TOWARDS A FAIR ALLOCATION OF RAW MATERIAL USE FOR INDICATORS OF RESOURCE EFFICIENCY

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Abstract

This paper examines the metrics used to assess the degree of efficiency of raw material utilization. Indicators of resource productivity used by various policy bodies typically divide gross domestic product (GDP) for, e.g., a country or a region, by an estimate of the amount of raw materials consumed by that country or region. But this estimate may be based on a variety of metrics defined using different system boundaries. This paper compares estimates of resource productivity calculated using three different metrics for raw material consumption: domestic material consumption (DMC), raw material consumption (RMC, i.e., "material footprint") and raw material input (RMI). The comparison is made using datasets published by UNEP and based on the EORA environmentally-extended multiple-region input-output model.

Keywords: Resource productivity, Economy-wide material flow accounting, Raw material equivalents, Material footprint, Environmental burdens, EUROSTAT, UNEP.

Introduction

The efficient utilization of raw materials constitutes one of the three pillars of the Raw Materials Initiative (CEC, 2008), which is a fundamental building block of Europe's policy with respect to the sustainable supply of raw materials. To be effective, policy implementation requires indicators that can help monitor progress and guide further orientations. An important indicator of the efficient utilization of raw materials, promoted in particular by Eurostat (EC, 2016), is resource productivity (RP) defined as the ratio between gross domestic product (GDP) and domestic material consumption (DMC). The DMC of a country, calculated using economy-wide material flow accounting (Fischer-Kowalski et al., 2011; Eurostat, 2001; Figure 1), adds imports (raw materials, finished and semi-finished products, in e.g. tons) to domestic extraction within the country and subtracts exports. Therefore RP is an indicator of wealth generated within a country per unit mass of raw material consumption.

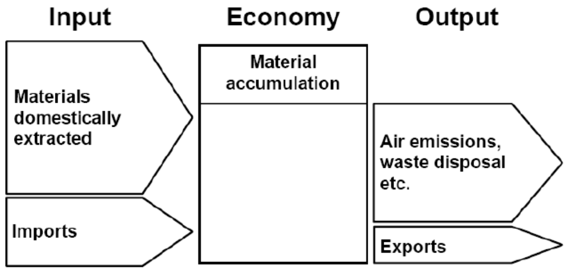

Figure 1: Scope of economy-wide material flow accounts (Eurostat, 2001).

A shortcoming of this indicator, well identified by, e.g., Eurostat (Schoer et al., 2012), Munoz et al. (2009), Wiedmann et al. (2013), is that DMC only considers imports and exports in terms of weight contents of raw materials, but does not account for the raw material consumption required to generate these imports or exports (i.e., "embedded" raw material consumption). To overcome this problem, indicators expressed in terms of raw material equivalents (RMEs) have been proposed. RMEs are upstream used material flows required along the production chain (Munoz et al., 2009). A raw material consumption (RMC), also referred to as "material footprint" (MF, Wiedmann et al., 2013, UNEP, 2016a), can be derived which is an analog to DMC expressed in terms of RMEs. Wiedmann et al. (2013) showed how the use of material footprint (RMC) "*as a measuring rod results in reduced resource productivity for import-dependent countries*".

In this paper we look at the influence that the choice of metrics has on estimates of resource productivity. The various metrics are based on the following definitions (Fischer-Kowalski et al., 2011; Eurostat, 2001 and others):

DE = domestic extraction
Imports = material amounts imported (weight at border)
Exports = material amounts exported (weight at border)
DMI = direct material input = DE + Imports (1)
DMC = direct material consumption = DE + Imports – Exports (2)
RME = raw material equivalents
RMC = raw material consumption (or material footprint; MF) = DMC expressed in RMEs =
DE + imports in RMEs – exports in RMEs (3)
RMI = raw material input = DMI in RMEs = DE + imports in RMEs (4)

Note that RMEs considered in the establishment of RMC (or RMI) are "used" raw materials: unused raw materials such as, e.g., overburden extracted during a mining operation in order to access an ore deposit, is therefore not taken into account. Such unused material would enter into the calculation of TMC (total material consumption; Fischer-Kowalski et al., 2011). On the other hand, the gangue, i.e., the worthless material that is closely mixed with a wanted mineral in an ore deposit and is separated during ore processing, is taken into account.

Multi-region input-output (MRIO) data

The increased spatial separation between production and consumption, with resource extraction and agricultural production performed in some parts of the world while industrial manufacturing and consumption take place in other parts, has led researchers to develop global analytical tools for addressing sustainability (Wiedmann et al., 2011), such as multi-region input-output (MRIO) models. Basic building blocks of these tools are economy-wide input-output tables (Leontief, 1986), which represent the interdependencies between the different branches of an economy, considering economic activities, imports, exports, final demand, etc. In Europe for example, individual member states provide yearly their national input-output tables including environmental accounts (NAMEAs) to Eurostat. But contrary to national tables compiled by, e.g., OECD or Eurostat, MRIO tables include full trade matrices between all countries (with off-diagonal matrices). MRIO tables also account for raw material consumption related to the production of imports or exports, based on the raw material equivalents (RMEs) mentioned above: when extended to material flows, MRIO models enable to estimate material equivalents of products, including those imported or exported. Therefore, MRIOs are sometimes referred to as “environmentally-extended, multi-region input-output tables”.

There currently exist several initiatives that are developing MRIO models (Wiedmann et al., 2011). One such initiative is the Exiopol dataset (Tukker et al., 2009) which aims at developing an environmentally-extended input-output framework for the EU-27. The dataset considers 27 EU countries, 16 non-EU countries or regions and 130 economic sectors. The GTAP 7 dataset (Narayanan and Walmsley, 2008) is made of symmetric input-output tables covering 113 countries and world regions with 57 economic sectors. Environmental extensions include greenhouse gas emissions, energy volumes, land use, etc. But one of the most complete MRIOs to-date is the Eora dataset (Lenzen et al., 2013, 2012). Eora disaggregates the world into 187 countries with a detail of up to 500 economic sectors. It also provides a historical time series from 1990 to 2010, i.e., two decades of data which help appreciate whether decoupling between economic growth and raw material consumption is occurring or not. The sources of data used for constructing the Eora dataset are input-output tables from national statistical offices, compendia of input-output tables from Eurostat or OECD, the UN National Accounts Main Aggregates Database (United Nations, 1982-present), UN Comtrade, etc.

The data published by UNEP (2016a, 2016b) on global material flows and resource productivity are based on the Eora dataset. The UNEP tables present a variety of parameters and metrics including DE, DMC, RMC (or MF), Imports and Exports, RMEs of imports and exports, consumption per capita, etc. Values are presented for 4 categories of raw materials: biomass, fossil fuels, metal ores and non-metal ores. The raw materials included within these categories are shown in Table 1. The data presented in the next section are based on summations of these four categories.

Category:	**Biomass**	**Fossil fuels**	**Metal ores**	**Non-metal ores**
Raw materials:	Wood fuel Crop residues Timber Fodder crops Grazed biomass Cereals Sugar crops Other	Natural gas Crude oil Lignite/brown coal Coking coal Bituminous coal Other	Zinc ore Copper ore Nicker ore Tin ore Iron ore Aluminium ore Precious metals ores Other	Salt Construction minerals Clays and kaolin Chemical and fertilizer minerals Other mining and quarrying products

Table 1: Raw materials included in the different categories of the UNEP (2016a, 2016b) dataset.

Comparing metrics of resource productivity

Indicators of resource productivity used by various policy agencies typically divide gross domestic product (GDP) by a measure of raw material use. Below we compare estimates of resource productivity obtained by dividing GDP (in US dollars expressed in purchasing power parity at 2005 constant prices) and three metrics of raw material use: DMC, RMC (i.e., “material footprint”) and RMI. These three ways of calculating resource productivity are noted below as, respectively, RP_{DMC}, RP_{RMC} and RP_{RMI}.

Figure 2 shows that, following which metrics are selected for raw material use, different countries fare more or less favourably in terms of resource productivity. Countries that have high levels of domestic extraction and are net exporters of raw materials, e.g., Chile and Australia, have values of RPRMC that are higher than RPDMC. Conversely, countries that are major importers of raw materials and/or products, with embedded raw material flows, have higher values of RPDMC than RPRMC. An extreme case is Hong Kong, which shows an enormous RPDMC, as it relies nearly entirely on imports. Countries like Luxemburg for example (for which the data are missing in the UNEP database) would show a similar picture. In all cases, values of RPRMI are lower or equal to the other two metrics, because exports are not retrieved from RMI.

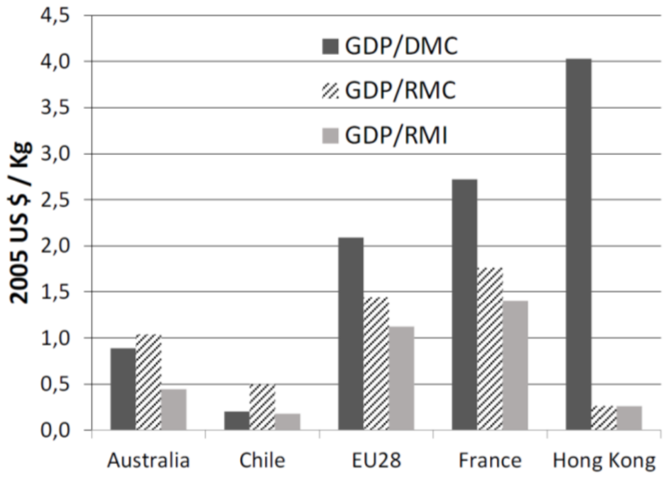

Figure 2: Estimates of resource productivity in 2010 based on three metrics of raw material use. Data from UNEP (2016b).

Looking at the data in terms of time-series provides information regarding the relative decoupling of economic growth and raw material consumption. If RP_{DMC} is the rod by which such decoupling is measured, then most countries considered appear to be on the right track in terms of creating more added-value per unit mass of used raw materials. But if upstream raw material flows, required along the production chain (RMEs), are accounted for, then the picture appears to be less optimistic. The discrepancy between RP_{DMC} on the one hand and RP_{RMC} (or RP_{RMI}) on the other hand, is particularly apparent in the case of the UK and Hong Kong data (Figure 3). Figure 3 illustrates the issue of “apparent decoupling” between economic growth and raw material consumption, which is one of the main motivations behind the development of environmentally-extended input-output tables (see, e.g., Wiedmann et al., 2008).

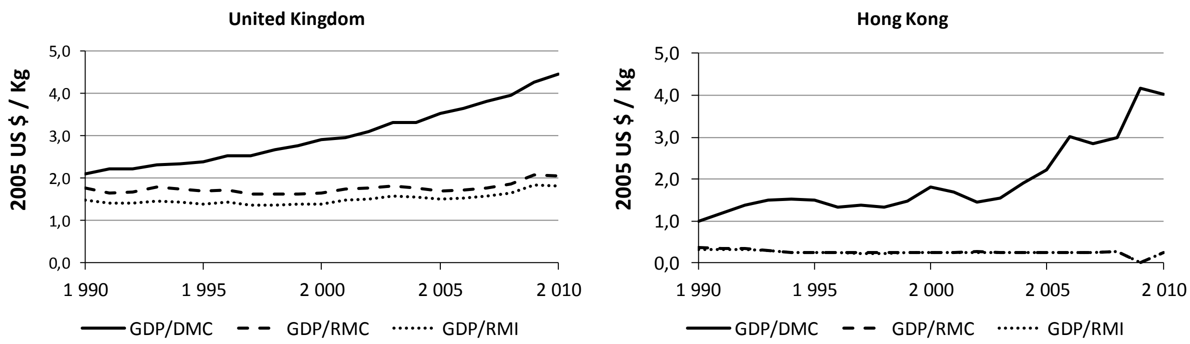

Figure 3: Trends in resource productivity based on the data of UNEP (2016b): UK and Hong Kong.

The discrepancy is also visible, albeit to a lesser extent, for the EU-28 and e.g. France in particular (Figure 4). When considered in terms of RMEs, decoupling between economic growth and raw material use in the EU-28 as a whole is not obvious. Worth noting in Figure 4 (right) is the sudden increase in all indicators starting from 2008. This is probably related to the financial crisis, which slowed down raw material consumption worldwide, while the impact on GDP was not as severe in relative terms.

Figure 5 shows the trends for two countries that are major producers and exporters of mineral raw materials; Chile and Australia. For these countries, the curves based on RMC as an indicator of raw material use are seen to lie above the curves based on DMC. This is because with RMC, raw materials embedded in exported products containing metals are retrieved from the metric. Although not shown here, data for China suggest an increase in resource productivity whichever the metric used.

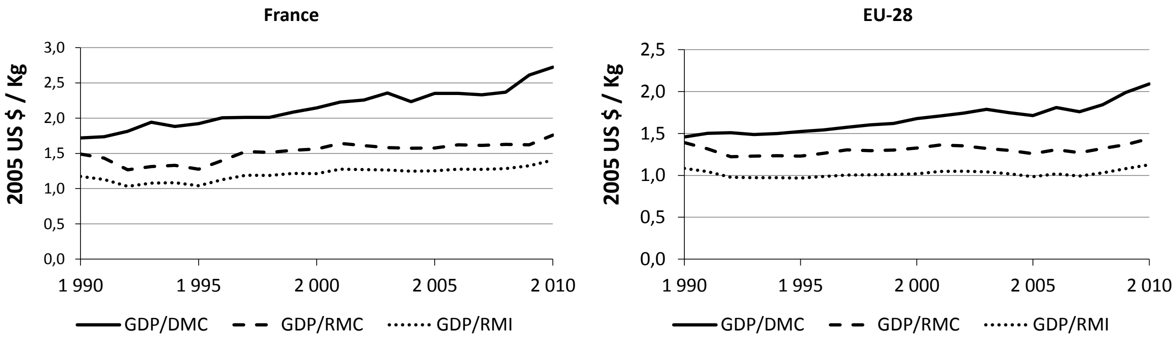

Figure 4: Trends in resource productivity based on the data of UNEP (2016b): France and EU-28.

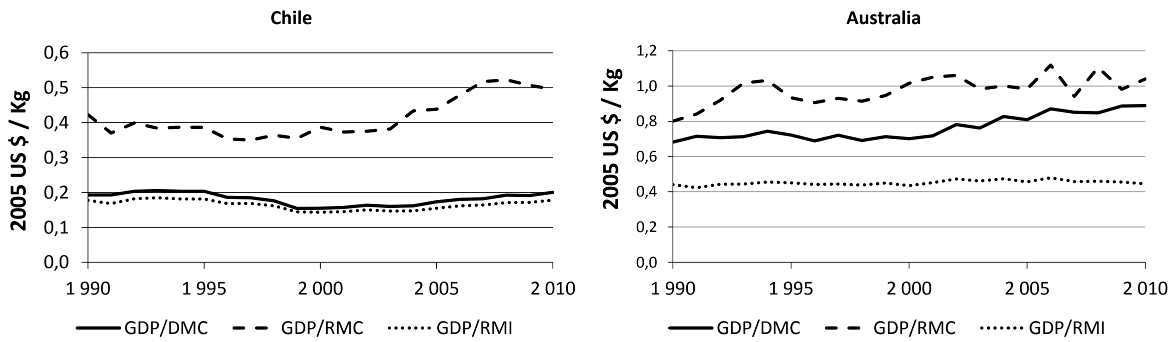

Figure 5: Trends in resource productivity based on the data of UNEP (2016b): Chile and Australia.

Conclusions

This paper compares estimates of resource productivity based on three different metrics of raw material use. It illustrates that DMC (domestic material consumption; Equation 2) tends to favour countries that are net importers of raw materials and/or finished or semi-finished goods, because raw material flows embedded in these imports are only accounted for in the domestic extraction of the exporting countries. DMC is a useful metric for highlighting countries that rely largely on domestic extraction, but it should not be used for estimating resource productivity. Taking the case of Europe, such a metric is damageable to the European extractive industry because it encourages the import of mineral raw materials rather than production from European sources. This is in contradiction with the second pillar of the Raw Materials Initiative (CEC, 2008) and promotes the import of raw materials from countries where environmental emissions are often much higher than if they were produced in Europe. RMC (or material footprint; Equation 3) is a far superior metric for estimating resource productivity, but it tends however to favour countries that are net exporters of raw materials because embedded raw materials in exported products or semis (e.g., copper mattes) are retrieved from the metric.

As an alternative, we suggest using RMI (raw material input; Equation 4) for estimating resource productivity. RMI is a measure of the quantities of raw materials used directly or indirectly by a country in order to create value, as reflected in GDP. It is expressed in raw material equivalents and provides a coherent basis for comparison with the economic wealth generated by a country. The fact that exports are not retrieved from the metric would seem more "fair" in terms of a shared responsibility for environmental burdens. Raw material flows embedded in exports participate in the creation of wealth reflected in GDP and therefore should not be retrieved from the indicator. It is worth noting that the German Resource Efficiency Programme (FME, 2016) has selected raw material input (RMI) as a basis for calculating raw material productivity. Despite inherent (and to a certain extent irreducible) uncertainties in environmentally-extended, trade-linked, multi-region input-output tables, it would seem important to further develop such tools in order to provide policy makers, but also the general public, with a realistic view of the true dependencies of our consumer societies on the use of raw materials. Realistic indicators are essential if policies in favour of a circular economy are to be effective.

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