Resources, Conservation and Recycling 105 (2015) 113–122

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Life cycle assessment of ferronickel production in Greece

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ARTICLE INFO

Article history:
Received 26 June 2015
Received in revised form 14 October 2015
Accepted 15 October 2015
Available online 14 November 2015

Keywords:
Ferronickel
LCA
Nickel laterite ore
Pyrometallurgy
Greenhouse gas emissions

ABSTRACT

Ferronickel (FeNi) is predominantly produced from nickeliferous laterite ores which are converted into a product with a nickel content of around 20%. With increasing emphasis being put on energy efficiency and global climate change, it is important for the nickel industry to further explore energy saving issues and to evaluate a number of potential opportunities for reducing the greenhouse gas footprint of primary FeNi production. The present study adopted a life cycle assessment (LCA) approach to assess energy consumption and greenhouse gas footprints of the main processing stages of a typical Greek nickel laterite ore for the production of ferronickel. In this context, a detailed life cycle directory was created based on facility-specific data and used for a holistic cradle-to-gate LCA analysis (including mining and the main ore processing routes). The following energy and environmental indicators were assessed: global warming potential (GWP), acidification potential (AP) and primary energy demand (PED). Using current FeNi production as a baseline scenario (BL), two alternative scenarios, namely (i) the green energy (GE) scenario that involves 50% substitution of fossil fuels mix (lignite and coal) with biochar and 50% substitution of lignite with renewable resources for electricity production, and (ii) the waste utilization (WU) scenario that includes 65% utilization of slag in the construction sector, to improve energy and waste utilization, minimize the adverse environmental impacts and therefore achieve more sustainable FeNi production were investigated. Results showed that the best alternative scenario for energy savings and reduction of associated GHG emissions during FeNi production was the GE scenario. With this scenario energy savings and GHG emissions were about 17% and 35% lower compared to BL scenario, respectively. Lower reduction in energy consumption (7%) and GHG emissions (13%) compared to the BL scenario was attained when the WU scenario was considered.

1. Introduction

Ferronickel (FeNi) and ferrochrome are the two main ferroalloys used for the production of stainless steel. It is predominantly produced from nickeliferous laterite ores which are converted via the pyro-metallurgical route into a product with a Ni content of around 20% (Crundwell et al., 2011a,b). Currently, only 42% of world primary Ni production is processed from laterite ores mainly through pyrometallurgical routes, with FeNi holding the highest share (~72%) among all nickel-based products (Zhou et al., 2015). However, pyrometallurgical laterite ore processing is much more energy intensive compared to sulphide ore processing (Mudd, 2010; Haque and Norgate, 2013) and it results in the production of large volumes of greenhouse gas (GHG) emissions and solid wastes (Norgate et al., 2007; Warner et al., 2006). In its efforts for energy conservation, emission reduction and process sustainability, metal industry has used several approaches to quantify its performance, that include among others ecological risk assessment (ERA), environmental performance and operational indicators, cost benefit analysis (CBA), materials flow analysis (MFA), and life cycle assessment (LCA) (Sorvari et al., 2011).

To date, LCA is considered the best approach for the assessment of sustainability in all industrial sectors (Finnveden et al., 2009). As a result, LCA has become an important tool for the metal industry, which faces a growing public pressure to act responsibly on climate change issues, to evaluate its environmental performance towards an improved sustainability (Eckelman, 2010). In particular, LCA addresses the potential environmental impacts, human health and resource concerns of any product or process over its entire life cycle, from raw material acquisition to manufacturing, use, end-of-life treatment, recycling and/or ultimate disposal (Yellishetty et al., 2011). While some LCA studies are available for the metal industry in general (van Berkel, 2007; Yellishetty et al., 2009; Paraskevas et al., 2015), the number of respective studies to

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http://dx.doi.org/10.1016/j.resconrec.2015.10.016

assess GHG emissions during FeNi production from laterite ores is limited (Eckelman, 2010; Haque and Norgate, 2013) and their results are restricted by certain limitations, including high degree of uncertainty, low robustness and insufficient applicability (Norgate and Jahanshahi, 2011). The main reasons for these constraints are either methodological and/or operational. Methodological constraints mainly include differences in the type of functional unit, source and availability of inventory data, transportation of raw materials, allocation procedures and cut-off rules used. On the other hand, operational constraints involve variations in ore grade, mineralogy and processing, as well as type of electrical energy (fuel grid mix) and thermal energy (solid fuels) used.

A common limitation in most LCA studies is that they include only metal production stages (e.g. smelting and refining) and thus they do not take into account impacts associated with mining. In addition, most studies rely on the use of imported nickel ores for FeNi production and in some cases they do not take into consideration the environmental impacts associated with raw materials transportation to production facilities. As highlighted by Eckelman (2010) and Northey et al. (2014), updated and detailed site-specific data about ore types, geology, topography and hydrology are required to improve reliability of the results in LCA studies.

In this context, the novelty of the present study consists in (i) the use of a complete bottom-up approach which considers up-to-date and site specific facility-process data for the inventory analysis, (ii) the inclusion of the mining sector, (iii) the consideration of environmental impacts associated with transportation of the raw materials and (iv) the analysis of alternative production scenarios that optimize the efficient use of both mineral and renewable energy resources.

The specific objectives of this study, which is the first one carried out for this sector in Greece, were to: (i) evaluate the life cycle of the "cradle-to-gate" FeNi production, (ii) identify the processing stages and hotspots that are energy intensive and cause the most important environmental impacts, (iii) propose two alternative scenarios, namely the green energy and the waste utilization, to minimize impacts and improve sustainability of the sector, and (iv) highlight crucial points for future research.

2. Ferronickel production in Greece

Greece is the only FeNi producer in the European Union, the third largest producer in Europe and one of the seven largest in the world. In 2012, approximately 95,000 t of granulated FeNi with 20% average Ni content was produced by the General Mining and Metallurgical S.A. LARCO from domestic nickeliferous laterite ore deposits. Ferronickel production at LARCO accounts for 32% and 4% of the European and world production, respectively and covers nearly 5% of the European annual market Ni demand (Apostolikas et al., 2009; USGS, 2015). A detailed schematic overview of FeNi production in LARCO is shown in Fig. 1. Further details of the FeNi production route in Greece are given in Supplementary material (S-1).

3. Methodology

An LCA approach was adopted to investigate the cumulative environmental impacts (energy and emissions) during the production of FeNi in Greece. According to the guidelines and specific requirements of the International Organization for Standardization (ISO) 14040–14044 standard series (ISO, 2006a,b), there are four main steps in an LCA study, namely, the goal and scope definition, the life cycle inventory analysis, the impact assessment and the interpretation as described below in detail.

3.1. Goal and scope definition

The goal of this LCA study was to quantify the energy consumption and greenhouse gas footprint of the existing metallurgical route (BL scenario) and also explore more sustainable and eco-friendly practices (GE and WU scenarios) that can be used in the FeNi production stages. According to ISO standard series (ISO, 2006a,b), the functional unit (FU) is defined as the quantified performance of a product system and is used as a reference unit in an LCA study. In the present study, the FU for each FeNi production scenario was defined as one tonne of produced FeNi with 20% Ni content. This is consistent with the general function of a production chain from the perspective of the major metallurgical companies,

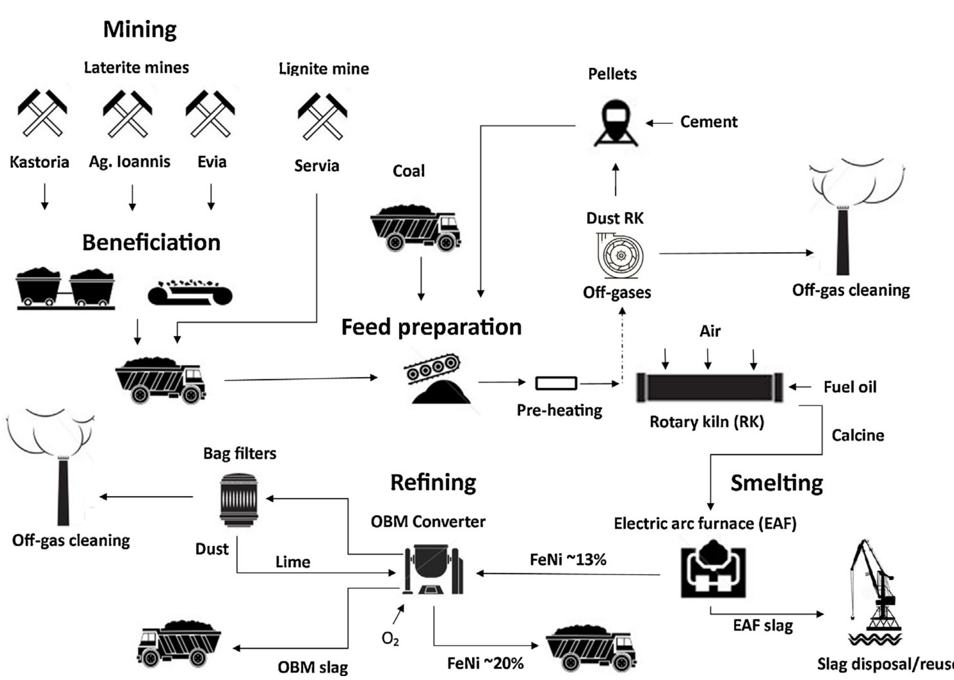

Fig. 1. Detailed schematic overview of FeNi production in LARCO.