Resources, Conservation & Recycling 140 (2019) 91–101

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

A transitional perspective of global and regional mineral material flows

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ARTICLE INFO

Keywords:
Material flow analysis
Resource productivity
Resource intensity
Precious minerals
Critical minerals

ABSTRACT

This article presents the first broad estimate of mineral use and efficiency taking into account two unique sets of mineral material groups (critical and precious) mostly used in the 21st century. It is therefore distinct from the previous studies which were focused on biomass and construction minerals. Standardized methodology for material flow accounting was applied based on long time series data from 1955 to 2015. Mineral flows, resource productivity, resource intensity, resource extraction, consumption and trade patterns were presented and compared, with differences and similarities verified. Our results showed that mineral use increased from 3 gigatons to 40 gigatons for metallic minerals, 3 gigatons to about 10 gigatons for fuel minerals, 20 million tons to about 100 million tons for critical minerals, and 200 tons to about 11,000 tons for precious minerals from 1955 to 2015. Regional metabolic rates ranged from 0.45 t/cap/a in Africa to 7 t/cap/a in Asia. Meanwhile, Europe and Western Offshoots presented decreasing trends, Asia highlighted surging mineral consumption while LACA presented increasing mineral domestic extraction. Western Offshoots, Latin America and the Caribbean and Africa were net exporters of metallic minerals while Asia emerged as a net importer in the last three decades. Different regions demonstrated different trends in material intensity and resource productivity. The impact of Gross Domestic Product (GDP), on Domestic Material Consumption (DMC), for different mineral groups in the different regions was investigated and discussed. Our results furnish critical intuition to future effective and efficient global and regional resource management.

1. Introduction

The production and consumption of mineral resources have always been linked to the different eras of human development and related economic activities. Different eras have been defined according to major materials used (Gosden, 2018). Prior to mineral age (500–800 years ago), biomass sustained humanity (Lynch, 2003). But the coming of the industrial revolution brought fundamental changes. Extraction of metal ores increased from 3% in 1900 to 5% in 1950 (Schaffartzik et al., 2016), but the worldwide production and consumption increased by 56% from 1995 to 2005 (Pothen and Schymura, 2014). The use of fossil energy carriers stimulated the utilization of more minerals for different purposes (Schandl and West, 2010; Schaffartzik et al., 2014). Consequently, global resource use increased from 8 gigatons (Gt) in 1900 to 71 Gt in 2010 alongside the metabolic rate from 4.6 to 10.3 t/cap/a (Krausmann et al., 2009; Mayer et al., 2017). Living standards and life expectancy are increasing whilst poverty rate has decreased (UNDP, 2016).

Mining is a critical societal issue that brings negative environmental impacts and pressures like global warming and climate change, land cover and land use change (Sonter et al., 2014; Teixidó-Figueras and Duro, 2015; Winter, 2014), which have converged in an unprecedented manner in global ecosystems (Lu et al., 2018), and there is thus an urgent need to save our "planetary boundaries" (Rockström et al., 2009; Fanning and O'Neill, 2016). In this regard, environmentalists, conservationists, economists, and policy makers need information systems that will give in-depth observations into the trends of minerals production and consumption. This greatly enhanced the development of Material Flow Accounting (MFA) indicators. MFA has provided comprehensive information and aggregated headline indicators on extraction, trade and use of minerals (Schaffartzik et al., 2014; Mayer et al., 2017). In recent years, many studies have been published on MFA.

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https://doi.org/10.1016/j.resconrec.2018.09.014
Received 9 May 2018; Received in revised form 11 September 2018; Accepted 12 September 2018
0921-3449/

Some studies focused on individual nations (Raupova et al., 2014; Krausmann et al., 2016), some on regions (West and Schandl, 2013), and some on global and country groupings (Krausmann et al., 2008, 2009). Krausmann et al. (2008) described the global metabolic transition and focused on the increasing magnitude and changing material flows. Schaffartzik et al. (2014) expressed a global transition from an agrarian economy to an industrial one. Bruckner et al. (2012) looked at the materials embodied in international trade and concluded that a country that imports more and export less risk being on an ecological trade deficit. Wiedmann et al. (2015) proposed the concepts and estimation of material footprints for nations and investigated the relative decoupling and absolute decoupling phenomena amongst countries. Schaffartzik et al. (2016) made strong arguments on the global patterns of metal extractivism, pointing out that metals provide the bones for industrial societies and emphasized on the exploitation of the anthropogenic stocks for reuse and recycling, especially those minerals used in bulk during industrialization like iron and aluminum. Calvo et al. (2018) investigated the MFA for critical minerals in EU-28 in order to show the importance of these raw materials while Palacios et al. (2018), analyzed the production, exports and imports of fuel and non-fuel minerals in 20 latin America and the Caribbean (LACA) countries. With the increasing demand for mineral resources and the environmental degradation caused by this activity, policy makers have not relented their efforts. As the extraction and use of mineral resources increased globally, resource scarcity and availability became a major concern. National and international political agendas on sustainable management of resources have been formulated and implemented (Table 1). Efforts from national, regional and international organizations have helped and will help reduce the environmental degradation caused by the production and consumption of mineral resources and shift economies toward a green growth paradigm. Jacobs (2012) defines green growth as “economic growth (GDP) which focuses on mitigating environmental degradation” while green growth according to OECD (2011), means “fostering economic growth and development while ensuring that natural resources continue to provide the environmental services on which humanity relies on”. A considerable body of literature has suggested that GDP affects DMC (Steger and Bleischwitz, 2011; Pothen and Schymura, 2014). Agnolucci et al. (2017) investigated the impacts of GDP on DMC in Europe, Zhang et al., (2018) elaborated on the metaphor of material environmental Kuznet curve (EKC) while we take a step forward to look at the relationship relationship in different regions for different material groups discussed in this paper.

Our goal is to investigate the transitional regimes within the mining industry taking into consideration new mineral groups (critical and precious). The aim of the work is to present the mineral flows, resource extraction, resource consumption, physical trade balances, resource intensities and resource productivities in different regions. Results from this work will provide information on non-monetary measures that can properly inform policy makers on global and regional resource management. Empirical data on domestic extraction (DE), domestic material consumption (DMC), material intensity (MI) and resource productivity (RP) provided in this manuscript could serve in future researches by linking the different regional trends in this paper to economic developing.

2. Methodology and materials

2.1. Framework and indicators of material flow analysis

MFA is a standard approach used to analyze flows in a certain system (Eurostat, 2001). Industrial ecology recognizes MFA as one of its major analytical tool that provides understandings of industrial metabolism. Without MFA, resource utilization and efficiency will be hard to dissect. MFA has been widely applied to evaluate socio-economic metabolism of countries (Eurostat, 2001, 2007, 2009). This paper followed recent relevant studies to select indicators for analysis. Schandl and West (2010) used the same indicators to calculate material efficiency for LACA while Krausmann et al. (2016) conducted the same in the former Union of Soviets Socialists Republics and the Russian Federation from 1900 to 2010. Schaffartzik et al. (2014) applied the same indicators to estimate global metabolic transition from 1950 to 2010. Based on the same indicators, Dong et al. (2017) estimated the material flows and resource productivity of three countries in Asia from 1970 to 2008. The following indicators were considered and applied:

(1) Domestic Extraction (DE), refers to the extraction of minerals from the domestic environment. Typically, it presents domestic resource exploration and is expressed as all the total annual amount of materials excluding water and air.
(2) Domestic Material Consumption (DMC), refers to the mineral consumption within a region. It presents regional and global wide resource consumption and is calculated as

$$DMC = DE + Im - Ex$$

(3) Physical Trade Balance (PTB), presents the global resource flows and how regions are dependent on resource supply. In other words it calculates the trade surplus or deficit of an economy. Its formula is:

$$PTB = Im - Exp$$

(4) Intensity indicators based on DMC was calculated using this formula

$$MI = DMC/GDP$$

(5) Resource productivity is calculated using the formula below. It expresses the economic output generated by a unit of resource consumption.

Table 1
Policies regarding resource production and consumption.

Policy	Objective	Reference
Sustainable Development Goals (SDG),	To visualize a world in which production and consumption of natural resources are sustainable	Cf (2015)
European Commission adopted European Circular Economy	To recognize the security of the supply of resources and resource efficiency as a crucial aspect for economies	European Commission (2015), Rizos et al. (2017).
Flagship Initiative for a Resource-Efficient Europe	To transform Europe into a high resource efficiency region by enhancing economic performance and reducing DMC	Commission (2011).
Green Economy Initiative	To motivate and encourage governments to invest in green economies	(GEI)
Organization for Economic Cooperation and Development (OECD)	To help governments to promote economic growth while reducing inefficient use of natural resources.	OECD (2009).
United Nations Metallic Development Organization (UNIDO)	To inform governments to look for new growth paradigms through industrial restructuring	UNIDO (1966).
Resource Efficiency Alliance	To protect natural resources and improve resource efficiency while emphasizing on reduce, reuse, recycle framework	Kazmierczyk et al. (2016)