RECENT ADVANCES AND INITIATIVES IN THE INTEGRATION OF ENVIRONMENTAL, SOCIAL AND GOVERNANCE (ESG) PRINCIPLES IN THE STEEL INDUSTRY: A BRIEF OVERVIEW.

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Abstract: Sustainable Development has been the target of continuous global efforts, aiming to reduce dependence on natural resources, increase waste reuse, promote social well-being, and preserve the environment. This article addresses the discussion of implementing ESG principles in the steel industry. Concepts and technologies such as "Green Steel," circular economy, recycling technologies, carbon capture and storage, and the use of renewable energies are explored. These approaches represent significant advancements towards a more sustainable steel sector, with meaningful socio-economic and environmental benefits.
Keywords: Steel Industry; Greenhouse Gases; ESG; Circular Economy; Green Steel.

AVANÇOS E INICIATIVAS RECENTES NA INTEGRAÇÃO DE PRINCÍPIOS AMBIENTAIS, SOCIAIS E DE GOVERNANÇA (ESG) NA INDÚSTRIA SIDERÚRGICA: UM BREVE PANORAMA.

Resumo: O Desenvolvimento Sustentável tem sido alvo de contínuos esforços globais, buscando reduzir a dependência de recursos naturais, aumentar a reutilização de resíduos, promover o bem-estar social e preservar o meio ambiente. Este artigo aborda a discussão da implementação dos princípios ESG na indústria siderúrgica. São explorados conceitos e tecnologias como "Aço Verde", a economia circular, as tecnologias de reciclagem, a captura e armazenamento de carbono e o uso de energias renováveis. Essas abordagens representam importantes avanços rumo a um setor siderúrgico mais sustentável, com benefícios socioeconômicos e ambientais significativos.

Palavras-chave: Siderurgia; Gases de efeito-estufa; ESG; Economia circular; Aço verde.

1. INTRODUCTION

Awareness of the importance of environmental, social, and governance (ESG) practices is increasingly present worldwide. The significant and beneficial impacts extend to organizations, society, and the environment.

The iron and steel industry has been attracting growing attention due to its high pollution rate, making it one of the largest greenhouse gas emitters in the world. These emissions result from the steel production process, involving high temperatures in coke-fueled furnaces, leading to intensive energy consumption and gas release into the atmosphere. In this context, the need for significant changes has become increasingly evident over the years [1,2]. Mallet et al. (2023) describe the decarbonization of the iron ore production industry as a daunting yet essential task. However, the literature indicates that there is no one-size-fits-all solution for decarbonizing this sector worldwide. This is because various factors such as infrastructure, local economy, and geographic location differ among industries, necessitating the adaptation of decarbonization strategies to the particularities of each case [3]

As the world becomes more conscious of ESG principles, technological innovations are being studied and proposed to make industries and society more responsible and sustainable. Initiatives such as Green Steel, recycling technologies, circular economy, carbon capture and storage, and the use of renewable energies have emerged, all aiming to promote compliance with ESG principles [4, 5]. Therefore, to achieve decarbonization in the iron and steel industry, some technologies are described in the literature as alternatives. These include hydrogen injection, solid biomass substitution, scrap recycling, carbon storage, electricity substitution, among others [3]. These approaches represent a significant advancement in the quest for solutions that enable economic and industrial growth in harmony with environmental preservation and social well-being.

2. METHODOLOGY

The research of scientific articles was conducted in reputable databases, including Google Scholar, Web of Science, ScienceDirect, and Scielo, using the following search terms: Environmental, Social, Governance (ESG), steel industry, environmental impacts in the steel industry, sustainable practices in steelmaking, and circular economy in steelmaking. The search was limited to articles published between 2021 and 2023. The relevant results underpin the present article, which is structured into 5 sections and aims to provide an updated literature review on recent advances and initiatives related to the integration of ESG principles in the steel industry.

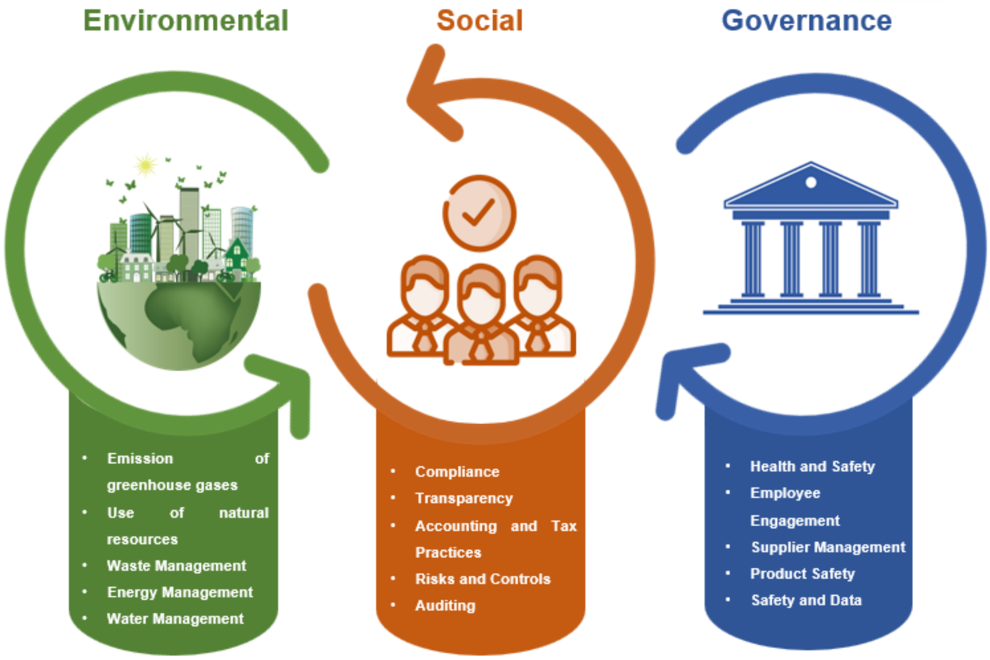
3. ENVIRONMENTAL, SOCIAL AND GOVERNANCE (ESG)

In recent years, efforts have been made to increase awareness, commitment, and investment in environmental, social, and governance (ESG) principles. Despite the recent focus on these principles, this agenda started to be established more than 50 years ago.

3.1 Concept and Origin

Environmental, Social, and Governance (ESG) entails a critical and different way of thinking and acting within organizations across various domains. This term corresponds to the pursuit of responsibility and concern for the environment and social well-being. Regarding environmental goals and targets, key points are considered, such as greenhouse gas emissions, the use of natural resources, waste management, water and energy usage, among others. Concerning the social aspect, initiatives and action plans focused on compliance, transparency, accounting and tax practices, risks and controls, and auditing become essential. Lastly, governance should be based on indicators of health and safety, employee engagement, supplier management, product safety, security, and data.

Figure 1. Schematic representation of Environmental, Social, and Governance (ESG).



It all began in 1972 at the 1st World Conference on the Environment - Stockholm Conference Eco, where the Stockholm Declaration and the Action Plan for the Human Environment were established. Initially, industrialized countries presented 26 principles linking economic growth, well-being of global populations, and air and water pollution. Only in 1992, at the United Nations Conference on Environment and Development - Rio 92, did all continents start to consider adhering to this agenda. In 2000, an independent international organization of standards and guidelines was established - the Global Reporting Initiative (GRI), aiming to understand and communicate the environmental, social, and governance impacts of organizations. As a result, the Principles of Sustainable Investments (PRI) and the Sustainability Accounting Standards Board (SASB) emerged as protocols to guide organizations.

Exclusively in 2004, the term ESG was solidified in the publication "Who Cares Wins" (a joint publication of the United Nations Global Compact and the World Bank) after more than 50 CEOs of major financial institutions gathered to find solutions for integrating ESG into markets and achieving satisfactory results for society.

In 2015, 193 member states of the United Nations - UN committed to a global action plan - Agenda 2030, covering the years from 2016 to 2030. This current plan includes 169 targets and 17 sustainable development goals aimed at encompassing the social, environmental, and economic development of governments, the private sector, civil society, and citizens as a whole. Also in 2015, the Paris Agreement adopted a new objective for sustainable reduction of greenhouse gas emissions (GHG).

4. INFLUENCE OF ESG PRINCIPLES IN THE STEEL INDUSTRY

In the environmental, social, and governance context of modernizing the steel industry, the pursuit of responsibility to mitigate negative impacts in the industry is considered of great importance and necessity. The integration of ESG principles involves practices, strategies, and guidelines related to the environment, social responsibility to society and the community, as well as company policies and administration processes [6]. According to Maybee et al. (2023), the influence of ESG principles within companies is a determining factor for success in transforming resources into production.

Regarding the iron and steel industry, social and environmental issues are the most complex and pressing challenges, as the global need is focused on energy transition, i.e., structural changes in long and short-term energy matrices. Such changes bring about reality and point to strategies and perspectives for operating licenses and resource supply [6, 7]. However, other factors have an impact, albeit slower and less noticeable, such as job loss or the need for rapid skills renewal resulting from global mining modernization[7]. Thus, technological innovations and sustainable development have been the subject of significant debates worldwide.

Among all mining processes: coking, sintering (pelletizing), iron and steel production, among others, the steel industry can be considered the weak link for green development [8]. However, even though environmental regulations have been taken, the effects and progress are slow.

The implementation of ESG directly and indirectly influences economic growth, not always revolving around "profits" and "prices," but rather values, growing responsibly while considering aspects of environmental preservation, social inequality mitigation, and transparent leadership and governance for society. According to Maybee et al. (2023), for the steel operation to be compatible with ESG, shareholders need to adopt a long-term perspective, even if the values are not measured solely in economic viability.

China is the world's largest carbon emitter [9]. Nechifor et al. (2020) highlight significant economic opportunities for China when considering the transition towards a circular economy, including improvements in competitiveness and gains in Gross Domestic Product (GDP). The authors further describe that Brazil, India, Australia, Russia, and other Asian developments, major regions producing iron ore, may face greater obstacles and negative points. However, this can be mitigated by steel prices and development costs.

5. RECENT ADVANCES IN TECHNOLOGICAL INNOVATIONS IN THE IRON AND STEEL INDUSTRY

The steel industry has often been associated with negative environmental impacts, making it seen as more harmful than beneficial. However, it is essential to highlight that minerals and metals are crucial for human existence [6], especially for their versatility, durability, and affordability [4]. Wang et al. (2023) propose that significant growth in green steel and hydrogen production in the international market is essential for investors and innovators to identify market signals and fundamentally drive the production and utilization of these resources. As a result, competition among steel mills increases with the reduction of global steel prices [10].

5.1 Green Steel

Undoubtedly, the steel industry plays a negative influential role in greenhouse gas emissions, accounting for approximately 7-9% of global emissions [2, 8]. Throughout the operation processes, gases such as CO, CO_2, H_2S, SO_2, NH_3, and H_2 are released, along with metallic fumes in the blast furnace, dust, and benzene. Consequently, the concept of decarbonization, i.e., the sustainable reduction of carbon emissions in the atmosphere, has been considered a potential innovation in the steel industry [11,12]. Recent highlights in the literature describe the use of green hydrogen to reduce CO_2 emissions in steel industries [1, 3, 12]. According to Souza Filho et al. (2022), green hydrogen produced through renewable energy will remain a significant bottleneck in the coming decades.

Currently, direct reduction routes using hydrogen and reduction by hydrogen plasma fusion are more promising alternatives in sustainable steelmaking [13]. Green steel emerged as a sustainable alternative to conventional steel production, involving the use of cleaner energy sources and technologies that contribute to the elimination or reduction of CO_2 emissions. The difference lies in the utilization of green hydrogen as a reducing agent for iron ore. When reacting with iron ore, the release of oxygen produces water, thereby avoiding the release of CO_2 in this stage of the process [14].

The continuous pursuit of productivity and efficiency improvement, the development of innovative high reaction rates, process acceleration, and the incorporation of ESG principles have driven the adoption of an innovative approach known as Process Intensification (PI). PI is a comprehensive approach encompassing spatial, thermodynamic, functional, and temporal aspects. Its proposal aims to facilitate waste recycling, eliminate hazards, and mitigate risks through a fundamentally safer design. The response to this methodology encompasses various contributions, such as increased productivity, improved sintering process quality, cost minimization, and emission reduction [15].

Angalakuditi et al. (2023) applied the Process Intensification (PI) approach to the iron ore sintering process, investigating the relevance of factors such as granulation, recycling of waste gases, fuel gas injection into the sinter bed, and emission reduction. Among several conclusions drawn from correlating these factors, hydrogen stood out as a potential process intensifier for sintering.

5.2 Circular Economy and Recycling Technologies

The circular economy is an innovative economic concept based on the reduction, reuse, recovery, and recycling of materials and energy, as highlighted by Griffin and Hammond (2021). The implementation of advanced recycling technologies enables a significant decrease in the consumption of natural resources and waste generation. One of the primary benefits of this practice is the substantial reduction in energy consumption and greenhouse gas emissions compared to steel production from virgin ore [5].

According to Arcelor Mittal, this measure results in approximately a 70% reduction in emissions. Each ton of recycled scrap allows saving 1.5 tons of iron ore, 0.65 tons of coal, and 0.3 tons of limestone, making a significant contribution to the conservation of these natural resources. Thus, the circular economy contributes to the mitigation of environmental impacts and promotes a more sustainable steel industry [5], with efforts from various global studies dedicated to ensuring sustainable development [10, 16].

As highlighted by Broadbent (2016), there are three main approaches regarding recycling methodologies: the cutoff approach, the end-of-life approach, and the 50:50 approach. The cutoff approach focuses solely on inputs, considering only the benefits within the study system. In this perspective, positive impacts generated during the recycling process are analyzed without taking into account the material's entire life cycle. On the other hand, the end-of-life approach covers the entire process in which the material is recycled after reaching the end of its useful life. In this approach, the environmental impact directly depends on the recycling rate at the end of the cycle, as the material treatment after use is essential for the overall assessment. Finally, the 50:50 approach incorporates both recycled content and end-of-life recycling. This approach is particularly useful when the benefits of investing in recycled content versus end-of-life recycling are unknown or uncertain. Therefore, the appropriate choice among these different approaches will depend on the specific circumstances of the study system, sustainability goals, and objectives, always seeking a balance between the environmental and economic benefits of recycling.

A study conducted by Taghipour et al. (2022) investigated the impact of government policies on a steel recycling company in Thailand, focusing on its integration into the circular economy. The study employed sustainability indicators and a structural equation model, meticulously analyzing the involvement of hundreds of employees responsible for steel recycling. The results obtained in Thailand have significant implications for other mills around the world that use or have an interest in adopting recycling technologies. However, some key factors, such as logistics, resource acquisition, costs, and infrastructure, need to be carefully considered for solutions to be truly meaningful. Therefore, the research indicates that government policies play a relevant role in promoting steel recycling and a more robust circular economy [16].

Likewise, Falsafi et al. (2022) presented an innovative proposal to valorize the production chain of steel slag from electric arc furnace scrap and secondary metallurgy. In this approach, essential key factors were identified, including applicable legislation, technology used, production volume, and economic considerations. The importance of aligning the market and technology is highlighted as a crucial factor in achieving a global common good. This implies that technological innovations should be in line with market demands and regulations, resulting in benefits for both the environment and the economy.

According to Yu et al. (2022), for the steel industry in China to continue developing, efficiency and technological innovation are fundamental steps. In India, one of the world's largest producers of iron and steel, innovation in research and development has been a focus to pave the way for technological breakthroughs and collaboration with relevant partners. Some activities are considered in India as potential improvements for the processes, such as the use of biogas, solar energy utilization, continuous injection of methane gas from coal bed, and the use of scrap in production processes. However, the strong dependence on coal and the lack of interest in green steel production contribute to challenges in implementing changes in this sector. Despite the potential to lead sustainable steel production, efforts to make such changes are currently inadequate [12].Mallet et al. (2023) also describe that India is currently seeking technological solutions to adopt and usually doesn't play the role of a developer. Efforts toward sustainability commitment and decarbonization in the Indian steel industry need to be consciously improved.

The aforementioned researches are highly relevant in providing guidance to other steel mills, encouraging the adoption of similar strategies to achieve sustainable results on a global scale. These studies represent valuable contributions to the field of industrial sustainability, offering insights and best practices that can be applied in different contexts [16, 17].

5.3 Carbon Capture and Storage

Carbon capture and storage (CCS) technology is a promising innovation that plays a crucial role in mitigating carbon emissions in the atmosphere [11, 18]. In this context, CO_2 is captured before it is released into the atmosphere and subsequently stored in suitable underground locations. This technique, known as carbon capture, can be achieved through three distinct approaches: post-combustion, pre-combustion, and oxy-combustion [11].

Over the past decade, this strategy has gained significant prominence, and large-scale projects related to this technology are already underway in countries such as the United States, Australia, and New Zealand. However, it is essential to highlight that the economic viability of carbon capture and storage (CCS) is intrinsically linked to the capital and labor costs involved in industrial production. While government policies are crucial in encouraging the adoption of CCS in the steel industry, it is of utmost importance to focus on cost reduction to avoid potential negative impacts on productivity and economic growth [18]. An alternative that can be rapidly suitable is energy-saving technologies [9].

5.4 Use of Renewable Energies

The search for the replacement of fossil sources in the steel industry is a growing global trend. The use of renewable energies is on the rise and gaining traction not only in steel production but also across all sectors worldwide.

Decarbonization of the steel industry can be achieved through the substitution of coal used in blast furnaces with biomass. This approach offers significant benefits, as biomass is widely available due to the diversity of crops and waste materials, and it is a renewable source with the potential to mitigate emissions [4]. Additionally, wind and solar energy also present promising alternatives to replace other forms of non-renewable energy in steelmaking operations.

6. CONCLUSION

When it comes to the focus on decarbonization, it is known that each technology has different potential for mitigating greenhouse gas emissions. In addition, the costs, the efforts involved and the geographic location of the steel mills demonstrate how the transformation of iron and steel production depends on cooperation between nations, taking into account economic and political aspects. Finally, it is concluded that awareness needs to be increasing and research and development must go hand in hand with the industry, incorporating the efficient use of energy resources and developing technologies to increasingly align steelmaking with ESG principles. It is essential to emphasize that, although the adoption of these principles does not always translate directly into monetary values for the steel companies, it is of great importance. The review briefly described the alternatives that the world is actively seeking to address environmental challenges. However, as this is a recent topic and considering the obstacles faced by the steel industry, new studies are emerging, and the tendency is for the world to find even more options to replace fossil carbon sources.

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7. REFERENCES

[1] D. PATNAIK, A. K. PATTANAIK, D. K. BAGAL, AND A. RATH, **"Reducing CO_2 emissions in the iron industry with green hydrogen**," Int J Hydrogen Energy, Jul. 2023, doi: 10.1016/j.ijhydene.2023.03.099.

[2] J. KIM ET AL., "**Decarbonizing the iron and steel industry: A systematic review of sociotechnical systems, technological innovations, and policy options**," Energy Research and Social Science, vol. 89. Elsevier Ltd, Jul. 01, 2022. doi: 10.1016/j.erss.2022.102565.

[3] C. WANG, S. D. C. WALSH, Z. WENG, M. W. HAYNES, A. FEITZ, AND D. SUMMERFIELD, "**Green steel: Synergies between the Australian iron ore industry and the production of green hydrogen,**" Int J Hydrogen Energy, 2023, doi: 10.1016/j.ijhydene.2023.05.041.

[4] P. W. GRIFFIN AND G. P. HAMMOND, "**The prospects for 'green steel' making in a net-zero economy: A UK perspective**," Global Transitions, vol. 3. KeAi Communications Co., pp. 72–86, Jan. 01, 2021. doi: 10.1016/j.glt.2021.03.001.

[5] C. BROADBENT, "**Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy,**" International Journal of Life Cycle Assessment, vol. 21, no. 11, pp. 1658–1665, Nov. 2016, doi: 10.1007/s11367-016-1081-1.

[6] N. S. CHIPANGAMATE, G. T. NWAILA, J. E. BOURDEAU, AND S. E. ZHANG, **"Integration of stakeholder engagement practices in pursuit of social licence to operate in a modernising mining industry,"** Resources Policy, vol. 85, Aug. 2023, doi: 10.1016/j.resourpol.2023.103851.

[7] B. MAYBEE, E. LILFORD, AND M. HITCH, "**Environmental, Social and Governance (ESG) risk, uncertainty, and the mining life cycle**," Extractive Industries and Society, vol. 14. Elsevier Ltd, Jun. 01, 2023. doi: 10.1016/j.exis.2023.101244.

[8] K. LI, D. ZOU, AND H. LI, "**Environmental regulation and green technical efficiency: A process-level data envelopment analysis from Chinese iron and steel enterprises**," Energy, vol. 277, Aug. 2023, doi: 10.1016/j.energy.2023.127662.

[9] X. YU AND C. TAN, "**China's pathway to carbon neutrality for the iron and steel industry**," Global Environmental Change, vol. 76, Sep. 2022, doi: 10.1016/j.gloenvcha.2022.102574.

[10] V. NECHIFOR, A. CALZADILLA, R. BLEISCHWITZ, M. WINNING, X. TIAN, AND A. USUBIAGA, "**Steel in a circular economy: Global implications of a green shift in China**," World Dev, vol. 127, Mar. 2020, doi: 10.1016/j.worlddev.2019.104775.

[11] A. G. OLABI, T. WILBERFORCE, K. ELSAID, E. T. SAYED, H. M. MAGHRABIE, AND M. A. ABDELKAREEM, "**Large scale application of carbon capture to process industries – A review**," Journal of Cleaner Production, vol. 362. Elsevier Ltd, Aug. 15, 2022. doi: 10.1016/j.jclepro.2022.132300.

[12] A. MALLETT AND P. PAL, "**Green transformation in the iron and steel industry in India: Rethinking patterns of innovation**," Energy Strategy Reviews, vol. 44. Elsevier Ltd, Nov. 01, 2022. doi: 10.1016/j.esr.2022.100968.

[13] I. R. SOUZA FILHO, Y. MA, D. RAABE, AND H. SPRINGER, "**Fundamentals of Green Steel Production: On the Role of Gas Pressure During Hydrogen Reduction of Iron Ores**," JOM, vol. 75, no. 7, pp. 2274–2286, Jul. 2023, doi: 10.1007/s11837-023-05829-z.

[14] I. R. SOUZA FILHO ET AL., "**Green steel at its crossroads: Hybrid hydrogen-based reduction of iron ores**," J Clean Prod, vol. 340, Mar. 2022, doi: 10.1016/j.jclepro.2022.130805.

[15] V. B. ANGALAKUDITI, A. APPALA, N. SINGH, L. R. SINGH, AND S. S. BARAL, "**A Process Intensification Approach to Improve Productivity, Quality, and Reducing Emissions in the Iron Ore Sintering Process**," Journal of Sustainable Metallurgy, vol. 9, no. 1, pp. 73–80, Mar. 2023, doi: 10.1007/s40831-023-00660-x.

[16] A. TAGHIPOUR, W. AKKALATHAM, N. EAKNARAJINDAWAT, AND A. I. STEFANAKIS, "**The impact of government policies and steel recycling companies' performance on sustainable management in a circular economy**," Resources Policy, vol. 77, Aug. 2022, doi: 10.1016/j.resourpol.2022.102663.

[17] M. FALSAFI AND R. FORNASIERO, "**Explorative Multiple-Case Research on the Scrap-Based Steel Slag Value Chain: Opportunities for Circular Econom**y," Sustainability (Switzerland), vol. 14, no. 4, Feb. 2022, doi: 10.3390/su14042284.

[18] H. LEE, J. LEE, AND Y. KOO, **"Economic impacts of carbon capture and storage on the steel industry–A hybrid energy system model incorporating technological change,"** Appl Energy, vol. 317, Jul. 2022, doi: 10.1016/j.apenergy.2022.119208.