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The environmental impacts of iron and steel industry: a life cycle assessment study

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ABSTRACT

This study conducts a life cycle assessment for iron and steel production in Turkey using SimaPro software and IMPACT 2002+ impact assessment method with the purpose of comparing the impacts of processes (coke making, sintering, iron making, steel making) and final products (billet, slab, hot rolled wire rod, hot rolled coil), concurrently. System boundary was set as cradle-to-gate and functional unit was selected as 1 ton of final steel product. Among the processes, steel making process exhibited the highest total environmental impact, which was followed by sintering. The highest impacts were in the categories of human health and climate change. Coke production process showed the highest impact on depletion of non-renewable energy sources while it was with a negative contribution in the climate change category because of the avoided external energy consumption due to the production of coke oven gas within the facility. The comparison of the impacts for different final products revealed that hot rolled coil causes the highest total environmental impact followed by hot rolled wire rod, billet and slab. In an attempt to evaluate the effect of having different production scenarios implemented in the facility, three different scenarios representing three different production ratios of semi-finished (billet and slab) and finished (wire rod and coil) products were considered and it was found that the highest impact would come out if all the products were the finished ones and the hot rolling of casting products covers approximately 24% of the total environmental impacts of the full production cycle of one ton of product. Based on the assessment results, suggestions for sustainable production were made.

1. Introduction

The iron and steel industry (ISI) is the world's biggest energy-consuming manufacturing industry with the largest share in the world's economy. In the iron and steel production over world, China takes the first place, and Japan, U.S. follow it. Turkey, with a 34.7 million tons production had a share of 2.1% of the total world production in 2013 (WSO, 2014) and ranked number eight among the steel-producing countries in the world. Meanwhile, in Europe, Turkey ranks number two after Germany (WSO, 2014). Iron and steel production is highly energy intensive and therefore it is associated highly with resource conservation, energy efficiency, and emissions reduction. The Turkish ISI accounting for about 25% of overall energy use in the manufacturing industry is therefore of particular interest in the context of environmental impacts.

In this context, life cycle assessment (LCA) provides a method for assessment of all environmental impacts associated with a service or product. Through the LCA analysis, all possible environmental loads of a service are ultimately classified according to their contribution to a number of environmental impacts, including ozone depletion potential, global warming potential and human toxicity. While LCA can be applied to compare the environmental impact of different products (product-based LCA), it can be also applied to compare different production processes or to evaluate the sub-processes in a production process between each other (process-based LCA) (Yilmaz et al., 2015). Hence, LCA can be used to determine the hotspots in a life cycle, i.e. the stages causing greatest environmental harm, so that these can be targeted for improvements (Nicholas et al., 2000).

Several studies on LCA for iron and steel industry have been conducted around the world. Most of these studies are product-based. For example, Seppala et al. (2002) carried out a LCA study

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to give a general view of the use of materials and energy, of the emissions and environmental impacts caused by the Finnish metal industry, and selected the functional unit was selected as one tonne of product at the factory gate. In another study, Norgate et al. (2007) also carried out a product-based LCA, selecting 1 kg of refined metal as the functional unit, and evaluated environmental impacts of steel and stainless steel in terms of global warming potential, solid waste burden and gross energy requirement. In a comprehensive study, Tongpool et al. (2010) compared the proportional impacts of different steel products (slab, hot-rolled, cold-rolled, hot-dipped galvanized, and electro-galvanized steels) in the categories of fossil fuels, global warming potential, ecotoxicity, minerals, carcinogens, and respiratory inorganics, and indicated that the hot-dipped galvanized steel is with the highest impacts. In a recent study, Gu et al. (2015) have developed a water footprint calculation model and calculated water footprint of steel from a life cycle assessment perspective. They have indicated that the steel plant poses a serious risk to the water environment.

In the process-based LCA category, there are also a number of studies of which the most recent one is by Burchart-Korol (2013). In this study, the impacts of steel production processes were compared for Poland, using the functional unit of one ton of cast steel. The production of pig iron in blast furnaces was found to have the highest impact on greenhouse gas emissions and fossil fuel consumption, while the sintering process was with the highest impact on respiratory inorganics category. In this study, although all possible impact categories were covered, only product considered was cast steel. Other products from iron and steel making were not reflected.

In the above-mentioned studies, the same impact assessment methods were used but the results are not still comparable since they have different basis. Furthermore, the impact categories considered in these studies are not also comparable to each other. So, it is hard to reach to a general conclusion out of these literature studies available. Moreover, to our knowledge, there is no study that considers the environmental impacts of all processes and all product types concurrently. Thus, it is clear that there is a need for further investigation to clarify the issues regarding the LCA for iron and steel industry. Moreover, the differences in the inventory data used could result in different results. In most of the studies, country specific inventory data were used; therefore, the results reported are somewhat specific to their country. In fact, conducting a LCA study specific to country is of vital importance in order to reach the realistic results representing country conditions.

In Turkey, as being one of the leading countries of the world's steel production, the concept of LCA has gained an interest by the Turkish steel industry by the day. In this regard, Turkish Steel Industry participated in a study conducted by the International Iron and Steel Institute (IISI) throughout the world in 2000 to communicate sustainable development activities of the world steel industry (Curran et al., 2006). The Turkish steel industries participated in this study were able to compare their raw material, energy consumptions and emission levels with the levels determined by IISI. In another study, Ertem et al. (2010) compared the specific energy consumptions of three integrated iron and steel producers in Turkey. However, there is no any other LCA study conducted on Turkish iron and steel industry. Therefore, the objective of the study is to conduct a country specific LCA study for the integrated iron and steel industry in Turkey and to add to the understanding of environmental impacts associated with all steel production process steps and all final product types concurrently, at an integrated plant. Moreover, the environmental effects of different production scenarios implemented in the facility, regarding the production ratios of semi-finished and finished products, were also explored. The findings from the present study is expected to help discovering the best opportunities for future impact reduction in steel production.

2. Materials and methods

2.1. Life-cycle assessment

LCA calculations were accomplished by using software SimaPro version 7.2.4 in compliance with ISO 14040 (2006) that defines four main steps within an LCA study: goal and scope definition, inventory modeling, impact assessment, and final interpretation.

2.1.1. Goal and scope definition

The goal of the study was to assess the environmental impacts of integrated iron and steel industries in Turkey and to compare the impacts associated with the sub-processes as well as the impacts associated with the final products.

The system boundary was assigned as "cradle to gate". Upstream processes, transportation, production processes and utility services were included to cradle to gate boundary. The upstream processes are acquisitions of raw materials, energy and auxiliary materials. The transportation stage indicates the transportation of materials such as raw materials, auxiliary materials and fuels. The production processes for steel production are divided into two; the main production system and the utility services. The main production system comprises of the following sub-processes; coke making (CM), sintering (S), blast furnaces (BF), basic oxygen furnaces (BOF), casting (C) and hot rolling (HR), as presented in Fig. S1 in Supporting Information (SI) section. The utility services include energy and water facilities and mechanical workshop. Energy facility comprises boiler, turbo generator, turbo blower, pure water, waste heat, and oxygen plants producing steam, electricity, compressed air, steam and oxygen respectively. Water facility supplies pure water, service water and sea water. Mechanical workshop is responsible for repair and manufacturing of machine parts. The mechanical workshop had been excluded during the LCA evaluations conducted for the sub-processes and products as the contribution of this unit to specific processes or products cannot be disintegrated.

2.1.2. Data inventory

The data inventory stage involves the quantification of flows and materials and energy required to produce the functional unit of interest. In the present study, a field study was carried out in one of the three integrated iron and steel production facilities in Turkey in order to collect the inventory data. The selected facility has the features to reveal the average values of integrated iron and steel industry in Turkey having the share of about 35% in steel production via integrated means. Thus, this facility is considered as a representative sample of Turkish integrated iron and steel industry in terms of manufacturing technologies and production capacity.

The information about acquisitions of raw materials, energy and auxiliary materials were not obtained from the facility, but, instead was taken from the inventories in the database of SimaPro. Among the databases involved, primarily Ecoinvent database was preferred. In case the information was not available in this database, the other databases (Dutch Input Output Database 95, ELCD, EU&DK Input Output Database, Industry data 2.0, USA Input Output Database 98 and USLCI) were used. The data not specific to country were directly taken from the databases whereas country-specific ones were selected according to the suitability to the country conditions such as geographical similarities as presented in Table S1 in SI. For example, the electricity provided by the network was adapted using the percentages of energy sources specific to electricity production in Turkey to reflect country-specific