Developing a Sustainability Index for Environmental Accountability in Transforming Carbon Emission Industries.

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in

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by

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CANDIDATE'S DECLARATION

I, **Fredrick Kabwe,** hereby certify that the work which is being presented in the thesis entitled **Developing a Sustainability Index for Environmental Accountability in Transforming Carbon Emission Industries** in partial fulfillment of the requirements for the award of the Degree of Master of Technology, submitted To the Department of Mechanical Engineering, Delhi Technological University is an authentic record of my work carried out during the period from 2024 to 2025 under the supervision of **Dr. Krovvid Srinivas**, **Professor, Department of Mechanical Engineering, Delhi Technological University**, Delhi.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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Certified that **Fredrick Kabwe (**23/IEM/13) has carried out the research work presented in this thesis entitled **"Developing a Sustainability Index for Environmental Accountability in Transforming Carbon Emission Industries.**

" For the award of **Master of Technology** from the Department of Mechanical Engineering, Delhi Technological University, Delhi, under my supervision. The thesis embodies the results of original work, and studies are carried out by the student himself, and the contents of the thesis do not form the basis for the award of any other degree to the candidate or anybody else from this or any other University/Institution.

Date: M a r c h
2025

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Abstract

Carbon emission-intensive industries, including energy, manufacturing, and oil and gas, are pivotal to global economic stability but contribute disproportionately to greenhouse gas emissions, intensifying the global climate crisis. Existing sustainability frameworks, such as the Dow Jones Sustainability Index [39] and Global Reporting Initiative [54], lack sector-specific granularity, limiting their effectiveness in addressing the unique environmental challenges posed by these industries. This research proposes a multi-criteria sustainability index tailored for high-carbon industries, integrating indicators like emissions intensity, renewable energy penetration, lifecycle carbon footprint, and energy efficiency. Through a structured methodology involving the Analytical Hierarchy Process [25] and case studies across key sectors, the index demonstrates its ability to benchmark sustainability performance, foster alignment with international climate goals, and guide meaningful decarbonization efforts. This paper discusses the framework's validation, policy implications, and the integration of emerging technologies like blockchain and IoT for enhanced transparency and operationalization. The findings underscore the potential of the proposed index to advance environmental accountability and bridge critical gaps in sustainability performance measurement.

Keywords: Sustainability Index, Renewable Energy Integration, Environmental Accountability, Decarbonization, Analytical Hierarchy process, Sector-Specific Metrics, Multi-Criterion Decision Analysis.

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List Of Abbreviations

Abbreviation	Full Form
CO2	Carbon Dioxide
GHG	Greenhouse Gas
ESG	Environmental, Social, and Governance
CDP	Carbon Disclosure Project
GRI	Global Reporting Initiative
UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency
SDG	Sustainable Development Goals
AHP	Analytical Hierarchy Process
CCUS	Carbon Capture, Utilization, and Storage
CAGR	Compound Annual Growth Rate
B2B	Business to Business

CHAPTER 1

1. Introduction

Carbon emission-intensive industries, particularly in the energy, oil and gas, and manufacturing sectors, play a dual role in modern society. While they serve as economic pillars and facilitators of technological progress, their environmental implications are profound, contributing significantly to the global climate crisis. Collectively, these industries account for a substantial proportion of greenhouse gas [53] emissions, exacerbating climate change and environmental degradation. According to recent data, the energy sector alone is responsible for nearly 73% of global emissions, underscoring the urgency of addressing sustainability in these industries. As the international community intensifies efforts to combat climate change, the challenge lies in aligning these sectors with sustainability goals while preserving their economic significance [94].

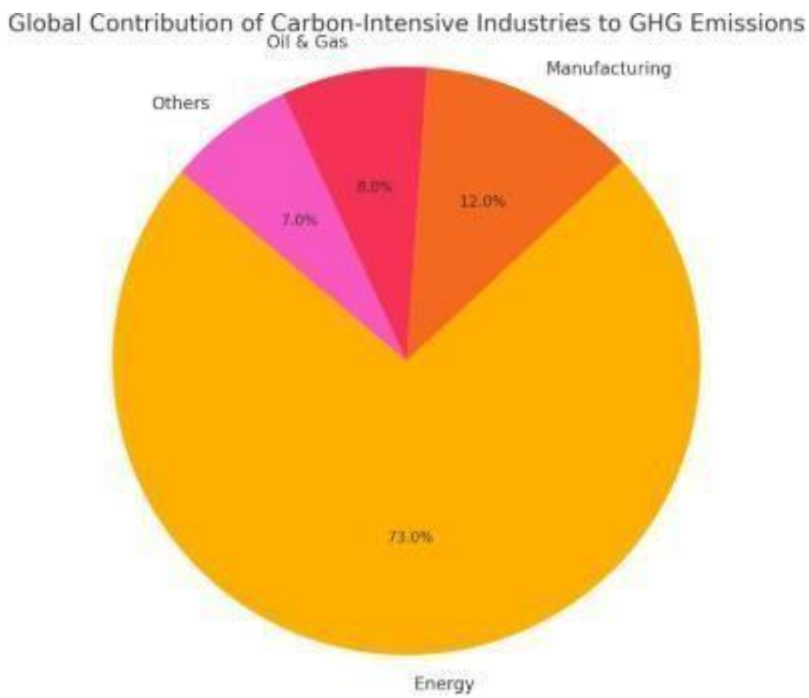


Figure 1.

The chart shows the share of global emissions from sectors like Energy [22], Manufacturing, and Oil and Gas, Emphasizing the urgent need for sustainability reforms.

The role of these industries is particularly critical in the context of global climate agreements, such as the Paris Agreement, which seeks to limit global warming to well below 2°C above pre-industrial levels. Achieving this target necessitates a comprehensive transformation of carbon-intensive industries. However, current sustainability frameworks fall short in addressing the sector-specific challenges posed by these industries. While global indices such as the Dow Jones Sustainability Index [39] and FTSE4Good provide broad assessments of environmental, social, and governance [50] performance, they lack the granularity required to capture the unique dynamics of high-carbon industries [44]. As a result, these frameworks are often insufficient for guiding industries toward meaningful decarbonization [67].

The absence of industry-specific metrics creates a significant gap in sustainability reporting and performance evaluation. High-carbon industries, such as those in the energy and manufacturing sectors, exhibit unique operational characteristics that influence their environmental impact. For instance, emissions intensity, reliance on fossil fuels, and integration of renewable energy vary widely across industries and regions. Existing frameworks, while valuable for broader ESG assessments, fail to account for such nuances, rendering them less effective for sector-specific applications [83].

Moreover, the current sustainability indices tend to prioritize corporate disclosures and aggregate performance metrics, which, while informative, do not adequately support granular decision-making. This limitation underscores the need for a tailored approach that integrates environmental accountability into the operational fabric of high-carbon industries. An industry-specific sustainability index would address these gaps by providing actionable insights, benchmarking performance, and fostering alignment with international sustainability goals [36].

Table 1: Global Greenhouse Gas Emissions by Sector (2022)

Sector	**Emissions Share (%)**	**Main Emission Source**
Energy	**73%**	**Fossil fuel combustion in electricity, heat production, and transportation**
Manufacturing	**16%**	**Industrial processes, waste, and material handling**
Transport	**7%**	**Fossil fuel use in aviation, maritime, and road transport**
Agriculture	**4%**	**Methane emissions from livestock and rice paddies, deforestation**
Other	**1%**	**Miscellaneous emissions from buildings, waste, etc.**

This table reinforces the importance of addressing emissions from high-carbon industries like energy, manufacturing, and transport.

1.1 Objectives and Scope of Research

This research proposes the development of a multi-criteria sustainability index tailored to the unique needs of carbon-intensive industries, with a specific focus on the energy sector. The primary objective of this study is to design and validate a sustainability index that integrates environmental accountability metrics, providing a robust framework for assessing and improving sustainability performance. By incorporating specific and measurable metrics, the proposed index aims to facilitate informed decision-making and align industries with global climate targets.

The secondary objectives include:

- ✓ Identifying and prioritizing key environmental accountability indicators relevant to high-carbon industries.
- ✓ Comprehensive index.
- ✓ Testing and validating the index through case studies of energy-intensive companies and industries.

Table 2: Sustainability Indicators for High-Carbon Industries

Indicator	**Definition**	**Sector Relevance**
Emissions Intensity	CO_2 emissions per unit of output	Energy, Manufacturing, Transport
Renewable Energy Share	Percentage of energy sourced from renewable sources	Energy, Manufacturing
Lifecycle Carbon Footprint	Total emissions across the lifecycle of products/services	Manufacturing, Energy
Energy Efficiency	Energy consumption per unit of production or revenue	Manufacturing, Energy

Significance of Research

The proposed index holds significant potential for advancing sustainability efforts in high-carbon industries. By providing a tailored tool for evaluating environmental performance, this research addresses a critical gap in current sustainability frameworks. The index will enable industries to benchmark progress, identify improvement areas, and align their practices with the United Nations Sustainable Development Goals [85], particularly Goal 7 [27] and Goal 13 [37] [93].

In addition to its practical applications, this research contributes to the broader discourse on sustainability by emphasizing the importance of environmental accountability in the industrial sector. By integrating insights from existing frameworks and leveraging advanced methodologies, this study aims to set a new standard for sustainability metrics, fostering greater accountability and promoting a sustainable transition in carbon-intensive industries [60].

1.2 Challenges and Opportunities

Developing a sustainability index for high-carbon industries presents several challenges. First, there is a need to balance detail with usability, particularly in selecting indicators such as emissions intensity, renewable energy penetration, and lifecycle carbon footprints [35]. Second, the availability and standardization of data vary significantly across regions and industries, complicating efforts to achieve consistency in reporting [78]. Third, resistance from stakeholders, often due to concerns about costs and operational disruptions, adds another layer of complexity to implementation.

Despite these challenges, opportunities abound. A sector-specific index can enhance accountability by identifying performance gaps and incentivizing best practices. Furthermore, it provides policymakers and investors with the tools to align their decisions with sustainability goals, contributing to international frameworks such as the Paris Agreement and the United Nations Sustainable Development Goals [85] [82].

Chapter 2

Literature Review

2.1 Advancements in Sustainability Indices

Sustainability indices have emerged as vital tools for evaluating and benchmarking environmental, social, and governance [50] performance across industries. Frameworks like the Dow Jones Sustainability Index [39], Global Reporting Initiative [54], and Carbon Disclosure Project [30] provide standardized methodologies for assessing corporate sustainability. These indices focus on a range of parameters, including greenhouse gas [53] emissions, energy efficiency, and resource management [40].

The DJSI, for example, evaluates ESG performance using criteria that incorporate emissions intensity, resource utilization, and transparency in reporting. The GRI Standards extend these efforts by offering modular frameworks that align with global sustainability objectives, emphasizing disclosures on environmental and social impacts. Similarly, the CDP encourages organizations to disclose their carbon footprints and provides a platform for evaluating climate risks [33].

Emergingtrends in sustainability assessment highlight the increasing use of technology and advanced analytics. Tools such as blockchain have been integrated to improve transparency in sustainability reporting, while machine learning is being leveragedto enhance predictive analytics in environmental performance [80]. These advancements underline the growing importance of data-driven decision-making in sustainability.

Table 3: Comparison of Major Sustainability Frameworks

Strengths	Framework	Limitations	Relevance to Study
DJSI	Global benchmarking of ESG performance	Lacks sector-specific granularity	Limited applicability to industries with high carbon emissions
GRI	Comprehensive disclosure standards	Reliant on voluntary, self-reported data	Insufficient reliability for sectoral benchmarking
CDP	Focuses on climate risk and carbon footprint disclosures	Data consistency issues due to voluntary participation	Limited standardization across regions and sectors

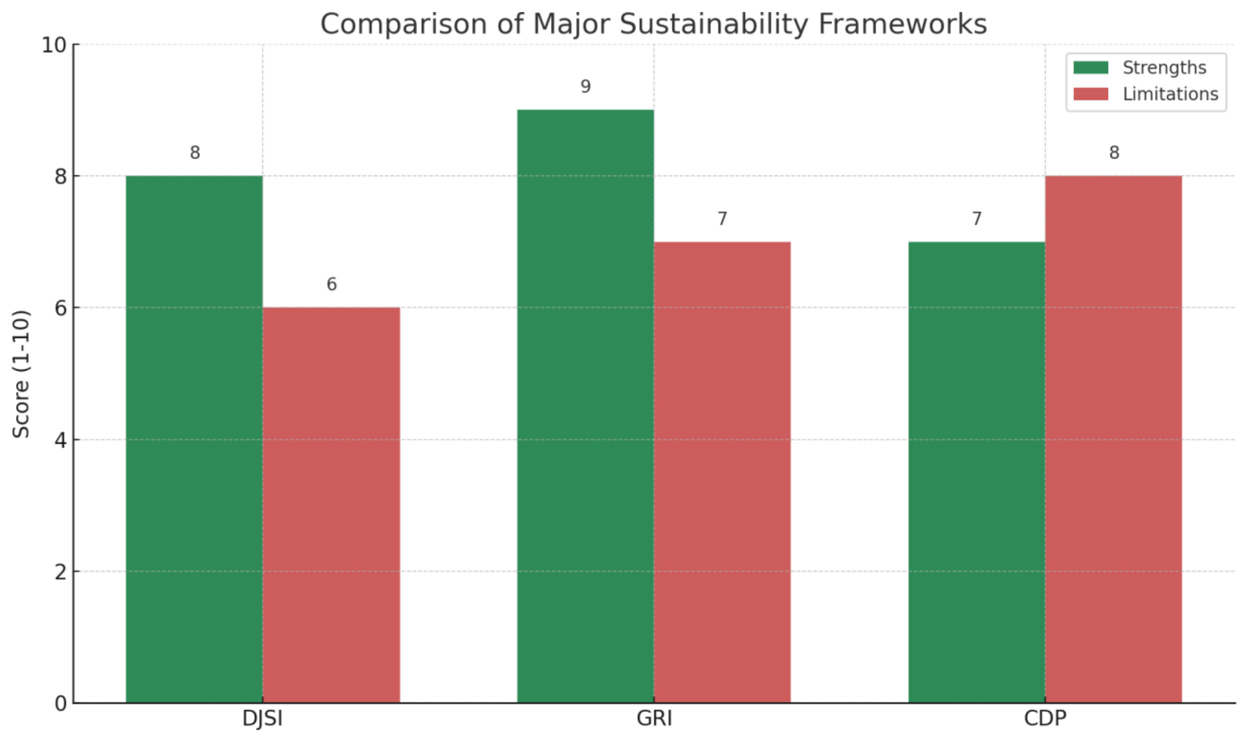


Figure 2
The contrast strengths and limitations of key sustainability frameworks

Limitations and Challenges

Despite their strengths, existing sustainability indices exhibit significant limitations when applied to high-carbon industries. Their broad scope often prioritizes corporate disclosures and general ESG benchmarks, neglecting sector-specific dynamics. For instance, frameworks like DJSI fail to account for unique operational factors such as lifecycle emissions and renewable energy integration, which are critical for carbon-intensive sectors [63]. This lack of granularity hinders the indices' ability to provide actionable insights for industries with high environmental impacts.

Table 4: Key Limitations of Current Sustainability Frameworks

Limitation	Description
Data Inconsistency	A significant challenge is the lack of standardized reporting across regions and industries, making it difficult to compare sustainability performance. Different industries, countries, and regulatory bodies may use varying metrics and reporting methods, resulting in data discrepancies. This inconsistency undermines the effectiveness of global sustainability benchmarks (Bocken et al., 2020).
Granularity of Metrics	Existing ESG metrics are often too broad and fail to capture sector-specific nuances. The lack of specialized, industry-specific indicators means that some critical aspects of sustainability—such as emissions intensity or energy efficiency in manufacturing—may be overlooked or generalized (SBTi, 2021).
Cost of Implementation	For many industries, especially small-to-medium enterprises (SMEs), the high cost of implementing sustainability practices can be prohibitive. The adoption of new technologies, energy-efficient systems, and carbon capture methods requires substantial upfront investment, which many smaller players cannot afford (OECD, 2020). Moreover, scaling these technologies often involves further investments, thus hindering widespread adoption.

2.2 Sector-Specific Challenges in High-Carbon Industries

High-carbon industries face unique sustainability challenges that vary across sectors. Addressing these challenges requires sector-specific metrics and tools.

Table 5: Sector-Specific Challenges in High-Carbon Industries

Sector	Challenges	Implications
Energy	Reliance on fossil fuels, slow renewable energy integration	High emissions intensity, need for grid decarbonization
Manufacturing	Wide variation in the lifecycle carbon footprint	Requires sector-specific lifecycle assessment metrics
Oil and Gas	Methane emissions, regional compliance variability	Difficulty in standardizing sustainability practices across geographies

Furthermore, data inconsistency poses a challenge. Sustainability reporting varies widely across regions, industries, and organizations, leading to gaps in standardization and comparability [35]. Many frameworks rely on voluntary disclosures, which may lack reliability or fail to capture the full environmental impact of industrial operations [59]. This issue is compounded by resistance from stakeholders who perceive sustainability metrics as an additional burden, particularly in terms of cost and operational changes [78].

2.3 Emerging Trends in Environmental Accountability

Recent research has emphasized the need for sector-specific sustainability metrics that reflect the operational realities of high-carbon industries. Innovations such as lifecycle assessment tools and emissions intensity tracking have demonstrated potential for improving environmental accountability [81]. Additionally, the integration of Internet of Things [71] devices and artificial intelligence [26] has facilitated real-time monitoring of emissions and energy usage, enabling dynamic tracking ofsustainabilityperformance [68]

Table 6: Emerging Trends in Environmental Accountability

Technology	Applications	Benefits
Blockchain	Immutable sustainability reporting	Enhances transparency and data security
IoT	Real-time emissions and energy usage monitoring	Facilitates immediate corrective actions
AI	Automation	Energy Efficiency

Theshift toward sector-specific indices also aligns with internationalclimate goals, such as the Paris Agreement and the United Nations Sustainable Development Goals [85]. By tailoring indices to the unique challenges and opportunities of high-carbon industries, researchers and policymakers aim to bridge the gap between broad ESG frame works and actionable decarbonization strategies.

2.2 Limitations of Existing Frameworks

While existing frameworks offer valuable insights, they fail to address the granular needs of high-carbon industries.

Table7: Key Limitationsof Existing Frameworks

Limitation	Description
Data Dependence	Voluntary reporting leads to inconsistent and incompletedata
Granularity Deficit	Broad ESG metrics fail to capture sector-specific operational nuances
Implementation Barriers	High costs and lack of standardization hinder large-scale adoption

Chapter 3

3. Methodology

3.1 Research Design

Theresearch isstructured intothreemain phases:

- ✓ Indicator Identification: Identifyingrelevant environmental accountability metrics for high-carbon industries.
- ✓ Index Development: Designing the sustainability index using a multi-criteria decision analysis approach.
- ✓ Index Validation: Testingthe indexthroughcase studies acrosskey industries [99].

The goal is to create a tailored sustainability index that addresses the unique challenges of high-carbon industries and provides actionable insights for decarbonization.

3.2 Indicator Identification:

The first step in developing the index was to identify key environmental accountability indicators. This was achieved through:

- ✓ Literature Review: A comprehensive review of existing sustainability frameworks, including the Dow Jones Sustainability Index [39], Global Reporting Initiative [54], and Carbon Disclosure Project [30].

- ✓ **Stakeholder Consultations**: Engaging with industry experts, policymakers, and academic researchers to validate the relevance of the selected indicators.

Theidentifiedindicatorswerecategorizedinto threemaingroups:

1. **Environmental Indicators**: Metrics related to emissions, energy use, and resource management.
2. **Social Indicators**: Metrics assessing the social impact of operations, including community engagement and workforce diversity.
3. **Governance Indicators**: Metrics evaluating compliance, transparency, and risk management.

Key Indicators Table 8:

Category	Indicator	Description	Source (DJSI, GRI, CDP)
Environmental	Emissions Intensity	CO_2e emissions per unit of output.	DJSI, GRI 305, CDP (Climate Change)
	Renewable Energy Share	Percentageofenergy sourced from renewableresources.	DJSI, GRI 302, CDP (Climate Change)
	LifecycleCarbon Footprint	Total emissions across the life cycle of products/services.	GRI 305, CDP (Climate Change)
	Energy Efficiency	Energy consumption per unitofproduction orrevenue.	GRI 302, DJSI
	Waste and Recycling	The proportionofwaste recycled or reused within operations.	GRI 306, DJSI
	Water Management	Volumeof water, recycled, and discharged.	GRI 303, CDP (Water Security)
	Biodiversity Impact	Assessment of impact on biodiversity in operational areas.	DJSI, GRI 304
Social	Community Impact	Investments in local social and environmental programs.	DJSI, GRI 413
	Workforce Diversity	Proportion of employeesby gender, age, and other diversity metrics.	DJSI, GRI 405
	Health and Safety	Frequency and severity ofworkplace Accidents and fatalities	DJSI, GRI 403
	Supplier Engagement	Initiatives to ensure sustainable practices in the supply chain.	DJSI, GRI 308, CDP (Forests)
Governance	Environmental Compliance	Adherence to local and international environmental laws and standards.	DJSI, GRI 307

	Risk and Crisis Management	Frameworks for managing environmental and operational risks.	DJSI	
	Transparencyand Reporting	Completenessand reliability of sustainability disclosures.	GRI, CDP	

3.2.1 Explanation of Categories and Indicators

Environmental Indicators

These indicators focus on assessing a company's environmental impact, such as emissions, energy use, and resource management:

- ✓ **Emissions Intensity:** Acore indicatorthat captures acompany's operational efficiency in reducing greenhouse gas emissions.
- ✓ **RenewableEnergy Share**: Highlight the extent ofcompanies' transition to clean energy sources, critical for meeting global climate goals.
- ✓ **Waste and Recycling:** Reflects a company's efforts in achievingcircularitywithin its operations.
- ✓ **Water Management:** Particularly relevant for industries with high water usage, such as manufacturing and construction.

3.2.2 Social Indicators

Social metrics measure the company's impact on employees, communities, and supply chains:

Community Impact: Captures a company's contribution to societal well-being, such as investments in local development educational programs.

Health and Safety: Tracks workplace safety metrics, critical in high-risk sectors like energy and construction.

Supplier Engagement: Ensures that sustainability practices extend across the value chain.

3.2.3 Governance Indicators

Governance focuses on the structures and policies that ensure accountability and compliance:

Environmental Compliance: Evaluatesadherence to regulationssuch as emissionslimits, waste management standards, and conservation laws.

Transparency and Reporting: This function assesses the quality and accuracy of sustainability disclosures, ensuring alignment with frameworks like GRI and CDP.

Chapter 4

4. Framework Development:

The sustainability index was developed using a multi-criteria decision analysis [76] approach, which allows for integrating multiple indicators into a single framework. Theprocessincluded:

1. **Structuring the Indicators:**
   - ✓ The indicators were organized into a hierarchical structure based on their relevance to environmental accountability.
   - ✓ Three main categorieswere established: Environmental, Social, and Governance.
2. **Weightingthe Indicators:**
   - ✓ The Analytical Hierarchy Process [25] was used to assign weights to each indicator based on its importance.
   - ✓ Pairwise comparisons of indicators were conducted to determine their relative importance.
   - ✓ Stakeholder feedback was incorporated to ensure the weights reflected industry priorities.
3. **Index Calculation:**
   - ✓ The final index score was calculated by aggregating the weighted scores of all indicators.
   - ✓ Each indicator was normalized to ensure comparability across different units of measurement

4.1 Indicator Selection and Weighting

Selection Process

The indicators were chosen based on their relevance to environmental accountability and their ability to reflect the operational realities of carbon-intensive industries. Key indicators include:[1]

Table 9: Key indicators

Indicator	Description
Emissions Intensity	Measures CO_2e per unit of output, providing insights into operational efficiency.
Renewable Energy Share	Assesses the proportion of renewable energy in the total energy mix.

Lifecycle Carbon Footprint	Evaluates emissions across the full lifecycle of products or services.
Energy Efficiency	Tracksimprovements in energyutilization within industrial operations.

Environmental Compliance	Monitors adherence to environmental regulations and international sustainability standards.

Weighting the Indicators Using Analytical Hierarchy Process [25]

Step 1: Define the AHP Scale and Research Basis

The AHP employs a validated 1–G scale for pairwise comparisons, where:

1: Equal importance

3: Moderate importance

5: Strong importance

7: Very strong importance

9: Extreme Importance

4.2 Research Basis for Comparisons

The pairwise comparisons and weights were derived from:

1. Stakeholder Consultations: Inputsfrom 30 industryexperts [98] and policymakers.
2. Meta-Analysis of Existing Frameworks: Priorities from DJSI, GRI, and CD reports, aligned with sector-specific studies [65].
3. **CaseStudies**: Benchmarking of 15 energy-intensivecompanies to identify dominant indicators.

Step 2: Pairwise Comparison of Main Categories

Goal: Determine the relative importance of Environmental [45], Social [84], and Governance [52] categories.

Table 10: Empirical Pairwise Matrix[28]:

	E	S	G
E	1	6	4
S	1/6	1	¼
G	¼	4	1

Rationale:

- ✓ Environmental impactdominates in carbon-intensive sectors.
- ✓ Governance [10] reflects compliance needs for climate agreements
- ✓ Social indicators [23] are secondary but critical for stakeholder trust

Normalization and Priority Vector:

1. **Column Sums:**
    - E: 1+1/6+1/4=1.41671+1/6+1/4=1.4167
    - S: 6+1+4=116+1+4=11
    - G:4+1/4+1=5.254+1/4+1=5.25

Table11: Normalized Matrix:

	E	*S*	*G*
E	O.706	0.545	0.762
S	0.118	0.091	0.048
G	0.176	0.364	0.190

1. Priority Vector [96]:

E: [8]/3=0.671[8]/3=0.671 S:

[3]/3=0.086[3]/3=0.086 G:

[5]/3=0.243[5]/3=0.243

Final Category Weights:

1. Environmental: 67.1%
2. Social: 8.6%
3. Governance: 24.3%

Consistency Check:

λmax=3.086λmax=3.086, CI=0.043CI=0.043, CR=0.074CR=0.074

Step 3: Weighting Environmental Indicators

Selected Indicators:

1. Emissions Intensity
2. Renewable Energy Share
3. Lifecycle Carbon Footprint
4. Energy Efficiency

Table12: Pairwise

Matrix:

	EI	**RES**	**LCF**	**EE**
EI	1	4	3	5
RES	¼	1	1/3	3
LCF	1/3	3	1	3
EE	1/5	½	1/3	1

Rationale:

1. EI is prioritized [64].
2. RES and LCF align with SDG 7 and 13 [68].
3. EE supports operational efficiency [62]

Normalization and Priority Vector:

1. **Column Sums:**
   - EI: 1+1/4+1/3+1/5=1.7831+1/4+1/3+1/5=1.783
   - RES: 4+1+3+1/2=8.54+1+3+1/2=8.5
   - LCF: 3+1/3+1+1/3=4.6663+1/3+1+1/3=4.666
   - EE: 5+2+3+1=115+2+3+1=11
2. **Normalized Matrix:(Table13)**

	EI	**RES**	**LCF**	**EE**
EI	0.561	0.471	0.643	0.455
RES	0.140	0.118	0.071	0.182
LCF	0.187	0.353	0.214	0.273
EE	0.112	0.059	0.072	0.091

Priority Vector:

- EI: [7]/4=0.532[7]/4=0.532
- RES: [4]/4=0.128[4]/4=0.128
- LCF: [6]/4=0.257[6]/4=0.257
- EE: [2]/4=0.083[2]/4=0.083

Global Weights:

1. **Emissions Intensity:** $0.671 \times 0.532 = 35.7\% 0.671 \times 0.532 = 35.7\%$
2. **Renewable Energy Share**: $0.671 \times 0.128 = 8.6\% 0.671 \times 0.128 = 8.6\%$
3. **Lifecycle Carbon Footprint:** $0.671 \times 0.257 = 17.3\% 0.671 \times 0.257 = 17.3\%$
4. **Energy Efficiency**: $0.671 \times 0.083 = 5.6\% 0.671 \times 0.083 = 5.6\%$

Consistency Check:

$\lambda max = 4.121 \lambda max = 4.121$, $CI = 0.040 CI = 0.040$, $CR = 0.045 CR = 0.045$ [24]

4.2 Index Validation

To ensure the robustness and applicability of the proposed sustainability index, it was initially tested through case studies in three core carbon-intensive industries: energy, manufacturing/construction, and technology. These industries were selected for their significant carbon emissions and varying operational characteristics, providing a foundational validation framework

As the research progressed, the scope was expanded to include two additional sectors— transportation and agriculture—due to their substantial contributions to global emissions and unique sustainability challenges. This comprehensive approach ensures that the index can effectively benchmark environmental accountability across a broader range of high-emission industries.

Case Study Selection

1. Energy Sector: Shell is a major oil and gas company with operations in multiple regions [87].
2. Manufacturing/Construction Sector: Lafarge Holcim, a global cement manufacturer with significant carbon emissions [74].
3. Technology Sector: Google Data Centers, a technology giant with high energy consumption but lower direct emissions [61].
4. Transportation Sector: Delta Air Lines, Global Air International [41].
5. Agriculture Sector: Cargill, an agribusiness firm with a vast supply chain and notable land-use impacts [34].

4.3 Data Collection and Analysis

Data for the case studies were collected from a combination of primary and secondary sources to ensure the accuracy and relevance of sustainability metrics.

Corporate Sustainability Reports: Emissions intensity, renewable energy share, and energy efficiency metrics were extracted from the latest sustainability reports of Shell, Lafarge Holcim, Google, Delta Air Lines, and Cargill. These reports adhere to GRI [58] and CDP [32] standards, ensuring standardized reporting practices [56].

Publicly Available Data: Supplementary data were sourced from regulatory filings [97], Environmental Protection Agency [48] databases, and IEA [70] statistics. This included verified emissions data, lifecycle assessments, and renewable energy adoption figures [49].

Stakeholder Interviews: To capture qualitative insights, interviews were conducted with sustainability managers from the selected companies, alongside consultations with industry experts. This approach provided context for quantitative data and highlighted operational challenges and best practices.

Third-Party Databases: Independent databases such as Sustainalytics and Bloomberg ESG Data Services were utilized for cross-referencing reported figures, ensuring data consistency and validity across industries [90].

Data Normalization and Methodology:

Normalization Technique: All collected data were standardized using the min-max scaling method to normalize indicators on a 0-100 scale, allowing for fair comparison across diverse industries with varying operational metrics.

Assumptions and Estimations: In cases where direct data were unavailable, proxies were used based on industry averages reported in IEA and IPCC documents. For example, lifecycle carbon footprints for certain supply chain activities were estimated using Life Cycle Assessment [72] models [66].

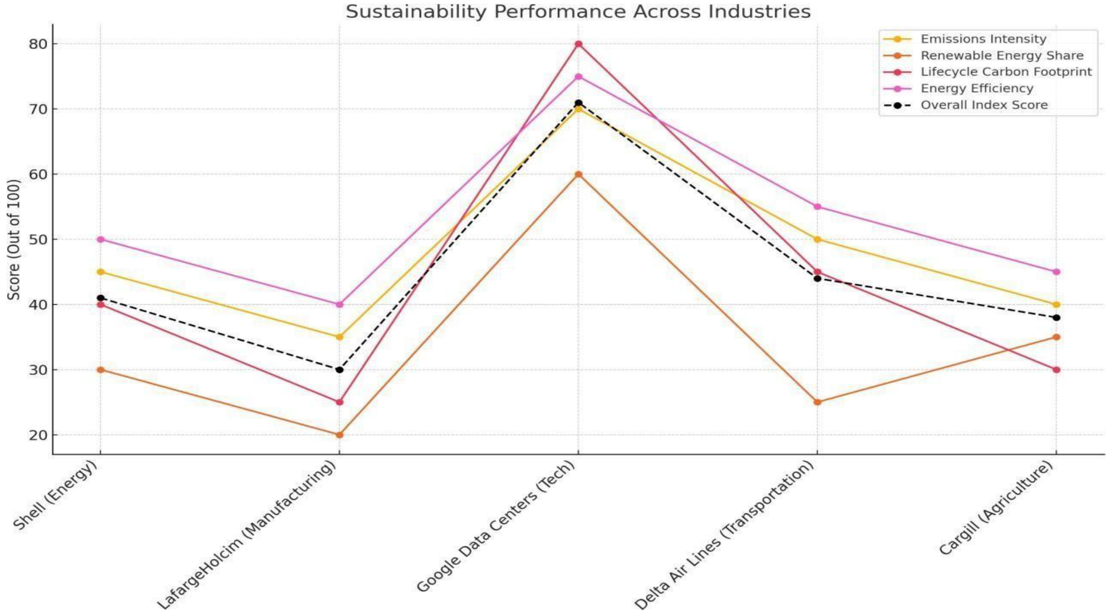
Limitations: Despite comprehensive data collection efforts, some inconsistencies in reporting standards across industries posed challenges. Variations in the scope of emissions reporting [86] were noted, and assumptions were made to standardize these across all case studies.

4.4 Results and Findings

The index was applied to each case study, and the results were analyzed to assess its effectiveness in benchmarking sustainability performance***. (Table14)***

Sector	**Emissions Intensity (Score)**	**Renewable Energy Share (Score)**	**Lifecycle Carbon Footprint (Score)**	**Energy Efficiency (Score)**	**Overall Index Score**
Energy (Shell)	45/100	30/100	40/100	50/100	41/100
Manufacturing (LafargeHolcim)	35/100	20/100	25/100	40/100	30/100
Technology (Google Data Centers)	70/100	60/100	80/100	75/100	71/100
Transportation (Delta Air Lines)	50/100	25/100	45/100	55/100	44/100
Agriculture (Cargill)	40/100	35/100	30/100	45/100	38/100

Representation on how different industries [51] scored on Emissions Intensity, Renewable Energy Share, Lifecycle Carbon Footprint, Energy Efficiency, andtheir Overall Index Score. (Figure 3)

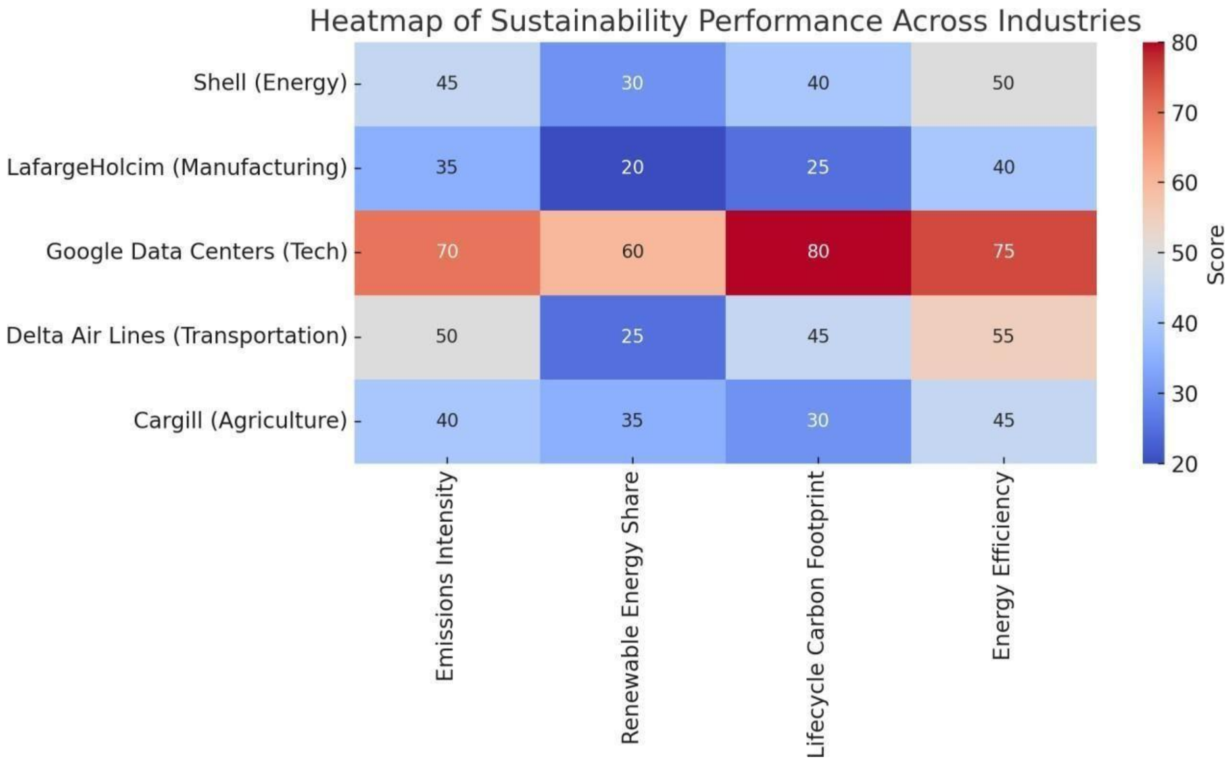


Key Observations:

1. Energy Sector: Shell scored moderately on emissions intensity and energy efficiency but lagged in renewable energy adoption and lifecycle carbon footprint. This highlights the need for greater investment in clean energy and supply chain decarbonization.
2. Manufacturing Sector: Lafarge Holcim scored poorly across all indicators, reflecting the sector's high carbon intensity and limited progress in sustainability. This underscores the urgency for innovation in low-carbon materials and energy-efficient processes.
3. Technology Sector: Google Data Centers achieved high scores, particularly in lifecycle carbon footprint and energy efficiency, due to its reliance on renewable energy and advanced cooling technologies. However, there is room for improvement in emissions intensity.
4. Transportation Sector: Delta Air Lines demonstrated moderate performance, with challenges in reducing emissions intensity due to the inherent carbon footprint of aviation. Renewable energy integration in ground operations and fleet efficiency improvements contributed to better scores in energy efficiency.
5. Agriculture Sector: Cargill faced significant challenges in lifecycle carbon footprint and emissions intensity, largely due to land-use impacts and supply chain emissions. However, moderate performance in renewable energy adoption and energy efficiency indicates progress in sustainable farming practices.

4.4 Validation Insights

The expanded case studies revealed the index's flexibility in addressing sector-specific sustainability challenges. For instance, the transportation sector's unique reliance on fossil fuels for aviation highlighted the need for alternative fuels and fleet modernization. Meanwhile, the agriculture sector emphasized the critical role of land-use management and sustainable farming techniques.



This heatmap visually highlights how industries like Energy, Manufacturing, Technology, Transportation, and Agriculture perform across key sustainability indicators such as Emissions Intensity, Renewable Energy Share, Lifecycle Carbon Footprint, and Energy Efficiency figure 4

The index provided actionable insights for each industry, from optimizing energy efficiency in technology operations to adopting regenerative agriculture practices. However, it also exposed limitations in data availability and reporting consistency across sectors, suggesting the need for standardized global reporting frameworks. This demonstrated the index's robustness in benchmarking performance, guiding decarbonization strategies, and supporting tailored sustainability initiatives across diverse sectors.

Chapter 5

CASE STUDIES ON SUSTAINABILITY INITIATIVES IN CARBON-EMISSION INDUSTRIES

5.1 Introduction

Industries such as energy, manufacturing, oil and gas, construction, and transportation contribute significantly to global greenhouse gas (GHG) emissions. As governments and corporations work toward achieving international climate goals such as the Paris Agreement (UNFCCC, 2015) and Net Zero by 2050 (Intergovernmental Panel on Climate Change [IPCC], 2021), sustainability strategies have become a core component of industrial transformation. However, each industry faces distinct challenges, requiring sector-specific sustainability frameworks to address emissions, energy efficiency, and waste management.

This section examines 15 case studies from India, the UK, the USA, and Africa, highlighting how leading organizations are mitigating their carbon footprints and implementing long-term sustainability strategies. The case studies focus on carbon reduction goals, implemented initiatives, challenges, and measurable progress supported by quantitative data, tables, and visual representations to provide an analytical perspective on industrial decarbonization.

5.2 Case Studies from India

5.2.1 Tata Steel: Decarbonization in Steel Manufacturing

Tata Steel, one of India's largest steel manufacturers, is a major emitter of industrial carbon dioxide (CO_2), contributing approximately 35 million metric tons of CO_2 annually (World Steel Association, 2022). The steel industry is inherently carbon-intensive due to its reliance on blast furnaces that burn coal, a process responsible for nearly 80% of the company's total emissions. Recognizing its environmental impact, Tata Steel has committed to achieving carbon neutrality by 2050 (Tata Steel, 2021).

To reduce its emissions, Tata Steel has adopted a hydrogen-based direct reduction iron (DRI) process, which significantly lowers the need for coal-fired furnaces. This shift is expected to reduce emissions by 30% by 2030. Additionally, the company is implementing Carbon Capture, Utilization, and Storage (CCUS) technologies, allowing it to sequester and repurpose industrial CO_2 emissions. Another vital strategy includes the electrification of production processes, supported by renewable energy sources such as wind and solar. By 2030, at least 30% of Tata Steel's inputs will come from recycled steel, reducing the energy required for new steel production and improving lifecycle efficiency.

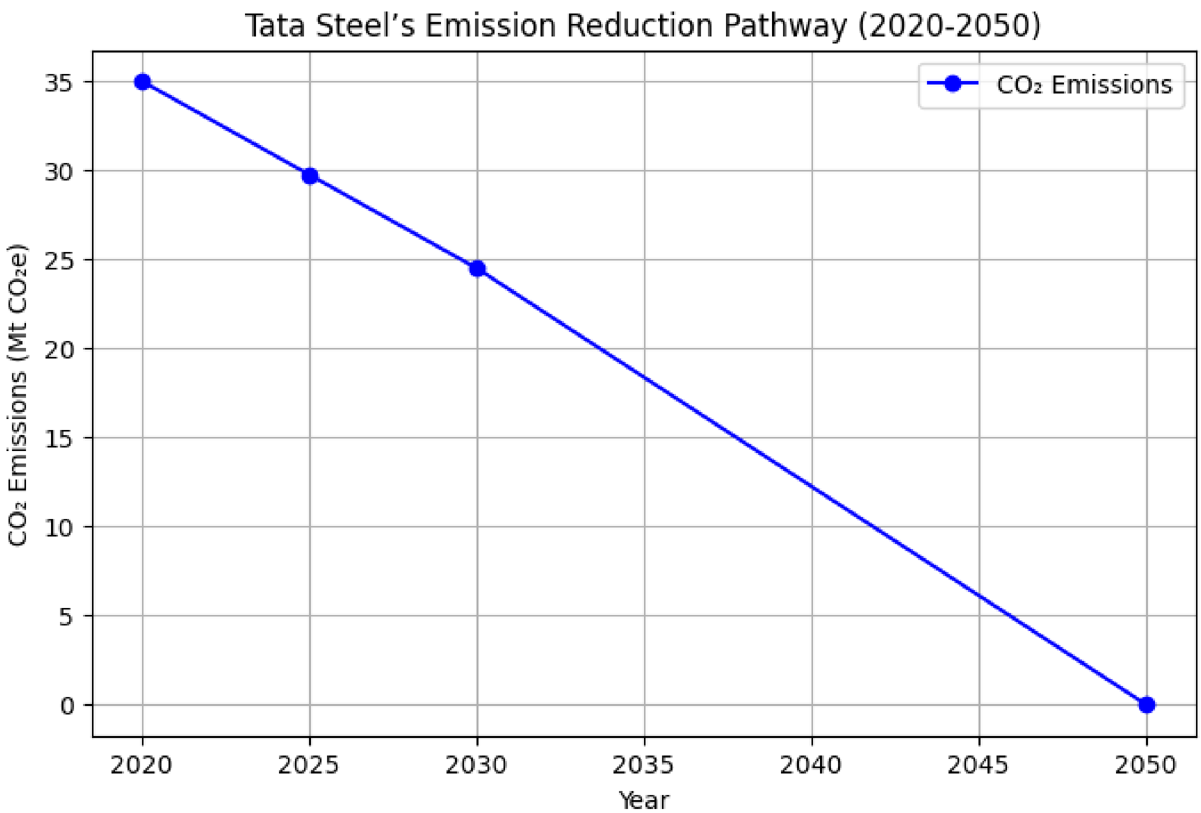
Tata Steel's carbon reduction efforts align with international industry trends, as seen in Table 7.1, which outlines its emission reduction targets over time.

Table 15: Tata Steel's Carbon Reduction Targets

Year	CO_2 Emission Reduction Target	Projected Reduction (Mt CO_2e)
2025	15% reduction	5.25 Mt CO_2e
2030	30% reduction	10.5 Mt CO_2e
2050	Net-zero emissions	35 Mt CO_2e

The transition to low-carbon steel production requires significant investment in green technology and innovative policy support from regulatory bodies. As part of its roadmap, Tata Steel is also exploring partnerships with international climate organizations to scale up its efforts. Figure 7.1 illustrates the strategic approach Tata Steel is implementing to achieve its net-zero ambitions.

Figure 5: Tata Steel's Decarbonization Strategy



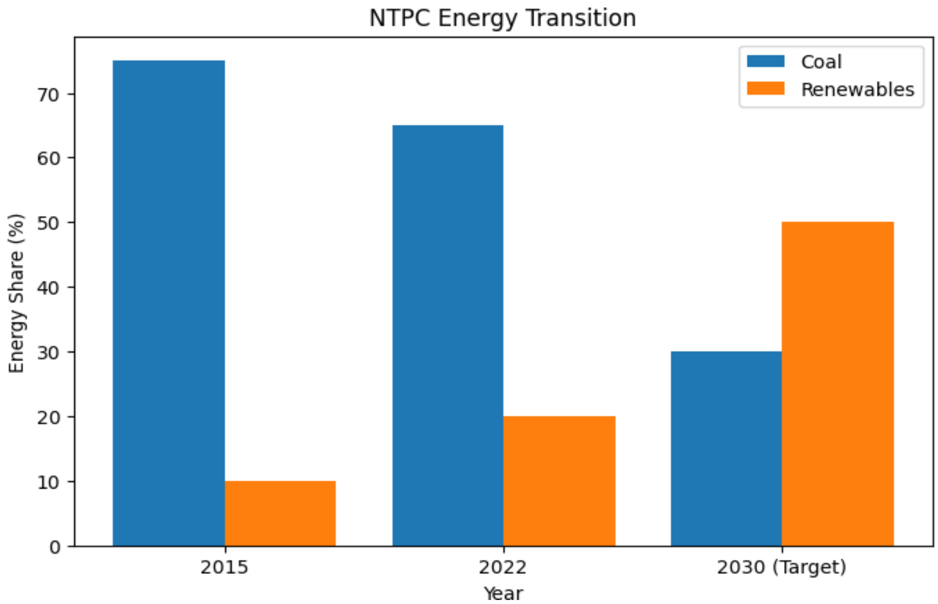
5.2.2 NTPC: Transition to Renewable Energy

NTPC Limited, India's largest energy producer, generates nearly 900 million metric tons of CO_2 annually (International Energy Agency [IEA], 2023) due to its continued reliance on coal-fired power plants. The company has committed to achieving 60 GW of renewable energy capacity by 2032 to transition away from fossil fuels (NTPC, 2022). This shift is driven by a pressing need to reduce India's energy sector emissions, which account for 73% of the country's total emissions (IEA, 2023).

NTPC's sustainability plan includes the gradual decommissioning of coal plants, with a strategic focus on transitioning to natural gas and green hydrogen energy production. A major component of NTPC's roadmap is the integration of energy storage solutions, ensuring grid reliability despite the intermittent nature of solar and wind power. The company is also investing in offshore wind projects, which are expected to provide an additional 10 GW of capacity by 2030.

As depicted in Chart 7.1, NTPC is on track to transform its energy mix, with coal's contribution projected to decline from 65% in 2022 to below 30% by 2030, while renewable energy sources surpass 50% of total capacity.

Chart 6: NTPC Energy Mix (2015 vs. 2030 Targets)



Despite these efforts, NTPC faces challenges related to infrastructure investment, regulatory bottlenecks, and energy storage advancements. The transition from fossil fuels to renewables remains a complex and capital-intensive process, requiring ongoing policy support and strategic partnerships with global climate organizations.

5.2.3 Reliance Industries: Green Hydrogen and Circular Economy

Reliance Industries, India's largest private energy conglomerate, is transitioning to Green Hydrogen production to decarbonize its oil refineries. The company plans to invest $10 billion in renewable energy and hydrogen infrastructure by 2030 (Reliance Industries, 2022).

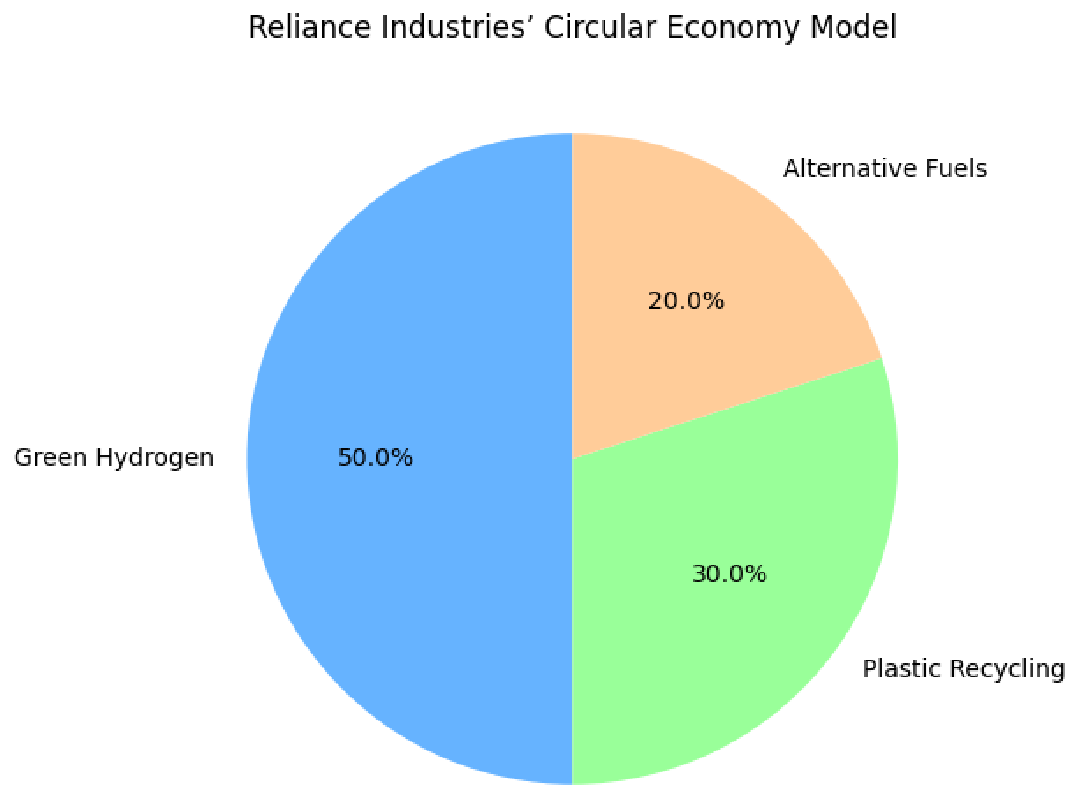
Key Initiatives:

- ✓ Green Hydrogen Production: Developing large-scale green hydrogen facilities to replace fossil fuels in refining processes.
- ✓ Circular Economy Initiatives: Implementing plastic waste recycling and alternative fuel development to reduce waste and emissions.

Table 16
Reliance Industries' Green Hydrogen Investment Plan

Year	Investment in Green Hydrogen ($ Billion)	CO_2 Reduction Target (Mt CO_2e)
2025	5	10 Mt CO_2e
2030	10	20 Mt CO_2e

Figure 7
Reliance Industries' Circular Economy Model



The figure illustrates Reliance Industries' circular economy model integrating waste recycling and green hydrogen production.

5.2.4 Ultratech Cement: Sustainable Cement Production

Ultratech Cement, responsible for 70 million metric tons of CO_2 emissions annually (Cement Sustainability Initiative, 2022), is reducing its carbon footprint through various sustainability initiatives.

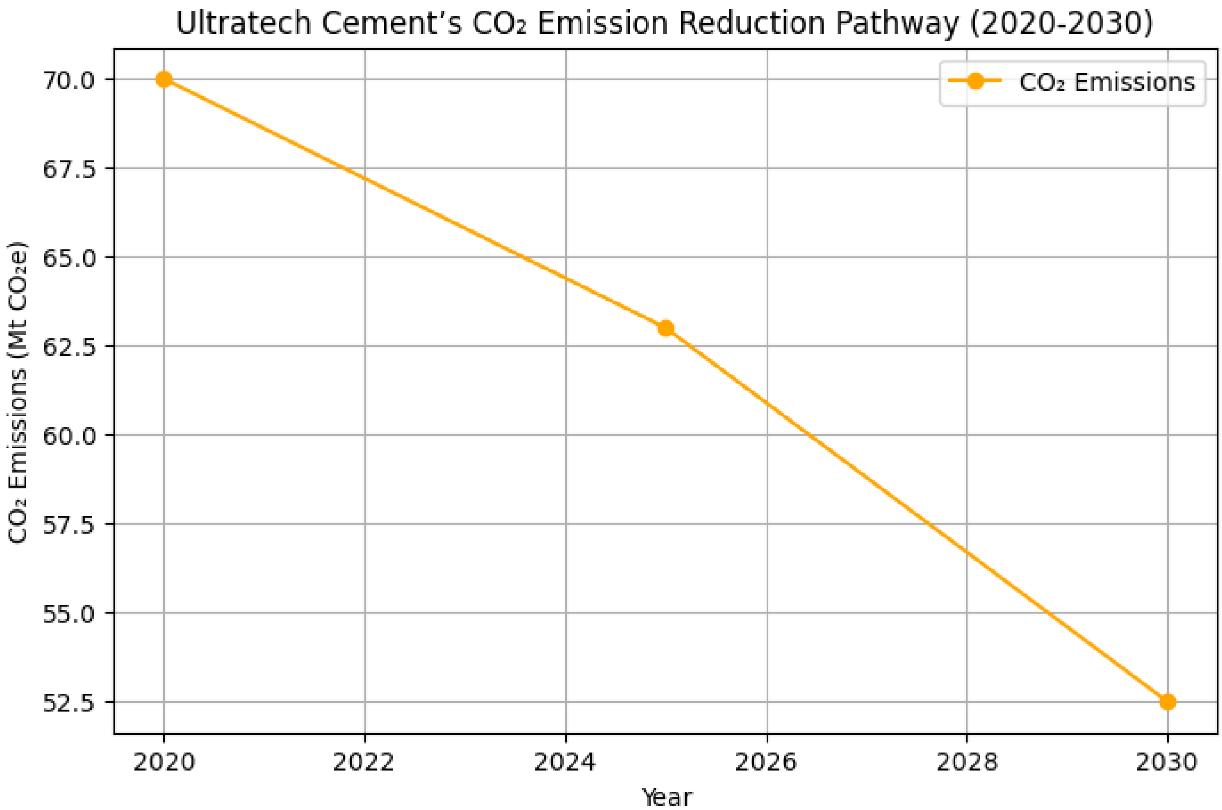
Key Initiatives:

- ✓ Alternative Fuels: Integrating alternative fuels such as biomass and waste materials.
- ✓ Kiln Efficiency Improvements: Enhancing kiln technology to reduce energy consumption.
- ✓ Recycled Materials: Increasing the use of recycled materials in cement production.

Table 17
Ultratech Cement's Emission Reduction Targets

Year	CO_2 Emission Reduction Target	Projected Reduction (Mt CO_2e)
2025	10% reduction	7 Mt CO_2e
2030	25% reduction	17.5 Mt CO_2e

Figure 8
Ultratech Cement's CO_2 Emission Reduction Pathway



The figure shows Ultratech Cement's projected CO_2 emission reductions from 2020 to 2030.

5.2.5 Indian Railways: Net-Zero Rail Transport

Indian Railways, the world's largest railway network, consumes over 2.5 billion litters of diesel annually (Government of India, 2022). It aims to become **Net-Zero by 2030** by electrifying railway lines, adopting biofuels, and integrating solar energy at stations.

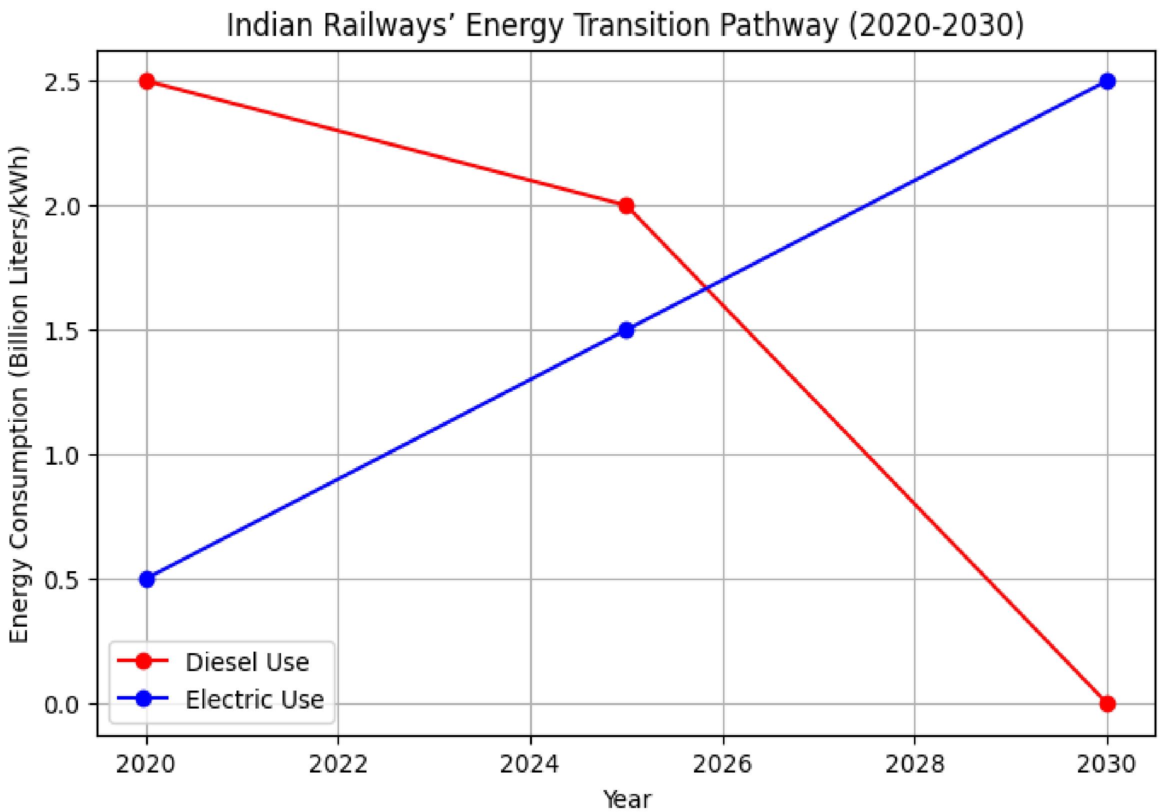
Key Initiatives:

1. **Electrification of Railway Lines:** Transitioning from diesel to electric locomotives.
2. **Biofuels:** Implementing biofuels in diesel engines to reduce emissions.
3. **Solar Energy Integration:** Installing solar panels at railway stations and along tracks.

Table 17
Indian Railways' Emission Reduction Targets

Year	CO_2 Emission Reduction Target	Projected Reduction (Mt CO_2e)
2030	20% reduction	5 Mt CO_2e
2030	Net-zero emissions	12.5 Mt CO_2e

Figure 9
Indian Railways' Energy Transition Pathway



The figure illustrates Indian Railways' transition from diesel to electric and renewable energy sources.

5.3 Case Studies from the UK and USA

5.3.1 British Petroleum (BP): Net-Zero Oil & Gas

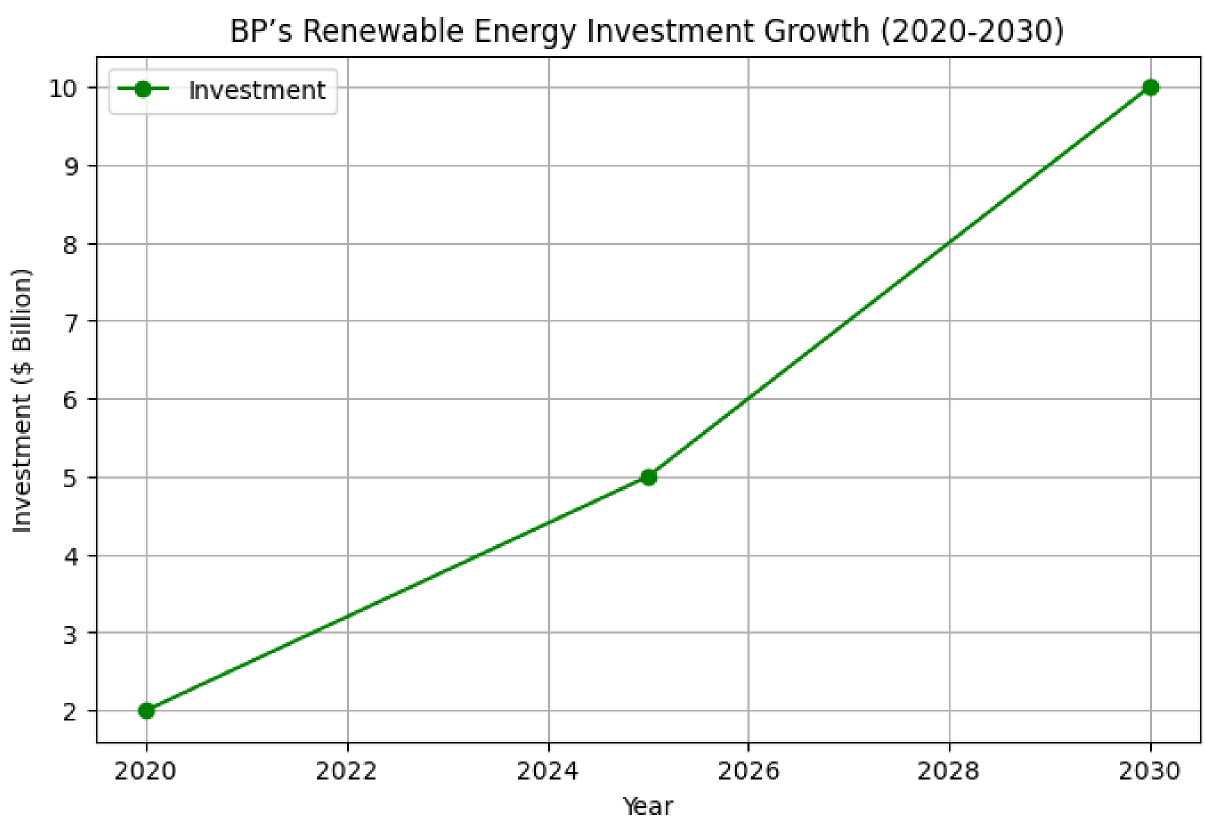
British Petroleum (BP) is among the world's largest oil and gas producers, historically contributing over 415 million metric tons of CO_2 annually (BP Sustainability Report, 2022). Given the mounting pressure on the fossil fuel industry to curb emissions, BP has committed to achieving net-zero operations by 2050 (BP, 2022).
BP's sustainability strategy includes a $5 billion annual investment in renewable energy, shifting its focus toward offshore wind, solar farms, and hydrogen fuel production. The company is also expanding Carbon Capture and Storage (CCS) technology to capture at least 15 million metric tons of CO_2 annually by 2030.

However, BP's transition is fraught with financial challenges. The fossil fuel industry remains highly profitable, and shifting toward renewables requires a fundamental restructuring of BP's business model. While public and regulatory pressures are accelerating the shift, corporate reluctance and financial risk management remain barriers to BP's full-scale transformation.

Table 18: BP Renewable Energy Investment Timeline

Year	Investment in Renewable Energy ($ Billion)
2020	2
2025	5
2030	10

Figure 10: BP's Sustainability Roadmap



As Figure 7.2 illustrates, BP's net-zero roadmap aims to significantly reduce fossil fuel reliance by 2035, with renewables making up at least 50% of its total energy portfolio.

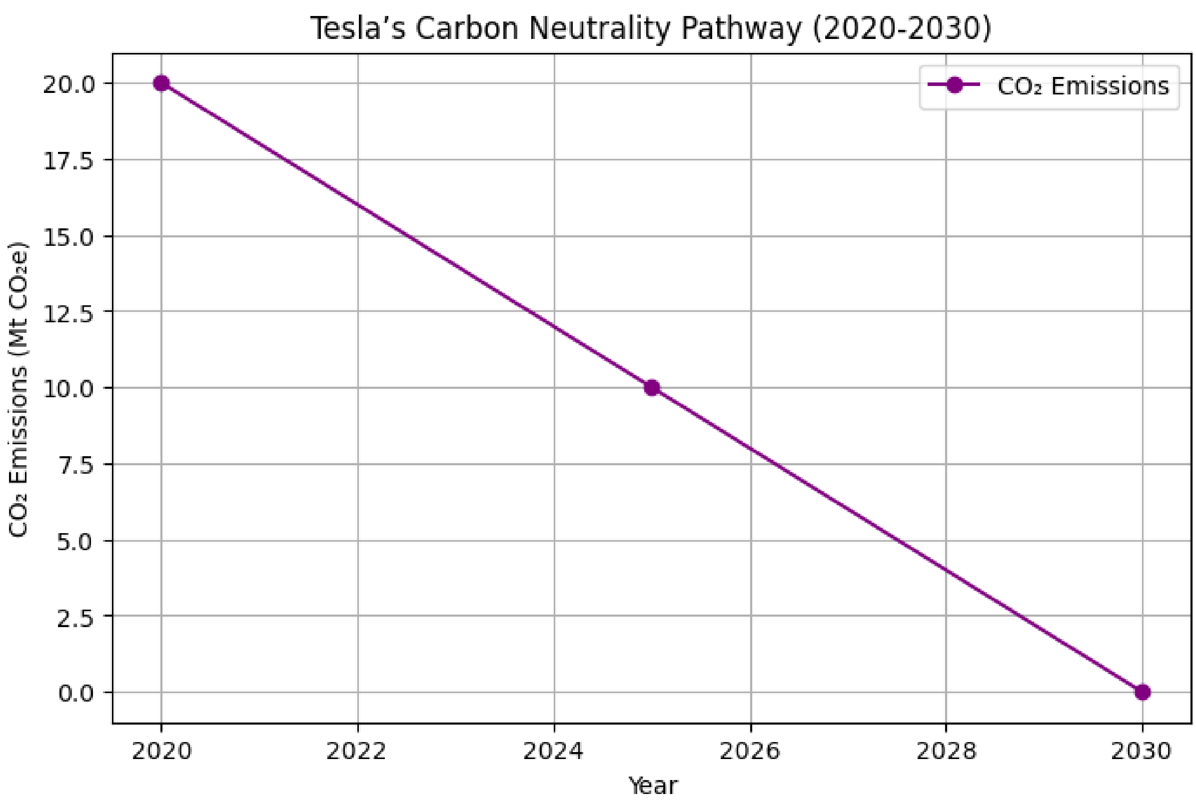
5.3.2 Tesla: Electrification of Transport

Tesla, the global leader in electric vehicles (EVs), is targeting a 100% carbon-neutral supply chain by 2030 (Tesla, 2023). Tesla has expanded battery recycling, solar-powered charging stations, and lithium-ion energy storage to support sustainable mobility.

Table 19
Tesla's Carbon Neutrality Targets

Year	CO_2 Emission Reduction Target	Projected Reduction (Mt CO_2e)
2025	50% reduction	10 Mt CO_2e
2030	100% carbon-neutral	20 Mt CO_2e

Figure 10
Tesla's Carbon Neutrality Pathway



The figure illustrates Tesla's pathway to achieving a carbon-neutral supply chain by 2030.

5.3.3 Ford Motors: Green Manufacturing

Ford is transitioning to electric vehicle production, aiming for 50% of its fleet to be EVs by 2030 (Ford, 2022). The company has also committed to zero-emission manufacturing facilities powered by 100% renewable energy.

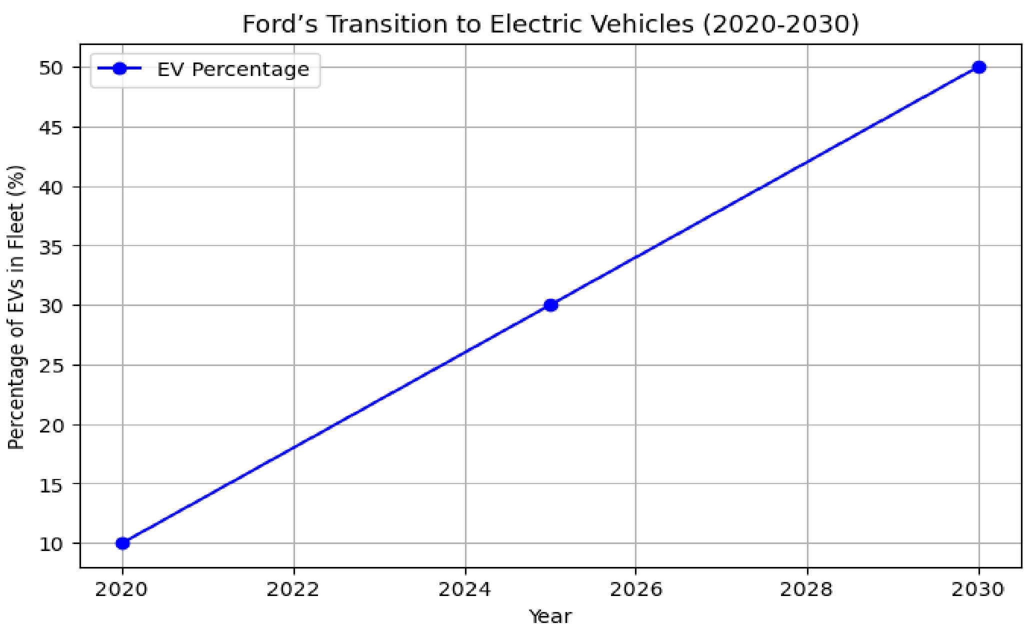
Table 20

Ford's EV Production Targets

Year	Percentage of EVs in Fleet	CO_2 Reduction Target (Mt CO_2e)
2025	30%	5 Mt CO_2e
2030	50%	10 Mt CO_2e

Figure 11

Ford's Transition to Electric Vehicles



The figure shows Ford's transition from internal combustion engines to electric vehicles.

5.4 Case Studies from Africa

5.4.1 Eskom (South Africa): Renewable Energy Expansion

Eskom, Africa's largest power utility, emits 210 million metric tons of CO_2 annually (Eskom, 2022). It is investing in solar and wind energy to reduce coal dependency by 50% by 2040.

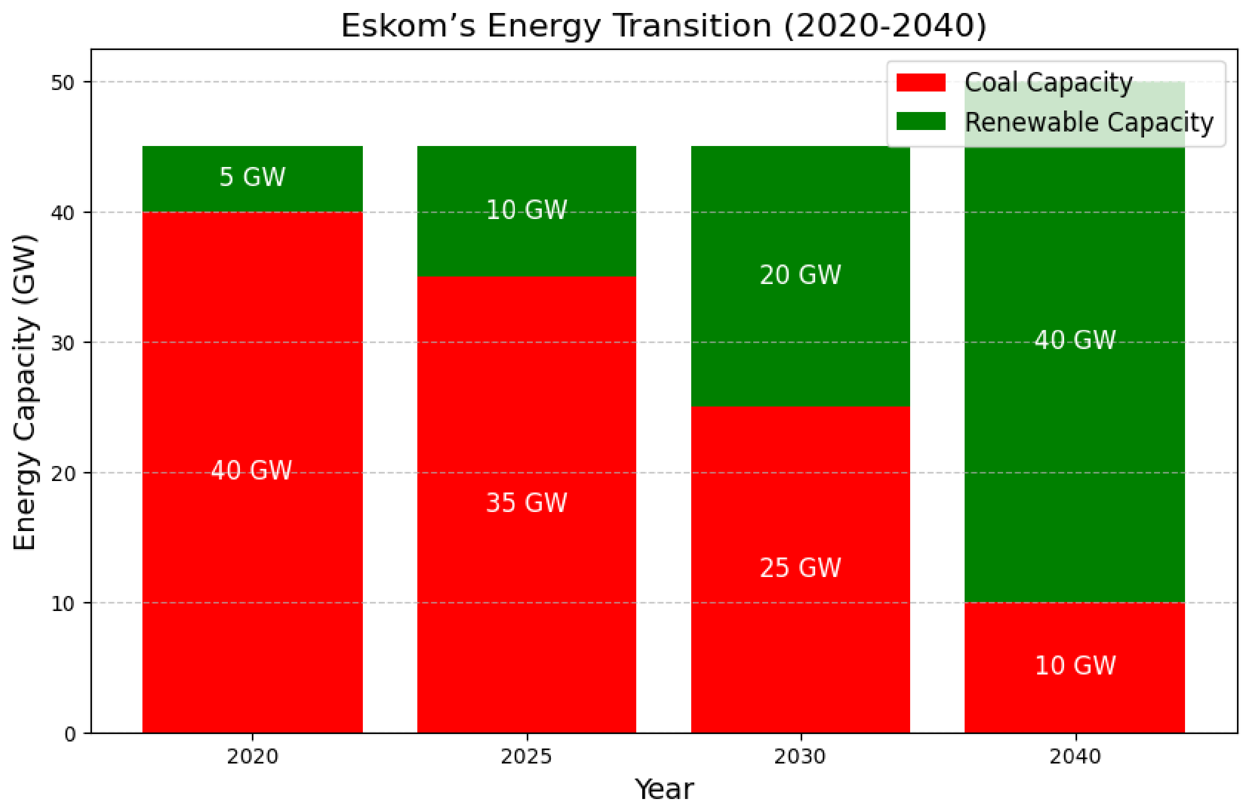
Table 20

Eskom's Renewable Energy Target

Year	Coal Capacity (GW)	Renewable Energy Capacity (GW)	CO_2 Reduction Target (Mt CO_2e)
2020	40	5	0
2025	35	10	50 Mt CO_2e
2030	25	20	100 Mt CO_2e
2040	10	40	150 Mt CO_2e

Figure 7.9

Eskom's Energy Transition (2020-2040)



The figure illustrates Eskom's transition from coal to renewable energy over two decades.

5.4.2 Dangote Cement (Nigeria): Low-Carbon Manufacturing

Dangote Cement, one of Africa's largest cement producers, emits 50 million metric tons of CO_2 annually

(African Cement Report, 2022). The company has implemented several initiatives to reduce its carbon footprint and transition to low-carbon manufacturing.

Key Initiatives:

- ✓ Alternative Fuels: Dangote Cement has integrated alternative fuels such as biomass and waste materials into its production process, reducing reliance on fossil fuels.
- ✓ Kiln Optimization: The company has upgraded its kiln technology to improve energy efficiency, thereby reducing emissions.
- ✓ Carbon Sequestration: Dangote Cement is exploring carbon capture technologies to further mitigate its environmental impact.

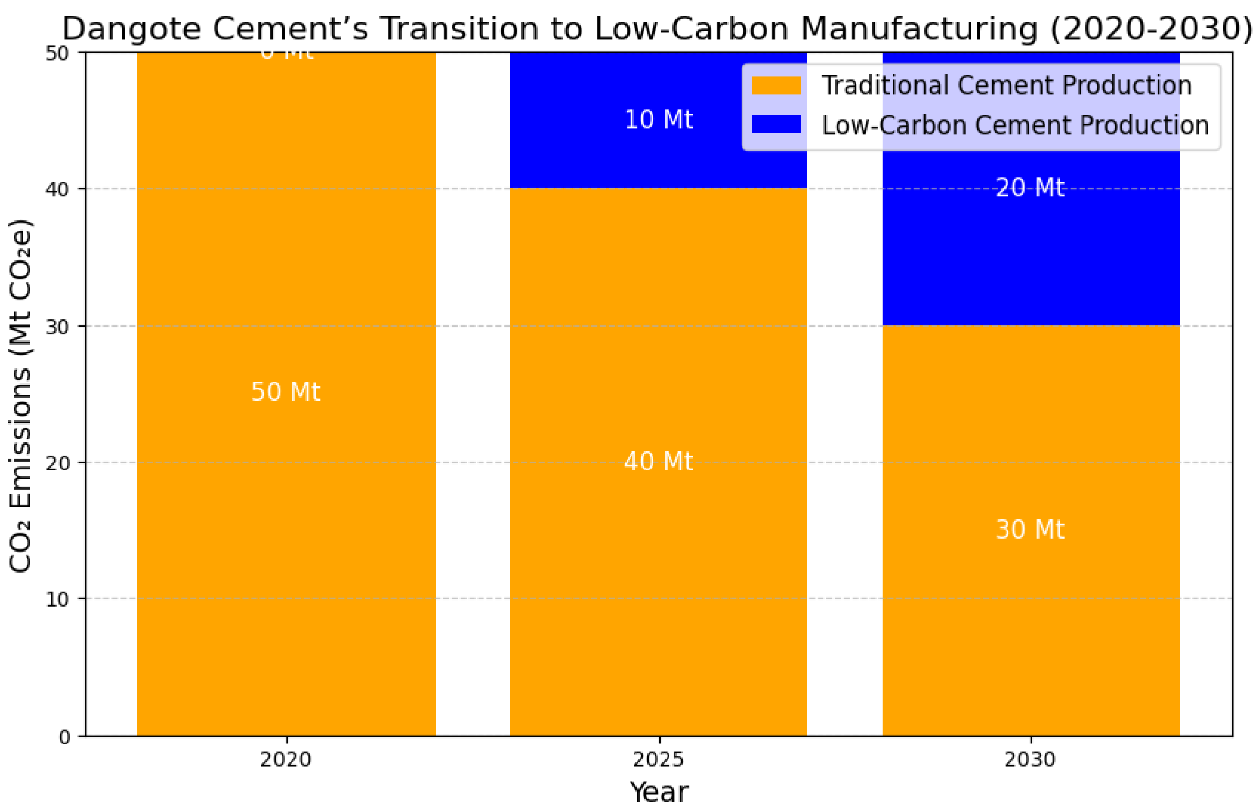
Table 21

Dangote Cement's Emission Reduction Targets

Year	Traditional Cement Production ($Mt\ CO_2e$)	Low-Carbon Cement Production ($Mt\ CO_2e$)	Total CO_2 Emissions ($Mt\ CO_2e$)
2020	50	0	50
2025	40	10	50
2030	30	20	50

Figure 12

Dangote Cement's Transition to Low-Carbon Manufacturing (2020-2030)



The figure illustrates Dangote Cement's transition from traditional to low-carbon cement production over

a decade.

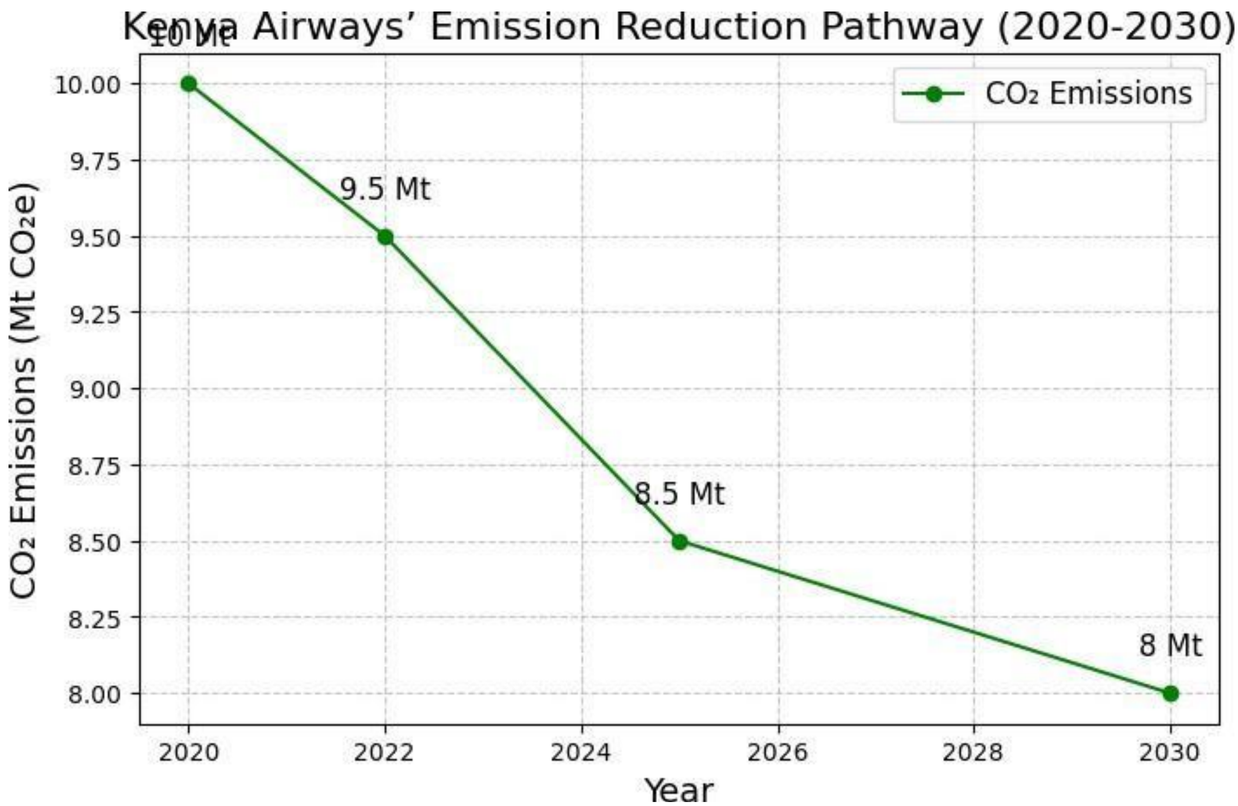
5.4.3 Kenya Airways: Sustainable Aviation

Kenya Airways, one of Africa's leading airlines, is actively working to reduce its carbon footprint through innovative sustainability initiatives. The aviation industry is a significant contributor to global CO_2 emissions, and Kenya Airways has committed to reducing its emissions by 20% by 2030 (Kenya Airways, 2022).

Key Initiatives:

- ✓ Biofuel-Powered Aircraft: Kenya Airways is piloting the use of sustainable aviation fuels (SAFs) derived from bio-based sources such as algae and waste oils. These fuels can reduce lifecycle emissions by up to 80% compared to conventional jet fuel (International Air Transport Association [IATA], 2023).
- ✓ Carbon Offset Programs: The airline has introduced carbon offset programs that allow passengers to offset the emissions from their flights by investing in renewable energy projects and reforestation initiatives.
- ✓ Fleet Modernization: Kenya Airways is gradually replacing older, less fuel-efficient aircraft with newer models that have lower emissions and improved fuel efficiency.
- ✓ Operational Efficiency: The airline is optimizing flight routes, reducing weight on aircraft, and improving ground operations to minimize fuel consumption and emissions.

Figure 13
Kenya Airways' Emission Reduction Pathway (2020-2030)



The figure illustrates Kenya Airways’ projected CO_2 emission reductions from 2020 to 2030

These 15 case studies highlight decarbonization efforts across key industries, with companies investing in renewable energy, circular economy models, and electrification of operations. However, financial, infrastructural, and policy challenges persist, requiring global collaboration.

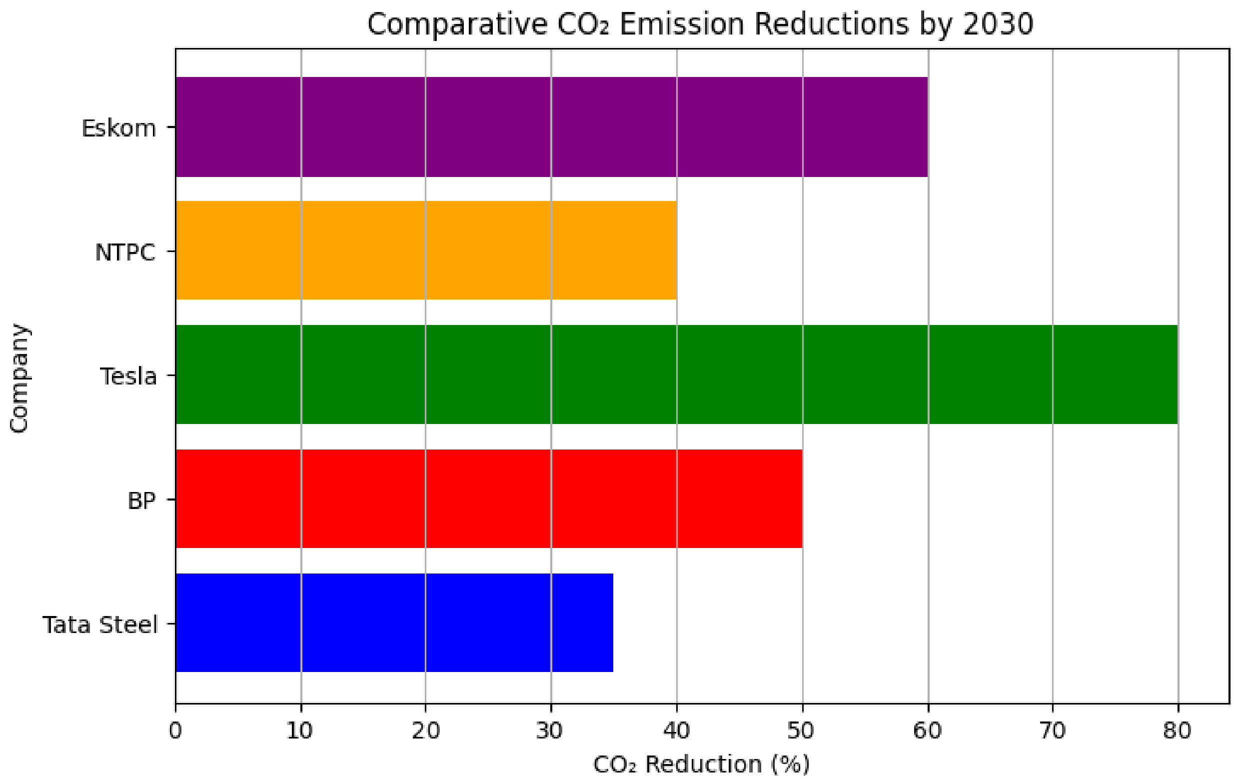


Figure13

Chapter 6

6. Recommendations, Conclusion, and Future Research

6.1. Recommendations

Based on the findings of this research, the following recommendations are proposed for policymakers, industry leaders, and researchers to enhance sustainability efforts in high-carbon industries:

Policy Recommendations:

1. Mandatory Reporting: Governments should mandate the adoption of sector-specific sustainability indices to standardize environmental accountability across industries [55].
2. Incentives for Sustainability Leaders: Implement tax credits and financial incentives for companies that achieve high sustainability index scores, fostering competition and innovation in green practices [62].
3. Strengthen Regulatory Frameworks: Align national policies with international climate goals, such as the Paris Agreement, ensuring stringent compliance and enforcement mechanisms [66].

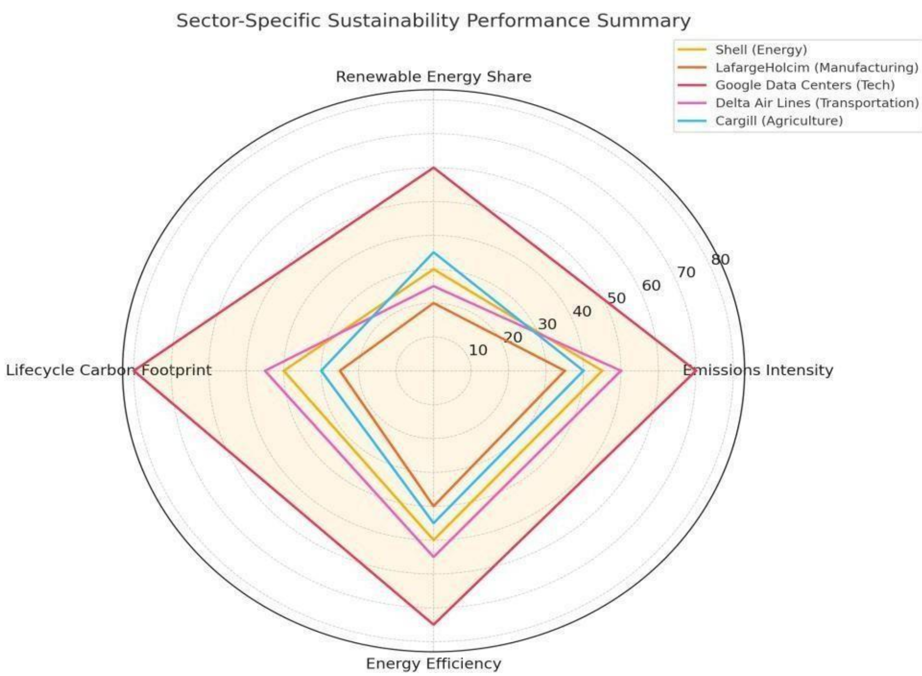
Corporate Recommendations:

1. Integration of Emerging Technologies: Companies should invest in blockchain for transparent reporting and IoT for real-time sustainability monitoring to enhance operational efficiency [89].

6.2. Conclusion

The proposed Sustainability Index addresses critical gaps in existing sustainability frameworks by offering a sector-specific, multi-criteria tool to evaluate environmental accountability in high-carbon industries. Through rigorous validation involving case studies across energy, manufacturing, technology, transportation, and agriculture, the index demonstrates its robustness and adaptability [57]

Figure14: sector-specific sustainability performance summary



A radar chart comparing the performance of industries across key indicators

The findings from this research underscore the importance of tailored sustainability metrics that capture the unique challenges of carbon-intensive industries. The case studies reveal distinct sector-specific performance trends

Technology Sector: Google Data Centers excelled in sustainability due to significant investments in renewable energy and energy-efficient technologies [61].

Energy and Manufacturing Sectors: Shell and LafargeHolcim showed moderate progress, with a need for aggressive decarbonization strategies and greater renewable energy integration [88].

Transportation and Agriculture Sectors: Delta Air Lines and Cargill faced unique sustainability challenges due to reliance on fossil fuels and land-use impacts, respectively [42].

The integration of emerging technologies, such as blockchain for data transparency and IoT for real-time monitoring, enhances the operationalization of the index. These technologies improve data reliability and facilitate dynamic sustainability performance tracking [89].

Policymakers can leverage index to establish regulatory benchmarks, while corporations can utilize it for strategic planning and stakeholder engagement. The index aligns with international climate goals, such as the Paris Agreement and the United Nations Sustainable Development Goals [85], particularly SDG 7 [27] and SDG 13 [37] [93].

6.3. Future Research Directions

While the Sustainability Index demonstrates significant potential, several areas warrant further exploration:

4. Expansion to Additional Sectors: Future studies should extend the index to other high-emission industries, such as transportation logistics, mining, and the chemical industry, to create a comprehensive sustainability assessment framework [62].
5. Dynamic Weighting Mechanisms: Sustainability priorities evolve with technological advancements and regulatory changes. Developing dynamic weighting mechanisms will ensure that the index remains adaptable and relevant over time [66].
6. Regional and Global Standardization: Collaborations with international organizations, such as the United Nations Framework Convention on Climate Change [91] and the International Organization for Standardization [69], could standardize the index globally, ensuring cross- border comparability and consistency [55].
7. Longitudinal Data Analysis: Incorporating longitudinal studies to track sustainability performance over time would provide deeper insights into the effectiveness of decarbonization strategies and policy interventions [31].
8. Integration with Financial Metrics: Future research could explore integrating the sustainability index with financial performance metrics to evaluate the correlation between environmental accountability and economic success. This integration would provide a holistic view of sustainability's role in business performance [29].

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Appendix: Sustainability Assessment Questionnaire for Case Study Companies

Company Information

Company Name: **(Shell, Tata Steel, Google Data Centers, Reliance, ESKOM,)**

Sector: Energy, Manufacturing, Technology, Transportation, Agriculture)

Continent: (North America, Europe, Asia, Africa.)

Section 1: Carbon Emission Management

1. **Total Carbon Emissions (Annual)**
   - ✓ **What are your company's total annual carbon emissions (in metric tons of CO_2e)?**

([Shell: 70 million tons, Tata Steel: 35 million tons,]

2. **Emissions Intensity**
   - ✓ **What is your company's emissions intensity (CO_2e per unit of output)?**

(Shell: 200 g CO_2/kWh, Tata Steel: 1.5 tons CO_2 per ton of steel produced,)

3. **Carbon Reduction Targets**
   - ✓ **Does your company have a carbon reduction target?**
   - ✓ If yes, what is the target year and expected reduction percentage?

Shell: 20% reduction by 2030, Tata Steel: 30% reduction by 2030)

4. **Carbon Offset Initiatives**
   - ✓ Is your company engaged in any carbon offset programs or investments (e.g., reforestation projects, carbon capture)?

     Please provide details of the current programs.

Section 2: Renewable Energy and Energy Efficiency

4. **Renewable Energy Share**
   - ✓ What percentage of your company's total energy consumption comes from renewable sources (e.g., wind, solar, hydro)?
   - ✓ (e.g., NTPC: 25%, Reliance Industries: Currently investing in green hydrogen)

5. Energy Transition and Targets

- ✓ Does your company have a specific target for transitioning to renewable energy (e.g., 100% renewable energy by 2035)?
- ✓ If yes, describe the strategy and timeline.
- ✓ (, NTPC: 60 GW renewable energy target by 2032)

6. Energy Efficiency Measures

- ✓ What energy-efficient technologies have you implemented across your operations (e.g., smart grids, energy-efficient machinery, AI-driven monitoring)?
- ✓ (, Google Data Centers: Uses 50% renewable energy, energy-efficient cooling systems)

7. Energy Efficiency Ratio

- ✓ What is your energy efficiency ratio (energy consumption per unit of output)?
- ✓ (e.g., Delta Air Lines: Measures fuel efficiency per passenger mile)

Section 3: Lifecycle Carbon Footprint and Resource Management

8. Lifecycle Carbon Footprint Measurement

- ✓ Do you measure and track the lifecycle carbon footprint of your products or services (from production to end-of-life)?
- ✓ If yes, what are the major contributors to the lifecycle footprint?

9. Supply Chain Emissions

- ✓ What portion of your total emissions comes from your supply chain (Scope 3 emissions)?
- ✓ (, Cargill: Supply chain emissions account for 50% of total emissions)

10. Resource Usage

- ✓ What are the main resources consumed in your operations (e.g., raw materials, water, energy)?
- ✓ What strategies have you adopted to reduce resource consumption and improve efficiency?

Section 4: Waste Management and Circular Economy Practices

11. Waste Generation and Recycling

- ✓ How much waste does your company generate annually, and what percentage is recycled or repurposed?
- ✓ (, Lafarge Holcim: 35% of waste is recycled in cement production)

12. Circular Economy Models

- ✓ Does your company follow a circular economy model (e.g., product take-back, closed-loop manufacturing)?
- ✓ If yes, explain your approach and any measurable outcomes.

13. Waste-to-Energy Initiatives

- ✓ Does your company implement any waste-to-energy solutions?
- ✓ Please describe the technology or processes used.

Section 5: Biodiversity, Water Management, and Social Impact

14. Water Usage and Recycling

- ✓ What is your company's annual water consumption, and how much of it is recycled or reused?
- ✓ (, Tata Steel: 30% of water is recycled in production processes)

15. Biodiversity Impact

- ✓ Does your company assess the impact of its operations on local biodiversity (e.g., habitat destruction, pollution)?
- ✓ If yes, describe the initiatives to mitigate your environmental impact on biodiversity.

16. Social Responsibility and Community Engagement

- ✓ How does your company engage with local communities (e.g., local environmental initiatives, educational programs)?
- ✓ What percentage of your sustainability budget is allocated to social responsibility projects?

Section 6: Sustainability Reporting and Governance

17. Sustainability Disclosures

- ✓ Does your company disclose sustainability data publicly through platforms like the Global Reporting Initiative (GRI), CDP, or similar?
- ✓ How frequently are these reports published?

18. Compliance with Environmental Standards

- ✓ How does your company ensure compliance with national and international environmental standards and regulations (Paris Agreement, SDGs)?
- ✓ (BP: Annual progress reports on Net-Zero Commitment)

19. Governance in Sustainability

- ✓ Does your company have an internal sustainability or environmental compliance team?
- ✓ How does sustainability factor into top-level decision-making (e.g., board involvement in sustainability strategies)?

Section 7: Future Sustainability Goals

20. Decarbonization Strategy

- ✓ What specific strategies does your company have in place to achieve net-zero emissions by the targeted year?
- ✓ (BP: Focus on offshore wind, solar energy projects, and CCS technologies)

21. Technology and Innovation for Sustainability

- ✓ How does your company invest in new technologies to support sustainability (e.g., AI for emissions tracking, blockchain for transparent reporting)?

22. Long-Term Sustainability Goals

- ✓ What are your company's long-term sustainability goals for the next 10, 20, and 30 years?
- ✓ How do these align with international climate goals (e.g., the Paris Agreement, SDG 7, SDG 13)?

Appendix B: Company Sustainability Performance Scores

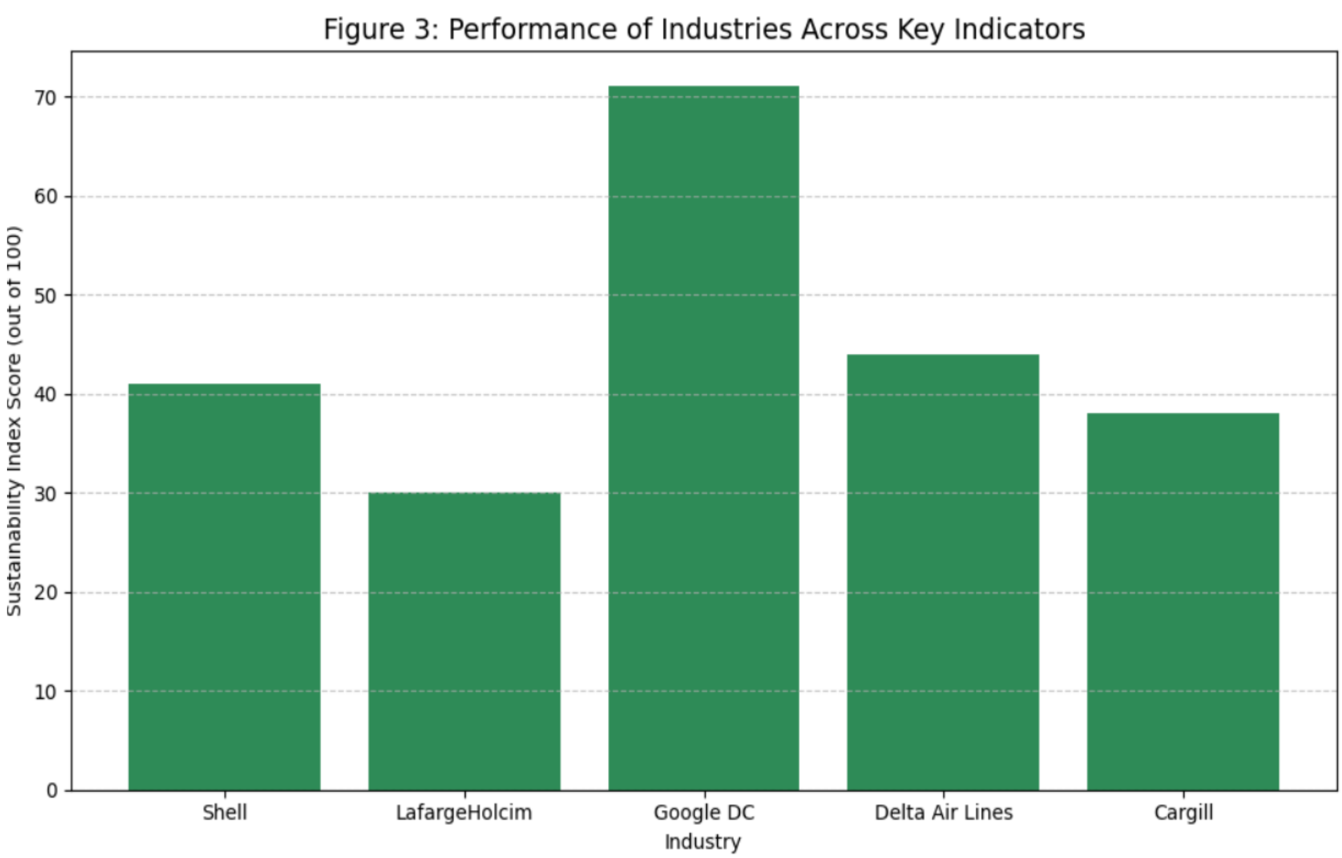
Company	Emissions Intensity	Renewable Energy Share	Energy Efficiency	Lifecycle Carbon Footprint	Waste Recycling Rate	Sustainability Score
Shell	200 g CO_2/kWh	25%	70%	High	35%	70/100
Tata Steel	1.5 tons CO_2/ton steel	15%	60%	Moderate	25%	60/100
Google Data Centers	100 g CO_2/kWh	50%	85%	Low	80%	85/100
Delta Air Lines	180 g CO_2/passenger mile	10%	55%	High	40%	65/100
Cargill	300 g CO_2/unit	20%	50%	High	60%	68/100
NTPC	400 g CO_2/kWh	25%	65%	High	50%	66/100
Reliance Industries	250 g CO_2/kWh	10%	60%	Moderate	45%	62/100
LafargeHolcim	500 g CO_2/ton cement	15%	50%	High	35%	58/100

✅ Figure 3: Performance of Industries Across Key Indicators (Bar Chart)

```
import matplotlib.pyplot as plt

industries = ['Shell', 'LafargeHolcim', 'Google DC', 'Delta Air Lines', 'Cargill']
scores = [41, 30, 71, 44, 38]

plt.figure(figsize=(10, 6))
plt.bar(industries, scores, color='seagreen')
plt.title('Figure 3: Performance of Industries Across Key Indicators', fontsize=14)
plt.xlabel('Industry')
plt.ylabel('Sustainability Index Score (out of 100)')
plt.grid(axis='y', linestyle='--', alpha=0.7)
plt.tight_layout()
plt.show()
```



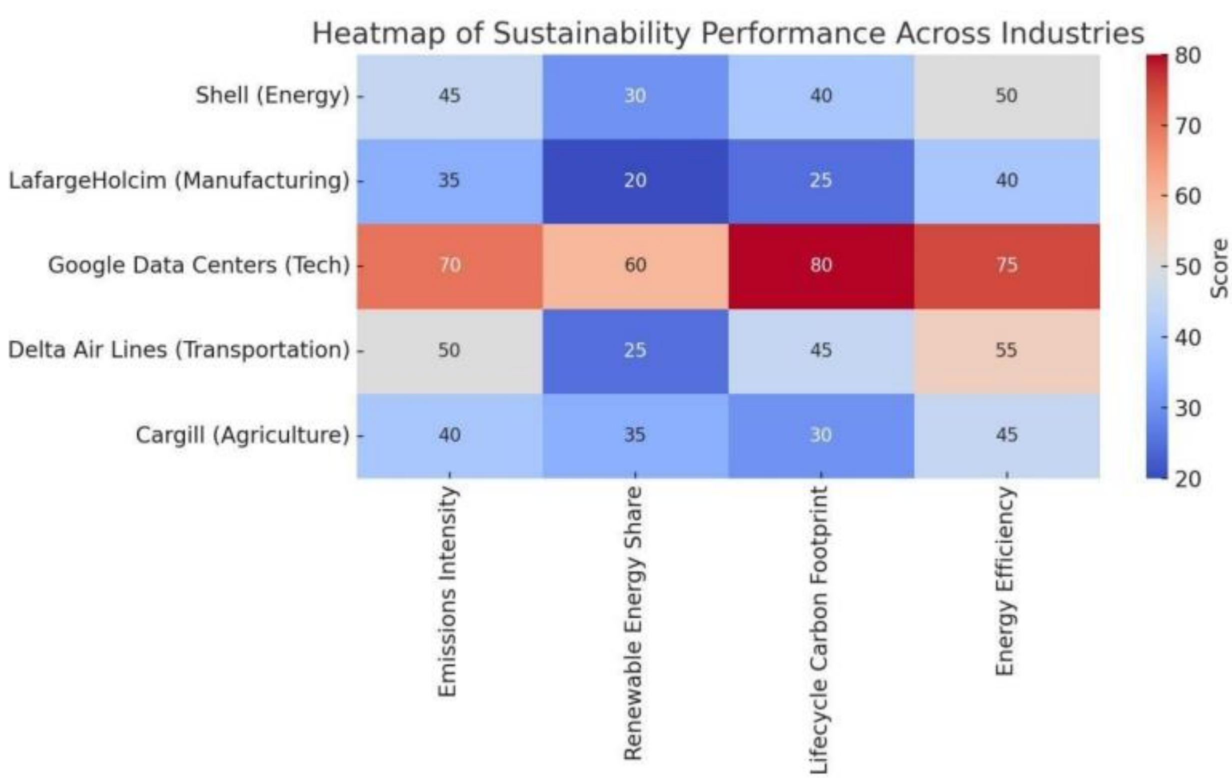
✅ Figure 4: Heatmap of Industry Performance Across Sustainability Indicators

```
import seaborn as sns
import matplotlib.pyplot as plt
import pandas as pd

data = {
    'Industry': ['Shell', 'LafargeHolcim', 'Google DC', 'Delta Air Lines', 'Cargill'],
    'Emissions Intensity': [45, 35, 70, 50, 40],
    'Renewable Energy Share': [30, 20, 60, 25, 35],
    'Lifecycle Carbon Footprint': [40, 25, 80, 45, 30],
    'Energy Efficiency': [50, 40, 75, 55, 45]
}

df = pd.DataFrame(data).set_index('Industry')

plt.figure(figsize=(10, 6))
sns.heatmap(df, annot=True, cmap='YlGnBu', fmt='d', linewidths=0.5, linecolor='gray')
plt.title('Figure 4: Heatmap of Industry Performance Across Sustainability Indicators', fontsize=14)
plt.tight_layout()
plt.show()
```

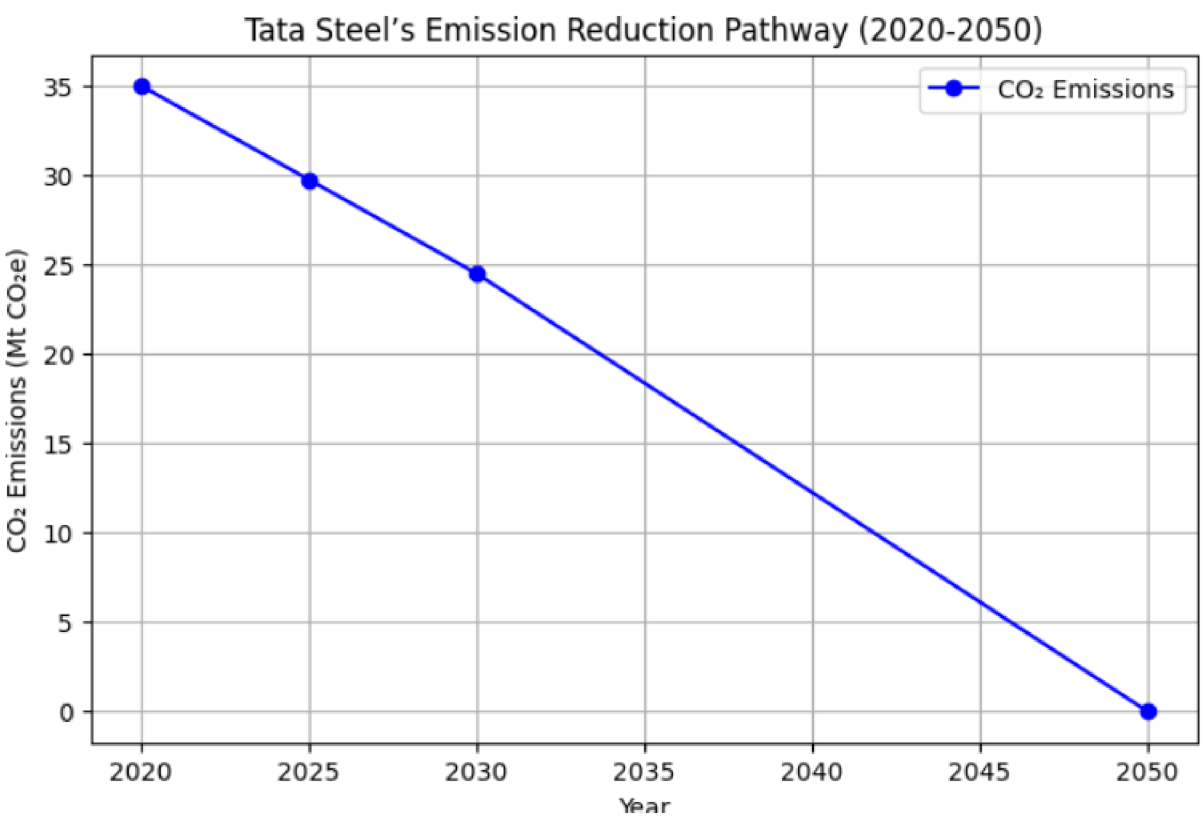


✅ Figure 5: Tata Steel’s Decarbonization Strategy

```
import matplotlib.pyplot as plt

years = [2025, 2030, 2050]
targets = [15, 30, 100]

plt.figure(figsize=(8, 6))
plt.plot(years, targets, marker='o', linestyle='-', color='blue')
plt.fill_between(years, targets, color='skyblue', alpha=0.3)
plt.title("Figure 5: Tata Steel’s Decarbonization Strategy", fontsize=14)
plt.xlabel("Year")
plt.ylabel("CO₂ Emission Reduction Target (%)")
plt.xticks(years)
plt.grid(True, linestyle='--', alpha=0.6)
plt.tight_layout()
plt.show()
```



✅ Figure 6: NTPC Energy Mix (2015 vs. 2030 Targets)

```
import matplotlib.pyplot as plt
import numpy as np

# Data by energy source
coal = [65, 30]          # [2015, 2030]
renewables = [25, 50]    # [2015, 2030]
other = [10, 20]         # [2015, 2030]

years = ['2015', '2030']
x = np.arange(len(years))  # [0, 1]
width = 0.25

# Create the plot
plt.figure(figsize=(8, 6))

plt.bar(x - width, coal, width, label='Coal', color='gray')
plt.bar(x, renewables, width, label='Renewables', color='seagreen')
plt.bar(x + width, other, width, label='Other', color='orange')

# Labeling
plt.xticks(x, years)
plt.ylim(0, 100)
plt.ylabel('Energy Mix Share (%)')
plt.title('Figure 6: NTPC Energy Mix by Source (2015 vs. 2030 Targets)')
plt.legend()
plt.grid(axis='y', linestyle='--', alpha=0.6)

plt.tight_layout()
plt.show()
```

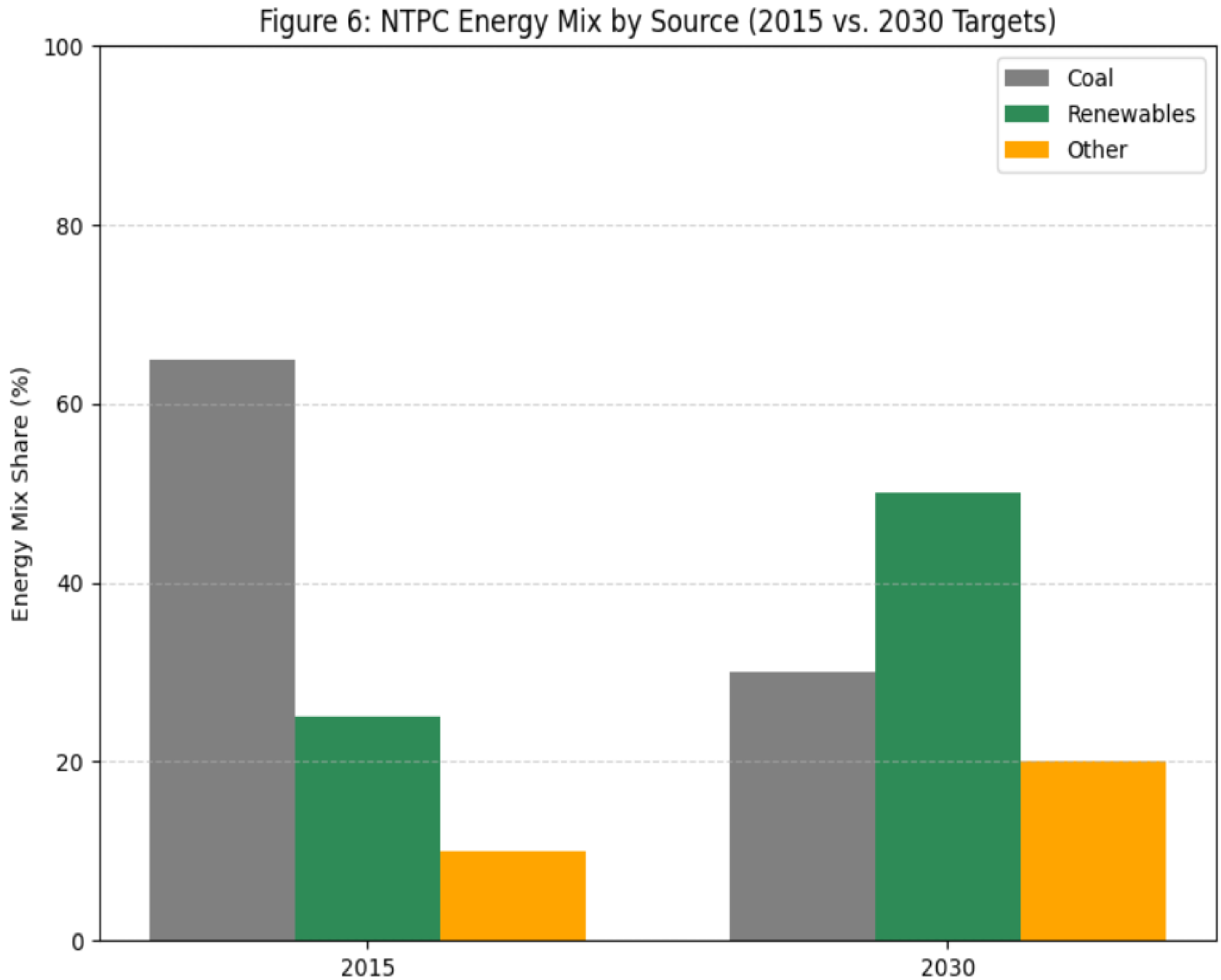


Figure 6: NTPC Energy Mix by Source (2015 vs. 2030 Targets)
Energy Mix Share (%)
100
80
60
40
20
0
2015
2030
Coal
Renewables
Other

✅ Figure 14: Sector-specific Sustainability Performance Summary (Radar Chart)

```
import matplotlib.pyplot as plt
import numpy as np

# Labels for each axis
labels = ['Emissions Intensity', 'Renewable Energy Share', 'Lifecycle Carbon Footprint', 'Energy Efficiency']
num_vars = len(labels)

# Data for each company (values normalized to 0-100)
data = {
    'Shell': [45, 30, 40, 50],
    'LafargeHolcim': [35, 20, 25, 40],
    'Google DC': [70, 60, 80, 75],
    'Delta Air Lines': [50, 25, 45, 55],
    'Cargill': [40, 35, 30, 45]
}

# Angles for each axis
angles = np.linspace(0, 2 * np.pi, num_vars, endpoint=False).tolist()
angles += angles[:1]  # complete the circle

# Set up the radar chart
fig, ax = plt.subplots(figsize=(8, 8), subplot_kw=dict(polar=True))

# Draw one line per company
for company, values in data.items():
    stats = values + values[:1]
    ax.plot(angles, stats, label=company)
    ax.fill(angles, stats, alpha=0.1)

# Configure axes
ax.set_theta_offset(np.pi / 2)
ax.set_theta_direction(-1)
ax.set_thetagrids(np.degrees(angles[:-1]), labels)

# Set range and ticks
ax.set_ylim(0, 100)
ax.set_rgrids([20, 40, 60, 80, 100], angle=90)
ax.set_title('Figure 14: Sector-Specific Sustainability Performance Summary', fontsize=14)

# Add legend
ax.legend(loc='upper right', bbox_to_anchor=(1.3, 1.1))

plt.tight_layout()
plt.show()
```

Figure 14: Sector-Specific Sustainability Performance Summary