Hanhee Kim, Alejandra Barrera and Niklas Hartmann

Comparative techno-economic analysis of industrial technologies for achieving carbon neutrality in steel and cement production

Hanhee Kim: Offenburg University of Applied Sciences, Institut für nachhaltige Energiesysteme (INES)
Badstrasse 24, Offenburg, Germany
+49 781/205-4878, hanhee.kim@hs-offenburg.de
Alejandra Barrera: Offenburg University of Applied Sciences
Badstraße 24, 77652 Offenburg, Germany
Niklas Hartmann: Offenburg University of Applied Sciences, Institut für nachhaltige Energiesysteme (INES)
Badstrasse 24, Offenburg, Germany
+49 781/205-4645, niklas.hartmann@hs-offenburg.de

Overview

Industry plays a key role in the energy transition. The goal of climate neutrality in 2050 can only be achieved through fundamental technological innovation in each industry sector. Especially, steelmaking and clinker production processes are considered extremely energy-intensive and carbon-dependent. The current existing capacity is emissions-intensive because it relies heavily on fossil fuels. The steel industry accounts for 28% of total industrial emissions, while the cement industry emits 26% of them, accounting for a total of 56%, with the two sectors emitting more than half of all industrial CO_2 emissions [1]. Emissions from the production of these bulk materials can be effectively reduced by reductions in indirect emissions through using zero-emission electricity, or direct carbon sequestration.
The purpose of this study is to present an alternative process between the steelmaking process and the clinker production process and to present prospects by comparing and analyzing the total cost with the conventional processes. It reflects, among other things, fluctuating energy costs for both industry sectors, providing practitioners with an up-to-date technology-economic analysis that they can refer to when investing in alternative technologies.

Methods

The task of this study is to evaluate and compare the total cost of carbon-neutral technology with conventional processes for steel and cement production. To this end, the current commercialized electrification technology and carbon capture storage (CCS) technology are investigated and the difference in bulk material production cost caused by the introduction of these technologies into each industry is analyzed. This takes into account specific market conditions (prices of raw materials, energy costs, etc.).
In addition, from 2026, CO_2 tax will be levied based on ETS-free allowances for sectors with a risk of carbon leakage (including the steel and cement industry), and as these free allowances are phased out, environmental costs borne by each industry should also be considered.

Results

1. Steel Production

Carbon reduction targets in steel production can be achieved using scrap-based electric arc furnace (EAF) production if using zero-emission electricity to eliminate indirect emissions [2].

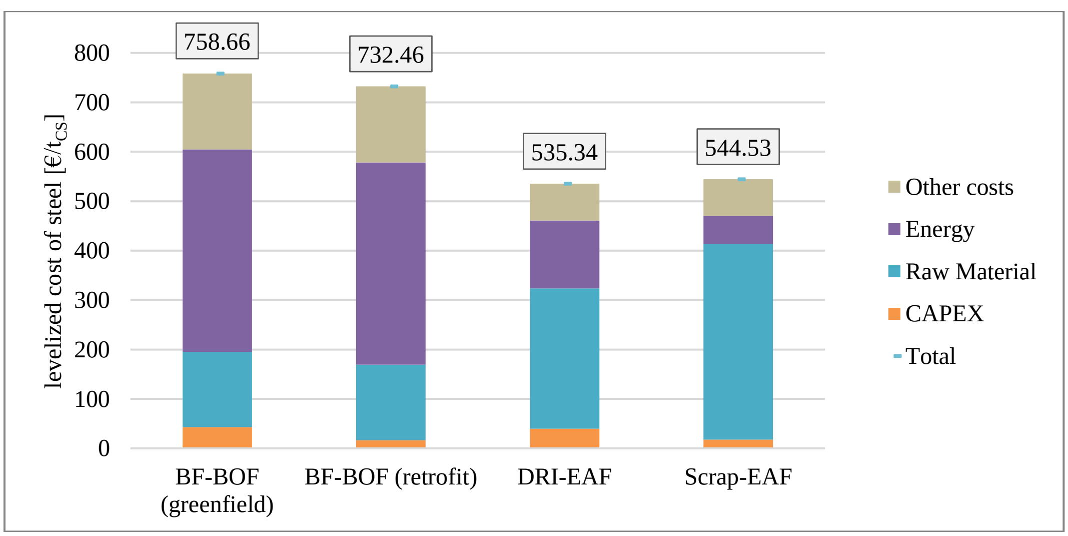

Figure 1*. Comparison of the levelized cost of steel of the different technologies for the year 2022 (Notes: CS = crude steel. BF-BOF = blast furnace-basic oxygen furnace. DRI-EAF = direct reduced iron-electric arc furnace)*

Figure 1 shows the results of the total cost for the year 2022. The production cost of steel applying energy and material cost data in 2022 shows different results from previous studies. Due to the rapid rise in fossil fuel energy prices, BF-BOF (greenfield) is 142% higher than the result of the DRI-EAF route. That is, the result of DRI-EAF is the lowest with 535.34 € per ton of crude steel. In the case of conventional scenarios, the main driving cost parameter is energy cost. In contrast, in alternative methods, raw material cost is the factor that accounts for the most significant portion of the total cost.

2. Cement Production

The introduction of CCS in the cement industry has the largest emission reduction among technologies that mitigate carbon emissions from the process. Cement plants also have favorable characteristics for CO_2 capture, such as relatively high CO_2 concentration in the flue gas, fewer discharge points, and stable operation [3]. Therefore, the applicability of the CCS technology was economically evaluated, focusing on the clinker process, which is the most polluted among cement production processes (Figure 2).

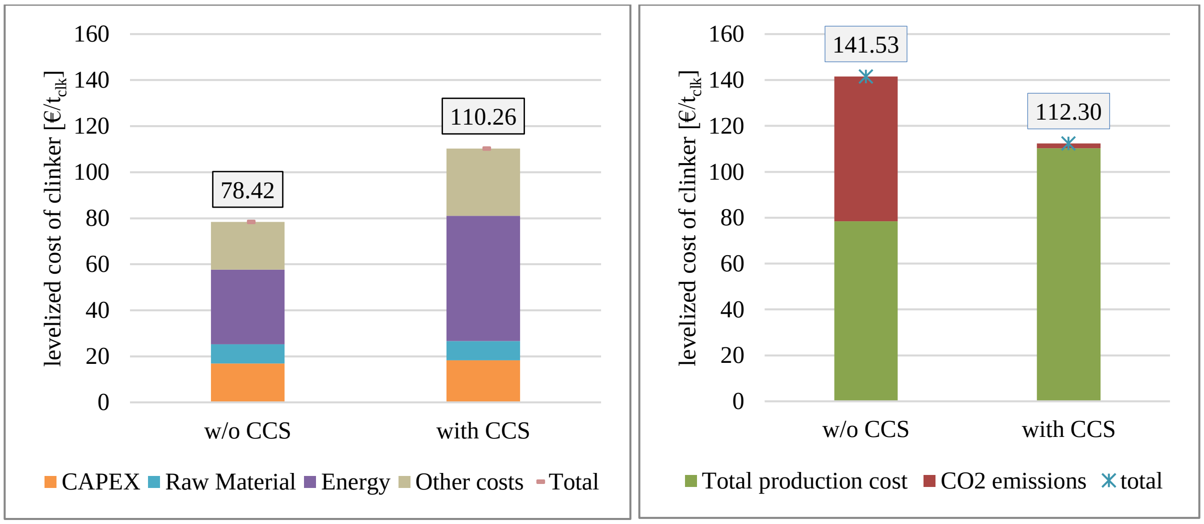

Figure 2*. left: Comparison of the levelized cost of clinker with and without CCS technology for the year 2022, right: Application of CO2 emission taxes for the year 2030 (Notes: CCS = carbon capture storage. clk = clinker.)*

Clinker production using CCS is very sensitive to electricity costs. As a result, energy costs are 168% higher than conventional technologies, which is a driving force behind the overall cost. As of 2030, when the CO_2 tax borne by the industry is added to the total cost based on the free allowance applied to clinker production, the process including CCS is more economical.

Conclusions

This paper presents a comparative cost estimate of carbon-neutral technologies for steel and cement plants. The cost analysis showed that for the steel sector, the DRI-EAF technology has the lowest steel cost (535.34 €/t_{CS}) and the existing technology increases the steel cost by 42% compared to the alternative technology due to the high energy cost in 2022. In the case of the CO_2 capture process applied to cement plants, the clinker cost was increased by about 40%, but considering the CO_2 emission taxes to be imposed in 2030, the clinker cost was reduced by 20%. In other words, when considering the environmental cost of the carbon tax, investment in alternative technologies is profitable. Due to the free allowance system that will be sequentially introduced in the two industries from 2026, carbon emissions will be able to become a new variable for evaluating investment profitability in the future.

References

[1] IEA; Energy Technology Perspectives 2020. Paris: IEA Publications; 2020. Available online: https://www.iea.org/reports/energy-technology-perspectives-2020 (accessed on 20 January 2023)

[2] Facchini, F.; Mossa, G.; Mummolo, G.; Vitti, M. An Economic Model to Assess Profitable Scenarios of EAF-Based Steelmaking Plants under Uncertain Conditions. Energies 2021, 14, 7395. https://doi.org/10.3390/en14217395

[3] Gardarsdottir, S.O.; De Lena, E.; Romano, M.; Roussanaly, S.; Voldsund, M.; Pérez-Calvo, J.-F.; Berstad, D.; Fu, C.; Anantharaman, R.; Sutter, D.; Gazzani, M.; Mazzotti, M.; Cinti, G. Comparison of Technologies for CO2 Capture from Cement Production—Part 2: Cost Analysis. Energies 2019, 12, 542. https://doi.org/10.3390/en12030542