TOWARDS A LOW-CARBON STEEL INDUSTRY: ECONOMIC POTENTIAL OF A FLEXIBLE OPERATION AND STORAGE OF INTERMEDIATE PRODUCTS

Michael Haendel Fraunhofer ISI, Breslauer Str. 48, 76139 Karlsruhe, Germany,+49 721 6809-676, michael.haendel@isi.fraunhofer.de
Simon Hirzel, Fraunhofer ISI, Breslauer Str. 48, 76139 Karlsruhe, Germany,+49 721 6809-405, simon.hirzel@isi.fraunhofer.de

Overview

The steel industry is a major emitter of CO_2 emissions with about 3,165 billion tonnes of CO_2 (7-9 % of total global CO_2 emissions) [1,2]. Steel is produced using primary and secondary routes. The secondary route recycles steel scrap in an electric arc furnace with relatively low energy demand and emissions. However, the amount of crude steel produced using the secondary route is limited by the availability of steel scrap. The primary route is, therefore, needed as well to meet the global demand for crude steel. This energy-intensive route reduces iron ore in a blast furnace using mainly coke and converts it into crude steel in the downstream basic oxygen furnace. This route is already close to its theoretical minimum for emissions. A promising alternative to primary steel production in terms of greenhouse gas emissions is the direct reduction process. This yields direct reduced iron (DRI) that can then be processed into crude steel in an electric arc furnace. By using natural gas as a reducing agent, considerable greenhouse gas emissions can already be saved compared to the traditional primary production route. Hydrogen from renewable electricity can also be used as a reducing agent to avoid emissions almost completely and meet climate protection targets. However, direct reduction has only been used to a limited extent to date (5.8 % of world production) [2,3], primarily in regions with low natural gas prices. Direct reduction combined with electrolysis offers the option to run production flexibly and to store intermediate products temporarily, as well. Given volatile energy carrier prices, this option makes it conceivable to run production when electricity and natural gas are cheap. The corresponding cost savings could contribute to improving the economic efficiency of this production route. The aim of this paper is to examine the economic potential of a flexibly-operated direct reduction plant combined with storage facilities for hydrogen and DRI.

Methods

The study starts by defining the system boundaries for the analysis. The cost-relevant process steps are identified and relevant technical parameters are determined. In particular, the factors of influence are identified that distinguish DRI production with natural gas from DRI production with hydrogen. Based on this, a linear optimization model is formulated. The model aims to determine the economically optimal operating and plant configuration considering variable energy prices. The operating and plant configuration contains, in particular, the operating mode of the intermediate product storages as well as the plant capacities. The optimization model covers the most important process steps of DRI production up to the transfer of the DRI to the electric arc furnace. The model considers the technical restrictions of individual plants, the most important energy and material flows and integrates major factors for assessing the plant's economic efficiency.

To demonstrate the model, a case study is carried out, which uses the optimization model with different parameter settings to draw conclusions for a flexibly operated steelworks and its storages. The case study, which assumes perfect foresight, examines steel production with the reducing agents natural gas and hydrogen for the status quo and the years 2030 and 2050. It compares a reference scenario without storage utilization and overcapacities with alternatives that allow more flexible operation. To analyze the transformation process to a low-carbon iron and steel industry, which is probably inevitable in the long term, the scenarios also take into account minimum quotas of DRI production quantities with hydrogen as well as different fees and levies on energy carrier prices. For the case study, both historical and forecast price time series are used for the different energy sources. Future electricity price time series are determined, for example, using a simple merit order model considering the future power plant portfolio. The analysis is carried out for one year in an hourly resolution and supplemented by a brief examination of the flexibility utilization in a minutely resolution.

Results

The preliminary results show that optimized operational management under perfect foresight can decrease production costs, especially through savings in energy source procurement costs. The use of storage facilities seems to bring economic benefits only in the long term. The storage capacities for DRI are in the range of the usual production compensation of a few weeks. Hydrogen storage facilities have a substantially smaller capacity, which is suitable for balancing production in the order of days, but also have larger economic potential.

Given the current regulatory framework, natural gas is used almost exclusively as a reduction agent for DRI. The use of green hydrogen does not seem to be economically competitive at present, but will improve in the long term. If adjusted fees and levies on natural gas and CO_2 emissions are considered, however, production can be shifted to the lower-emission hydrogen-based production route completely. With a minimum quota for a proportion of DRI that is produced with green hydrogen, the production transformation can be carried out step by step with slightly increased production costs for DRI. In the long term, it may even make sense for steel manufacturers to develop overcapacities at low minimum quotas when setting up electrolyzers for the first time, as these can bring economic advantages through flexible operation.

Conclusions

The presented linear optimization model can depict the flexible operation of a direct reduction plant with natural gas and with green hydrogen as the reducing agent from technical and economic perspectives for different boundary conditions. By using the model, it is possible to gain a better understanding of the economic challenges and regulatory implications associated with the transition to a low-carbon iron and steel industry. Initial results indicate a cost-saving potential due to flexible operation using storage facilities. In reality, however, various uncertainties, such as the development of energy carrier prices, are likely to reduce the cost-saving potential, which means that production can only be adjusted to fluctuations in energy carrier prices to a limited extent. In order to make electricity cheaper to use than natural gas, intervention in the regulatory framework seems unavoidable to enable the transition to hydrogen-based steel production with as few emissions as possible in the long term. A gradual switch to green hydrogen seems to be feasible with minimum quotas and allows costs to be controlled to a certain extent. Given the different conditions, especially for brownfield plants, it is important to examine to what extent the model can be tansferred to installations other than the example considered here. Because of the typically long plant lifetimes and limited capacities of the plant constructors, a transformation path for steel production should be defined at an early stage to achieve the climate protection targets and should not neglect countries with large iron and steel industries like China.

References

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