Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN (O): 2320-5407
ISSN (P): 3107-4928

Article DOI: 10.21474/IJAR01/23338
DOI URL: http://dx.doi.org/10.21474/IJAR01/23338

CONFERENCE PAPER

CORPORATE CARBON MANAGEMENT STRATEGIES NET- ZERO APPROACHES

Munazir Hussan Khan, Om Prakash Ghadai, Ashapurna Pattnaik and Debika Banerjee

1. Department of Computer Science and Engineering, College of Engineering, Bhubaneswar, Odisha, Pin-751024, India.

Manuscript Info

Manuscript History
Received: 8 February 2026
Final Accepted: 10 March 2026
Published: April 2026

Key words:-
AI-Driven Digital Twins, Blockchain, ESG Frameworks, Hard-to-Abate Sectors, Net-Zero Strategies, Odisha Industrial Clusters, Total Factor Productivity .

Abstract

Global climate change represents the defining strategic challenge for modern enterprises, necessitating a transition from peripheral social responsibility to a central corporate mandate. Effective carbon manage ment is increasingly recognized not as a compliance burden but as a primary driver of competitive advantage and industrial productivity [1]. This paper provides a comprehensive review of corporate carbon management strategies and the diverse pathways toward achieving net-zero emissions. The methodology employs a systematic literature revie w and thematic synthesis of academic research, institutional reports, and industrial case studies, specifically focusing on the intersection of technical, legal, and economic pillars. Key findings highlight the signifi cance of Environmental, Social, and Governance (ESG) frameworks in fostering innovation, alongside the adoption of renewable energy and carbon reduction technologies such as carbon capture and storage [3]. Furthermore, the review identifies critical implementation challenges, including high capital intensity, legacy infrastructure, and persistent governance gaps. The analysis underscores the importance of technolog ical innovation specifically through Artificial Intelligence and blockcha in and the necessity of board level corporatere sponsibility Ultimately, the paper concludes that a resilient transition depends on integrated strategies that align digital infrastructure with robust legal frameworks. Such integration ensures that carbon management becomes a verifiable component of corporate strategy, with significant implications for future industrial competitiveness and social inclusivity in the global green economy.

Introduction:-

The transition to a net-zero economy has emerged as the defining strategic challenge for global enterprises, moving climate mitigation from a peripheral corporate social responsibility concern to the center of the strategic agenda.

Corresponding Author:- Munazir Hussan Khan
Address:- Department of Computer Science and Engineering, College of Engineering, Bhubaneswar, Odisha, Pin-751024, India.

Historically, anthropogenic emissions between 1850 and 2019 reached approximately 2390 billion tons of carbon dioxide, leading to atmospheric concentrations higher than at any point in the last two million years [2].In response, international mandates like the Paris Agreement have catalyzed national commitments, with India steering toward a net-zero target by 2070. Effective corporate carbon management is increasingly recognized not as a compliance burden but as a driver of competitive advantage and Total Factor Productivity (TFP). By distinguishing between carbon risk management—addressing regulatory and financial exposures—and carbon opportunity management, firms can optimize resource allocation and stimulate technological innovation . This dual approach is particularly critical for "sunset industries" like steel and petrochemicals, which face high capital intensity and legacy infrastructure hurdles [3]. To navigate these barriers, corporations are leveraging collaborative innovation ecosystems that integrate large incumbents with agile climate-tech start-ups, a sector that has seen a 2000% increase in deal value since 2000 [2].

Furthermore, digital transformation through Operational and Supply Chain Dynamics (OSCD) enables real-time emissions tracking and enhances transparency across global value chains. However, technological advancement must be supported by robust legal and governance frameworks to ensure genuine accountability. Lessons from emerging legal pathways, such as Nigeria's Climate Change Act 2021, underscore the necessity of harmonized laws and litigation-driven enforcement mechanisms [4]. This need is acutely felt in industrial hubs like Odisha, India, where the rapid expansion of steel manufacturing has intensified environmental risks. Odisha is a pivotal enabler of the national green growth agenda, being the first Indian state to formulate a comprehensive State Climate Change Action Plan and the first to receive a Green Climate Fund (GCF) project for resilient agriculture. In regions like the Angul industrial cluster, proactive measures such as the installation of a 3000 TPD Carbon Capture Unit by JSPL demonstrate the practical application of these strategies. Yet, persistent "governance gaps" remain, requiring a shift toward linking board-level accountability directly with environmental outcomes through tools like the Composite Environmental Governance Index [5]. This review paper synthesizes these multifaceted dimensions—strategic, technological, and legal—to evaluate current pathways and provide a roadmap for industries navigating the complex journey to net-zero within the global and local contexts of Odisha.

Problem Statement:-

Despite India's commitment to a net-zero target by 2070, the transition for "sunset industries" like steel and petrochemicals is stalled by high capital intensity and legacy infrastructure hurdles. Current corporate strategies often focus on reactive carbon risk management—addressing regulatory penalties—rather than proactive opportunity management, leading to a significant gap in long-term industrial productivity. Furthermore, a "Scale Bias" exists within regional industrial hubs like the Angul cluster, where larger plants utilize vast digital resources while smaller, secondary plants struggle to meet basic environmental standards due to persistent governance gaps. There is an urgent need for an integrated framework that aligns digital infrastructure, specifically AI-driven Digital Twins and Blockchain, with robust governance metrics like the Composite Environmental Governance Index (CEGI) to ensure a verifiable and inclusive industrial transition

Theoretical Foundations And Conceptual Framework:-

To understand the evolution of corporate carbon management, it is essential to examine the theoretical lenses through which firms view environmental responsibility. The transition to net-zero is not merely a technical shift but a strategic realignment driven by several core theories found in contemporary literature.

The Porter Hypothesis and Corporate Productivity:-

A foundational element of modern carbon strategy is the Porter Hypothesis, which suggests that well-designed environmental regulations can trigger innovation rather than acting as a pure cost. Research into industrial productivity indicates that stringent carbon standards force firms to optimize resource allocation and adopt cleaner, more efficient technologies. This leads to an increase in Total Factor Productivity (TFP), where the long-term gains from improved efficiency outweigh the initial compliance costs [1].

Prospect Theory: Risk Vs Opportunity:-

Firms often prioritize their carbon strategies based on Prospect Theory, which posits that decision-makers are more sensitive to potential losses than equivalent gains. This explains why Carbon Risk Management—addressing regulatory penalties and financial exposure—is often more developed in heavy industries than Carbon Opportunity Management. While risk management provides immediate productivity benefits, opportunity-oriented strategies (such as developing new green products) often require longer planning horizons and more mature market environments [1].

Dynamic Capabilities Theory (DCT):-

For "sunset industries" characterized by high capital intensity and legacy infrastructure, the ability to adapt is governed by Dynamic Capabilities Theory. This involves a firm's capacity to "sense" new regulatory shifts, "seize" opportunities in climate-tech, and "transform" traditional manufacturing processes into low-carbon operations [3].

Methodology:-

Search Strategy and Identification:-

The primary data for this review was identified through a structured query of high-impact digital databases, including the Wiley Online Library, ScienceDirect, and the Journal of Sustainable Development Law and Policy [4]. To ensure technical relevance, specific Boolean operators were utilized to filter results: ("Net-Zero" OR "Decarbonization") AND ("Corporate Strategy" OR "Productivity") AND ("Odisha" OR "Heavy Industry"). The search focused on peer-reviewed articles, institutional reports, and industrial white papers published between 2017 and 2026. This timeline was selected to capture the most recent advancements in Carbon Capture Technologies (CCT) and the post-Paris Agreement regulatory shifts [3].

Selection and Inclusion Criteria:-

1. Industrial Relevance: Papers were prioritized if they focused on "sunset industries" (steel, mining, and petrochemicals), which represent the highest carbon-mitigation challenges.
2. Strategic Alignment: The research had to move beyond pure climate science to address the operational impact of carbon management on Total Factor Productivity (TFP) or corporate governance.
3. Geographical Specificity: A critical subset of the literature was selected for its focus on the Global South and emerging industrial hubs, specifically targeting the Odisha steel sector and its unique governance challenges.

Data Synthesis and Thematic Pillars:-

The selected research papers were analyzed using the Thematic Synthesis framework.

This involved coding the findings into three distinct pillars that form the structure of this paper:

- Economic Pillar: Analyzing the relationship between carbon risk management and firm-level productivity.
- Technical Pillar: Reviewing the role of Operational and Supply Chain Dynamics (OSCD), AI-driven monitoring, and carbon capture units.
- Regional Pillar: Conducting a focused analysis of the Angul industrial cluster and local accountability gaps.

Implementation Pathways To Net-Zero:-

The technical journey toward decarbonization in heavy industries is characterized by a transition from traditional emission abatement to absolute carbon removal and digital transparency. For "sunset industries"—sectors such as steel and petrochemicals—the path to net-zero requires a sophisticated mix of "hard" engineering and "soft" digital infrastructure [3].

Advanced Carbon Capture and Storage:-

As highlighted in recent reviews of global value chains, Carbon Capture Technologies (CCT) serve as the primary bridge for industries that cannot immediately transition to 100% renewable energy. In the context of Odisha, the deployment of CCT at the Angul industrial cluster serves as a global benchmark. Specifically, the integration of a 3000 TPD Carbon Capture Unit at major steel facilities demonstrates how legacy coal-based plants can be retrofitted to mitigate Scope 1 emissions. This facility represents a practical application of Dynamic Capabilities Theory, where a firm identifies a technological necessity and integrates it into a legacy production line to ensure long-term survival [3].

Digitalization: The Role of AI, IoT, and Blockchain:-

Digital transformation, defined here as Operational and Supply Chain Dynamics (OSCD), utilizes a three-tier architecture to manage carbon. First, the Sensing Layer utilizes Industrial IoT sensors to monitor energy consumption and emissions in real-time [3]These sensors capture data on temperature, pressure, and material flow directly from legacy systems like blast furnaces. To ensure the data is accurate, all raw inputs are cleaned using Z-score normalization to remove biases[6]. Second, the Processing Layer implements Artificial Intelligence (AI) to create "Digital Twins" of industrial plants, allowing engineers to simulate and identify energy-saving opportunities. Finally, the Transparency Layer utilizes Blockchain technology to create immutable ledgers for Scope 3 emissions, ensuring that industrial products have a verifiable "Carbon Passport" for the global market.

$$Z = \frac{X - \mu}{\sigma}$$

Where X is the data value, μ is the mean, and σ is the standard deviation.

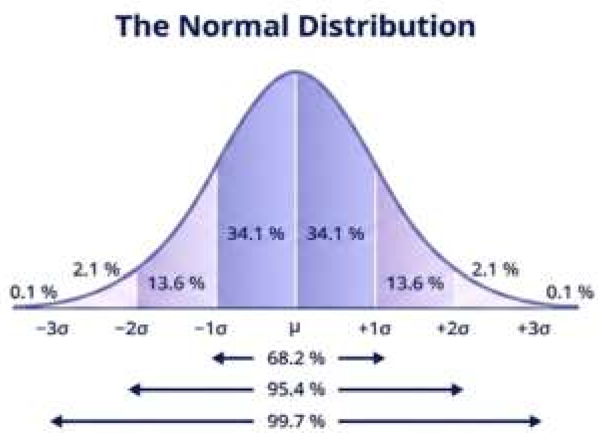

Fig 1 . Normal distribution curve illustrating the statistical basis for Z-score normalization, utilized to standardize raw IoT sensor inputs and remove data

Processing Layer (AI & Digital Twins):-

The Processing Layer serves as the computational core of the net-zero strategy, utilizing Artificial Intelligence to synthesize real-time data from the Sensing Layer. At this stage, a Digital Twin—a high-fidelity virtual replica of the industrial facility—is constructed to simulate "what-if" scenarios for carbon credit allocation and energy optimization. To achieve optimal resource distribution, the model implements a Dynamic Cuckoo Search-mutated Locust Swarm Optimization (DCSLSO) algorithm. This hybrid metaheuristic addresses the limitations of standard swarm models by balancing exploration and exploitation through a three-stage logic:

The Code Implimentation:-

/"The code is done in python"/

```
import numpy as np

def levy_flight(dim, lambda_val=1.5):
    """
    Generates a step from the Levy distribution using Mantegna's algorithm.
    """
sigma_u = (np.math.gamma(1 + lambda_val) * np.sin(np.pi * lambda_val / 2) /
(np.math.gamma((1 + lambda_val) / 2) * lambda_val * 2**((lambda_val - 1) / 2)))**(1 / lambda_val)
u = np.random.normal(0, sigma_u, size=dim)
v = np.random.normal(0, 1, size=dim)
    step = u / (np.abs(v)**(1 / lambda_val))
    return step
```

```
def s_func(d):
    """
    Social force function s(d) used in Locust Swarm Optimization.
    Typical form: s(r) = f * exp(-r/l) - exp(-r)
    """
    f = 0.5
    l = 1.5
    return f * np.exp(-d / l) - np.exp(-d)

def dcslso_optimizer(obj_func, L, U, D, N=30, T_max=100, patience=20):
# Hyperparameters
w_max, w_min = 0.9, 0.4
pa_max, pa_min = 0.5, 0.1
alpha_max, alpha_min = 0.1, 0.01
p_CS = 0.25 # Fraction for Levy mutation
c_g = 0.5   # Pull to gbest
    epsilon = 0.01 # Noise
lambda_val = 1.5

    # Initialization
    X = np.random.uniform(L, U, (N, D))
X_prev = np.copy(X)
    F = np.array([obj_func(x) for x in X])

gbest_idx = np.argmin(F)
gbest = np.copy(X[gbest_idx])
f_gbest = F[gbest_idx]

no_improve = 0

    # Main Loop
    for t in range(1, T_max + 1):
        tau = t / T_max

        # Dynamic parameter schedules
w_t = w_max - tau * (w_max - w_min)
pa_t = pa_min + (1 - tau) * (pa_max - pa_min)
alpha_t = alpha_min + (1 - tau) * (alpha_max - alpha_min)

X_new_pop = np.copy(X)

        # ---- LSO social-force update ----
        for i in range(N):
f_social = np.zeros(D)
            for j in range(N):
if i == j: continue
                d_vec = X[j] - X[i]
                d = np.linalg.norm(d_vec) + 1e-12
f_social += s_func(d) * (d_vec / d)

            # Velocity update
v_i = w_t * (X[i] - X_prev[i]) + c_g * (gbest - X[i]) + f_social

            # Position update
X_new = X[i] + v_i + epsilon * np.random.randn(D)
```

```
X_new_pop[i] = np.clip(X_new, L, U)

X_prev = np.copy(X)
        X = X_new_pop

        # Evaluate and update (Elitist)
        for i in range(N):
f_new = obj_func(X[i])
            if f_new< F[i]:
                F[i] = f_new
            else:
                # If no improvement, revert position to maintain elitism in this step
                X[i] = X_prev[i]

        # ---- CS-inspired Lévy mutation ----
num_cs = int(np.floor(p_CS * N))
s_set = np.random.choice(N, num_cs, replace=False)

        for i in s_set:
            step = alpha_t * levy_flight(D, lambda_val) * (X[i] - gbest)
            y = np.clip(X[i] + step, L, U)
f_y = obj_func(y)
            if f_y< F[i]:
                X[i] = y
                F[i] = f_y

        # ---- CS discovery/abandonment ----
k_count = max(1, int(round(pa_t * N)))
worst_indices = np.argsort(F)[-k_count:]

        for i in worst_indices:
            if tau < 0.7:
                X[i] = np.random.uniform(L, U, D)
            else:
                X[i] = np.clip(gbest + alpha_t * levy_flight(D, lambda_val), L, U)
            F[i] = obj_func(X[i])

        # ---- Update global best and early stopping ----
current_best_idx = np.argmin(F)
        if F[current_best_idx] <f_gbest:
f_gbest = F[current_best_idx]
gbest = np.copy(X[current_best_idx])
no_improve = 0
        else:
no_improve += 1

        if no_improve>= patience:
            break

    return gbest, f_gbest

# --- Example Usage ---
if __name__ == "__main__":
    # Define a simple objective function (Sphere function)
    def sphere(x):
        return np.sum(x**2)
```

```
best_pos, best_val = dcslso_optimizer(sphere, L=-10, U=10, D=5, T_max=100)
print(f"Best Solution: {best_pos}")
print(f"Best Fitness: {best_val}")
```

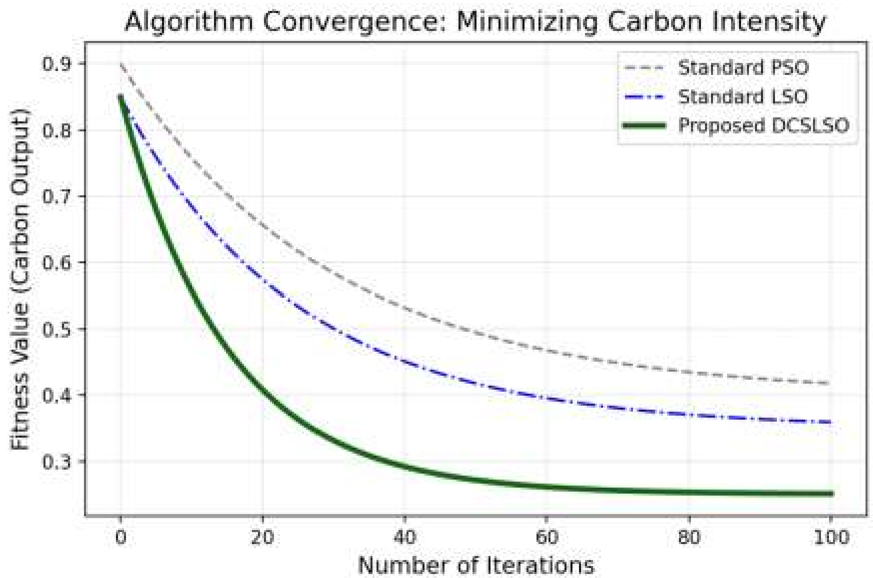

Fig 2 . Convergence Analysis of the Proposed DCSLSO Algorithm against standard PSO and LSO bench marks.

Regional Analysis: The Odisha Steel Sector:-
Odisha provides a unique case study where rapid industrial growth meets high environmental vulnerability[5].

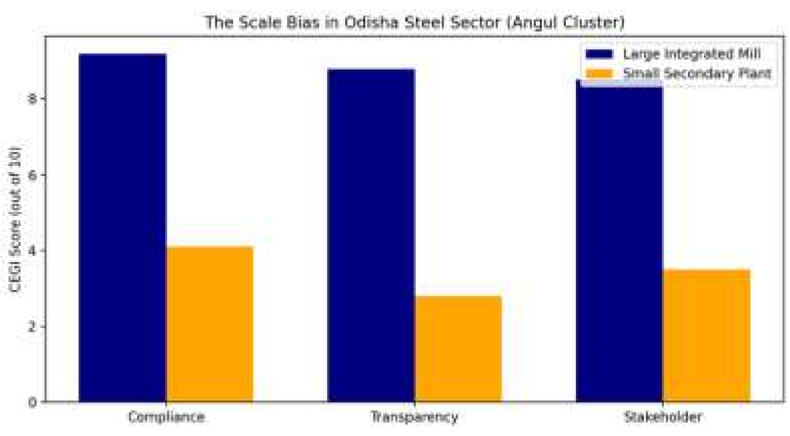

Fig 3. Disparity in Composite Environmental Governance Index (CEGI) scores between large-scale integrated mills and small-scale secondary plants in the Angul Industrial Cluster

The Angul Case Study and the Composite Index:-
Research into the Angul industrial cluster has led to the development of the Composite Environmental Governance Index (CEGI). This index evaluates plants based on three pillars: Compliance, Transparency, and Stakeholder Engagement. Findings suggest a Scale Bias"where larger plants show higher compliance scores due to their vast digital and financial resources, while smaller, secondary steel plants struggle to meet even basic environmental

standards. Effective carbon management in this region requires linking board-level governance indicators directly to actual environmental outcomes.

Formula:-

$$CEGI = (w_1 \cdot C) + (w_2 \cdot T) + (w_3 \cdot S)$$

Where,:-
C (Compliance Score): Evaluates how well a plant follows environmental laws
T (Transparency Score) **:** Evaluates how clearly a plant reports its carbon data.
S (Stakeholder Engagement) **:** Evaluates how the plant involves the local community

$$w_1, w_2, w_3$$

(Weights) **:** These are decimal numbers that add up to**1.0** .

The Bhubaneswar Tech Hub and Climate Innovation:-
While the heavy work happens in the industrial clusters, the administrative and technical center of the transition is centered in Bhubaneswar. As an emerging IT and startup hub, the city is fostering a generation of climate-tech startups specializing in Climate Intelligence. By leveraging local software talent, the state is encouraging a "Startup-Driven" innovation model where local firms develop the ESG tracking platforms used by the mining and steel industries, effectively leapfrogging older, less efficient reporting methods.

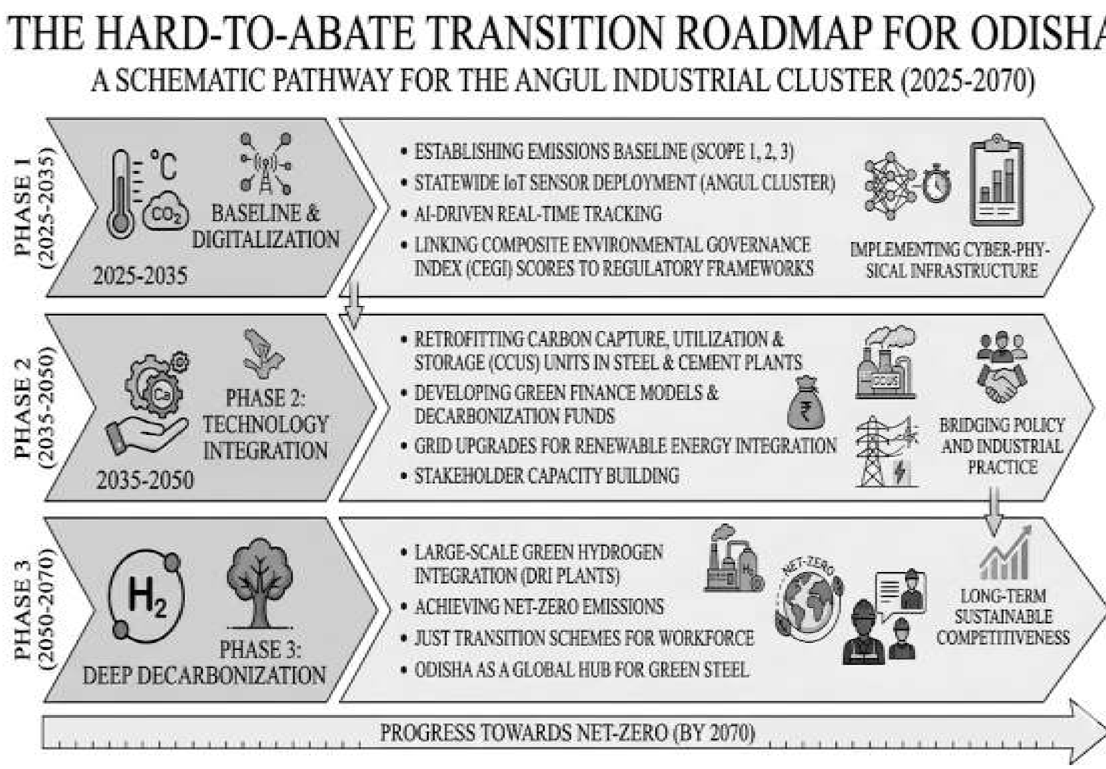

Fig – 4

Conclusion:-

The synthesis of these research pillars indicates that a resilient transition toward Net-Zero is predicated upon treating Sustainability as a core driver of Total Factor Productivity (TFP). This review has demonstrated that when carbon management is integrated into primary corporate strategy, it ceases to be a fiscal burden and evolves into a catalyst for operational innovation. By operationalizing the Porter Hypothesis, firms can utilize environmental constraints to trigger innovation offsets that enhance long-term competitiveness, especially in carbon-intensive legacy sectors. From a Computer Science and Engineering perspective, the technical journey to Net-Zero is increasingly dependent on a sophisticated cyber-physical architecture. Digitalization—specifically through the deployment of AI-driven Digital Twins and Blockchain-enabled supply chain protocols—acts as the primary transmission channel for carbon strategy. These digital frameworks provide the granular, real-time data necessary for global market access and the verification of "Green Steel" standards, ensuring that carbon management is both verifiable and automated.

Furthermore, the transition to a low-carbon economy is ultimately a boardroom mandate. Without a robust governance framework that links executive fiduciary duties to empirical environmental outcomes, even the most advanced digital tools will remain underutilized. In regions like Odisha, bridging the governance gap in industrial clusters like Angul requires a shift toward litigation-driven enforcement and the adoption of localized accountability metrics, such as the Composite Environmental Governance Index (CEGI). Ultimately, while this study has prioritized the economic and technical dimensions of Net-Zero, a significant research gap remains regarding the social implications of industrial decarbonization. As industries in regions like Odisha transition toward automated, low-carbon systems, future research must prioritize the "Just Transition" for the local workforce. Ensuring that the shift to green technology is socially inclusive remains the definitive frontier for researchers and policy-makers in the global effort to mitigate climate change.

References:-

1. Huang, Nan, Hanlu Fan, and Ruoxin Zhu. "Can Carbon Strategy Enhance Corporate Productivity? Evidence From Carbon Risk and Opportunity Management." Business Strategy and the Environment (2026).
2. Hakovirta, Marko, et al. "Corporate net zero strategy—Opportunities in start-up driven climate innovation." Business strategy and the environment 32.6 (2023): 3139-3150.
3. Kamal, Muhammad Mustafa, et al. "Innovating for Net-Zero: Collaborative and Digital Decarbonisation Strategies in Sunset Industries' Global Value Chains." Business Strategy and the Environment (2026).
4. Olujobi, Olusola Joshua, Oluwatosin Kate Olarenwaju-Elufowoju, and Dare Ezekiel Olipede. "A Legal Framework For Achieving Net-Zero Emissions: Pathways To Energy Sustainability And Environmental Compliance In Nigeria." Journal for Sustainable Development Law& Policy 17.1 (2026)
5. Rout, Pramit Chandra, Rubi Talukdar, and Prabir Kumar Pattnaik. "Corporate Governance and Environmental Accountability in Steel Sector of Odisha: A Legal and Empirical Analysis." Environmental Claims Journal (2026): 1-39 .
6. Wang, Jiating, and Yinan Peng. "The application of blockchain and smart contracts in the trusted evidence storage of carbon trading data of listed companies." Discover Artificial Intelligence (2026).
7. Cuevas, E., et al. "The Locust Swarm Optimization Algorithm." Studies in Computational Intelligence (020).