STEEL CIRCULAR ECONOMY IN THE CIVIL CONSTRUCTION: A STUDY CASE OF STEEL INDUSTRY

ECONOMIA CIRCULAR DO AÇO NA CONSTRUÇÃO CIVIL: ESTUDO DE CASO DE SIDERÚRGICA

ECONOMÍA CIRCULAR DEL ACERO EN LA CONSTRUCCIÓN: ESTUDIO DE CASO DE UNA EMPRESA SIDERÚRGICA

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ABSTRACT
This research aims to describe a case study of the application of the circular economy of steel in a steel industry, demonstrating the impacts on economic, social and environmental sustainability. The methodology employed included a case study with stages of literature review, field investigation and analysis of collected data. The field investigation consisted of direct observation and analysis of documents, as well as visits and interviews with the managers of the studied company. The analysis of the results considered CO2 emissions, energy consumption, use of raw materials and recycling of co-products, mainly. The results demonstrated the positive impacts of the business model in the context of the circular economy, with the reduction of greenhouse gas emissions by approximately 50% compared to the global average; 8.90% reduction in energy spent during steel manufacturing from 2019 to 2020, despite the 5.53% increase in production in the year. It should be noted that each year a greater percentage of waste is reused, with a maximum value of 78.88% in 2020. The main contribution of this work consists in the systematization of the actions that characterize the circular economy in the steel industry, through which it encourages sustainable processes in the civil construction industry. The sector can be one of the drivers of the transition to a circular economy by reducing the consumption of raw materials and energy, in addition to greenhouse gas emissions, increasing profitability and having a sustainable approach.

KEYWORDS
Circular economy; sustainability; steel mills; greenhouse gas emissions; construction industry.

RESUMO
Esta pesquisa tem por objetivo descrever estudo de caso da aplicação da economia circular do aço em siderúrgica, demonstrando os impactos para a sustentabilidade econômica, social e do meio-ambiente. A metodologia empregada contemplou estudo de caso com etapas de revisão da literatura, investigação em campo e análise dos dados coletados. A investigação em campo consistiu em observação direta e análise de documentação, além de visitas e entrevistas com os gestores da empresa estudada. A análise dos resultados considerou principalmente as emissões de CO2, consumo de energia, uso de matérias-primas e reciclagem de coprodutos. Os resultados demonstraram os impactos positivos do modelo de negócio no contexto da economia circular, com a redução de emissão de gases de

efeito estufa (GEE) aproximadamente 50% em relação à média global; redução da energia gasta durante fabricação do aço de 2019 a 2020 em 8,90%, mesmo diante do aumento da produção no ano de 5,53%. Destaca-se que a cada ano é reaproveitada uma maior percentagem de resíduos, com um valor máximo de 78,88% em 2020. A principal contribuição deste trabalho consiste na sistematização das ações que caracterizam a economia circular em siderúrgica, através da qual se incentiva processos sustentáveis na indústria da construção civil. O setor pode ser um dos motores da transição para uma economia circular ao reduzir o consumo de matérias-primas e energia, além das emissões de GEE, aumentar a rentabilidade e ter uma abordagem sustentável.

PALAVRAS-CHAVE
Economia circular; sustentabilidade; siderúrgicas; emissão de gases de efeito estufa; indústria da construção.

RESUMEN
El objetivo de esta investigación es describir un estudio de caso sobre la aplicación de la economía circular en la siderurgia, demostrando las repercusiones en la sostenibilidad económica, social y medioambiental. La metodología empleada incluyó un estudio de caso con etapas de revisión bibliográfica, investigación de campo y análisis de los datos recogidos. Los resultados mostraron los impactos positivos del modelo de negocio en el contexto de la economía circular, con una reducción de las emisiones de gases de efecto invernadero (GEI) de aproximadamente el 50% en comparación con la media mundial; una reducción del 8,90% de la energía utilizada para fabricar acero de 2019 a 2020, incluso ante un aumento del 5,53% de la producción en el año. Cabe destacar que cada año se reutiliza un mayor porcentaje de residuos, con un valor máximo del 78,88% en 2020. La principal aportación de este trabajo es sistematizar las acciones que caracterizan la economía circular en la siderurgia, a través de las cuales se fomentan los procesos sostenibles en la industria de la construcción. El sector puede ser uno de los impulsores de la transición hacia una economía circular reduciendo el consumo de materias primas y energía, así como las emisiones.

PALABRAS CLAVE
Economía circular; sostenibilidad; acerías; emisiones de gases de efecto invernadero; industria de la construcción.

1. INTRODUCTION

Civil construction is responsible for 38% of greenhouse gases emitted into the atmosphere, being pointed out as the industry with the greatest impact on environmental sustainability (HUANG *et al*., 2018; UNITED NATIONS ENVIRONMENT PROGRAMME, 2020). In addition, the sector is the largest consumer of raw material, generating about 35% of municipal landfill waste (GHAFFAR *et al*., 2020).

This situation is a social challenge due to the increasing volume of construction waste, where in Brazil presents more than 60% of the collection of municipal solid waste (MSW) in cities, as a consequence of a linear economic model (ABRELPE, 2020). As an option to reduce the use of primary materials and their environmental impacts, through different strategies that replace the end of life, such as reduction, reuse and recycling of materials in production/distribution and consumption processes, the circular economy stands out (KIRCHHERR *et al*., 2017; LI *et al*., 2022). The Circular Economy (infinite cycle), proposes changes in the way of thinking and acting in relation to the consumption of goods and services, favoring the reintegration of waste to the productive cycle/consumption infinite times (RUIZ *et al*., 2020; MANNHEIM, 2022).

In Brazil, the main regulatory framework that addresses the circular economy is the National Solid Waste Policy (NSWP), introduced in 2010 by Law 12,305 (BRAZIL, 2010). Brazil can be considered a pioneer in the countries of Latin America and the Caribbean to implement legislation related to waste management (GUARNIERI *et al*., 2020). However, the circular economy is not formally expressed in national laws and has been approached in a decentralized way, with incipient implementation and the concept still little understood (JESUS *et al*., 2023).

Circular Economy systems are based on the reuse, repair, reconditioning, remanufacturing, and recycling of products. The return to the production cycle, allows treating waste in a biological and technical way, being thought from its design so that they can recirculate safely and with quality, expanding the possibilities of business related directly or indirectly to the Circular Economy (ABDALLA; SAMPAIO, 2018; FRANCONI; CESCHIN; PECK, 2022; SHEVCHENKO *et al*., 2023).

The circular economy covers several areas, including industrial, through remanufacturing, which allows the transformation of used or defective products into new products, with a new life cycle (ALAMEREW; BRISSAUD, 2020; MISHRA *et al*., 2023). Particularly in the steel industry is no different. Currently, steel company in Brazil are distributed in 10 Brazilian states, with the highest concentration in the Southeast region, 92% of production (ELLEN MACARTHUR FOUNDATION, 2017). Steel is the most recyclable material in the world and can be continuously recycled without loss of quality and reused as raw material through scrap. The adoption of the circular economy concept in the sector has enabled the intelligent and effective reuse of raw materials, inputs, and waste (BRAZIL STEEL INSTITUTE, 2017).

Given the context presented, this paper aims to describe through a case study the application of circular steel economy in a steel company, demonstrating the impacts caused by the business model of the company in economic, social, and environmental sustainability. The main analyses of the case study include CO2 emissions, energy consumption, use of raw materials, and recycling of co-products.

STEEL PRODUCTION AND THE CIRCULAR ECONOMY

The International Labor Organization considers that the steel sector accounts for 3% of the employed people in the world, contributing about 3.8% of the global GDP (WORLD STEEL ASSOCIATION, 2020) According to the World Steel Association (2021), it is estimated that world demand for steel will double by 2050, a situation that greatly contributes to increased resource consumption, since among the industrial segments, the steel is the largest consumer of energy (MILFORD *et al*., 2011; HOLAPPA, 2020).

Given the situation, the steel production process is crucial for the strategic and sustainable growth of this segment, as well as reassess the current business model. According to the Brazil Steel Institute (2020), there are two types of steel plants: integrated (use iron ore as raw material in a majority way) and semi-integrated (use scrap as the main source of steel production). Figure 01 illustrates the steel production process.

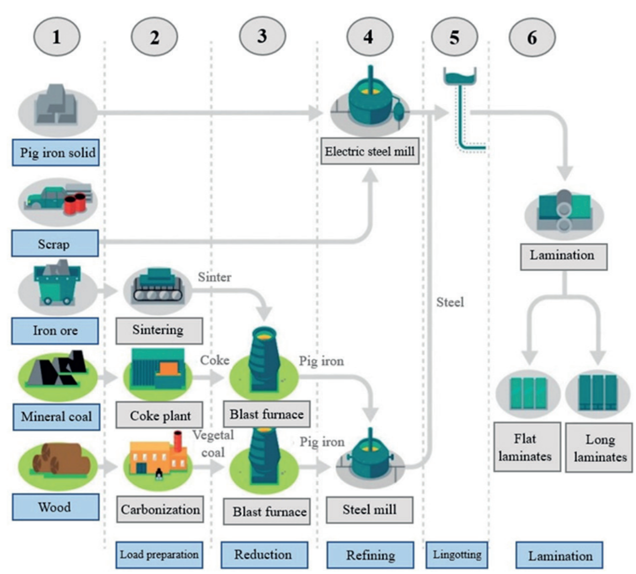

Figure 01: Steel production.
Source: Brazil Steel Institute (2017).

In the integrated plants, the first step consists in the preparation of raw material (Step 1) - iron ore - which is processed via pelletization (agglomeration of fines into pellets of defined size for blast furnace efficiency) or via sintering (prepared for physical and chemical characteristics). The addition of sinter, coke, and wood (Step 2) inside the blast furnace (Step 3) promotes the production of pig iron (iron and carbon alloy), through the reduction induced by coke. Still in Step 3 are added the fluxes and scoring with the function of forming compounds with higher melting point when aggregating with impurities of iron ore and coal. In the refining (Step 4) is inserted oxygen to the process to oxidize carbon, manganese, silicon, and phosphorus present in pig iron. This process is developed in the steel mill, via LD/BOF converter (Lins-Donawitz/ Basic Oxygen Furnace).

Subsequently, the liquid metal goes to casting (Step 5), followed by mechanical forming through lamination (Step 6).

In the semi-integrated plants, focus of this work - business model of the circular economy, the production of steel occurs by the fusion of metal load (scrap, pig iron) in the electric steelworks/ electric furnace in the refining (Step 4), eliminating Steps 2 and 3, following for the casting (Step 5) and rolling (Step 6).

The main advantage of semi-integrated plants is the absence of the iron ore reduction step, which reduces the complexity of the production process while allowing lower costs and lower greenhouse gas emissions. According to data from the World Steel Association (2021), one ton of steel produced with recycled ferrous scrap is equivalent to ceasing to emit 1.5 tons of greenhouse gases. Figure 02 illustrates the CO2 emission by integrated and semi-integrated plants.

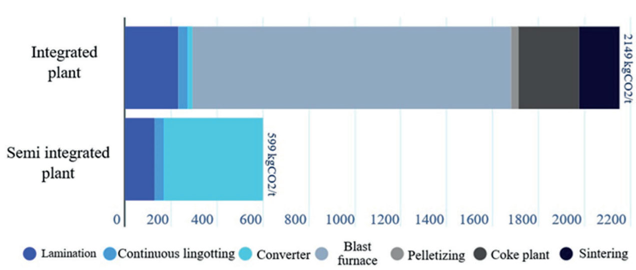

Figure 02: Integrated versus semi-integrated power plants in CO2 emission.
Source: Chalabyan et al. (2019).

In addition to being less polluting, the semi-integrated plants have other advantages: activated and deactivated more easily, can produce steel in smaller quantities, more flexible with the adjustments of production levels according to steel demand and makes the use of scrap exposing less to the availability of iron ore (MERCADO, 2018). The global trend is that there is an increasing adoption of semi-integrated plants (also called mini-mills), since in 2020, the world crude steel production was already 27.7% through semi-integrated plants; while the rest in integrated plants (WORLD STEEL ASSOCIATION, 2021).

The role of the semi-integrated steel plant is fundamental to the circular economy in the processing of scrap steel, contributing to the preservation of the environment by reducing the amount of material deposited in landfills and inadequate sites. In addition, the semi-integrated plant reduces the energy use required in the steel production process by minimizing CO2 emissions and generates job opportunities for thousands of people through an extensive chain of scrap collection and processing for recycling.

3. METHODOLOGY

For the development of the present work, the qualitative research method was adopted with a case study. According to Godoy (1995), qualitative research starts from issues or focuses that have broad interests, where, as the study develops, these interests are defined.

In general, this type of research seeks to obtain descriptive data on people, places and interactive processes through direct contact of the researcher with the situation being studied. Emphasizing that the definition of qualitative research will not be restricted to the object of study or even by its purpose, but mainly by the way the object is studied. Dias Filho (2008) highlights the main elements to typify qualitative research. They are qualitative research has the natural environment as a direct source of data and the researcher as its main instrument; qualitative research is descriptive; the concern with the process is much greater than with the product; meaning is the essential concern in the qualitative approach and data analysis tends to follow an inductive process.

Thus, this research becomes qualitative, as it focuses on the analysis and description of the steel production process, seeking to address the business model towards a circular economy in a case study of a semi-integrated plant, and its importance for environmental, economic, and social sustainability. According to Lara and Molina (2011), case study is a research category whose objective is a unit that is analyzed in depth and that two circumstances must be observed: nature and scope of the unit; complexity of the case study determined by the theoretical supports that guide the work of the researcher.

This work is structured in 3 topics. The first is a literature review focused on the conceptual aspects and foundation on the subject. Followed by field research and, finally, the analysis of collected data, in which actions are described to achieve the objective and expected results.

3.1. Literature review

The narrative literature review was made to build the theoretical framework, which becomes important for the thematic contextualization addressed. The literature survey is the location and obtaining of documents to assess the availability of material that will support the topic of research work. Collection sites can be in libraries, government or private agencies, institutions, individuals, collections, scientific articles. Thus, is separated the documents collected according to the search criteria (GONÇALVES, 2019).

We used strong authors about the theme to build the theoretical framework, to contextualize the theme. From bibliographical research, which took place in articles and course completion papers in the period 2015-2021 on the academic google platform. And also, platforms to obtain technical information such as the Brazil Steel Institute and World Steel Association.

3.2. Field investigation with descriptive analysis

The present work consists of field research of descriptive nature, with sources of evidence adopted as: direct observation and analysis of documents. A case study was carried out in order to evaluate the sectors of the steel production process, visits were made to the areas to obtain a technical and professional view, as shown in Figure 03.

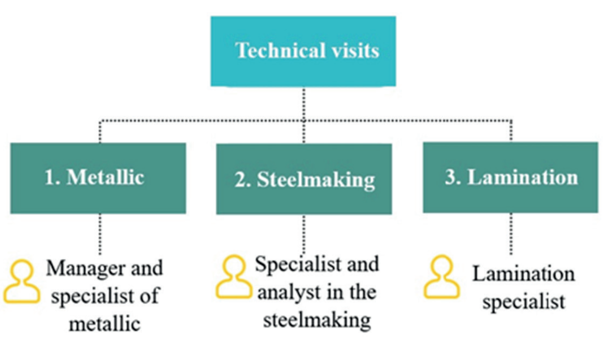

Figure 03: Technical visits to the steel sectors studied.
Source: Elaborated by the authors.

Thus, interviews were conducted with the manager and specialist in the area of metal, in which they are responsible for the marketing and receipt of scrap at the plant. Interviews were also conducted with the specialist and analyst of the steel mill sector, in which he is responsible for the transformation of scrap into billet and the rolling specialist to understand how the process of transformation of the billet into rebar occurs. Because it is qualitative research, the interview was chosen as a complementary instrument of data collection, which also allows to obtain information from the study subjects through oral interaction (VARGAS-JIMÉNEZ, 2012).

3.3. Analysis of the collected data

Data analysis was made from documentary research and field investigation, in which the information was compiled and critically analyzed in order to characterize and describe the steel plant process. The documentary research strategy was used to mediate the discussion with the literature, retrieving technical standards, materials made available by the steel plant studied - courses, materials and the company's website. The 2020 annual report was also retrieved, since it was the last one published. The main analyses of the case study are presented in Table 01.

Parameter	*Quantification*
CO2 Emissions	*Total emission (tCO2) and per ton of steel (tCO2/t steel)*
Energy consumption	*Total energy consumption per ton of steel (GJ/t steel)*
Raw Materials	*Tons of Pig Iron, Alloys, Fuels and Scrap*
Co-products	*Recycling (%)*

Table 01: Main analysis of the case study.
Source: Elaborated by the authors.

4. RESULTS AND DISCUSSIONS

The company studied operates in the steelmaking segment, as a producer of flat steel, long steel, iron ore, and has integrated and semi-integrated mills. It also operates in the market by recycling scrap, which represents 73% of its raw material, the scrap is then transformed into steel and returned to society in civil construction, agriculture, automobiles, infrastructure, and energy. Nechifor *et al.* (2020) indicate that the adoption of scrap as an input in the steel industry favors the reduction of negative environmental impacts and provides a direction for a circular economy. The use of recycled materials and new technologies in steel production requires the use of fewer resources, encouraging a circularity in production

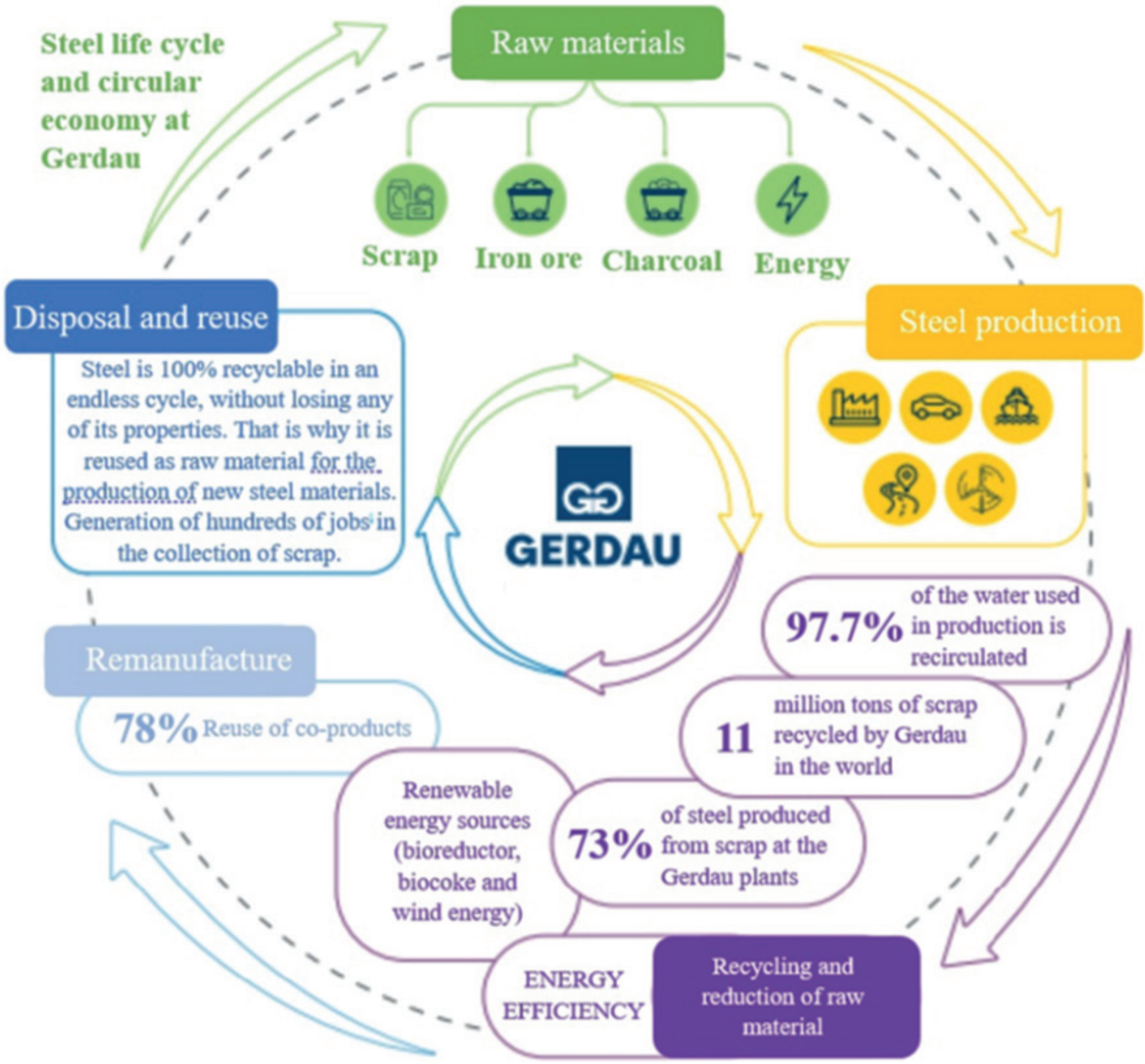

Figure 04: Summary scheme of the circular economy of the company studied.
Source: Adapted by the author of the annual report 2020 of the company studied (GERDAU, 2020).

processes (MULVANEY *et al*., 2021). For these reasons the business model of the company studied is characterized as circular economy.

The company has been seeking to balance the economic, social and environmental pillars by adopting various initiatives and practices aligned with the concept of circular economy, through environmental investments, environmental education training to employees, preserving and conserving forests. Figure 04 presents a summarized scheme of the circular economy of the studied company.

The circular model adopted in the studied plant has brought relevant results for sustainability, mainly by CO2 emissions, which is the main greenhouse gas emitted by the steel industry (DI SCHINO, 2019). In the analysis of the production of greenhouse gases directly (scope 01 - includes the emission sources: industrial processes; stationary combustion; mobile combustion) and indirect (scope 02 - includes the emission sources: acquired electric energy), it is possible to perceive the reduction of gas emissions compared to 2019 in Table 02. Although in Scope 01 there is an increase in CO2 emissions from 2019 to 2020, which is explained by the higher steel production. The company

Production of greenhouse gases	***2019***	***2020***
Scope 01	*9,056,519*	*9,198,407 (+1.57%)*
Biogenic emissions of CO_2	*1,891,560*	*1,738,243 (-8.10%)*
Scope 02	*2,890,986*	*2,082,515 (-27.96%)*

Table 02: Direct greenhouse gas emissions, in tons of CO2.
Source: Data collected from the 2020 annual report of the company studied (GERDAU, 2020).

reported 12,453,099 tons in 2019 versus 13,142,345.30 tons in 2020, an increase of 5.53%. In this sense, the CO2 emission per ton steel produced is presented in Figure 05.

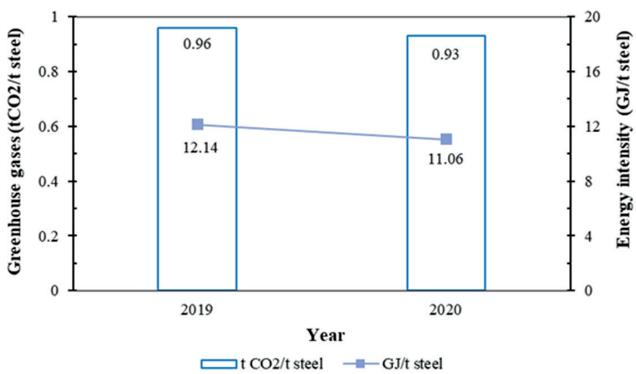

Figure 05: CO2 emission and energy intensity per ton steel produced.
Source: Adapted by the author of the annual report 2020 of the company studied (GERDAU, 2020)

The intensity of greenhouse gas emissions has decreased compared to 2019, reaching 0.93 tCO2/t of steel produced, which represents approximately half of the global steel industry average: 1.83 tCO2/t steel produced (Pandit *et al*., 2020). This reduction is attributed to the use of both scrap and semi-integrated plants. Nechifor *et al*. (2020) points out that for each ton of steel produced from scrap there is a 60% reduction in CO2. Di Schino (2019) indicates that semi-integrated plants have lower CO2 emissions than integrated plants.

The use of carbon from renewable forest origin, recycling scrap and the reuse of gases, and focus on a circular and sustainable model reflects the carbon intensity being below the global average of the steel industry. This intensity also includes the integrated plants, which despite the increase in production, achieved a better performance compared to the previous year, reducing the emission of gases. Pinto *et al*. (2018) show that the Brazilian steel industry can reduce greenhouse gas emissions through the use of charcoal under a regulatory policy that ensures its production in a sustainable way, value for steel products produced under this strategy.

Among the industrial sectors, the steel industry is the largest energy consumer, most of which comes from fossil fuels; therefore, energy consumption and CO2 emissions are related (CONEJO *et al*., 2020; JONES; HASTINGS-SIMON, 2021). The company studied managed to reduce total energy consumption from 151,201,598.91 GJ (2019) to 145,365,489.33 GJ (2020), a reduction of 3.86%, even after having increased its steel production by 2020. This reduction in energy consumption is due to the introduction of renewable sources, as shown in Figure 04.

Figure 05 shows the total energy consumption per ton of steel, highlighting an improvement in this indicator for 2020, from 12.14 to 11.06 GJ/t steel (-8.90%). According to International Energy Agency (2019), the energy consumption in the steel industry is approximately 20 GJ/t steel, where the company presents a reduction of this indicator by 44.70%. This result is in agreement with Nechifor *et al*. (2020) and Mulvaney *et al*. (2021) who indicate that the use of recycled steel can demand up to 40 and 60% less energy, respectively. Finally, it is important to highlight that in the company's integrated plants, about 92% of the gases generated are reused in the steel manufacturing process. These gases are used in the production of electrical and thermal energy for the industrial plants themselves, contributing to the energy efficiency of the plants.

4.1. Scrap

With the use of scrap, the company studied reduced the demand for natural resources, energy consumption and minimized the emission of gases (Figure 05) and can contribute to the reduction of the amount of material deposited in landfills and inadequate places and also in reducing the production of gases. In 2020 11 million tons of ferrous scrap were recycled, which is equivalent to 1,089 times the weight of the Eiffel Tower, located in Paris, France. The recycling of 1 ton of scrap metal is equivalent to no emission of 1.5 t of greenhouse gases (Broadbent, 2016; Mulvaney *et al*. 2021). In this sense, the company had stopped emitting 16.5 million tons of gases that would boost the greenhouse effect. Thus, showing the effects that a circular business model can bring in the steel process to minimize the impact on the environment.

Some studies (BROADBENT, 2016; Wang *et al*., 2018), through the Life Cycle Assessment (LCA) methodology, show that the incorporation of recycling in steel is an integral part of the circular economy model that promotes zero waste; reducing the amount of materials used, and encouraging the reuse and recycling of materials. The company has managed to reduce the use of raw materials including Pig Iron, which is responsible for shedding high energy in integrated mill process and has managed to maintain scrap recycling as 73% as a raw material source compared to the previous year (2019), as shown in Table 03.

Co-products

During the steel production process, the generation of waste becomes inevitable, the studied company seeks the development of technological routes with the reuse of these materials in its own plants or for other productive

Raw Materials	*2018*	*2019*	*2020*
Pig iron (internal and external)	*4,320,298.68*	*3,995,328.55*	*3,889,719.60*
Alloys	*232,194.94*	*192,497.89*	*211,926.81*
Carburantes	*184,640.75*	*125,045.42*	*170,237.72*
Scrap/ total raw material from recycling	*14,273,236.62*	*11,548,789.24*	*11,482,790.78*

Table 03: Analysis of raw materials (in tons).
Source: Data collected from the 2020 annual report of the company studied (GERDAU, 2020).

Types of waste	*Description*
Dangerous Industrial Waste	*Oil, grease, granulated blast furnace slag, steel slag, steel mill slurry, flask powder, coal powder, crude AF slag; granular AF slag; ACI mud; ACI slag, EAF dust, EAF slag, non-ferrous metals and crushing, dross, and mill scale. The potential significant impacts of these residues are: soil, surface water and groundwater contamination.*
Non-dangerous Industrial Waste	*Tires, scrap, scrap land. The potential significant impacts of these wastes are: Impact potential and soil quality change.*
Non-industrial dangerous waste	*Waste from the health area, lamps, etc. The potential significant impacts can be related to the handling in the case of sharp objects and correct disposal of waste from the health area.*
Non-dangerous non-industrial waste	*Waste from civil works, wood to form concrete and waste from cesspools. The potential significant impacts of these residues are: civil construction waste and wood, has no potential for contamination; whereas the waste from the pit can cause contamination of the ground water.*

Table 04: Types of waste generated in the industry.
Source: Data collected from the 2020 annual report of the company studied (GERDAU, 2020).

purposes and markets, in order to reduce the need for landfills and deposits. Thus, the company maintains a research team focused on the development of this sector, called co-products, based on the principles of circular economy and sustainability, contributing to preserve natural resources, save energy and reduce the disposal of polluting materials, reusing and recycling materials that would previously be discarded as waste. The production process of the studied plant generates the residues shown in Table 04.

The generation of waste in the industrial steel manufacturing process grew: 6,413,895, 6,399,671 and 7,345,566 t for 2018, 2019 and 2020, respectively, with an increase of 14.53% in 2020 compared to 2018, which is also explained by the growth in steel production. According to Figure 06, despite the increase in waste generated, the company also managed to increase the volume of waste reused in the process, 78.88% for 2020. Another important data that the company made available were the products that are in stock, and those that do not yet have a defined destination. 329,377 t of products in stock for 2020 are reported. In addition, the number of tailings produced decreased from 271,656 t in 2018 to 243,725 t in 2020.

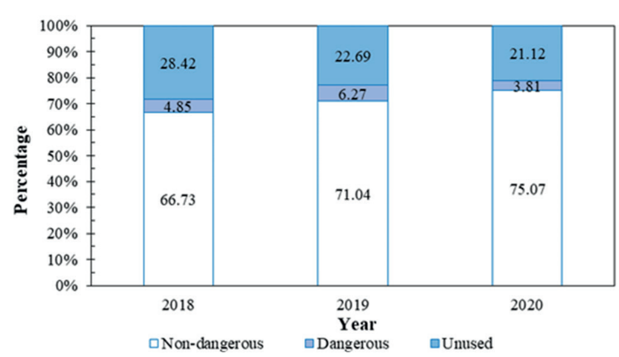

Figure 06: Evolution in waste disposal in the industry studied.
Source: Adapted by the author from the 2020 annual report of the company studied (GERDAU, 2020).

According to the company studied the percentage of reuse of co-products has grown over the years, from 71.58% in 2018 to 78.88% in 2020, which reinforces the idea of circular economy, energy management and innovation and digital transformation. In addition, the percentage of reuse directly impacts the production of greenhouse gases by volume of steel (tCO2/t steel), which also decreases, with the addition of other aspects of this circular model such as the use of scrap as raw material (73% of the total company and as the main raw material of the studied plant). According to the company, the goal for 2021 is to increase the reuse of this waste to 95%, further contributing to the sustainability and minimization of greenhouse gases. The operating result of co-products in 2020 generated revenue less expenses of US$ 96,471,668.02.

The co-products resulting from the steel industry, such as powder, sludge, slag, among others, are recycled and transformed into new products for other industries, especially construction. For example, 97% of the total amount of slag produced is recovered, where 78% is used in cement manufacturing, 21% in road construction and the rest in agriculture as fertilizer (Ardelean *et al*., 2022). However, it is necessary to develop new technologies to improve the quality of co-products, thus ensuring their reuse with a sustainable approach, lower environmental impact and greater energy efficiency (BRANCA *et al*., 2020).

Although the company studied shows positive results for a circular economy with a focus on the use of recycled materials and energy efficiency, Di Schino (2019) indicates that the growth in demand for steel may limit the production of semi-integrated plants due to the availability of scrap. Brazil's total steel capacity is estimated to increase from 47.9 (2018) to 70.7 Mt (2020), an increase of 47.6%; however, scrap availability will also increase, from 9.9 Mt (2018) to 21.1 Mt (2030), an increase of 114.14% (NECHIFOR *et al*., 2020). In this sense, it can be ensured that the growth of scrap availability is higher than the growth of steel demand. Pauliuk *et al*. (2012) point out that the supply of scrap could increase by 2050, but advanced recycling technologies are needed.

The steel industry has potential in the circular economy, mainly with semi-integrated plants and scrap. However, to ensure economic success (profitability and competitiveness) and sustainability, it is necessary to develop new technologies aimed at recycling scrap and other materials (HORVÁTH *et al*., 2019; JONES; HASTINGS-SIMON, 2021).

5. CONCLUSSIONS

The development of the present case study allowed a descriptive analysis of the processes of a semi-integrated plants in the production of steel, from the entry of scrap in the plant to the rolling for the final product, and the evaluation of the impacts of the circular business model introduced in the company, in which it represents a set of integrated and semi-integrated plants.

Measures to introduce circular economy in the company resulted in 73% of the raw materials of the scrap company. It was able to recycle 11 million tons of ferrous scrap and no longer emits approximately 16.5 million tons of greenhouse gases.

Despite the increase in steel production from 12,453,099 t (2019) to 13,142,345.30 t (2020), the company managed to reduce the greenhouse gas emission intensity from 0.96 tCO2/t steel (2019) to 0.93 tCO2/t steel (2020) which represents approximately half of the global steel industry average of 1.83 CO^2/t. The company also managed to reduce its total energy consumption in 2020 compared to 2019, from 12.14 GJ/t to 11.06 GJ/t. Although the generation of waste during the process has grown from 2018 to 2020, growth of 14.53%, the reuse of this waste also grew from 71.58 to 78.88%. In this sense, reuse is one of the pillars of the company that characterizes it as sustainable.

It can be seen that the use of scrap brings benefits to the steel sector as less energy expenditure, as well as minimizes the amount of gases that generate greenhouse effect. In addition, since Brazil has a considerable amount of scrap in the market, the application of the circular economy in steel becomes viable and a gain in the economy and sustainability. This scenario generates a new market for buying and selling scrap, known in the company studied as the metallic sector.

For the Circular Economy to be installed in Brazil, mainly, it is necessary to be environmentally and financially sustainable. Through the results obtained, it can be seen that steel mills have the potential to produce a considerable percentage of waste and this brings enormous opportunity for the introduction of the circular economy business model. Scrap as raw material is added value to waste that would be disposed of in nature and minimizing the use of natural resources, In addition, when steel losses occur in the process, the material can be scrapped and returned as primal matter. The waste generated during production, such as slag, becomes co-products and is sold to companies that use this material as a raw material, making profit for enterprise and developing new job opportunities. With this, one can realize the importance of this business model for the future of society and the environment.

It is also necessary the presence of public policies, laws, and regulations to encourage recycling and regularization of the scrap market. In addition to promoting the circularity of the proposal, through a commitment of consumers at each stage of the process, qualitative analysis and Saving process losses.

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