ENVIRONMENTAL SCIENCE & POLICY 14 (2011) 650–663

available at www.sciencedirect.com

ScienceDirect

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

Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects

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ARTICLE INFO

Published on line 28 May 2011

Keywords:
Iron and steel
Recycling
Life cycle
Energy
Residuals and policy

ABSTRACT

This paper reports on historical analysis of the steel industry in which crude steel production trends are quantified for the period from 1950 to 2006. On the basis of this analysis, the future production of steel for the world is estimated using regression analysis. The historical analysis shows that the world steel production increased from 187 Mt to 1299 Mt in that period. In addition, the paper also reports on historical (1950–2006) steel scrap consumption and was compared with crude steel and electric arc furnace (EAF) steel production. Since 1950, scrap consumption by steel industry worldwide has been growing at 12% per annum whereas the EAF share of steel production has been increasing at 66% per annum. Furthermore, since 1987 iron ore prices have increased at 24% per annum whereas scrap prices have grown by 13% per annum.

From the analysis on environmental benefits of steel recycling, it was established that there are numerous advantages of scrap utilisation. The major environmental benefits of increased scrap usage comes from the very fact that production of one tonne of steel through the EAF route consumes only 9–12.5 GJ/tcs, whereas the BOF steel consumes 28–31 GJ/tcs and consequently enormous reduction in CO_2 emissions. In addition, a discussion on various alloying elements in steel and their presence in residual concentrations in the scrap on steel properties is also presented. Finally, this paper presents a discussion on policy issues that could enhance the use of scrap in steel-making is also presented.

1. Introduction

Historically metals have been linked with industrial development and improved living standards, and thus play an important role in our modern societies. Human civilisations have been known after their concurrent metals' use, such as the copper age, bronze age and iron age, etc. Metal recycling has several potential benefits, primarily due to: (a) its ability to direct the end-of-life wastes (scrap) away from landfills and (b) achieving resource stewardship through conservation (Chen, 1995). Metal recycling is undertaken mainly because of altruistic reasons, economic imperatives and legal considerations. Muller et al. (2006) argued that from an economic perspective it is always cheaper to recycle steel than to mine virgin ore and move it through the process of making new steel. Steel is the world's most used and recycled metal, and in the US alone, almost 75 million tonnes (Mt) of steel were recycled or exported for recycling in 2008 compared with their total steel production of 91 Mt (Steel Recycling Institute,

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1462-9011/$ – see front matter
doi:10.1016/j.envsci.2011.04.008

2010a). However, the critical limiting factor is the availability of sufficient steel scrap, as much steel remains locked in its current use (such as in durables, automobiles and bridges), compelling the steel industry to rely on mining virgin ore to supplement the production of new steel.

The main objective of the paper is to evaluate the benefits of recycling of steel to our society from technical, economical and environmental perspectives. By complementing the work done by Reck et al. (2010), McLellan et al. (2009), Johnsona et al. (2008) and Davis et al. (2007), this paper aims to advance our understanding about steel recycling. The paper is organised into two parts. The first part of the paper will primarily focus on the world steel industry's production trends, trends in scrap consumption, recycling rates and environmental resource inventories and includes a review of different models used to predict CO_2 emissions under different recycling scenarios. The second part will present a brief review on problems of quality in multistage recycling and finally a review of the policy on steel recycling.

2. Methodology and data sources

This section of the paper presents a brief overview on the methodology adopted and various data sources being used in this study. The production and exports data covers 1950 through to 2006 (in some cases to 2008 depending on availability or otherwise). Throughout this paper, the steel tonnages refer to their crude steel (CS) equivalents and are expressed in metric tonnes unless mentioned otherwise. The modelling of future production and consumption was done using regression analysis of the historical data.

In this paper the discussions focus only on Australia, Brazil, China, Europe 36 (36 countries of the European Union), India, Japan, Korea, Russia, Ukraine, and USA. Because, in 2007 these countries together have contributed to more than 87% of world's steel and hence are assumed to represent the trends of the rest of the world. For most of the modelling, regression analysis of the historical statistical data was used.

The data on steel production trends, steel recycling rates, per capita steel consumption and environmental resource use and emissions was gathered using a range of sources including various government, industry supported associations and/or from research literature. Besides, the data was also sourced from a range of journals and Internet sites. Specifics about individual data sources are explained below:

- World steel consumption and production, steel recycling rates and scrap consumption statistical information: Steel Recycling Institute (2010a), USGS (2010a,b), World Steel Association (2010d), ISSB (2008), World Steel Association (2009), EUROFER (2006), Steel Statistical Year Book (1999), Fenton (1998), Wilshire et al. (1983) and CEC (1965).
- Environmental indicators and energy use in steel industry: World Steel Association (2010a,b,c), UK Steel (2010), Steel Recycling Institute (2010b), Steel University (2010), World Steel Association (2008, 2010b), European Commission (2008), IPCC (2006), Lubetsky and Steiner (2006), Birat (2002), Kim and Worrell (2002), European Commission (2001), Beer et al. (1998), American Iron and Steel Institute (1997) and Worrell et al. (1997).
- World population and GDP statistical information: The World Bank (2010), United Nations (2010).
- Prices of iron ore and steel scrap: OneSteel (2010), USGS (2010a,b), The Tex Report Ltd. (2008).

In calculating CO_2 emissions emanating from the steel operations, a full cradle to steel factory gate emissions approach was used. Furthermore, it was also assumed that primary steel was produced in an integrated steel mill (IM), which emits 2.1 t of CO_2 per tonne of crude steel whereas the steel production at an Electric Arc Furnace mill (EAF) will result in 0.6 t of CO_2 per tonne of crude steel.

3. Trends in world steel production and scrap consumption

In this section of the paper we discuss the methodology and results of the analysis focusing on current and future steel consumption and production trends of the world. Based on the historical production and consumption data, the future steel production projections were made by using regression analysis. In this analysis, we have projected the trends in steel production and consumption to the year 2030.

3.1. *Steel production trends*

Steel production can occur at an integrated facility from iron ore or at a secondary facility, which produce steel mainly from recycled steel scrap. Integrated facilities typically include coke production, blast furnaces, and basic oxygen steel making furnaces (BOFs), or in some cases open hearth furnaces (OHFs). Raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into finished steel products. Secondary steel making most often occurs in electric arc furnaces (EAFs).

The steel production varied over the study period (1950–2006) in the selected countries/regions. Overall, apart from short-lived recessions, the world's crude steel production has been climbing steadily ever since large scale production of steel began. Table 1 presents a comparison of steel production through different production routes and their respective rankings of different countries in the world. In 2007 China produced a maximum quantity of BOF steel (90% of total steel produced by China) followed by Europe 36 (55%), Japan (74%), Russia (57%) and USA (42%). The maximum steel through EAF route was produced by Europe-36 (44%) followed by USA (58%), China (9.5%), Japan (26%) and India (58%) (Table 1). In steel production through OHF, Ukraine ranks first (45%) followed by Russia (16.5%) and India (1.9%) (Table 1).

Fig. 1 presents historical trends in EAF steel production as a percentage of total steel produced (1950–2006) by selected countries (on left: Australia, Brazil, Europe 36, Japan, Korea and Ukraine; on right: China, India, Russia, USA and World). Using regression analysis of time series data (of the world), the trend of the world's EAF steel production was established (right of Fig. 1). The coefficients of determination value