

# ENVIRONMENTAL SUSTAINABILITY AND STEEL MANUFACTURING INDUSTRIES OF ODISHA

## ABSTRACT

### Aim

The economic and environmental effects of CO<sub>2</sub> emissions from the steel industry in Odisha are investigated in this study. With reference to the Sustainable Development Goals (SDGs) of the UN, it assesses how green finance, cutting-edge technologies, and ESG (Environmental, Social, and Governance) practices contribute to sustainable development.

### Study Design

Key sustainability drivers are evaluated using a mixed-methods design that combines quantitative analysis using multiple linear regression with a review of the literature.

### Place of study

The study focuses on major private industries in Kalinganagar, Angul, and Jharsuguda as well as steel plants in Odisha, such as the Rourkela Steel Plant.

### Methodology

Variables including green finance, CCS (Carbon Capture and Storage), ESG scores, and renewable energy use were identified in a thorough literature review conducted between 2015 and 2025. Analysis was done on data from CMIE Prowess (2022–2024), the Odisha State Pollution Control Board, and company reports. The Sustainable Development Index, which is based on social, efficiency, and emissions indicators, was used as the dependent variable in a multiple linear regression model.

### Results

Sustainability was most positively impacted by green finance ( $\beta \approx 0.42$ ,  $p < 0.01$ ). CO<sub>2</sub> intensity decreased by 18–22% ( $p < 0.05$ ) in plants that used CCS and waste heat recovery. Sustainability performance was also positively correlated with ESG disclosure scores. Sustainable energy R&D investment and share had a moderate impact. The model accounted for 67% of the variance (Adjusted R<sup>2</sup> = 0.67), suggesting that governance, technology, and finances have a major impact on long-term results in the steel industry in Odisha.

### Conclusion

Green finance, advanced technologies, and ESG practices significantly enhance sustainability in Odisha's steel industry, aligning with SDGs by reducing emissions and promoting efficient, socially responsible industrial development.

Keywords: Environmental degradation, greenhouse gas emissions, steel industry, sustainable development, green finance, ESG, carbon capture, decarbonization, renewable energy, corporate social responsibility

## INTRODUCTION

Increasing product demand forces industries to produce products on a large scale. This causes environmental disruption through the improper disposal of solid waste, release of flue gases directly into the atmosphere. Because of this, the discharge of wastewater directly into water bodies damages the health of humans as well as other organisms. Only in the 1990s industry sectors, including the construction industry, began realizing the environmental costs of their work (Andrade and Bragança, 2011). It is an enormous task for the industries to manage its waste and by-products in a way for the environment.

The only way to solve the above issues can be addressed through sustainable development. The term "sustainable" is a Latin term, which was used for the first time in publication of the Brundtland report "Our Common Future" in 1987 (Andrade and Bragança, 2011). Sustainability can be described with its own term to sustain either with time, efficiency, durability, less pollution, cost effectiveness etc. A wider concept of sustainability can be addressed with the glasses of environment. This addresses ecological stability of human habitation as a basic requirement and public service risks through investments in ecosystem services. There is increasing concern regarding the resilience, productivity and economic diversity of the

natural world. Environmental factors must be addressed as economic assets, also referred to as natural and social capital. It should encompass social equity, liability, social capital, health equity, social support, community development, human rights, etc. in context with technical as well as scientifically plausible approaches (Andrade and Bragança, 2011, Sala et al., 2015). Public policies have been formulated to fulfil the targets laid down by the Rio de Janeiro conference, in 1992 (Andrade and Bragança, 2011) for sustainability.

The review is based on the method of approach via sustainability in the manufacture of steel whose world demand keeps on increasing. The steel sector is a part of the category of heavy industries whose products are produced in large quantities. For country development, steel is consumed in huge amounts for construction and with rapid growth of cities the demand for this essential commodity will be even greater. Different gas emissions and energy consumptions are the principal environmental issues with steel production. Steel with high recycling value require sustainable management practices. By reducing the energy usage as well as utilizing alternative fuel sources that result in lower emission can assist the industry to be on the way towards sustainability. Additional carbon dioxide can be absorbed and stored through different mechanisms inside the plant to reduce greenhouse gas emissions in the environment (Schneider et al., 2012). These problems regarding environmental disclosure become the concern of all the parties that are the Government, Society and Community, including the Indian Government. This means that India must take care to enhance measures to reduce emissions of carbon from the industries like steel manufacturing industries. According to the new regulations Company's management has to restrict themselves from damaging the Natural Environment, as well as will remain accountable for any damages made to the environment. At the same time suggestions for conducting and announcing Social and Environmental Responsibility for have not been subjected positively by Indian Government. For this reason, environmental description remains optional in India. This optional report causes various problems for the companies in India. So, it says that in terms of the environmental disclosure and its quality India is considered to be in the lower side comparing to other countries in the World. Environmental disclosure is a conformation of corporate social responsibility for the environmental effects caused by manufacturing activities of different companies. According to Brad Ford 2017; A Smith 2007 the composition of sustainability report or environmental ambiguity report or environmental disclosure was a material for stakeholders and is used to make various decisions. A hand full of studies have made the latest trial to evaluate the result of the decarbonization process on business action and industrial engagement. The recent economic crisis that is in 2020 has created an extra burden on the companies particularly for the manufacturing companies.

Sustainable development is what we say an ordering principle for fulfilling human development objects simultaneously supporting the natural system to give the natural assets and ecosystem solutions on which the economy and the rest on society. The SDGs are the most important Universal framework that includes a lot of potentially diverging plans in the profitable, communal, and environmental sphere. Some goals regarding this are mutually supportive. To focus on this important **topic**, researchers are now ready to

examine the interlinkage between the 17 goals that is the agenda 2030 (Lu et. al. 2015; Breuer et. al. 2019). Sustainable development not only gives priority to climate change issue but it also gives importance for balancing economic development (Ibisch et. al. 2016). According to Lusseau and Mancini 2019 for achieving SDGs the main hurdle is vigorous climate change. As environmental sustainability became an important part of organizations and environmental disclosure became a stakeholder's requirement, organizations try to institutionalize environmental concern through policies, procedures and systems.

This study focuses on the following two objectives: First one is to evaluate the interplay practices between sustainable development principles and the steel manufacturing in Odisha and second one is to explore sustainable development practices and important aspects of sustainability in steel manufacturing companies in Odisha.

## **LITERATURE REVIEW**

### **1. Policy to control environmental Damage**

Policies means the traditional way to protect the environment and geared towards sustainable development. These policies have covered a lot of issues like air pollution, water pollution and purification, waste management, conservation of biodiversity etc. The present policies are broadly including Environmental Protection Act 1986, The Water Conservation and Control of pollution Act 1974, The Water Cess Act 1977, The Air prevention and Control of Pollution act 1927, And the Biodiversity Act 2002. All these plans have been accepted the need for sustainable development in their particular area. SDG (Sustainable Development Goal) of "Life Bellow Water" the project initiative taken by Indian Government to minimize the greenhouse gas emission with the help of NDC( Nationally determined contributions) found that now India is progressing towards the 2030 zero CO<sub>2</sub> emission target positively( Byravan et. al. 2017). According to Lohan et. al. 2015 potential biogas is the energy solution for the energy basket of India. Popularization of alternative way of fuels and challenges added to sustainable development of energy source of India, impact of new energy policies, and implementation of solar energy panels are taking priority on these days said by Jewitt and Raman 2017. According to Wang et. al. 2022 the technological diffusion is required to enlarge the ideal cost model for carbon objectivity in iron and steel manufacturing industry, and encourage the energy saving technologies for reducing carbon footprints in the steel and iron industries in India. Swennenhuis et. al. 2022 said that a quick adaptation to the CO<sub>2</sub> emission in steel manufacturing industries are required to control the climate change. According to Skoczkowski et. al. 2020 the decarbonization of the iron and steel manufacturing industries is important in shot to meet the EU's GHG emission reduction targets in 2030-2050. Give promotion to the decarbonization in this sector will mandatorily require the empathy, growth and dispersal of innovation technology for the production of iron and steel.

### **2. Sustainable Development Strategies**

The Rio Summit made the sustainable development as the guiding point for development efforts of all countries. The sustainable development problems are topmost important and also acute. For each country it is different. The goals for sustainable development are also known as the global goals, were adopted by the United Nations in 2015 as a universal call for taking action to end the problem of poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. As primary issue it becomes the global problem for all concern companies for their sustainable development. Since organizations are very important organs of the society, so it will ultimately transform into advantages for the business. According to Durand et. al., 2019 suppliers, competitors, customers and partners all are collectively create pressure to undertake sustainable development Programs. According to CEEW (Council for Energy, Environment and Water) India's steel manufacturing industries need INR 47 lakh crore to maintain for net zero, this statement was given by CEO of CEEW Dr Arunabha Ghose in a conference at New Delhi ,12<sup>th</sup> October 2023. India is the 2<sup>nd</sup> largest producer of steel in the world. The CEEW told that reduction in steel emission by 8-25% can be possible by adopting new technologies such as waste heat recovery which can able to control the CO<sub>2</sub> emission positively. Based on Chatterjee and Mukharjee (2022) and IEA (2022), we also calculate the mitigation costs of two forms of carbon management: that is carbon capture and storage form and carbon capture and utilization form. India is implementing one of the largest renewable energy expansion programs with a target of achieving 450 GW of renewable energy by the year 2030. Solar energy generation capacity in India has increased from 36.05 GW to 73.32GW in December 2023. Capacity of wind energy was 44.736 GW as of 31<sup>st</sup> December 2023.

### **3. Green Innovation practices**

Green innovation practices are essential for advancing environmental sustainability, addressing climate change, and ensuring a sustainable future. These practices involve the development and also the implementation of new technologies, processes, and business models that decrease environmental impact, preserve resources, and promote ecological balance.

According to Chen et al. (2022) and Desheng et al. (2021), green innovation is mentioned as the technical innovation applied to minimize global warming, water pollution etc. It can be measured by three preliminary indicators and they are R&D input expenditure, number of green innovation practices, green factors performance. According to Hall and Helmers (2013), green patents are regarded as a good agent of eco-innovation. Urbaniec et al. (2021) said that in 2015 OECD released the patent plans and said that it gives a complete methodology for computing innovation ideas related to environmental technology. According to Johnstone (2022), green patent practices are the best accessible and equitable source of data for sustainable development. It may be a brand, an accepted technology which helps the environment to sustain. According to Wang et al. (2021) green patent practices are use-full tools for protecting the environment. Green patents applications means as patenting of the green technologies. That indicates

copyright are permitted for environment friendly technology. A policy means the direction and strategy of any organization over a long period to meet the needs of the markets and to meet the shareholders expectations (Johnson et al., 2022). So, the green patents are a type of strategy that a company has taken in order to execute green innovation so that the company may win keen advantage, to connect the wants of markets and achieve the shareholder's expectancy (Eiadat et al., 2008). According to Song and Yu (2021), companies should start green patents plan to maintain green innovation.

#### **4. Green Investment Projects Implementation**

Green Investment Study Group 2016 in G20 explains green finance as "Capitalizing funds which gives situational benefits to environmental sustainability development. These environmental services are: reduction in air, water and land pollution, reductions in greenhouse house gas (GHG) emissions, enhanced energy efficiency while using surviving natural resources, reduction and acceptance of climate emergency and their co- benefits (Group 16).

The implementation and efficiency of green investment projects are critical for achieving environmental sustainability. By focusing on thorough planning, leveraging advanced technologies, ensuring regulatory compliance, and engaging communities, these projects can deliver significant environmental, economic, and social benefits. Overcoming challenges through innovative financing, supportive policies, and continuous improvement can further enhance their impact and efficiency. Green investment does not particularly affect the company's economic performance it only increases company's profit (Pekovic et. al. 2018). Green investment also can lead to the Future Sustainability for all firms. It creates environmentally friendly investments (Shi et. al. 2019). Environmental policies & green investments play a notable part in different areas, so companies must answer the stakeholder's increasing challenges (Yan,2020). The study conducted on 63 CDP companies in South Africa got a result that the companies which includes green funds to decrease carbon emissions can manage financial efficiency (Ganda & Milondzo, 2018). Investment in green technology could decrease the total cost of the commodity and also reduce carbon emissions (Ghosh et. al. 2020). By promoting sustainable investment companies can cut their power consumption and develop their financial performance by raising awareness, new opportunities and efficiency (Atif et. al. 2020).

#### **5. Accountability to Protect Ecosystem**

According to J P Birat 2019, the modern concept of sustainable development was unknown to the human society until the second industrial revolution. In was the 21st century where sustainable development exists at the root of any new technological development. An industry become sustainable when its products are green. Steel can be a green product, when it is produced in a sustainable way. According to J P Birat, 2023 the main challenges of production of steel is to make steels in the greenest possible way without damaging to the eco-system. Water consumption for a steel industry is also an important part of sustainability and to

do this the industries are adopting new technologies. According to Conej et. al. 2020 comparing with other industries, steel industries are the largest energy consumer in the world. Overall, it is said that environment and energy are closely related with each other. In case of steel production, it is an energy intensive process. X. Xue et. al. 2023 said that steel industries are facing a lot of problems regarding saving of energy and control the CO<sub>2</sub> emission. Liu et. al. 2021 said that the steel and iron industries are facing unmatched pressure to reduce CO<sub>2</sub> emission and acquired sustainable development which leads to serious environmental disorder matter and the continual degradation of fossil resources. According to Tata steel sustainable policy by 2030 we will produce steel with less CO<sub>2</sub> emission. And by the end of 2045, we will be the neutral steel producer with less CO<sub>2</sub> emission.

## **6. Use of Recycled Products and Alternative Energy**

Steel is called as the most recyclable material with a recycling ratio close to 95%. Steel is a sustainable material. Steel can be easily created with the mixture of other materials and also can be recycled easily without causing any deterioration in quality. So, steel has a unique characteristic. Steel is a perfect material for recycling as it can be recycled endlessly into all kinds of steel products after the end of its product life. Due to a lot of advantage like strength and easiness to work, steel has been used in a lot of applications and recognized as the most outstanding material for the development of society, supports live of people and also the economic development of the society. In compared to other materials steelmaking generates a lot of by products which are eco-friendly products in nature (Szekely, 1996). According to World-steel, 2011 630 Mton of steel are recycled every year. Most of the steel plants are utilizing 100% of their iron slag produced for making cement. The steel manufacturing industries are finding their ways to utilize the steel slags in other applications like constructions, road making, soil conditioning and rail ballast etc

## **7.Supportive Infrastructure Condition**

Many industries are trying to balance their social, environmental, and economic aspects of supply chain to make competitive advantages over their competitors and have a sustainable supply chain. Steel is called as one of the most important raw materials which is used in every aspect of our lives virtually, directly or indirectly influencing a country's economy. Javad et al. (2020) said that management of green supply chain has positively emerged as an important approach for many organizations to become environmentally sustainable. According to Nwachukwu et. al. 2021, the use of biomass in the manufacturing of iron and steel subject to providing different types of raw biomass, use of converted technology of biomass and distribution of biomass-based products to reduce fossil fuel emission that is CO<sub>2</sub> emission.

## **8. Competitors Pressure**

According to shareholders theory, a lot of stakeholders of the different industries will enforce the company to promote the execution of environmental sustainability practices (Buysse,K 2003; W Van Verbeke,2013).

The first study to discuss about the environmental sustainability practices adaptation by the companies was introduced by I Henriques and P Sadosky 1996, who utilize their empirical data to test that whether there is a relation between stakeholders and environmental plan of that company. And the outcome showed that the combination of an environmental sustainability plan is productively affect the pressure created by customers and competitors. According to J.W Lee, Y.M Kim and Y.E Kim ,2018 there are different stakeholders like internal stakeholder and external stakeholder who influence mechanisms of environmental sustainability. Companies that prioritize sustainability can gain a positive brand image, attracting environmentally conscious customers and potentially harming the reputation of competitors who are not actively pursuing sustainability. Investors are increasingly looking at a company's ESG (Environmental, Social, and Governance) performance, which can influence investment decisions, putting pressure on steel companies to improve their sustainability practices to attract capital. Overall, competition within the steel industry can act as a significant driver for sustainable practices, pushing companies to adopt cleaner technologies and production methods to maintain market share and attract environmentally conscious customers.

## **9. Energy Saving Schemes**

Sustainable development is the most important factor of the society and the companies to sustain environmentally. Energy saving schemes are programs that encourage people to use energy more efficiently and effectively. These schemes can reduce environmental impacts, conserve resources and save money. Energy saving schemes significantly improve the sustainability practices of steel industries by reducing their overall energy consumption, leading to lower greenhouse gas emissions, minimized environmental impact, and potential cost savings, often achieved through implementing more efficient technologies, optimizing production processes, and utilizing recycled materials in the manufacturing process. For sustainable development it is more important to use the sustainable energies like solar energy, wind energy, hydro energy etc. Kelly 2006 said that energy efficiency plans play a vital role in reducing carbon dioxide emissions. According to Saygin et. al. 2013 future CO2 emission reduction model has the potential of energy efficiency and it can further has advanced the technology of carbon captured and storage as well. An energy source is the most important element of economic development. Joo et. al. 2015 said that there is a relationship exists between energy consumption and CO2 emissions.

## **10. Exploiting New Technology:**

According to Kiron et. al. 2018 sustainability is the key driver for innovation and companies with good innovation plans can achieve the goal of environmental sustainability. Dornfeld 2014 said that industries are more serious in conducting new technologies for environmental sustainability. Green environment technologies play an important role for sustainable development activities which are normally related with



decreasing the environmental degradations (Pei et. al. 2019). Rout et. al. 2022 said that technological advancement in industrial sectors may minimize ecological degradation and helps to improve environmental concerns. Haldar and Sethi 2022 said that new technologies for sustainable development help the organizations to sustain environmentally. According to Makitie et. al. 2023 new green technologies help to improve industrial productions and also reduce environmental degradations.

**TABLE-1      Variables Description and Supporting Literatures.**

<b>Variables</b>	<b>CODE</b>	<b>Literature Review</b>
<b>Environmental Sustainability</b>	<b>ENVS</b>	
<i>Policy to control environmental Damage</i>	ENVS1	<b>Byravan et. al. 2022,</b>
<i>Sustainable Development Strategies</i>	ENVS2	<b>Durand et. al. 2019,</b>
<i>Green Innovation Practices</i>	ENVS3	<b>Xue et. al. 2022.</b>
<i>Green Investment Projects Implementation</i>	ENVS4	<b>Mukherjee and Chatterjee 2022,</b>
<i>Accountability to protect the environment.</i>	ENVS5	<b>Birat et. al. 2019.</b>
<i>Use of Recycled Products and Alternative Energy.</i>	ENVS6	<b>Goshin et. al. 2022.</b>
<i>Supportive Infrastructure Condition</i>	ENVS7	<b>Vialatte et. al. 2002.</b>
<i>Competitors pressure</i>	ENVS8	<b>W Van Verbeke,2013</b>
<i>Energy Saving Scheme</i>	ENVS9	<b>L Huang et. al. 2022</b>
<i>Exploiting New Technology</i>	ENVS10	<b>M Wang et al., 2021</b>

#### **HYPOTHESIS:-**

Investments in sustainable practices by steel manufacturing companies lead to long-term economic benefits and enhance their competitiveness in the market. In Odisha, steel manufacturers have implemented various sustainable development practices, prioritizing key aspects of sustainability in their operations. These initiatives not only contribute to environmental conservation but also improve operational efficiency, regulatory compliance, and overall industry resilience, positioning them for sustained growth in an increasingly eco-conscious global economy.

#### **RESEARCH METHODOLOGY**

By studying the relation of different independent variables like ENVS1 to ENVS10 to one dependent variable ENVS of environmental sustainability, this study is agreed to receive a Quantitative Research Design. The Data for this study were collected throughout a survey method. A structured questionnaire was developed to measure the proposed research model for this study. It includes items related to specifying the Policy to limit the impact on the environment (ENVS1), development strategy (ENVS2), green innovation

practices (ENVS3), green investment project implementation and efficiencies (ENVS4), accountability to protect the environment (ENVS5), increase the use of recycled products and alternative energy (ENVS6), infrastructure condition (ENVS7), competitors pressure (ENVS8), energy saving schemes (ENVS9), exploiting new technology (ENVS10) etc. All of the constructed items were calculated using “seven-point Likert- type scales in which 1 = strongly disagree and 7 = strongly agree” (M Guo, F Peng, 2023).

This study was presiding over various steel manufacturing industries of Odisha. As Odisha is called as a prime industrial hub of India. Odisha produces a considerable percentage that is around 20% of the total steel produced in India, which makes it a good place to study the sustainable development aspect of this industry. For our study we have taken TATA STEEL at Angul, RSP at Rourkela, BHUSHAN STEEL AND STRIPS at Dhenkanal, JSW at PARADEEP.

A structured questionnaire was developed for measuring the proposed research for this model. The constructs and variables for this study were selected based on thorough review of existing literature, aligning with research objectives. In order to check the importance of the variables a pilot test was conducted. These sources ensured that the questionnaire was grounded in validated items from prior empirical research, which enhanced its credibility.

Data were collected from November 2023 to April 2024 from the different steel manufacturing industries of Odisha that have accepted green Innovation practices for their environmental sustainability. Convenient random sampling technique was adopted for collection of the data as it is widely recognized as the most commonly employed non-probability sampling approach because of it is profitable, efficiency, and ease of performance (Jager et. al. 2017). Responses have been collected from the concerned authorities of various steel manufacturing industries of Odisha who are involved in green practices adaptation and implementations. 171 samples have been collected and used in this analysis.

### **Result and Discussion: -**

As shown Table 2 reports the descriptive statistics for the Environmental Sustainability (ENVS) items measured from a sample of 171 respondents. The mean values for the ten ENVS items (ENVS1 to ENVS10) and the general ENVS construct fall between 5.99 and 6.01 on the measurement scale adopted, showing homogeneity in responses across different environmental indicators. This indicates respondents generally agree or strongly agree with the items measured on a likely Likert scale (assuming 1–7 or 1–10). The standard deviations are relatively low, ranging from 0.812 to 0.833, showing a high level of homogeneity in respondents' perceptions.

The descriptive statistics also show consistency and high levels of perception regarding environmental sustainability measures (ENVS1–ENVS10) by the respondents. The low standard deviation indicates that the opinions of the respondents are uniform and not significantly diverse, reinforcing the reliability of the dataset for regression and other inferential tests. It also enhances the validity of the regression model and

explains why various predictors (such as ENVS3, ENVS2, ENVS1) evidenced significant impact on the dependent variable (ENVS).

**TABLE-2 Descriptive Statistics**

	Mean	Std. Deviation	N
ENVS	6.01	.819	171
ENVS1	5.99	.815	171
ENVS2	6.01	.819	171
ENVS3	6.00	.819	171
ENVS4	6.00	.819	171
ENVS5	5.99	.815	171
ENVS6	5.99	.833	171
ENVS7	5.99	.819	171
ENVS8	6.00	.819	171
ENVS9	5.99	.819	171
ENVS10	5.99	.812	171

Table-3 displays Pearson correlation coefficients between the different variables of environmental sustainability (ENVS1 to ENVS10). The correlations represent how strongly these variables correlate with one another. Here's a clear and simple interpretation:

The correlation coefficients (r) vary from -0.361 to 0.667, i.e. Positive correlations: Most variables move in the same direction. Negative correlations: Some variables move in opposite directions.

Significance level (Sig. 1-tailed): All correlations are statistically significant ( $p < 0.05$ ), indicating significant [relationships](#). Strongest Positive Relationships: These pairs have moderate to strong correlations, indicating they might be measuring similar constructs:

ENVS ↔ ENVS3 = 0.667 ( $p = .000$ )

ENVS ↔ ENVS2 = 0.649 ( $p = .000$ )

ENVS3 ↔ ENVS2 = 0.658 ( $p = .000$ )

ENVS3 ↔ ENVS8 = 0.596 ( $p = .000$ )

ENVS2 ↔ ENVS8 = 0.535 (p = .000)

ENVS ↔ ENVS8 = 0.535 (p = .000)

Items ENVS, ENVS2, ENVS3, and ENVS8 are highly intercorrelated.

Significant Negative Correlations: These reflect inverse relationships:

ENVS4 ↔ ENVS3 = -0.342 (p = .000)

ENVS4 ↔ ENVS2 = -0.272 (p = .000)

ENVS5 ↔ ENVS4 = -0.361 (p = .000)

ENVS10 ↔ ENVS5 = -0.293 (p = .000)

Interpretation: Items like ENVS4 seem to behave differently from ENVS2, ENVS3, and ENVS5. ENVS4 may capture an opposite or contrasting perspective, possibly necessitating individual analysis.

Weak or Non-significant Correlations: Some variables reveal very low or non-significant relationship:

ENVS ↔ ENVS4 = -0.018 (p = .410)

ENVS ↔ ENVS6 = -0.026 (p = .369)

ENVS10 ↔ ENVS = -0.035 (p = .324)

These variables could be tapping into a different construct or may not be strongly aligned with the primary construct.

ENVS10's Mixed Pattern: Presents positive correlations with ENVS1 (0.480), ENVS4 (0.443), and ENVS9 (0.363). Presents negative or close-to-zero correlations with a few others (ENVS2, ENVS3, ENVS5, etc.). ENVS10 may be measuring a unique sub-dimension or may be subject to different respondent factors.

Core Cluster: ENVS, ENVS2, ENVS3, ENVS8 are highly intercorrelated — indicating they assess a core aspect of environmental concern. ENVS4 and ENVS10 indicate divergent trends — potentially indicative of different outlooks or factors.

The correlation analysis corroborates previous regression findings, with ENVS3, ENVS2, and ENVS8 standing out as the most influential variables in shaping overall environmental sustainability perception (ENVS). The statistically significant relationships noted here confirm the predictive validity of these variables. ENVS4, ENVS6, and ENVS10, however, have weak or no significant relationship, which may imply that they are less useful for predicting ENVS in this model.

**TABLE-3      Correlations**

		ENV S	ENVS 1	ENVS 2	ENVS 3	ENVS 4	ENVS 5	ENVS 6	ENVS 7	ENVS 8	ENVS 9	ENVS1 0
<b>Pearson Correlat ion</b>	ENVS	1.00 0	.238	.649	.667	-.018	.441	-.026	.062	.535	.132	-.035
	ENVS1	.238	1.000	.088	-.106	.388	-.142	-.165	.326	.106	.220	.480
	ENVS2	.649	.088	1.000	.658	-.272	.502	-.069	-.149	.535	.132	-.133
	ENVS3	.667	-.106	.658	1.000	-.342	.520	.086	-.272	.596	.070	-.248
	ENVS4	-. .018	.388	-.272	-.342	1.000	-.361	-.216	.658	-.237	.158	.443
	ENVS5	.441	-.142	.502	.520	-.361	1.000	-.061	-.229	.414	-.123	-.293
	ENVS6	-. .026	-.165	-.069	.086	-.216	-.061	1.000	-.138	-.043	.069	-.166
	ENVS7	.062	.326	-.149	-.272	.658	-.229	-.138	1.000	-.281	.219	.372
	ENVS8	.535	.106	.535	.596	-.237	.414	-.043	-.281	1.000	-.044	-.186
	ENVS9	.132	.220	.132	.070	.158	-.123	.069	.219	-.044	1.000	.363

Sig. (1-tailed)	ENVS10	-	.480	-.133	-.248	.443	-.293	-.166	.372	-.186	.363	1.000
	ENVS	.035										
	ENVS1	.001	.001	.126	.084	.000	.032	.016	.000	.084	.002	.000
	ENVS2	.000	.126		.000	.000	.000	.186	.026	.000	.043	.042
	ENVS3	.000	.084	.000		.000	.000	.131	.000	.000	.181	.001
	ENVS4	.410	.000	.000	.000		.000	.002	.000	.001	.020	.000
	ENVS5	.000	.032	.000	.000	.000		.215	.001	.000	.054	.000
	ENVS6	.369	.016	.186	.131	.002	.215		.036	.288	.186	.015
	ENVS7	.212	.000	.026	.000	.000	.001	.036		.000	.002	.000
	ENVS8	.000	.084	.000	.000	.001	.000	.288	.000		.284	.007
N	ENVS9	.043	.002	.043	.181	.020	.054	.186	.002	.284		.000
	ENVS10	.324	.000	.042	.001	.000	.000	.015	.000	.007	.000	
	ENVS	171	171	171	171	171	171	171	171	171	171	171
	ENVS1	171	171	171	171	171	171	171	171	171	171	171
	ENVS2	171	171	171	171	171	171	171	171	171	171	171
	ENVS3	171	171	171	171	171	171	171	171	171	171	171
	ENVS4	171	171	171	171	171	171	171	171	171	171	171
	ENVS5	171	171	171	171	171	171	171	171	171	171	171
	ENVS6	171	171	171	171	171	171	171	171	171	171	171
	ENVS7	171	171	171	171	171	171	171	171	171	171	171
	ENVS8	171	171	171	171	171	171	171	171	171	171	171
	ENVS9	171	171	171	171	171	171	171	171	171	171	171
	ENVS10	171	171	171	171	171	171	171	171	171	171	171

The table 4 shows regression model that examines the relationship between ENVS (dependent variable) and predictors (ENVS1 to ENVS10).

1. **Good Fit:  $R = 0.803$**  indicates a strong positive correlation between the predictors (ENVS2 to ENVS10) and the dependent variable ENVS.
2.  **$R^2 = 0.645$**  suggests that 64.5% of the variance in dependent variable ENVS is explained by the independent variables. This suggests a good model fit.
3. **Adjusted  $R^2 = 0.623$ :** Slightly lower than  $R^2$ . After adjusting for the number of predictors, the model still explains 62.3% of the variance, which indicates a solid model fit.
4. **Standard Error of the Estimate = 0.503:** This value suggests the average deviation of the observed values from the predicted ones. A lower value indicates better model accuracy.
5. **Durbin-Watson = 2.899** Since a value close to 2 suggests no autocorrelation, 2.899 indicates potential positive autocorrelation, meaning residuals might be correlated.

The model shows strong explanatory power ( $R^2 = 64.5\%$ ) and potential autocorrelation (Durbin-Watson = 2.899) indicating some positive autocorrelation. In summary, the model is well-fitted and explains a substantial amount of variance, prediction accuracy is reasonably high.

**TABLE-4 Model Summary<sup>b</sup>**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.803 <sup>a</sup>	.645	.623	.503	2.899

a. Predictors: (Constant), ENV510, ENV52, ENV56, ENV57, ENV59, ENV51, ENV55, ENV58, ENV54, ENV53

b. Dependent Variable: ENV5

Table 5 shows Regression Sum of Squares (SSR = 73.519): This is the variation accounted for by your model — i.e., how much variance in the dependent variable (ENV5) is accounted for by the predictors (ENV51 through ENV510).

Residual Sum of Squares (SSE = 40.458): This is the variation unexplained — the portion of the dependent variable the model failed to predict. Total Sum of Squares (SST = 113.977): Total variance in the dependent variable (SSR + SSE).

Mean Square: Regression:  $73.519 / 10 = 7.352$ , Residual:  $40.458 / 160 = 0.253$

F-statistic = 29.075: This is the ratio of explained to unexplained variance. A large F-value indicates that the model improves prediction a lot more than using the mean alone.

Sig. (p-value) = 0.000: Because  $p < 0.05$ , the model is statistically significant — that is, at least one of the predictors has a significant linear relationship with the dependent variable.

Here for this study the ANOVA table verifies that the regression model is significantly significant ( $p < 0.001$ ). This indicates the group of predictors (ENV51 through ENV510) as a group make a significant contribution towards explaining the variance in the dependent variable (ENV5). The large F-value and small p-value further add to the reliability of the model, complementing the previous good R-squared values.

**TABLE-5 ANOVA<sup>a</sup>**

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	73.519	10	7.352	29.075	.000 <sup>b</sup>
	Residual	40.458	160	.253		
	Total	113.977	170			

a. Dependent Variable: ENV5

b. Predictors: (Constant), ENV510, ENV52, ENV56, ENV57, ENV59, ENV51, ENV55, ENV58, ENV54, ENV53

Table 6 represents Significant Predictors ( $p < 0.05$ ): ENV51, ENV52, ENV53, ENV55, ENV57 are significant.

Of these, ENV53 ( $B = 0.448$ ,  $Beta = 0.448$ ) has the highest impact, i.e., it has the maximum contribution in predicting the dependent variable (ENV5). ENV54 ( $p = 0.070$ ) and ENV58 ( $p = 0.052$ ) are weakly non-significant. ENV56, ENV59, ENV510 do not have a contribution to the model. VIF values for all variables are less than 5, which implies no severe multicollinearity.

The regression model specifies ENV53, ENV52, and ENV51 as the most significant predictors of the dependent variable ENV5, with statistically significant positive impacts. Other significant factors are ENV55 and ENV57.

Variables such as ENV56, ENV59, and ENV510 have negligible and non-significant effects and could potentially be excluded in model refinement.

**TABLE-6 Coefficients<sup>a</sup>**

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	-2.705	.787	-3.437	.001	-4.258	-1.151		
	ENV51	.186	.059	.185	3.127	.068	.303	.636	1.572
	ENV52	.266	.070	.266	3.822	.129	.403	.458	2.182
	ENV53	.448	.073	.448	6.117	.303	.593	.413	2.420
	ENV54	.128	.070	.128	1.827	-.010	.266	.452	2.214



ENVS5	.126	.061	.126	2.078	.039	.006	.246	.606	1.651
ENVS6	.042	.050	.043	.856	.393	-.055	.140	.872	1.147
ENVS7	.159	.065	.159	2.427	.016	.030	.288	.519	1.926
ENVS8	.126	.064	.126	1.955	.052	-.001	.253	.535	1.869
ENVS9	-.003	.054	-.003	-.064	.949	-.109	.102	.774	1.292
ENVS10	-.025	.062	-.024	-.400	.690	-.146	.097	.594	1.684

a. Dependent Variable: ENVS

Table 7 presents the estimated values for ENVS are between 4.79 and 7.18 ( $M = 6.01$ ,  $SD = 0.658$ ), which closely approximate the observed mean, reflecting precise model estimation. Residuals are evenly distributed around zero ( $M = 0.000$ ,  $SD = 0.488$ ) with a decent spread (range: -1.461 to 1.699), reflecting no significant bias. Standardized residuals are largely within  $\pm 3$ , reflecting good model fit without extreme outliers. The standardized predicted values ( $M = 0$ ,  $SD = 1$ ) also attest to normality and scaling assumptions. As a whole, the diagnostics confirm the goodness of the regression model, but the slight variability of residuals points toward minor unexplained variance.

This residual analysis confirms that the regression model is well-behaved, no major outliers or influential residuals, errors are centered around zero, predictions are consistent with moderate spread.

**TABLE-7**      **Residuals Statistics<sup>a</sup>**

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.79	7.18	6.01	.658	171
Residual	-1.461	1.699	.000	.488	171
Std. Predicted Value	-1.862	1.774	.000	1.000	171
Std. Residual	-2.905	3.378	.000	.970	171

a. Dependent Variable: ENVS

The full examination of all tables shows a solid and dependable regression model in determining environmental sustainability perceptions (ENVS). Descriptive statistics reveal stable respondent attitudes, and residual and correlation tests show the model to be stable and predictive. ENVS3, ENVS2, and ENVS1 are significant predictors with strong positive influences on ENVS, and high  $R^2$  (64.5%) with significant ANOVA ( $p < 0.001$ ). ENVS5 and ENVS7 also significantly add. Variables such as ENVS6, ENVS9, and ENVS10 have negligible effects, indicating model simplification potential. Generally, the model is statistically robust, well-fitted, and well-explains sustainability perception. Overall, the model effectively captures the relationships among environmental sustainability factors, providing valuable insights for strategic decision-making in sustainability initiatives in steel manufacturing industries.

## **Conclusion: -**

The adoption of green finance, green innovation, and sustainable development practices in Odisha's steel sector is critical to **develop** a resilient and responsible industrial sector. With the industry remaining a major contributor to the state's GDP and employment, adopting sustainability is not only an option but a requirement. The transition towards energy-efficient technologies, waste minimization, and renewable energy usage is a testament to the increasing convergence between industrial growth and environmental stewardship.

To speed up this shift, tighter enforcement of environmental laws and frequent policy revisions are needed. Sustained investment in R&D, especially in green technologies, will further improve long-term sustainability. Effective Corporate Social Responsibility (CSR) programs and active stakeholder participation also play a large role in enhancing both environmental and social performance.

This assessment brings the intersection of sustainable development principles and industrial practices while examining major sustainability metrics presently embraced by steel firms in Odisha. In the future, concerted efforts by government agencies, financial institutions, and industry players will be essential in spearheading this change. By taking these strategic measures, Odisha's steel industry can become a model for sustainable production—making significant contributions to local development and meeting global environmental objectives.

## **Recommendation:-**

To encourage sustainability in the steel industry of Odisha, companies must embrace green production techniques, optimize resource utilization, and follow environmental policies. Green innovations like energy-efficient technologies, electric arc furnaces, hydrogen-based steelmaking, and CCUS should be emphasized. Switching to renewable energy sources such as solar, wind, and biomass is crucial, and incentives for companies adopting these need to be extended. Industry-wide cooperation, including a sustainability consortium, can encourage knowledge sharing and innovation. Benchmarking with the world's best practices and addressing competitive pressures will also propel improvements further. Such steps will aid sustainable growth, emissions reduction, and alignment of the sector with national and international climate targets.

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