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Original article

Global assessment of biomass suitability for ironmaking – Opportunities for co-location of sustainable biomass, iron and steel production and supportive policies

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ABSTRACT

Iron and steel production processes are amongst the biggest industrial contributors to the global carbon emissions, and national as well as international obligations are set to drive their significant emission reductions. One of the possible strategies is to partially substitute fossil fuels used during the iron ore reduction process by sustainably-sourced biomass. The extent of the opportunities for such fuel switching, however, varies for each country. Theoretically, biomass into ironmaking should be only supported for countries which present co-location of sustainably domestically sourced biomass in sufficient quantity, a substantial iron and steel industry and supportive national policies.

Using a multi-criteria global suitability assessment approach developed in this research, the status of countries' steel industry, sustainable biomass resources and supportive policies were examined for top 40 steel production countries via the blast furnace ironmaking route. The results highlight those countries with significant potential to use domestically sourced biomass for such application and advance the efficient use of the limited biomass resources from the global perspective. Specifically countries such as Canada, Sweden, China, USA and France were identified as the most suitable, but other countries present opportunities that could be overcome if the corresponding barriers are identified.

Introduction

The iron and steel sector is the largest industrial CO_2 emitter, contributing to nearly 7% of the total global industrial greenhouse gas emissions [1] and requiring on average of 800 kg of coal for every metric ton of crude steel [2]. Due to the importance of steel's numerous applications in economic development and in low carbon technologies, increasing demand for steel products has been forecasted until at least 2050 [3]. Therefore to limit global warming below 2 °C, it is estimated the sector must lower the CO_2 emissions relative to those in 2011 by 13% by 2025 [4]. Application of sustainably sourced biomass has been identified as an effective short term CO_2 mitigation strategy for ironmaking [5]. Materials for iron and steel production, such as iron ore, limestone and metallurgical coal/coke are globally traded, hence so can be biomass for use in ironmaking. However, fuel switching for those geographic locations that have a sufficient amount of nationally produced biomass can additionally:

- reduce emissions by eliminating those occurring from very long distance bulk transport of the fossil fuels – for example, Borjesson and Gustavsson [6] estimated that sourcing biomass regionally could emit over 70% less of CO_2 emissions than importing coal;
- benefit the local economy – looking at Brazil for example, one can see that support for local agriculture can be a very significant political driver for biomass utilization [7];
- provide the steel industry with a better opportunity to control the sustainability of biomass sourcing – keep the regulation of the sustainability of biomass supply and use within the same government.

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The objective of the work is hence to identify which countries have the potential to use domestic biomass resources for emission reduction purposes in their iron and steel industry.

The importance of emission reduction within the iron and steel sector is acknowledged by the industry, but its low profitability [8], the current economic uncertainty, oversupply of steel on the market together with maintaining competitive advantage limit any low carbon technological investments in this sector [9]. As biomass production is different to fossil fuels, biomass could reduce the industry's issues related to the fluctuation of the fossil fuel prices, as well as overcome concerns related to fuel security and diversity - as long as an efficient utilization of the limited biomass resources is reached and biomass is sustainably sourced. Sustainable sourcing in this work is defined as a biomass supply chain that preserves or enhances the role of biomass in the already existing ecosystem. Therefore, to be treated as suitable in the present work, policies incentivizing biomass use for ironmaking applications should not only include the appropriateness of biomass for the given country [10] but also cover strategies for its sustainable sourcing.

Multiple review papers recently published on biomass utilization within iron and steel plants [11–13] indicate a rising interest in such application from both academia and industry. The greatest potential for on-site biomass integration is for the integrated blast furnace-basic oxygen furnace (BF-BOF) route [14], which provides 73% of the world's steel [15]. Here, biomass can partially substitute for fossil fuels at the coke making stage [16], in the sintering process [17] or directly in the blast furnace [18]. The varied characteristics that different biomass types have, as well as the diverse upgrading technologies, provide multiple possibilities, but also complex constraints for its utilization within the ironmaking process [19]. Mathieson et al. [14] estimated that biomass can overall reduce up to 58% of net CO_2 emissions from a common BF-BOF route. Such emission saving, however, can be only achieved when the utilized biomass is satisfying carbon neutrality, and it is required that the governments provide support and control to the private and third sector to achieve biomass adoption [20].

The uncertainty in the whole system viability of biomass use is currently a bigger drawback than the technical limitations of using such fuel in the process [21]. The fuel cost and availability [22,23], and rising concerns about sustainability of biomass supply [24] greatly limit its further deployment. A study by Thrän et al. [25] identified that the biomass potential greatly varies under different scenarios and for different regions. Hence the overall question of where the use of bioenergy in the iron and steel making industry is actually suitable can only be answered meaningfully in context. This is because the size of the steel industry, nature and origin of biomass resources and policies all differ between countries.

Knowledge on the regional fitness of bioenergy for iron and steel industry also benefits both the steel industry and policy formulation, in the latter case aiming at supporting long term sustainability of renewable energy integration [26]. As an illustration of the different outcomes of general, versus country specific studies, a previous general study on the electricity sector identified bioenergy as the least suitable amongst all renewables [27], but a different study stated that bioenergy can play an important role in more site-specific energy projects [26]. Hence bioenergy application is not suitable for every application and across all locations, and should be supported only after its suitability for the specific location and application is assessed. Increasing confidence in such suitability is especially important at present, as currently the integration of renewable fuels into ironmaking is not attractive for investors and requires substantial support and co-operation from policy makers to promote it [28].

Location suitability studies have been done primarily on electricity generation from renewables, such as wind [29,30] and solar [31], which demonstrated the different suitability of renewables for different locations on national as well as international level. However, there is a gap in literature for bioenergy and particularly its application into industries such as iron and steel. Wang et al. [32] and Suopajärvi and Fabritius [33] analyzed the possibility of biomass use for iron making in Sweden and Finland, respectively, but those countries correspond together to less than 1% of the total global crude steel production via BF-BOF [15]. The gap leaves decision makers in steel producing countries across the world with the strategic decision of whether the adoption of bioenergy in the industry is actually a suitable strategy for its decarbonization. The present study was done to bridge the gap and reveal how opportunities or barriers differ between countries and ensure sustainable use of biomass.

The overall aim of this work is to identify and down select countries which are potentially suitable for integrating bioenergy into their iron and steel making processes via the BF-BOF route. Specifically, the study covers bioenergy possibilities within coke oven, sinter plant as well as blast furnace (for top charging as well as pulverized coal injection). The specific objectives are:

- to develop a Global Suitability Index, an assessment framework that uses steel production, bioenergy and policy factors for each country to provide a quantitative measure of suitability for domestically sourced biomass use in blast furnace ironmaking; and
- to provide an informed judgment for which countries domestically sourced bioenergy in blast furnace ironmaking should be further considered.

Defining the suitability of countries convincingly requires in depth analysis, such as detailed techno-economic and life cycle assessment [34], which implies a significant investment of time and effort. The current work is the initial step before such analyses are performed. As such, it avoids expending effort on detailed studies of unsuitable locations, but also allows the policy community to evaluate countries which would not be considered otherwise.

Previously, there have been various efforts to develop indices that identify and/or rank entities by their fitness as a function of purpose or context. Some key examples of these are the:

- Habitat Suitability Index [35], the approach popular for ecosystem assessment studies;
- World Trilemma Index [36] for comparison countries based on their ability to provide sustainable energy policies; and
- Land Suitability Index [37] evaluating the land suitability for the defined use.

Adaption of each of these indices, in isolation, would be able to indicate the fitness of deployment of bioenergy in iron and steelmaking across the world, but only from a single perspective. Instead, to provide a holistic picture, it is necessary to integrate these into a single index that captures the key top level factors as a function of geography. The methodology used in the present paper for achieving this integration is to formulate a new multi-criteria global suitability assessment. The work concentrates exclusively on the BF-BOF route, and there bioenergy opportunities specifically presented by the coke oven, sinter plant and blast furnace, to facilitate comparison of like with like. However, with suitable input data, the presented approach can be adapted to other routes to iron and steel production and a Global Suitability Index methodology could readily be modified to consider the insertion of renewables into other industries. A key focus of the work is to reduce the extent of subjectivity in assessing fitness for purpose, when compared with established methods [38], although this cannot be eliminated entirely.

The next Section "Methodology" describes the Global Suitability Index, the methodology developed for this assessment study, followed by the obtained results. Section "Discussion" compares the outcomes with the current practice and summarizes the model's limitations and future improvements. The final Section presents the conclusions of the study.