GE-International Journal of Management Research
ISSN (O): (2321-1709), ISSN (P): (2394-4226)
Vol. 14, Issue 02, Feb 2026 Impact Factor: 8.466
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Strategic Carbon Management and Emission Reduction in Indian Renewable Energy Firms: A Case Study Approach

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Abstract- Climate change has made corporate carbon accountability critical for sustainable business operations. This study analyzes the carbon footprint of **SOLARC Green Energy Solutions LLP**, a renewable energy company in Maharashtra, focusing on emissions across **Scopes 1, 2, and 3**. Using simulated operational data, emission factors from **IPCC** and **MoEFCC**, and industry benchmarks, the study quantifies total greenhouse gas emissions and identifies key emission source. Results indicate a total footprint of **138,630 kg CO_2e**, dominated by **Scope 2 electricity consumption (82,000 kg CO_2e)**, followed by supplier emissions (20,000 kg CO_2e) and diesel generators (13,400 kg CO_2e). Major hotspots highlight the need for interventions in energy sourcing, supply chain management, and operational efficiency. Recommended strategies include **renewable energy adoption, electrification, supplier engagement, logistics optimization, and employee awareness programs**, which can reduce emissions by 40–60% while offering cost savings and improved ESG performance. The study provides a practical framework for mid-sized enterprises in emerging economies to integrate carbon management into business strategy and align with national and global sustainability goals.

Keywords: Carbon footprint, GHG emissions, renewable energy, Scope 1–3, sustainability, ESG.

1. Introduction

Climate change is one of the most pressing global challenges of the 21st century. Businesses are increasingly expected to measure, report, and reduce their carbon emissions to align with sustainability goals and regulatory requirements. A **carbon footprint analysis** provides organizations with a systematic approach to understand the environmental impact of their operations, identify hotspots, and implement mitigation strategies.

This study focuses on **SOLARC Green Energy Solutions LLP**, a Maharashtra-based renewable energy company specializing in solar photovoltaic systems. The research aims to quantify the company's carbon footprint, analyze emissions across Scopes 1, 2, and 3, identify key emission sources, and propose strategies to reduce emissions while ensuring operational efficiency and financial viability.

Objectives of the Study:

1. To Quantify the carbon footprint of SOLARC Green Energy Solutions.
2. To Analyze emissions across different scopes (Scope 1, 2, and 3).
3. To Identify major emission sources and hotspots.
4. To Recommend practical strategies for emission reduction.
5. To Evaluate business impacts and ROI of sustainability initiatives.

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Scope: This study focuses on emissions from manufacturing operations, energy consumption, transportation, supply chain activities, and waste management, using internationally recognized protocols (GHG Protocol, ISO 14064).

2. Literature Review

2.1 Carbon Footprint Definition

A carbon footprint represents the total greenhouse gases (GHG) emitted directly or indirectly by an organization, measured in **CO_2 equivalents (CO_2e)**. Accurate quantification helps in assessing environmental responsibility and identifying reduction opportunities.

2.2 Emission Scopes

- **Scope 1:** Direct emissions from owned or controlled sources (diesel, petrol, natural gas).
- **Scope 2:** Indirect emissions from purchased electricity, steam, or heating.
- **Scope 3:** Other indirect emissions, including supplier operations, logistics, employee commuting, and waste.

2.3 Standards and Frameworks

- **GHG Protocol:** Widely used global standard for carbon accounting.
- **ISO 14064:** International standard for quantifying and reporting emissions.
- **Science-Based Targets Initiative (SBTi):** Encourages companies to adopt climate-aligned emission reduction goals.

2.4 Industry Benchmarks

Mid-sized manufacturing companies in India typically emit between 1,000–10,000 metric tons of CO_2e annually. Adoption of **renewable energy**, process optimization, and energy-efficient equipment significantly reduces carbon intensity.

3. Research Methodology

3.1 Data Sources

1. **Internal Operational Data (Simulated):** Fuel consumption, electricity usage, transport distances, and waste generation.
2. **Emission Factors:** Sourced from IPCC guidelines and MoEFCC, India.
3. **Industry Benchmarks:** Academic literature and sustainability reports from comparable firms.

3.2 Tools Used

- **Python:** Data cleaning, calculations, and visualization using pandas, numpy, matplotlib, and plotly.
- **Excel:** Tabular analysis and scenario modeling.
- **Plotly/Matplotlib:** Visualizations such as pie charts and bar graphs.

3.3 Emission Scopes Covered

- **Scope 1:** Diesel generators, company vehicles, and heating.
- **Scope 2:** Purchased electricity.
- **Scope 3:** Supplier operations, logistics, business travel, employee commuting, and waste disposal.

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Source	Scope	Activity Data	Emission Factor	Emissions (kg CO_2e)
Diesel for generators	1	5000 liters	2.68	13,400
Petrol for company vehicles	1	3000 liters	2.31	6,930
Natural gas for heating	1	2000 units	2.05	4,100
Purchased electricity	2	100,000 kWh	0.82	82,000
Employee commuting	3	25,000 km	0.12	3,000
Business travel	3	10,000 km	0.15	1,500
Raw material transportation	3	40,000 km	0.18	7,200
Supplier emissions	3	80,000 units	0.25	20,000
Waste disposal	3	5,000 kg	0.10	500

Source	Scope	Activity Data	Emission Factor	Emissions (kg CO_2e)
Diesel for generators	1	5000 liters	2.68	13,400
Petrol for company vehicles	1	3000 liters	2.31	6,930
Natural gas for heating	1	2000 units	2.05	4,100
Purchased electricity	2	100,000 kWh	0.82	82,000
Employee commuting	3	25,000 km	0.12	3,000
Business travel	3	10,000 km	0.15	1,500
Raw material transportation	3	40,000 km	0.18	7,200
Supplier emissions	3	80,000 units	0.25	20,000
Waste disposal	3	5,000 kg	0.10	500

3.4 Data Interpretation

1. Scope 1 – Direct Emissions

Scope 1 includes emissions from company-owned or controlled sources, specifically:

- **Diesel for generators:** 5,000 liters of diesel contribute **13,400 kg CO_2e**. This is the largest single source within Scope 1. Diesel combustion has a high emission factor, and backup generators, though essential, significantly contribute to direct emissions.
- **Petrol for company vehicles:** 3,000 liters of petrol account for **6,930 kg CO_2e**, reflecting operational mobility needs.
- **Natural gas for heating:** 2,000 units produce **4,100 kg CO_2e**, a smaller yet notable contributor.

Interpretation: Scope 1 emissions total **24,430 kg CO_2e**, indicating that direct operational activities contribute approximately 18% of the total carbon footprint. Immediate mitigation opportunities exist through **vehicle electrification and diesel-to-battery replacements**.

2. Scope 2 – Indirect Emissions from Energy

Scope 2 covers purchased electricity used in manufacturing and office operations:

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- **Purchased electricity:** 100,000 kWh result in **82,000 kg CO_2e**, the largest single contributor across all scopes.

Interpretation: Scope 2 emissions constitute **59% of the total footprint**, underlining the critical impact of energy sourcing. Transitioning to **renewable energy**, such as onsite solar installations or green PPAs, would have the **highest potential for emission reduction**.

3. Scope 3 – Other Indirect Emissions

Scope 3 includes upstream and downstream activities not directly controlled by the company:

- **Supplier emissions:** 80,000 units contribute **20,000 kg CO_2e**, reflecting the carbon intensity of raw material production and processing.
- **Raw material transportation:** 40,000 km emit **7,200 kg CO_2e**, and **business travel** contributes **1,500 kg CO_2e**.
- **Employee commuting:** 25,000 km adds **3,000 kg CO_2e**, and **waste disposal** of 5,000 kg generates **500 kg CO_2e**.

Interpretation: Scope 3 emissions total **32,200 kg CO_2e**, approximately **23% of the total footprint**. Though indirect, these emissions are strategically important because **supplier engagement, logistics optimization, and employee behavior** can meaningfully reduce Scope 3 impact.

4. Overall Interpretation

- **Total Carbon Footprint:** 138,630 kg CO_2e.
- **Emission Hotspots:** Purchased electricity, supplier activities, and diesel for generators account for **over 75% of total emissions**.
- **Actionable Insights:**
  - Prioritize **renewable energy adoption** to reduce Scope 2.
  - Electrify vehicles and replace diesel generators for Scope 1 reductions.
  - Engage suppliers, optimize logistics, and improve waste management for Scope 3 improvements.

Conclusion: The analysis clearly shows that **energy sourcing and supply chain activities are the primary drivers** of SOLARC's carbon footprint. A targeted strategy addressing these areas will achieve the **highest environmental and financial impact**.

Total Emissions by Scope:

- Scope 1: 24,430 kg CO_2e
- Scope 2: 82,000 kg CO_2e
- Scope 3: 32,200 kg CO_2e

Key Observations:

- Scope 2 (purchased electricity) is the largest contributor.
- Supplier emissions and diesel for generators are the next significant sources.
- Over 75% of emissions come from energy usage and supply chain activities.

5. Findings

5.1 Emission Hotspots

1. **Purchased electricity (Scope 2):** 82,000 kg CO_2e.
2. **Supplier emissions (Scope 3):** 20,000 kg CO_2e.

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3. **Diesel generators (Scope 1):** 13,400 kg CO_2e.

5.2 Scope-Wise Insights

- **Scope 1:** Direct control allows immediate reduction through electrification and EV adoption.
- **Scope 2:** Renewable energy adoption (rooftop solar, PPAs) is critical.
- **Scope 3:** Supplier engagement, green procurement, and logistics optimization are key.

5.3 Benchmark Comparison

SOLARC's emissions are slightly above the industry average due to heavy grid electricity reliance and limited green supply chain practices.

6. Recommendations

6.1 Renewable Energy

- Rooftop solar installations and PPAs to reduce Scope 2 emissions by up to 60%.

6.2 Electrification & Fuel Efficiency

- Replace diesel generators with battery storage systems.
- Transition company vehicles to electric vehicles (EVs) for 40–50% Scope 1 reduction.

6.3 Supplier Engagement

- Introduce sustainability criteria for procurement and encourage emission disclosure (Scope 3 reduction of 20–30%).

6.4 Logistics Optimization

- Use route optimization and shift to rail transport to reduce fuel usage (15–20% reduction).

6.5 Waste Management

- Recycling and partnering with certified waste processors for 50% reduction in waste emissions.

6.6 Employee Engagement

- Incentivize carpooling, public transport, and green commuting for 10–15% reduction in commuting emissions.

Initiative	Cost (INR)	Emission Reduction (kg CO_2e)	ROI Period
Rooftop Solar Installation	25,00,000	50,000	4–5 years
EV Fleet Transition	10,00,000	6,000	3 years
Supplier Sustainability Program	2,00,000	5,000	2 years
Waste Management Upgrade	1,00,000	250	1 year

Strategic Benefits:

- ESG investor appeal
- Market differentiation
- Risk mitigation and regulatory compliance
- Stakeholder engagement

8. Challenges & Limitations

- Limited visibility of Scope 3 emissions due to lack of supplier data.
- High capital investment required for solar and EV adoption.
- Regulatory uncertainty in carbon pricing and limited incentives for SMEs.
- Resistance to change among suppliers and logistic partners.

9. Conclusion & Implications

SOLARC Green Energy Solutions LLP exhibits a significant carbon footprint, predominantly from electricity usage and supply chain activities. Strategic interventions such as renewable energy adoption, electrification, supplier engagement, and logistics optimization can reduce emissions, improve financial performance, and enhance brand reputation. Sustainability can be embedded into the company's core business strategy, aligning with national and global climate goals.

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