DIGITALISATION-BASED OPTIMIZATION OF STEEL PRODUCTION FOR COMPETITIVENESS AND SUSTAINABILITY

[1]Slavomír HUBATKA, [1]Branislav BUĽKO, [2]Dana BARICOVÁ, [1]Peter DEMETER, [1]Lukáš FOGARAŠ, [1]Jaroslav DEMETER, [1]Martina HRUBOVČÁKOVÁ

[1]TUKE - Technical University of Košice, Košice, Slovakia, EU, slavomir.hubatka@tuke.sk

[2]Research - Innovation and Technology Center, Košice, Slovakia, EU, dana.baricova@vtp.sk

https://doi.org/10.37904/metal.2023.4746

Abstract

The metallurgical sector is one of the main pillars of European industry. Steel is important not only for modern economies of developed countries but is an essential part of building infrastructure in developing countries, and thus in the coming decades, global demand for steel is expected to increase to meet growing social and economic needs. Currently, however, the steel industry is among the top three producers of CO_2 emissions. Steel producers have a great opportunity to achieve greenhouse gas emission reductions and improve energy consumption efficiency, thereby increasing their competitiveness, mainly through optimizing, digitalization and innovating the production process by introducing low-carbon technologies and increasing the efficiency of raw material and energy resources. This scientific article is focused on developing advanced mathematical prediction models and analysis of steel production processes. By utilizing modern BAT and ITs technologies, this research aims to improve the competitiveness of the steel industry by optimizing production processes and through the integration of datasets and analysis techniques contribute to reducing the carbon emissions in steel production through energy consumption optimization and the implementation of sustainable practices. Through the utilization of mathematical prediction models and advanced analysis techniques, the article aims to optimize steel production processes and enhance the competitiveness of the metallurgical sector.

Keywords: Decarbonization, metallurgy, emissions, steel industry, digitalization

1. INTRODUCTION

The steel industry is facing a significant challenge in reducing its carbon emissions while meeting the increasing demand for steel worldwide. To address this challenge, the industry is currently undergoing a transformation period that is evolving in two directions. The first direction is the development of completely new low-emission technologies that can potentially reduce the carbon footprint of steel production significantly. For example, the use of hydrogen as a reducing agent can significantly reduce emissions since it only produces water vapor as a by-product. Other innovative approaches include the reduction of iron ore in hydrogen plasma, which offers the potential for zero-emission steelmaking. However, these new technologies require significant investment and time to develop and implement [1,2]. The second direction is the optimization of existing technologies to reduce their carbon emissions. Since new low-emission technologies are still in the development phase, it is necessary to bridge the period until they are introduced. The optimization of existing technologies includes measures such as improving energy efficiency, use of alternative fuels, and recycling more steel to reduce the need for raw materials. To achieve the goal of reducing energy consumption and CO_2 emissions in the European iron and steel industry, incorporating Best Available Techniques (BATs) and Innovative Technologies (ITs) can be instrumental. The focus of this article is to introduce a methodology and model that is aimed at assessing the possibilities of improving energy efficiency and decreasing CO_2 emissions in the industry up to 2030. The proposed methodology and model lay particular emphasis on leveraging digitization tools to predict the transition phase of reducing CO_2 emissions, improving energy efficiency, achieving long-term cost reduction and competitiveness [3,4].

2. METHODOLOGY

This scientific article proposes a methodology that involves the development of advanced mathematical prediction models for the steel production process. The objective of the model is to optimize steel production processes and enhance the competitiveness of the metallurgical sector, while simultaneously reducing carbon emissions through energy consumption optimization and the implementation of sustainable technologies and practices. The research employs modern IT technologies to integrate datasets and analysis techniques, thus contributing to the reduction of carbon emissions in steel production in a more effective and efficient manner. The proposed methodology commences by collecting data pertaining to the steel production process, including information on energy consumption and CO_2 emission production. The collected data is utilized to construct mathematical prediction models for the production process. These models are developed with the primary aim of analyzing the production process and identifying potential areas where the implementation of Best Available Techniques (BATs) and Innovative Technologies (ITs) can reduce energy consumption, lower production costs, and minimize CO_2 emissions. Additionally, the models are employed to predict the impact of various process modifications on energy consumption and CO_2 emissions. **Figure 1** represents schematic overview of simplified methodology model of Brown-field steel plant. For the purposes of this article, the simplified model does not incorporate various direct and indirect factors that may influence the transformation of brown-field steel plants.

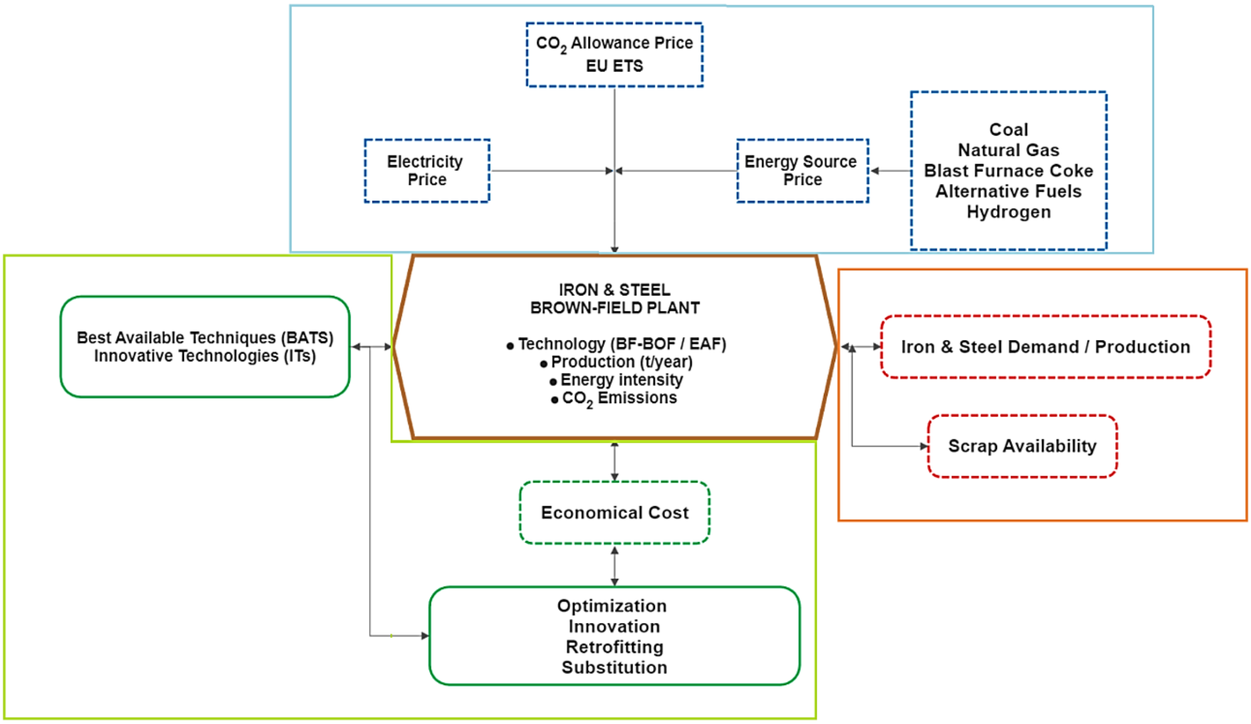

Figure 1 Methodology model of Brown-field plant - Schematic overview

The initial stage of process (brown diagram) involves conducting a comprehensive assessment of the current plant, including the evaluation of the production process, the identification of potential operational and technical deficiencies, and the analysis of environmental impact. The next stage (green diagram) involves the development of a detailed plan for the plant's modernization, which typically includes upgrading existing equipment, introducing innovative technologies, and implementing energy-efficient practices. This stage is based on implementation of Best Available Technologies (BATs) and Innovative Technologies (ITs). An important step is to evaluate the impact of the prices of input energy sources, the price of electricity and the price of EU ETS emission allowances (blue diagram). This involves conducting a detailed analysis of the current plant's energy consumption, cost structures, and environmental impact, specifically with regards to the aforementioned factors. Given the European Union's ambitious goal of achieving a 55% reduction in emissions by 2030 compared to 1990 levels and achieving carbon neutrality by 2050, it is crucial to optimize existing technologies to reduce their carbon emissions. While new low-emission technologies are still in the development phase, it is necessary to bridge the gap and continue reducing emissions using existing technology. This transitional period is critical to ensure that emissions are reduced at the necessary rate to achieve long-term environmental sustainability goals. Therefore, it is essential to prioritize the optimization of current technology to achieve significant reductions in emissions in the short term while new technologies are being developed and implemented. **Figure 2** represents two main methods of steel production - Primary steel production and Secondary steel production, which are currently used, and their related inputs. **Table 1** and **Figure 3** portray the current status of global and European steel production concerning the parameters of production, energy consumption, and CO_2 emissions [5,6,7].

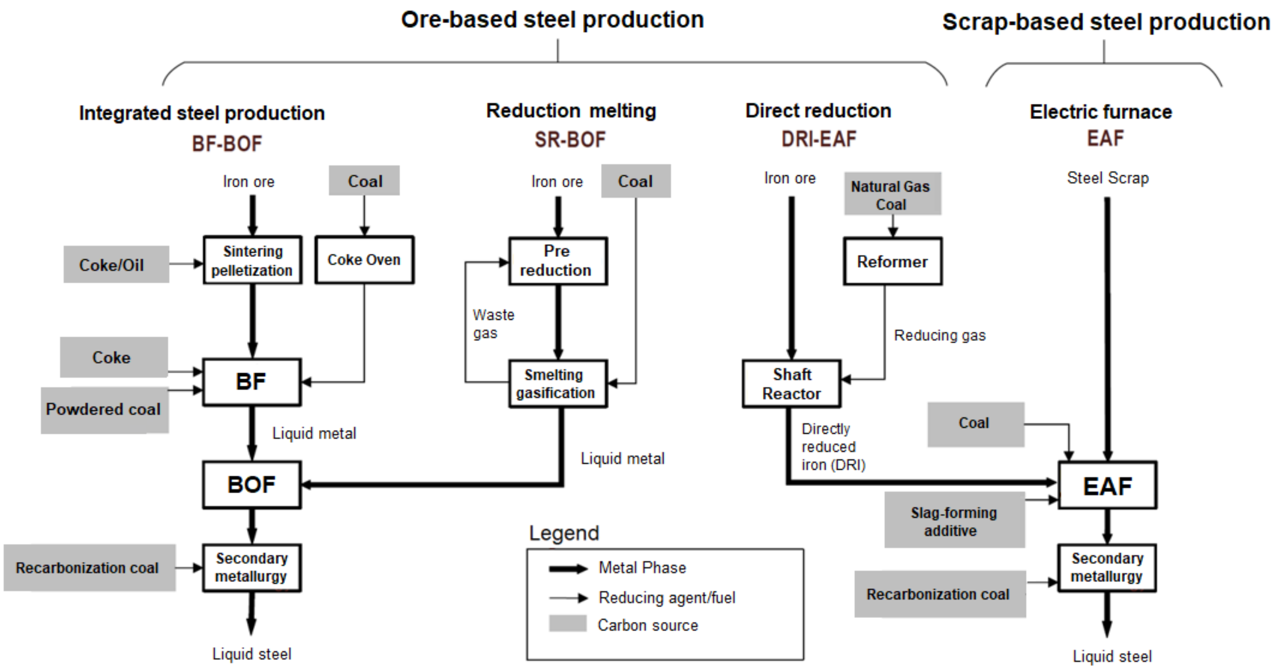

Figure 2 Two main methods of steel production - Ore-based steel production and Scrap-based steel production, and their related inputs

Table 1 Conventional technologies in steel mills and their energy consumption and emission production for the year 2019

Production process	Share of total global production	Share of total Europe production	Net energy consumption (GJ/t Steel)	Direct CO_2 emissions (kg CO_2/t Steel)
BF-BOF	71%	57,4%	21 - 23	1700 - 2200
DRI-EAF Scrap-EAF	29%	42,6%	17 - 22	1000
			2,1 - 5,2	300-400

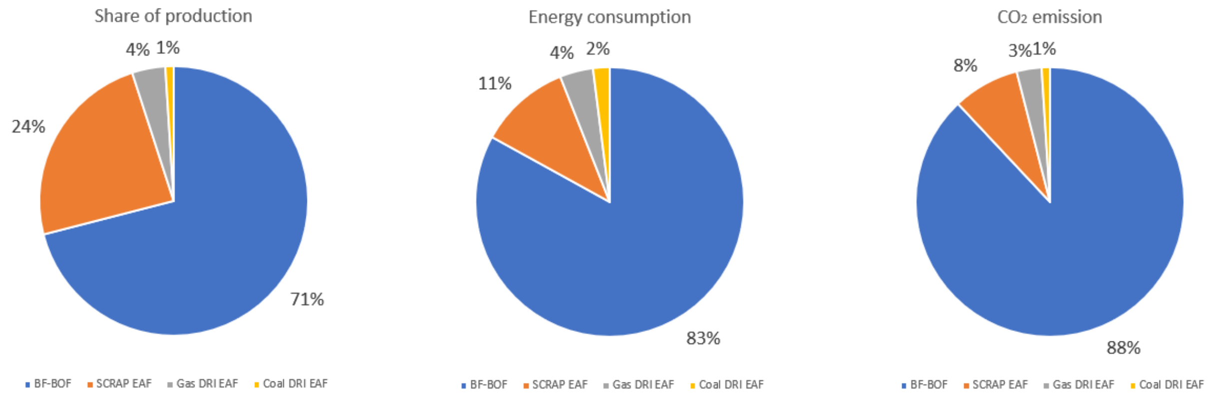

Figure 3 Share of worldwide steel production, energy consumption and CO_2 emissions percentage via different steelmaking process

During the production of one ton of steel in an integrated steel plant, the direct emissions of CO_2 are estimated to be in the range of 1.7 to 2.2 tons. Considering the current market price of emission permits, which stands at 90 euros per ton of CO_2, it can be inferred that the implementation of the EU Emissions Trading System (ETS) would lead to a cost increase of approximately 180 euros per ton of steel in comparison to the competition. The technological pathways aimed at optimizing the BF-BOF process in the short-term are predominantly focused on the blast furnace process, which stands out as one of the primary sources of CO_2 emissions [5,8]. **Figure 4** shows a combination of basic options for reducing emissions in the blast furnace process, including BAT technologies - partial replacement of fossil carbon (biomass) and increased injection of powdered coal, natural gas, plastic or reducing gas into the blast furnace (H_2), as well as storage and utilization of carbon oxides contained in blast furnace gas (CCU, CCS) [1,4].

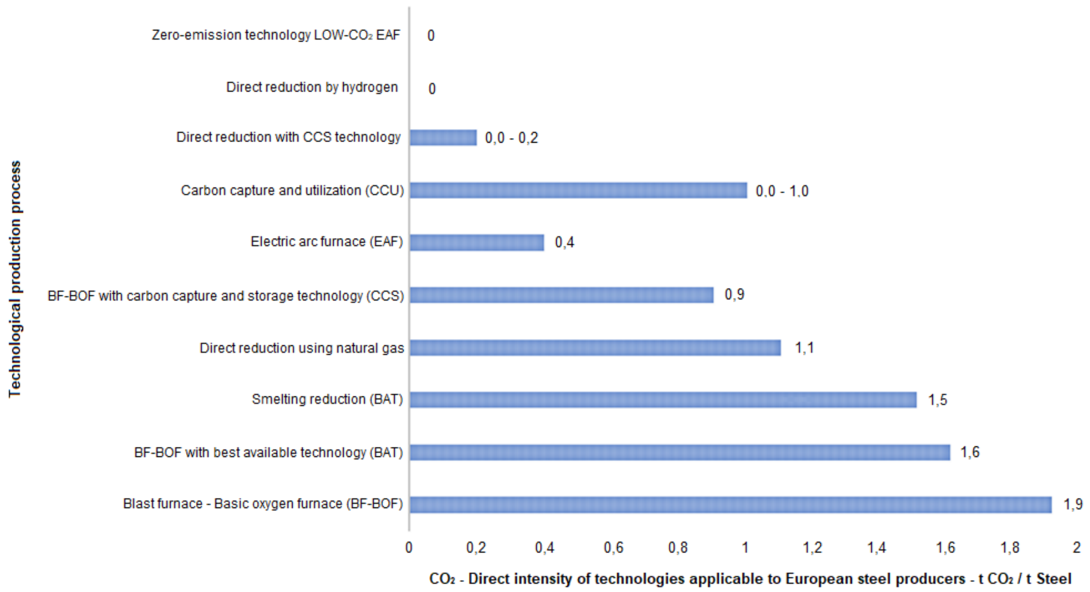

Figure 4 Technologies based on direct CO_2 intensity applicable to European steel producers

3. RESULTS AND DISCUSION

Consider a specific instance of steelworks with a yearly output of 3,000,000 tons of hot-rolled coil steel and a Scope 1 emission intensity of 2,000 kg CO_2/t steel. The number of free emission allowances allocated under the European Union Emissions Trading System (EU ETS) in 2016 was 4 million with a 2,2% yearly decline after 2020. With the current exchange price of Hot-Rolled Coil steel at 850€ and the cost of the emission permit at 90€, the emissions generated during production amount to 180€ of the total production cost of the product, comprising a substantial cost that exceeds 20% of the final product's total cost. For the purpose of this publication, it should be noted that in EU ETS Phase 4, changes in activity levels may impact the amount of free allocation, either positively or negatively, with adjustments made on the basis of yearly reported activity levels. However, the level of free allocated emission allowances until 2030 will remain unaffected as the amount of produced product does not vary significantly.

In order to maintain production capacity until 2030, innovation will be incorporated into the production process through the implementation of Best Available Techniques (BATs) and CCS/CCU to optimize existing technology. This is deemed necessary due to the ongoing development phase of new low-emission technologies, which have not yet been introduced, thereby requiring a bridging period. The possibility of transitioning from blast furnaces and basic oxygen furnaces (BF-BOF) to new electric arc furnaces (EAF) with direct CO_2 emissions at level of 140 tCO_2/t Steel for scrap-based production is contingent on significant investment costs and the accessibility of scrap in the steel plant's broader vicinity. **Figure 5** illustrates the direct carbon dioxide (CO_2) emissions resulting from steel production via two methods: integrated production (a) and transition to scrap-based Electric Arc Furnace (EAF) production (b), and (c) the variation in the total direct CO_2 emissions by technology (European Commission) [9].

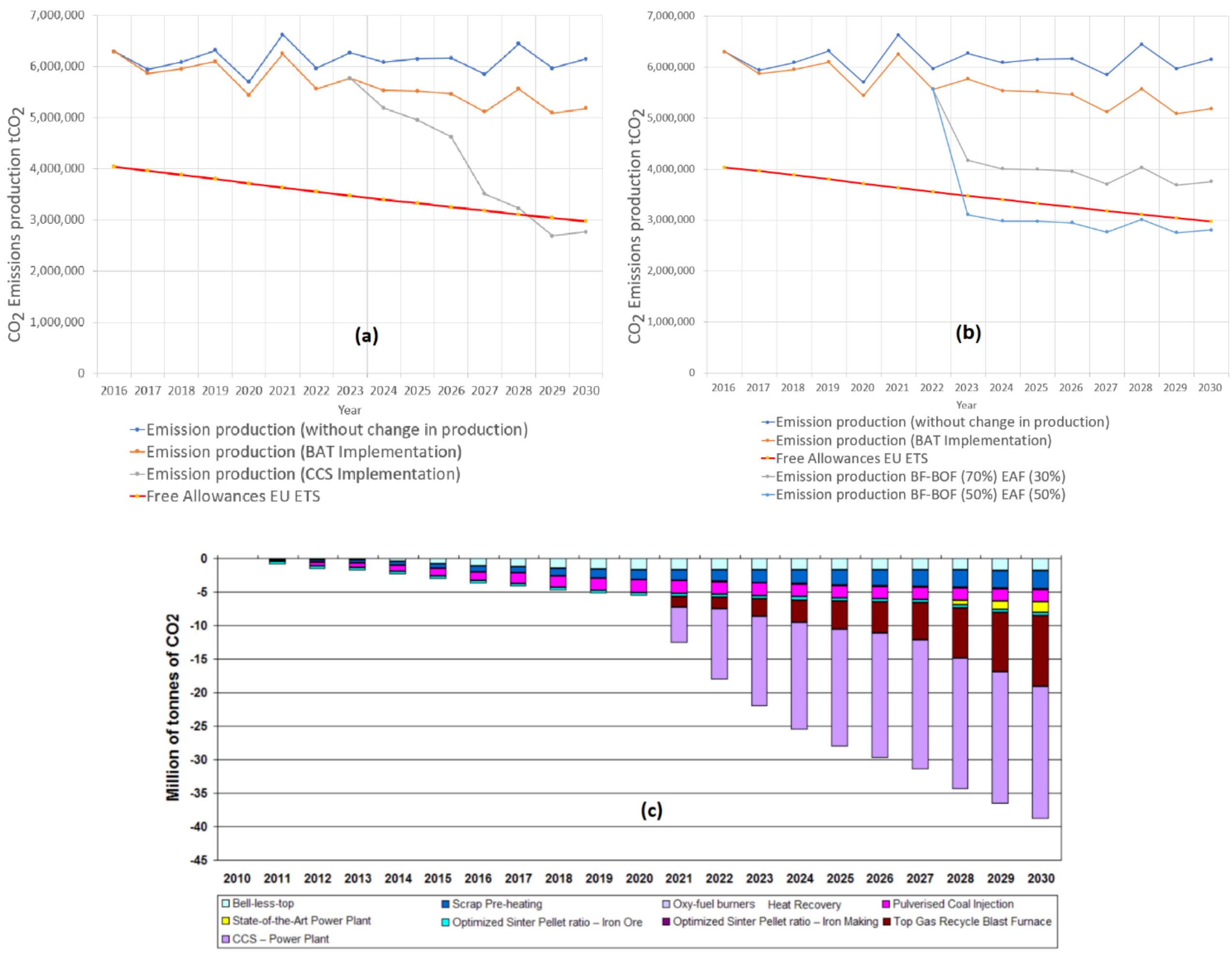

Figure 5 Direct CO_2 emissions from steel production for the integrated production (a) and transition for scrap-based EAF production (b), (c) represents the baseline variation in the total direct CO_2 emissions by technology

4. CONCLUSION

To summarize, the steel industry plays a vital role in the global economy, but its high CO_2 emissions pose a significant environmental challenge. Therefore, optimizing steel production through the implementation of low-carbon technologies and enhancing energy efficiency is imperative to secure the industry's sustainability. This scientific article proposes the development of advanced mathematical prediction models and analysis of steel production processes, utilizing modern Best Available Technologies (BAT) and Information Technologies (ITs) to optimize the production process and reduce carbon emissions. The integration of datasets and analysis techniques can further reduce the carbon footprint of steel production, while enhancing the competitiveness of the European metallurgical sector. These innovative approaches have the potential to enable the steel industry to achieve sustainable growth and long-term success. To achieve the energy and climate objectives, it is imperative for each steel manufacturer to undertake substantial endeavors aimed at mitigating emissions from steel production by the year 2050. The industry's transformation presents inherent difficulties, as it must occur seamlessly within the production process or with minimal constraints, thereby ensuring the preservation of both employment opportunities and the demand for steel.

ACKNOWLEDGEMENTS

This research work was performed under the grant project no. 1/0212/21 and was financially supported by VEGA ME SR AND SAS.

REFERENCES

[1] S. HUBATKA, et all. Decarbonisation of the steel industry - pathway to brighter future - Slovakia and Czech Republic case study, [online]. [cit. 2023-04-19]. Available from: https://doi.org/10.37904/metal.2021.4300

[2] International Energy Agency, Iron and Steel Technology Roadmap. [online]. [cit. 2023-04-19]. Available from: https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[3] Best Available Techniques (BAT) Reference Document for Iron and Steel Production, European Comission, ISBN 978-92-79-26475-7, doi:10.2791/97469, [online]. [cit. 2023-04-19]. Available from: https://op.europa.eu/en/publication-detail/-/publication/eaa047e8-644c-4149-bdcb-9dde79c64a12

[4] Material Economics (2019). Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry, [online]. [cit. 2023-04-19]. Available from: https://materialeconomics.com/publications/industrial-transformation-2050

[5] European Parliament, Carbon-free steel production - Cost reduction options and usage of existing gas infrastructure, [online]. [cit. 2023-04-19]. Available from: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/690008/EPRS_STU(2021)690008_EN.pdf

[6] Manuel BAILERA, Pilar LISBONA, Begoña PEÑA, Luis M. ROMEO. A review on CO2 mitigation in the Iron and Steel industry through Power to X processes, Journal of CO_2 Utilization, ISSN 2212-9820, [online]. [cit. 2023-04-19]. Available from: https://doi.org/10.1016/j.jcou.2021.101456

[7] STAVROPOULOS, P.; PANAGIOTOPOULOU, V.C.; PAPACHARALAMPOPOULOS, A.; AIVALIOTIS, P.; GEORGOPOULOS, D.; SMYRNIOTAKIS, K. A Framework for CO2 Emission Reduction in Manufacturing Industries: A Steel Industry Case. Designs. 2022, vol. 6, no. 22. Available from: https://doi.org/10.3390/designs6020022

[8] SONG, J.; JIANG, Z.; BAO, C.; XU, A. Comparison of Energy Consumption and CO2 Emission for Three Steel Production Routes-Integrated Steel Plant Equipped with Blast Furnace, Oxygen Blast Furnace or COREX. *Metals*. 2019, vol. 9, no. 364. Available from: https://doi.org/10.3390/met9030364

[9] PARDO N, MOYA RIVERA J, VATOPOULOS K. Prospective Scenarios on Energy Efficiency and CO2 Emissions in the EU Iron and Steel Industry. EUR 25543. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC74811.