact Assessment Method Uncertainty

- The use of ReCiPe 2016 Midpoint (H) indicators provides a comprehensive and internationally accepted set of environmental impact categories. However, midpoint indicators inherently carry characterisation model uncertainty, particularly for toxicity, ecotoxicity, and land-use categories, which depend on complex environmental fate and exposure modelling.
- Impact category results should be interpreted in a relative and comparative context, rather than as absolute measures of environmental damage.

### 6.4 Temporal and Geographical Representativeness

The LCA represents a snapshot in time based on currently available datasets and does not account for future technological improvements, policy changes, or decarbonisation of electricity and material supply chains. Geographical representativeness is limited to India-relevant proxy datasets, and results may differ if alternative regional or supplier-specific data are used.

Despite the identified limitations, the study applies transparent, conservative, and internationally accepted assumptions, and the results are considered fit-for-purpose for comparative product assessment and sustainability reporting.

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