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Analysis

How Countries' Resource Use History Matters for Human Well-being – An Investigation of Global Patterns in Cumulative Material Flows from 1950 to 2010

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ABSTRACT

Global resource use has been expanding rapidly after 1950 and improved material living conditions and human well-being of large parts of the global population. We here apply a cumulative long-term perspective to gain broader insights into the material requirements of human well-being, the role of trade and the history of environmental pressures than the usual perspective of annual or most recent flows would reveal. Furthermore, we investigate environmental pressures expressed as cumulative extraction per area over the last 60 years. To both ends, we utilize cumulative data on material flows on domestic material inputs (DMI) and domestic extraction (DE) for 148 countries from 1950 - to 2010 and the Social Progress Index. We find that a high level of well-being required at least 460 t/cap of cumulative material inputs from 1950- to 2010. An analysis of the relation between cumulative flows and current human well-being shows statistically significant that at similar levels of cumulative material inputs, biophysical export-orientation of a country has a weak negative influence on well-being. When the Sustainable Development Goals are to be achieved, the scientific community and policy makers have to consider the history of development of resource use to better understand the future challenges ahead.

1. Introduction

Global resource use has been growing constantly since the beginning of the 20th century, from approximately 8 billion tons (Gt) in 1900 to 71 Gt in 2010, a nearly 9-fold increase (Krausmann et al., 2008; Schaffartzik et al., 2014). The metabolic scale is driven by a range of natural and socio-economic factors such as resource endowment, economic development and population size. Alongside a world population that grew by a factor of 4, the material requirements of sustaining one individual (i.e., the metabolic rate) increased significantly, from 4.6 to 10.3 t/cap/yr (Krausmann et al., 2009). At the same time, unprecedented progress has been made in terms of human well-being, which is reflected in rising living standards, a reduction in the rate of extreme poverty, and rising life expectancy (United Nations Development Programme, 2016). The Millennium development goals have been declared a success in hindsight, yet a considerable part of the global population still lives in poverty, while the excessive resource consumption of the global North has led to numerous global environmental problems (Sachs, 2015).

In 2016, the Sustainable Development Goals (SDGs) officially came into force (United Nations, 2016). The 17 different SDGs entwine economic, social and environmental targets such as ending extreme poverty or sustained, inclusive and sustainable economic growth (economic dimension), reducing inequality and promoting peaceful, inclusive and just societies (social dimension), and tackling global environmental change (environmental dimension). The SDGs thus recognize that the stable functioning of the earth's systems is a prerequisite for a prosperous society and that a certain level of material wealth is also indispensable to ending poverty and hunger and satisfying basic human needs. If the Sustainable Development Goals are to be achieved, addressing the growing affluence of developed countries and the need for development in poor countries demands drastic measures in all countries. Based on different levels of resource use within and between countries, equity-based questions of distribution and re-distribution come into play and raise the question of how available resources should be distributed (Hajer et al., 2015).

Numerous empirical studies have found that, following rapid gains in human development with increasing resource and energy use, saturation occurs (Martínez and Ebenhack, 2008). At this point, human development no longer improves substantially, although resource and energy use still grows (Easterlin, 1974; Easterlin et al., 2010; Lamb et al., 2014; Sachs, 2015; Steinberger et al., 2012; Steinberger and Roberts, 2010). The SDGs further acknowledge economic growth as an important factor in achieving sustainable development (United Nations, 2016). For example, in poor countries, income growth enables

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people to purchase material goods and services that satisfy their basic human needs (Howarth, 2012). However, at a certain point, human well-being does not grow along with income, while resource use does (Steinberger and Roberts, 2010). Hence, Herman Daily stated in an essay published in (2015), reprising an argument he first made 40 years ago, that "*The prevailing obsession with economic growth puts us on the path to ecological collapse, sacrificing the very sustenance of our well-being and survival*". The close coupling between economic growth and resource use (Ayres, 1996; Brundtland et al., 1987; Daly, 2015; Fischer-Kowalski, 1998; Fischer-Kowalski and Hüttler, 1998; Georgescu-Roegen, 1986) has continued to raise concerns about sustainability, mostly because of scarce evidence that absolute decoupling between economic growth and resource use has taken place (Akenji and Bengtsson, 2014; Steinberger et al., 2013; UNEP, 2011).

Mainly based on empirical observations, there has been widespread concern that since the great acceleration of the 1950s, ecosystems are threatened to a very dangerous extent by the ever-increasing economic mobilization of natural resources (Rockström et al., 2009; Steffen et al., 2015, 2007). The regional and qualitative proliferation of global social metabolism has been associated with a wide range of environmental and social pressures. These pressures occur throughout the whole life cycle, from resource extraction to consumption to disposal or recycling. Martinez-Alier et al. (2016) found that most socio-environmental conflicts – in their database of >1000 conflicts – are caused by resource extraction and its adverse side effects, while carbon emissions or other forms of pollution also occur during the consumption and disposal of material products and the services they provide. Yet, different environmental pressures also depend on the resource that is extracted, with the most significant differences being between biomass (a renewable resource) and non-renewable resources such as minerals and fossil fuels (Bunker and Ciccantell, 2005; Foley et al., 2011, 2005; Griggs et al., 2013; Kastner et al., 2012; Martinez-Alier, 2002; Temper and Martinez-Alier, 2012; UNEP, 2011). The conversion of natural to agricultural lands for the production of biomass has continuously altered the landscape (Erb et al., 2016; Sanderson et al., 2002) and resulted in a massive change in bio-geochemical flows, biodiversity loss and deforestation, and social changes such as rural migration. The extraction of non-renewable resources such as fossil fuels and metal ores has led to scarcities on the input side and to overstressing of the sink capacities of the atmosphere (IPCC Climate Change, 2013; Schaffartzik et al., 2016).

Such changes in the environment have a strong feedback into societal relations. French anthropologist Maurice Godelier has established the link between culture and history in the introduction to "The Mental and the Material" (1986, p.1): *"Human beings have a history because they transform nature*." Based on this argument that the human appropriation of nature modifies nature and that this modified nature in turn stimulates social change, Fischer-Kowalski and Weisz (1999, p. 243) define human societies as *"hybrids between a natural, material world and a cultural world of recursive communication", whose* material elements are structurally coupled to the autopoietic communication system. In this case, everything that affects these material elements of a society affects society itself.

In this manuscript, we investigate how social progress is linked to a history of resource use, thus providing a comparative assessment of whether improvements in the social dimension of sustainable development have been achieved without a quantitative increase in society's resource bases and subsequent pressures on the environment. To estimate society's resource base, we make use of material flow accounting, which provides indicators that quantify the annual resource flows to a socio-economic system, i.e., countries. We here measure the cumulative material flows over the period from 1950 to 2010 and thus extend the temporal boundary from one year – which is common in material flow accounting – to 60 years for our cross-country comparison of 148 countries. Cumulative material flows are different from social in-use stocks like buildings and infrastructure. Pauliuk and Mueller (2014) describe social in-use stocks as determinants of the long-term dynamics of social metabolism, as they remain in use for a relatively long time and shape the future flows of materials and energy. Social in-use stocks are usually processed materials (i.e., from ores to steel bars), are accumulated in built structures within societies, and provide services, for example, as roads or buildings (Fishman et al., 2015; Lin et al., in press; Pauliuk et al., 2013; Wiedenhofer et al., 2015). In contrast to in-use stocks, cumulative material flows are flows and not stocks, but parts of these flows are stock-building and used to build up and maintain infrastructure and large machinery, while other parts of these flows are used for direct consumption, such as human nutrition and energy provision and get converted into gaseous emissions (mainly carbon dioxide [CO_2]) and other residues, normally in a period shorter than one year. Based on such an understanding of cumulative material flows, we assume that social progress requires sufficient resource use over an extended period of time, be it for direct consumption or stock-building. Therefore, in this work we do not explicitly estimate the dynamics of in-use stocks; rather, we are interested in the cumulative history of resource use of biomass, fossil fuels, metal ores, and construction minerals and their relationship to human well-being and social development.

The following sections begin with a comparison of current and cumulative material use between world regions in relation to the cumulative and current populations of countries and country groups. We then continue with an analysis of cumulative material extraction in relation to land area and through a cross-country comparison of extracted renewable and non-renewable resources during the last six decades. We further cluster countries based on their physical trade balances – whether they are net consumers or net suppliers, and finally, we investigate the link between social progress and resource input at the country level to better understand which resource use patterns are associated with higher and lower levels of human well-being. We do so by applying a cross-country comparison of a country's material base and trade patterns with the Social Progress Indicator (SPI), an indicator of social and environmental performance (Porter et al. 2015).

2. Materials and Methods

We here present cumulative material flows for 148 individual countries and world regions for the period from 1950 to 2010. Economy-wide Material Flow Accounting (EW-MFA) compiles annual inflows of physical matter (except water and air) into socio-economic systems, thus quantifying economy-wide material use in tons (EUROSTAT, 2012; Fischer-Kowalski et al., 2011). We base our analysis on an EW-MFA dataset by Schaffartzik et al. (2014), which comprises annual flows of 65 material types and aggregates them into five main material groups, i.e., biomass, fossil energy carriers, metal ores, industrial and construction minerals (i.e., non-metallic minerals), and traded products that cannot be allocated to one of the main raw material groups. These data include material flows that were extracted from the domestic environment of a country (domestic extraction, DE), and all physical imports (Im) and physical exports (Ex) for the years 1950, 1960 (1962), 1970, 1980, 1990, 2000, 2005, and 2010, mostly based on international statistical sources. The indicators that are used in the following chapters are all calculated based on these three types of flows. Further details on data gathering, aggregation procedures, and necessary methodological adaptions are described in Krausmann (2009) and Schaffartzik et al. (2014).

EW-MFA commonly uses annual time-steps, which is consistent with most statistical databases (e.g., FAO statistics) and allows comparison with socio-economic indicators such as GDP and population statistics. For this study, however, we have used the annual data and summed it up for the period from 1950 to 2010 to derive the total values for DE, imports and exports (except for Fig. 2b, where we have added biomass only, and 2c for all other materials). Whenever we refer to cumulative flows in this manuscript, we add the acronym $_{1950–2010}$ to the respective indicator.

$$DE_{1950–2010} = DE_{1950} + DE_{1951} + \ldots + DE_{2010} \quad (1)$$