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Advancing factors influencing resource productivity through the use of the material utility framework

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A B S T R A C T

In this paper, we propose 'material utility' as a new concept for analyzing the influencing factors of resource productivity (RP). We demonstrate the application of this concept by empirically analyzing direct and indirect factors influencing RP. Results indicate the following: (1) RP is essentially an aggregate of the efficiency of a material's major utility for different resource categories by weight of their respective utility coefficients. (2) The direct factors influencing RP are utility coefficient (C), intensity of utility use in economic sectors (T) and economic structure (S); whereby C, T and S respectively contribute 7%, 119%, and −26% to the decline of fossil energy intensity (the inverse of RP for fossil energy) in China during the period of 1980–2010. (3) The indirect factors influencing RP are resource quality, technology and economic structure. Specifically, RP can be increased by using higher quality resources, e.g., metal ore with higher ore grade. One unit (1%) increase in research and development (R&D) expenditure intensity and percentage of tertiary industry will result in 427 US$/ton and 40 US$/ton increase in RP, respectively. This research suggests new avenues for improving the accuracy of RP as an indicator and for policy measurement for increasing RP.

1. Introduction

In contribution to sustainable resource consumption and emissions, researchers have designed numerous tools based on the economy-wide material flow analysis (EW-MFA) approach for monitoring the flow of materials at the macro-economic level (Chen et al., 2015; Chen and Chen, 2016; Kovanda et al., 2012; Schoer et al., 2012). Based on this approach, one of the most widespread and popular tools is resource productivity (RP) (Steinberger and Krausmann, 2011). As RP is measured by Gross Domestic Product (GDP) output per material use, improving RP, which means producing more with less, stands at the center of tackling environmental pollution and resource scarcity challenges (Gan et al., 2013).

Although there are many diverging opinions surrounding accounting aggregation methods and proper usage of RP as a robust and informative indicator (Bringzu et al., 2003; Cleveland and Ruth, 1999; Kleijn, 2001; Steinberger et al., 2010; Lifset, 2001; Steinberger and Krausmann, 2011; Van der Voet et al., 2005b), the RP indicator continues to be extensively used by institutions (EC, 2008; OECD, 2013; UNEP, 2013) and governments (FSOG, 2012; Japan, 2008; PRC, 2011). In the E.U., RP is the main indicator of 'A Resource Efficient Europe' - a flagship initiative of the Europe 2020 Strategy (EC, 2011); in China, improving RP by 15% was targeted for a resource-saving and environmental friendly society in the country's 12-th Five-Year Plan (PRC, 2011). These national and international policy targets testify to the critical importance given by policymakers and practitioners to research focusing on the underlying dynamics of RP.

Previous research has contributed to the development of accounting methods relevant to EW-MFA indicators (Fischer-Kowalski et al., 2011; Lutter et al., 2016) and numerous case studies have been conducted on both the national and urban level in this regard (Browne et al., 2011; Kalmykova et al., 2015, 2016,

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2016; Pothen and Schymura, 2015; Sastre et al., 2015; Seppälä et al., 2011; Schoer et al., 2013; Wang et al., 2014; Wu et al., 2016). However, studies examining the factors influencing RP are few and this topic is relatively under researched. Moreover, there is currently no wide consensus on the factors influencing RP in the literature.

In this paper, we propose a conceptual framework for analyzing factors influencing RP and use this framework to analyse how RP is influenced by its socio-economic and environmental factors. Section 2 reviews the research progress of RP on its influencing factors. Section 3 describes the concept of material utility and presents a new framework for analyzing the influencing factors of RP using the concept of material utility with combination of IDA. Section 4 empirically examines how RP is affected by its influencing factors using scenario and regression analysis. Section 5 discusses the results of this research and proposes policy recommendation for the advancement of the RP indicator. A conclusion follows in Section 6.

2. Literature review

Table 1 lists the most recent studies on factors influencing RP. These studies can be categorized into two streams. In the first stream, regression analysis has been used to elaborate on factors influencing RP (Wang et al., 2016). In the second stream, index decomposition analysis (IDA), has been used to explain the influencing dynamics of RP (Hashimoto et al., 2008). Although some factors are frequently discussed in both research streams, e.g., income levels, it is evident that researchers have not reached any consensus on the proposed factors. Moreover, the factors influencing RP discussed in the literature are mainly socio-economic factors and environmental factors are often not taken under consideration. To the best of our knowledge, only national temperature, rainfall (Van der Voet et al., 2005a) and resource endowment (Giljum et al., 2010) have been proposed as environmental factors influencing RP, while the resource quality, e.g., iron percentage in iron ores, have received little or no attention.

In this paper, we propose 'material utility' as a new concept for reflecting the useful components of a material. Using this concept, we propose a conceptual framework for analyzing the socio-economic and environmental factors influencing RP.

3. Method

3.1. The concept of material utility

The demand for materials in a socio-economic system is not demand for the material itself but demand for their utility and therefore all materials are simply the carriers of their utilities. To account for the utility of materials, one must consider that only certain parts of a material are useful while other parts are either wasted, dissipated, or transformed into pollutants. For example, the smelting of a metal ore, e.g., raw iron, extracts the higher purities of iron as the main useful component, while other components, e.g. silica, aluminum, sulfur, and phosphorus are considered slag and less useful. Therefore, material utility in essence is the physical component (or component equivalent) of a material based on its metabolic stage. These stages include, raw materials, e.g., iron ore; semi-products, e.g., iron concentrate and crude steel; products, e.g., mechanical equipment; and waste resources, e.g., steel scrap.

Referring to the above definition of material utility, numerous utilities can be identified for different types of materials. Although there are multiple end-uses for materials, there is a major utility for almost every category of resource from the perspective of material metabolism. In this study, we consider only the major utility of materials for simplification. Due to the law of mass balance in material metabolism, the amount of material used for a major utility usually accounts for a large proportion of the total amount of a material's usage. As a result, this simplification will not significantly affect the results of our analysis.

Table 2 describes the major utilities for a selection of materials from the four EW-MFA resource categories of fossil resource, metal ores, non-metallic minerals, and biomass. For fossil energy, the vast majority of coal, crude oil, and natural gas are in the final process stage and used as fuel to produce heat, while only a small percentage are used for other purposes. For example, natural gas is partly used to produce nitrogen fertilizer and crude oil is used to produce chemical solvents, and polymer materials. Therefore, it can be argued that heat is the major utility of fossil energy. Unlike fossil energy, metal ores are not dissipative and the major utilities of metal ores are the corresponding metals, e.g., iron and copper are the main utilities for respectively iron ore and copper ore resources. For non-metallic minerals, the key chemical elements and their

Table 1
Previous studies on factors influencing resource productivity (RP).

Study	Countries	Method	Important factors influencing RP
Van der Voet et al. (2005a)	EU	Regression	GDP per capita; structure of the economy; temperature and rainfall in a country; the size of a country
Hashimoto et al. (2008)	Japan	Index decomposition analysis (IDA)	Recycling; induced material-use intensity; demand structure; and average propensity to import
Steinberger et al. (2010)	175 world countries	Regression	Income
Giljum et al. (2010)	19 Asian countries	Not mentioned	Economic structure; resource endowment; international trade
Steger and Bleischwitz (2011)	EU	Regression	Energy use; construction sector and its industries; the mobility variables (length of networks, car possession); the service sector
Steinberger and Krausmann (2011)	165 world countries	Regression	Income
Bleischwitz and Bringezu (2011)	Not mentioned	Not mentioned	Construction activities; structure of the energy system; imports and international trade
Gan et al. (2013)	51 world countries	Regression	Income level; population density; and economic structure
Wiedmann et al. (2015)	137 world countries	Regression	GDP per capital; domestic extraction per capital; population density
Wang et al. (2016)	China	Regression	Energy intensity for secondary industry; tertiary industry value added per GDP; trade openness; domestic extraction per capita

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