Quantifying Emissions

Carbon and Other Greenhouse Gases in Diesel Generator Manufacturing

Comprehensive Lifecycle Analysis to Promote Sustainable Practices

December 2024

Environmental Environmental Impact Analysis: Carbon Footprint of Diesel Generator Manufacturing Analysis

Introduction

Manufacturing a Diesel Generator (DG) Set which involves multiple processes, from raw material extraction to the final assembly. Each stage emits greenhouse gases (GHGs) and pollutants. This document estimates the emissions with a focus on carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases which are a part of GHG, BRSR or ESG disclosure.

2. Emission Scope and Boundaries

The emissions are categorized as follows as defined in ESG, BRSR

- Scope 1: Direct emissions from manufacturing processes and equipment.
- Scope 2: Indirect emissions from purchased electricity and energy.
- Scope 3: Emissions from raw material extraction, transport, and distribution.

3. Breakdown of Emission Sources

3.1 Raw Material Extraction and Production

Primary materials for DG Set include:

- Steel (structural parts, housing)
- Copper (wiring, alternator components)
- Aluminum (engine components, parts)
- Plastics (casing, insulation)

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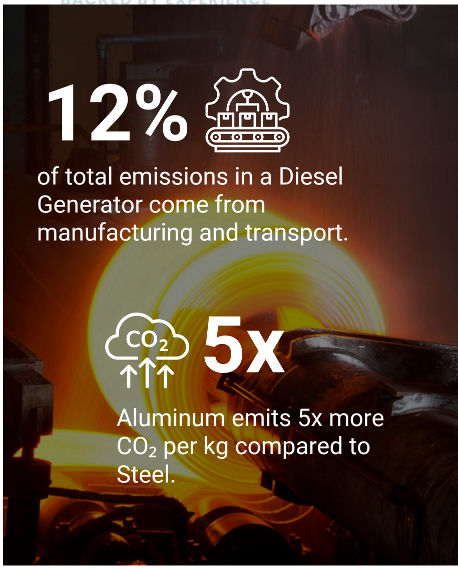
Emission Estimates (kg CO_2-eq per kg material)

Material	Emission Factor (kg CO_2-eq/kg)	Source
Steel	2.0 - 3.0	World Steel Association
Copper	4.0 - 5.0	ICMM Lifecycle Report
Aluminum	10.0 - 15.0	International Aluminium Inst.
Plastics	2.5 - 3.0	PlasticsEurope LCA Report



Estimated Contribution:

- For a 1-ton DG Set, approximately 800 kg steel, 50 kg copper, 20 kg aluminum, and 30 kg plastics are used.
- Total emissions ≈ 2,900 kg CO_2-eq.

Steel emits 2.0–3.0 kg CO_2 per kg due to energy-intensive processes like smelting and rolling, though it is recyclable and widely used for structural parts. Copper, emitting 4.0–5.0 kg CO_2 per kg, is vital for wiring and alternator components but has high emissions due to complex refining and mining processes. Aluminum emits 10.0–15.0 kg CO_2 per kg, driven by electricity-intensive smelting, making it 5x more carbon-intensive than steel, despite being lightweight and recyclable.

Plastics, with 2.5–3.0 kg CO_2 per kg, contribute minimally but are derived from petrochemicals, posing waste management challenges. Aluminum and copper have the highest relative emissions due to high energy demands.

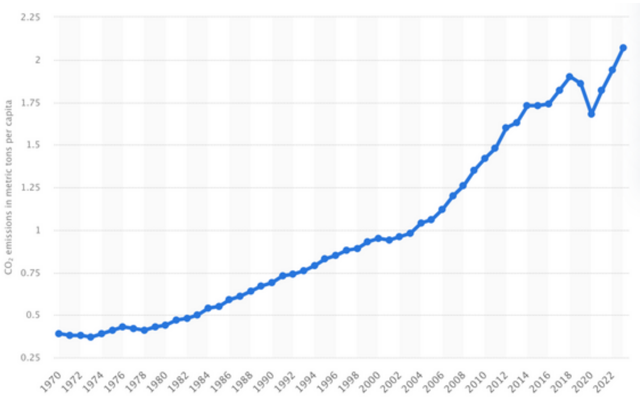
Recycling aluminum and copper can cut emissions significantly, while low-carbon steel and bioplastics offer sustainable alternatives. Material optimization and sustainable sourcing can drastically reduce emissions in DG manufacturing. These materials' emissions reflect their energy intensity and potential for future innovation.

Tracking Carbon Emissions: A Global and Indian Perspective

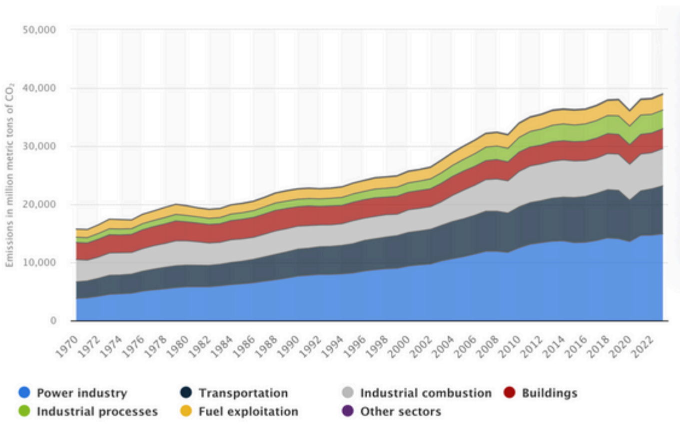
Analyzing CO_2 contributions from fossil fuels and industrial processes, and exploring actionable solutions for emission reduction.

Carbon dioxide (CO_2) emissions from fossil fuel and industrial purposes in India from 1970 to 2023

Carbon dioxide emissions from fossil fuel use and industrial purposes in India increased 7.8 percent in 2023, to a new record high of 2.9 billion metric tons ($GtCO_2$). India's annual fossil CO_2 emissions have roughly tripled since the turn of the century, owing to the country's rapid economic development.



CO_2 Emission in metric tons per capita
Source : Statista



Emissions by process in million metric tons of CO_2
Source : Statista

Global fossil carbon dioxide emissions from 1970 to 2023

Global CO_2 emissions have risen steadily since 1970, with major contributors being the power industry, transportation, industrial combustion, buildings, and industrial processes. The power industry leads emissions due to fossil-based electricity generation, followed by transportation from vehicles and industrial combustion from manufacturing processes. Buildings and fuel exploitation add significantly due to urbanization and fossil fuel extraction.

Solutions

- **Repairing renewable energy systems** to extend their lifespan and reduce fossil fuel reliance.
- **Vehicle maintenance and retrofitting** to cut emissions and avoid new production.
- **Refurbishing industrial equipment** to enhance efficiency and avoid energy-intensive replacements.
- **Building retrofits with energy-efficient** technologies to lower operational emissions.
- **Recycling materials like steel and aluminum** to reduce the need for virgin material production.

Emission Estimates (kg CO_2-eq per kg material)

Material	Weight (kg)	Emission Factor (kg CO_2-eq/kg)	Total Emissions (kg CO_2-eq)	Source
Steel	800	2.5 (Average of 2.0-3.0)	2,000	World Steel Association
Copper	50	4.5 (Average of 4.0-5.0)	225	ICMM Lifecycle Report
Aluminum	20	12.5 (Average of 10.0-15.0)	250	International Aluminium Inst.
Plastics	30	2.75 (Average of 2.5-3.0)	82.5	PlasticsEurope LCA Report
Manufacturing Energy & Transport	-	-	342.5	Assumed for machining, transport
Total			**2,900**	

The table summarizes the emissions for manufacturing a 1-ton Diesel Generator (DG) Set **totaling 2,900 kg CO_2-eq**. Steel contributes the highest emissions (2,000 kg CO_2-eq, 69%) as it forms the DG's structural frame. Steel's high emissions **stem from energy-intensive smelting**, though recycling can significantly reduce its footprint. Copper (225 kg CO_2-eq, 7.7%) **is crucial for wiring and alternator components**, with emissions driven by mining and refining processes. Aluminum (250 kg CO_2-eq, 8.6%) is used in lightweight engine components but is **5x more carbon-intensive than steel** due to electricity-intensive smelting, highlighting the importance of recycling aluminum.

Plastics contribute 82.5 kg CO_2-eq (2.8%), primarily from petrochemical-based production, posing waste management challenges. Manufacturing processes and transport together add 342.5 kg CO_2-eq (11.8%) including emissions from machining, welding, and logistics. **Transport inefficiencies such as multiple trips amplify this contribution.**

Steel and aluminum are the primary emission hotspots due to their significant usage and high carbon intensity. **Recycling materials like steel, aluminum, and copper can reduce emissions by up to 90%**. Addressing emissions from transport and manufacturing through renewable energy and efficient logistics can further lower the carbon footprint. For instance, using hydrogen in steel production or switching to electric-powered transport vehicles could cut emissions drastically. This breakdown underscores the need to adopt sustainable material sourcing, improve recycling, and transition to cleaner manufacturing technologies for meaningful emission reductions.

Lifecycle Stages of Diesel Generators: Cradle to Grave

Understanding emissions at each stage and exploring strategies for reduction through repair, retrofitting, and recycling.

Manufacturing New Generators

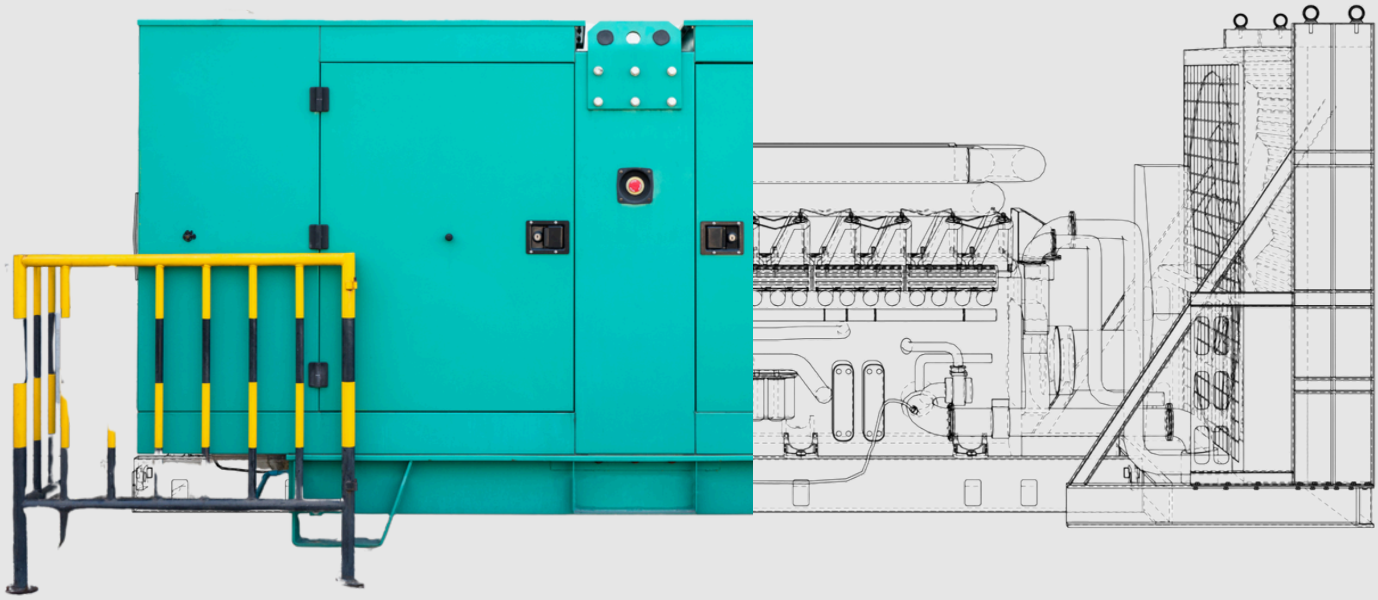
High emissions result from raw material production (steel, copper, aluminum) and energy-intensive manufacturing processes.

Transport and Deployment

Emissions are generated during the logistics of delivering new DG sets to sites.

Usage and Operational Emissions

DG Set emit significant CO_2 and NOx during operation due to fossil fuel combustion.



Aging Equipment and Inefficiencies

As DGs age, efficiency decreases, increasing operational emissions.

Refurbishing and Retrofitting

Repairing and retrofitting old DGs with emission control technologies (RECD) and hybrid capabilities (ESS integration) significantly reduces emissions compared to manufacturing new ones.

Recycling and Reuse

Decommissioned DG materials like steel, copper, and aluminum are recycled, reducing the need for virgin material production.

3.2 Manufacturing Processes

Processes include cutting, welding, machining, and assembly using energy-intensive equipment.

Source	Emission Factor (kg CO_2/kWh)	Energy Use (kWh/unit)	Process
IEA, 2023	0.82 (India Grid Avg.)	30	Welding (Electric)
IEA, 2023	0.82	20	Machining
IEA, 2023	0.82	15	Painting (Electric)

Estimated Contribution:

- Total energy: **65 kWh**
- Emissions: **53.3 kg CO_2**.

3.3 Transport Emissions

Raw material and component transport to the manufacturing facility.

Transport Mode	Distance (km)	Emission Factor (g CO_2/ton-km)	Calculated Emissions (kg CO_2)	Source
Road (Truck)	300	62.0	1×300×62/1000 = **18.6**	DEFRA Emission Factors
Sea Transport (Cummins USA)	1000	14.0	1×1000×14/1000 = **14.0**	IMO GHG Study 2020
			32.6 kg CO_2	

Estimated Contribution:

- *For 1 ton of raw material, road and sea transport ≈ **100 kg CO_2**.*

Assumptions

- *Variations in distances.*
- *Multiple trips or inefficiencies in logistics.*
- *Inclusion of additional transport factors not explicitly mentioned (e.g., handling, stops).*

3.4 Assembly and Testing

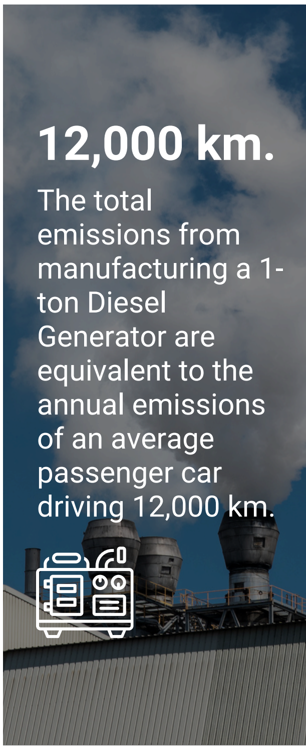
Generators undergo assembly and quality testing using diesel fuel.

Process	Fuel Consumption (L)	Emission Factor (kg CO_2/L)	Other Gases (kg)
DG Testing	5	2.67 (CO_2)	NOx: 0.007, SO_2: 0.005

Estimated Contribution:
- CO_2 **13.35 kg**
- NOx **0.035 kg**, SO_2 **0.025 kg**

4 Total Emissions Summary

Emission Source	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	Other Gases
Raw Material Production	2,900	0.01	0.02	-
Manufacturing Processes	53.3	-	-	-
Transport	100	-	-	-
Assembly and Testing	13.35	0.001	0.002	NOx: 0.035, SO_2: 0.025
Total Estimated Emissions	**3,066.65**	**0.011**	**0.022**	**NOx, SO_2**



The estimated carbon emissions for manufacturing a **1-ton Diesel Generator Set** is approximately **3,066.65 kg CO_2-eq.** Other emissions include CH_4, N_2O, NOx, and SO_2. The largest contributions come from raw material production (94.5%) and energy-intensive manufacturing processes.

5. Sources

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Driving Innovation for a Cleaner Future

Leveraging advanced technologies and sustainable materials to optimize energy usage and reduce emissions.

Importance of Clean Energy Transition

Transitioning to clean energy is no longer optional—it's essential for global sustainability. Data shows that the energy sector accounts for 73% of global greenhouse gas emissions, making innovations in energy efficiency and clean technologies critical. Solutions like IoT, digital twins, and sustainable materials enable industries to track, reduce, and mitigate emissions, ensuring compliance with environmental goals while enhancing operational efficiency. By adopting clean energy strategies, industries pave the way for a sustainable future, reducing reliance on fossil fuels and minimizing environmental impact.

Technologies Leading the Way

Digital Twins

Digital models of manufacturing processes simulate operations in real time, identifying inefficiencies and optimizing energy use. This reduces waste, streamlines production, and cuts energy-related emissions making manufacturing processes greener and more sustainable.

25%

Can reduce manufacturing energy use and emissions by up to 25%, optimizing production processes.

IoT for Predictive Maintenance

IoT-enabled DGs monitor performance continuously, predict failures, and ensure timely maintenance. This reduces fuel wastage, lowers emissions, and extends equipment lifespan, contributing to operational sustainability.

30%

Lowers unplanned downtime by 30%, improving efficiency and cutting operational emissions by 15%.

Sustainable Materials

Research into biodegradable plastics, low-carbon alloys, and recycled components is transforming manufacturing. These materials minimize emissions during production and disposal, aligning industries with circular economy principles.

40%

Adoption of low-carbon alloys and biodegradable plastics can reduce material-related emissions by 40% compared to conventional materials.

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