Science of the Total Environment 586 (2017) 730–737

Contents lists available at ScienceDirect

Science of the Total Environment

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

Global land-use change hidden behind nickel consumption

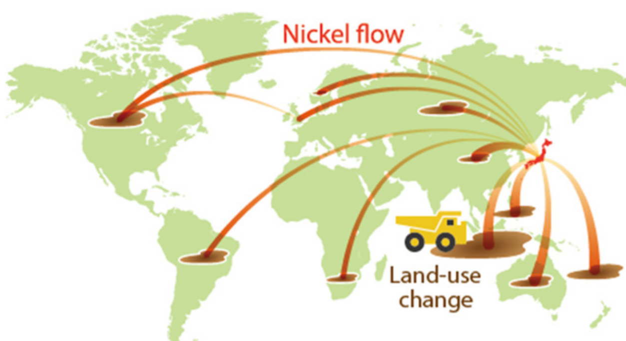
Kenichi Nakajima [a,*], Keisuke Nansai [a], Kazuyo Matsubae [b], Makoto Tomita [c], Wataru Takayanagi [a], Tetsuya Nagasaka [d]

[a] Center for Material Cycles and Waste Management Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan
[b] Department of Environmental Studies for Advanced Society, Graduate School of Environmental Studies, Tohoku University, Miyagi 980-8579, Japan
[c] Department of Arts, School of Humanities and Culture, Tokai University, 4-1-1 Kitakaname, Hiratsuka, Kanagawa, 259-1292, Japan
[d] Department of Metallurgy, Materials Science and Materials Processing, Graduate School of Engineering, Tohoku University, 6-6-2 Aoba, Aramaki, Aoba-ku, Sendai, Miyagi 980-8579, Japan

HIGHLIGHTS

- Worldwide nickel flow among 231 countries and regions was clarified.
- Land-use changes far removed from the place of consumption were detected.
- Links between Japan's final demand and the global supply chain were quantified.
- A global link input–output model (GLIO, a hybrid multiregional model) was used.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 November 2016
Received in revised form 6 February 2017
Accepted 6 February 2017
Available online 21 February 2017

Editor: D. Barcelo

Keywords:
Material flow analysis (MFA)
Nickel
Mining
Land-use change
Input-output analysis
Global supply chain

ABSTRACT

Economic growth is associated with a rapid rise in the use of natural resources within the economy, and has potential environmental impacts at local and/or global scales. In today's globalized economy, each country has indirect flows supporting its economic activities, and natural resource consumption through supply chains influences environmental impacts far removed from the place of consumption. One way to control environmental impacts associated with consumption of natural resources is to identify the consumption of natural resources and the associated environmental impacts through the global supply chain. In this study, we used a global link input–output model (GLIO, a hybrid multiregional input–output model) to detect the linkages between national nickel consumption and mining-associated global land-use changes. We focused on nickel, whose global demand has risen rapidly in recent years, as a case study. The estimated area of land-use change around the world caused by nickel mining in 2005 was 1.9 km^2, and that induced by Japanese final demand for nickel was 0.38 km^2. Our modeling also revealed that the areas of greatest land-use change associated with nickel mining were concentrated in only a few countries and regions far removed from the place of consumption. For example, 57.7% of the world's land-use changes caused by nickel mining were concentrated in five countries in 2005: Australia, 13.7%; Russia, 12.9%; Indonesia, 12.5%; New Caledonia, 10.4%; and Colombia, 8.2%. The mining-associated land-use change induced by Japanese final demand accounted for 19.5% of the total area affected by land-use change caused by nickel mining. The top three countries accounted for 70.6% (Indonesia: 47.0%, New Caledonia: 16.0%, and Australia: 7.7%), and the top five accounted for 82.4% (the Philippines: 7.5%, and Canada: 4.3%, in addition to the top three countries and regions).

* Corresponding author.
E-mail address: nakajima.kenichi@nies.go.jp (K. Nakajima).

http://dx.doi.org/10.1016/j.scitotenv.2017.02.049

1. Introduction

UNEP's International Resource Panel (UNEP-IRP) has pointed out the importance of decoupling resource use and negative environmental impacts from economic activity (United Nations Environmental Programme, International Resource Panel, UNEP IRP, 2011). Economic growth is associated with a rapid rise in the use of natural resources within the economy (Van Vuuren et al. 1999), and has potential environmental impacts at local and/or global scales. In today's globalized economy, each country has indirect flows supporting its economic activities, and international trade chains influence environmental burdens far removed from the place of consumption (Hertwich and Peters 2009, Lenzen et al. 2012a, b, Nansai et al. 2015, Wiedmann et al. 2013, Godar et al. 2015, Meng et al. 2015, Weinzettel et al. 2013). This situation emphasizes the importance of examining environmental burdens as a global systemic phenomenon, instead of viewing any given producer in isolation.

Economic growth has brought about increased use of metals (Van Vuuren et al. 1999), and sometimes green technology, such as low-carbon power generation, has triggered a rapid rise in the use of metals and minerals (Kleijn et al. 2011). Although metals are invaluable materials for society, the rising demand for them raises concerns about the introduction of environmental problems. In recent years, especially, the mining industry has been under considerable pressure to improve its environmental and social performance. The World Resource Institute (WRI) (2003) and Durán et al. (2013) mapped global indicators of ecosystems and communities that are vulnerable to the negative impacts of mining, and their reports indicated significant overlap between the world's active mines and strictly protected areas. These results indicate the importance of identifying areas prone to negative environmental impacts by mining activities, not only on a global scale but also on a local scale.

Fundamental to reducing natural resource consumption and controlling the material cycle is knowledge about the flow of substances. Material flow analysis (MFA) (e.g., Reck and Graedel 2012, Reck et al. 2008, Reck and Rotter 2012, Daigo et al. 2010, Nakajima et al. 2013) is an excellent tool to quantify material and/or substance balances in specific areas for resource and waste management. However, except for a few studies (e.g., Nansai et al. 2014, 2015, Lenzen et al. 2012a, b), standard economy-wide MFAs have not sufficiently detailed the linkages between national consumption and global flows and/or environmental impacts. This makes it extremely difficult to understand negative environmental impacts far removed from the place of consumption, and to make clear who should be responsible for sustainable resource use.

In this study, we focused on nickel, whose global demand has risen rapidly in recent years, as a case study with which to discuss linkages between local consumption and global impacts. Global nickel production has shown significant long-term growth, including near exponential growth since 1950, from about 0.01×10^6 t-Ni in 1900 to 1.6×10^6 t-Ni in 2007 (Mudd 2010). Nickel and nickel-containing materials play a crucial role in modern society, with uses in numerous types of infrastructure and technology (e.g., power stations, oil and gas plants, transport infrastructure, medical equipment, food preparation equipment, and buildings). Nickel is also a critical resource for low-carbon technologies, such as stainless steel pipes for carbon capture and storage, nickel-based super alloys for ultra-supercritical power generation, and Li-ion or Ni-MH batteries for electric vehicles. Nickel is selected for these uses because of its specific properties, such as high corrosion resistance, high toughness, high strength at high and low temperatures, and its range of special magnetic and electronic properties. At the same time, environmental risks and challenges are always attached throughout the life cycle of nickel-containing materials (Nakajima et al. 2014), such as the huge energy consumption and environmental impacts (e.g., GHG emissions, sulfur oxide emission, and solid waste) associated with cradle-to-gate nickel production (Norgate et al. 2007, Seppälä et al. 2002) and heavy metal pollution caused by the nickel industry (Norseth 1994, Moiseenko and Kudryavtseva 2001). The impact on biodiversity caused by mining nickel ore has received particular attention in recent years (Mudd 2010, Nakajima et al. 2014, Jaffré et al. 2010, Pascal et al. 2008 Moran et al. 2016), because mining activities have impacted the removal of native vegetation and its destruction by the deposition of mine waste. Mudd (2010) pointed out potential conflict between nickel mining and biodiversity in Indonesia. In the case of New Caledonia, Jaffré et al. (2010) showed the impact of habitat reduction and fragmentation by nickel mining activities, Pascal et al. (2008) discussed biodiversity risks posed by an increase in nickel mining activities, and Moran et al. (2016) showed the serious linkage between biodiversity pressure and nickel mining activities. Although the relationship between biodiversity impact and land-use change caused by nickel mining is not universal, these countries and regions are known as biodiversity-rich regions (Myers et al. 2000, Jaffré et al. 2010).

The purpose of this study was to detect linkages between local consumption and mining-associated land-use change far removed from the place of consumption as a global systemic phenomenon. We focused on nickel, whose global demand has risen rapidly in recent years, as a case study. The goal was to clarify worldwide nickel flow in global trade and to detect the distribution of land-use changes by nickel mining far removed from the place of consumption. For this purpose, we used a global link input–output model (GLIO) (Nansai et al. 2009). Because Japan is a major importer of nickel and the world's leading nickel-producing country, this study quantified the links between Japan's final demand for nickel and the global supply chain. The analysis was primarily performed using 2005 data, because the Japanese IO table is fixed. In the case of nickel, economy-wide MFAs have been conducted, and although these indicated global and/or national demand for nickel and losses of nickel in the anthropogenic cycle (Reck et al. 2008, Reck and Rotter 2012, Daigo et al. 2010), they are not sufficiently detailed with respect to linking national consumption to global impacts.

2. Materials and methods

2.1. Nickel flow in global trade

Nakajima et al. (2014) estimated the global flow of nickel to identify global nickel movement associated with global trade in 2005 with an MFA method by Nansai et al. (2014). We updated the global flow estimates by improving the nickel content values of several trade commodities and recompiled a dataset, $t_{pq}^{(k)}$, which indicates the amount of nickel moving from country p to q, contained in the trade of commodity k. To ensure the MFA's global system boundary, we considered 231 countries and regions for p and q as listed in Table S1 in the Supplementary material. We selected all commodities assumed to contain nickel among the approximately 6000 commodities defined by the HS (Harmonized Commodity Description and Coding System) code with 6-digit classification numbers and aggregated the selected ones into 123 commodity groups (2-digit: 9 commodities; 4-digit: 84 commodities; 6-digit: 30 commodities). The list of commodities is shown in Table S2 in the Supplementary material.