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Coupling versus Decoupling? Challenging Evidence over the Link between Economic Growth and Resource Use

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Abstract: With the UN indicating that climate objectives are well off track, the dependency of the economy on resources remains a crucial issue demanding holistic consideration. As a key global sustainability issue, the linkage between resource use and economic growth has long been under heated debate. The increasing amount of resources used for economic growth has elevated environmentalists' concerns over resource scarcity and environmental impacts, suggesting the existence of coupling between resources and the economy. In contrast, the declining Material Intensity (MI)—resources needed to produce one unit of Gross Domestic Product (GDP)—has led to optimism for many economists and decision makers with far reaching implications for resources and economic policies. Through novel divergence indicators by using long-term datasets, we find that there has been increasing divergence between total and per capita resources use and MI at both the global and the national level. This increasing divergence is due to the faster growth in the total and per capita amount of resources rather than the reduction in the amount of resources per unit of GDP (MI). These divergences indicate underappreciated challenges and opportunities for sustainable economic growth, resource management and implementation of circular economy policies.

Keywords: decoupling; sustainable development; natural resources; resources management

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1. Introduction

The link between resources and economy (R–E link) is commonly evaluated by the total and per capita amounts of resources used in economic growth and the so-called Material Intensity (MI), namely the amount of resources required per unit of GDP [1,2]. Remarkably, these trends follow drastically different trajectories which mark an increasing divergence over the years [3,4]. On one hand, the dramatically increasing total and per capita amount of non-renewable natural resources used for economic development indicates a strong coupling, worrying many environmental scientists who are concerned about resource depletion and environmental damage [5–7]. On the other hand, the MI is declining in the vast majority of national economies due to several factors such as technological advances, outsourcing of heavy industry, and the restructuring of economies toward the service sector [1,8–12]. This is the so-called decoupling effect that provides empirical evidence for the lack of concern over the scarcity of natural resources, an optimism adopted by several scholars, including some Nobel laureates in economics [13,14]. Such vastly different perspectives, based on different measures, have led to decades of hot debates over the dependency of growth on natural resources and sustainability prospects [15–22].

An examination of previous research indicates that coupling and decoupling have often been analyzed and interpreted separately, and that, in some cases, the crucial questions have been neither raised nor answered properly [1,12]. In the present paper, we attempt a rather holistic approach by comparing long-term trends in coupling and decoupling at the global and national levels. We use long-term data on GDP, population, and resources at the global level (1900–2009), two major developed post-industrial countries (USA 1870–2005 and Japan 1878–2005), and two rapidly developing countries (India 1961–2008 and China 1970–2008). These countries were selected upon availability of standardized long-run data and because of their importance in the global economy (they accounted for almost 1/2 (≈46%)) of global GDP in August 2021 [23]. We estimate the divergence between the total amount of resource use and the resources required to produce one unit of GDP (MI). Furthermore, in order to capture the effect of population size in resource use, we also estimate the divergence between the per capita use of resources and MI. All data are based on the Material Flow Analysis (MFA) framework and its "offspring" databases that provide reliable, standardized, and comparable datasets [24]. The proposed composite indicators aspire to capture the driving force behind the occurred divergence between the increasing trends of total and per capita resource use and decreasing MI trends at both the global and the national level. If the MI decreasing trend is the main contributing factor of the estimated divergence, then decoupling may be actual. On the other hand, if the DMC and DMC per capita increasing trends are the main contributing factors of the estimated divergence, then decoupling may not be substantial, and thus the R–E link is characterized by coupling trends.

2. Materials and Methods

All the estimates are in accordance with the standards set by the economy-wide Material Flow Analysis framework (MFA). Recently developed, the MFA sets standards for monitoring and quantifying natural resources consumed for economic growth. The MFA induced the construction of standardized long-run databases for many countries as well as the global economy. These databases feed recent empirical studies and reports concerning the link between the economy and resources [3,9,10,24]. MFA is adopted by statistical offices in many countries and international organizations such as the European Union, the United Nations, the IMF, the OECD, and the World Bank [8,25–28], while indicators and estimates based on the MFA are today an integral part of international environmental-economic accounting and reporting tools, such as NAMEA [29] and SEEA [25].

MFA covers the direct material flows [30] entering the economy, actual resources used along the production process of all products. Direct use is disaggregated into four main material flows: biomass, construction minerals, fossil energy carriers, and ores/industrial (non-metallic) minerals.

2.1. Main Variables and Indicators

Our empirical analysis is based on the following core indicators of MFA:

- The total use of resources is defined as Domestic Material Consumption (DMC): the net flow of a material used domestically in a national economy. DMC is calculated as: domestic extraction of resources minus resources exports plus resources imports. The total use of resources at the global level is defined as Global DMC. We adopt the definition given by Krausmann et al. [3] who assume that, at the global level, the net international resource trade is zero and, consequently, global DMC = global extraction of resources. DMC is measured in 1000 tons per year.
- The per capita use of resources is defined as DMC per capita = DMC/Population, measured as tons per person per year (t/per/yr).
- The R–E link is defined as the Material Intensity (MI) of the economy, estimated through the DMC/GDP ratio, indicating the number of resources required to produce one unit of GDP. MI is measured as "kilograms of resources per dollar per year" (kg/$/yr).

In addition, based on MFA's core indicators, we propose novel composite divergence indicators, which are defined as follows:

$$\mathrm{Div_t} = \left(\left[\frac{(\mathrm{DMC_t} - \mathrm{DMC_{t0}})}{\mathrm{DMC_{t0}}} \right] * 100\% - \left[\frac{\mathrm{MI_t} - \mathrm{MI_{t0}}}{\mathrm{MI_{t0}}} \right] * 100\% \right) \quad (1)$$

$$RC_{DMC} = \left(\frac{\left(\frac{DMC_t - DMC_{t0}}{DMC_{t0}} \right)}{Div_t} * 100\% \right) \quad (2)$$

$$RC_{MI} = \left(\frac{\left(\frac{MI_t - MI_{t0}}{MI_{t0}} \right)}{Div_t} * 100\% \right) \quad (3)$$

where the Divergence (Div) between total Domestic Material Consumption (DMC) and Material Intensity (MI) at time t is defined as (see Equation (1)) the difference of their percentage changes from the first year ($_{t0}$) with available data: $Div_t = [(DMC_t - DMC_{t0})/DMC_{t0}] * 100\% - [(MI_t - MI_{t0})/MI_{t0}] * 100\%$. The relative contribution (RC) of DMC and MI to their divergence is estimated (see Equations (2) and (3)) as the percental contribution of their % change to the Divergence: relative contribution of $DMC_t = [[(DMC_t - DMC_{t0})/DMC_{t0}]/Divergence_t] * 100\%$ and relative contribution of $MI_t = [[(MI_t - MI_{t0})/MI_{t0}]/Divergence_t\ ] * 100\%$. Relative contributions of DMC and MI sum up to 100%.

Similarly, by accordingly converting the prototype of Equations (1)–(3), the divergence (Div) between per capita use of resources (DMC per capita) and MI at time t is defined as the difference between their percental changes from the first year ($_{t0}$) with available data: $Div_t = [(DMC\ per\ capita_t - DMC\ per\ capita_{t0})/DMC\ per\ capita_{t0}] * 100\% - [(MI_t - MI_{t0})/MI_{t0}] * 100\%$. The relative contribution (RC) of DMC per capita and DMC/GDP to their divergence is estimated as the percental contribution of their % change to the Divergence: relative contribution of DMC per $capita_t = [[(DMC\ per\ capita_t - DMC\ per\ capita_{t0})/DMC\ per\ capita_{t0}]/Divergence_t] * 100\%$ and relative contribution of $MI_t = [[(MI_t - MI_{t0})/MI_{t0}]/Divergence] * 100\%$. The percental contributions of DMC per capita and MI sum up to 100%.

2.2. Data Availability

2.2.1. Resource Use (Material Flows)

Data of DMC for the global level, the United States, Japan, and India are drawn from Alpen Adria Universitat, Institute of Social Ecology [3,31–33], and for China are drawn from CSIRO and UNEP [34].

2.2.2. GDP

All data on GDP are drawn from [35,36], except for the global GDP value of the year 2009 which is drawn from The Conference Board Total Economy Database [23]. The GDP is measured in millions of 1990 International Geary–Khamis USD per year. The "1990 international Geary-Khamis dollars" are purchasing power parities (PPPs) used to monitor the value of production on standard prices. The "1990 international Geary-Khamis dollars" are calculated using a specific method devised to account for inflation and trends in international prices. Information on the computation of the PPPs in Geary–Khamis dollars is available at [37].

2.2.3. Population

All data on population are drawn from Maddison [35,36].

3. Results

The results presented in Figure 1 demonstrate an increasing divergence between MI and total resources use. The MI demonstrates a declining trend, with very short periods of increase or stability, for the global economy from the beginning of the 20th century, reaching 64% between 1900 and 2009. The same trends hold for all the four national economies, in periods with available data, resulting in an aggregate decrease of 80% for the USA (1870–2005), 50% for Japan (1878–2005), 7% for China (1970–2008), and 62% for India (1961–2008). On the contrary, the total use of resources constantly increased at the global level and in all countries, reaching 857% at the global level, 1721% in the USA, 4786% in

Japan, 1203% in China, and 283% in India, for the aforementioned respective periods. These trends induce an increasing divergence between total resource use and MI. The divergence increased by 921% between 1900 and 2009 for the global economy, 4272% (1878–2005) for Japan, 1801% (1870–2005) for the U.S., 1210% (1970–2008) for China, and 345% (1961–2008) for India (Figure 1). According to Figure 2, the occurring divergence is mainly driven by the relative contribution of rapid increase in total resource use, which is much faster than the reduction in MI. Evidently, the divergence trends (Figure 1) and the respective relative contribution of each variable to their divergence (Figure 2) indicate that, during the last century, the global, as well as the four national economies, have increased their dependency on natural resources much faster than the improvement of efficiency in resource use. In that context, the relationship between the R–E link is characterized by coupling trends.

Similarly, there is an increasing divergence between "the use of resources per capita" and MI (Figure 3). The per capita use of resources shows an increasing trajectory globally up to 120% (1900–2009), in China by 705% (1970–2008), in India by 48% (1961–2008), in Japan by 1291% (1878–2005), and in the USA by 148% (1870–2005). These trends result in an increasing divergence between per capita resources use and resources per unit of GDP (MI), reaching up to 184% (1900–2009) at the global level, 1198% (1878–2005) for Japan, 712% (1970–2008) for China, 228% (1870–2005) for the US, and 110% (1961–2008) for India (Figure 3). Figure 4 indicates that, apart from Japan, the per capita resource use contributed relatively more to the divergence than the improvement in the efficiency of resource use, especially after the early 1960s for the global level, where the relative percental contribution of per capita resources surpasses the relative percental contribution of MI to their divergence (Figure 4).

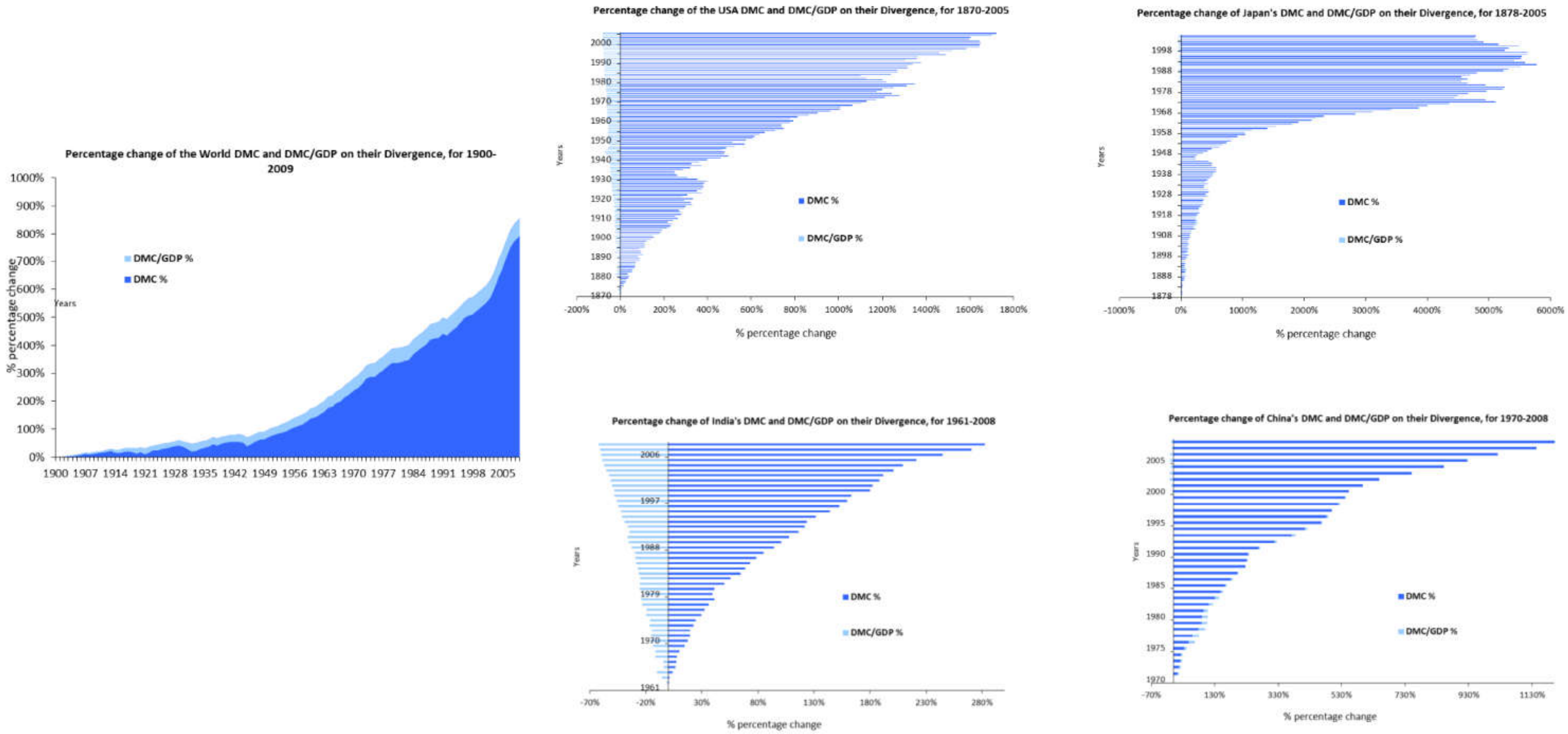

Figure 1. Divergence between the percentage change of the total resource use (DMC%) and resources required to produce one unit of GDP [(DMC/GDP)%]: the global level, the United States, Japan, China, and India.

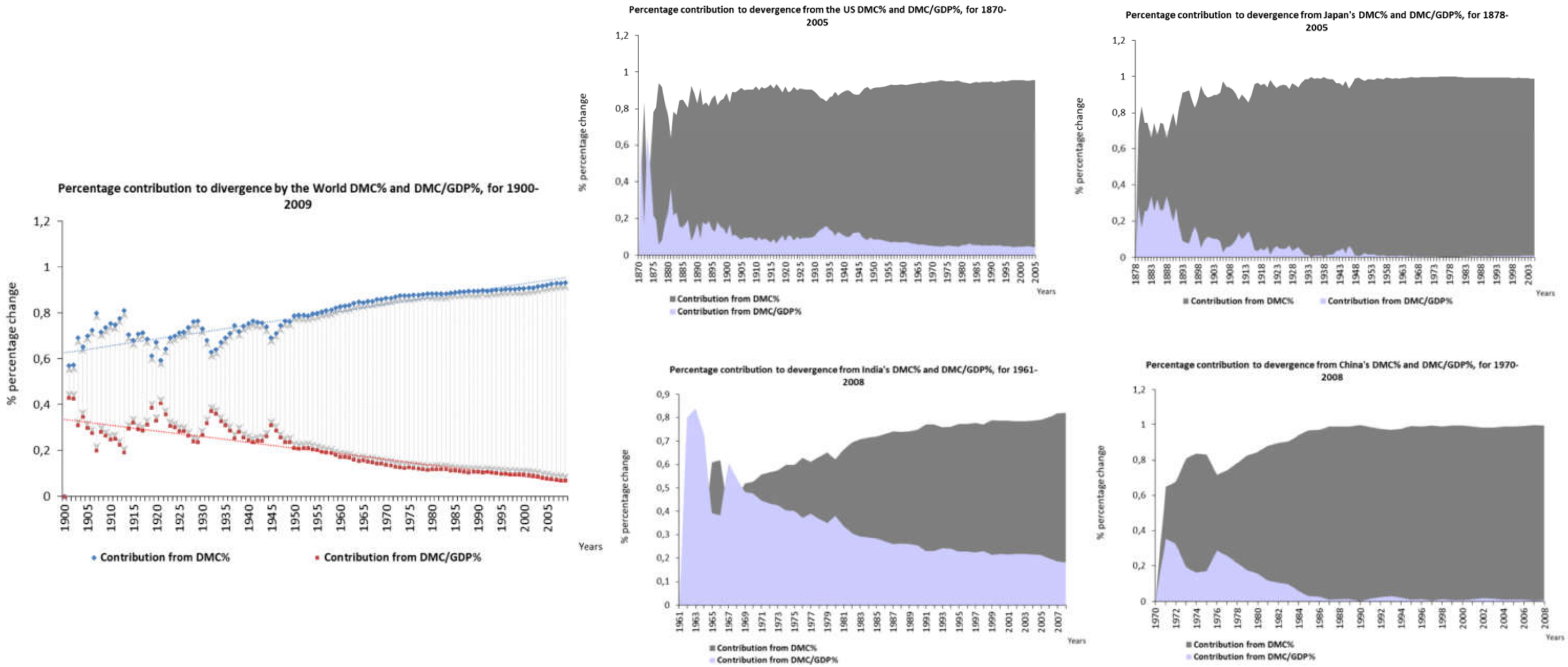

Figure 2. The percentage contribution of the percent change of the resource use (DMC%) and the % change in the resources required to produce one unit of GDP [(DMC/GDP)%] to their divergence: the global level, the United States, Japan, China, and India.

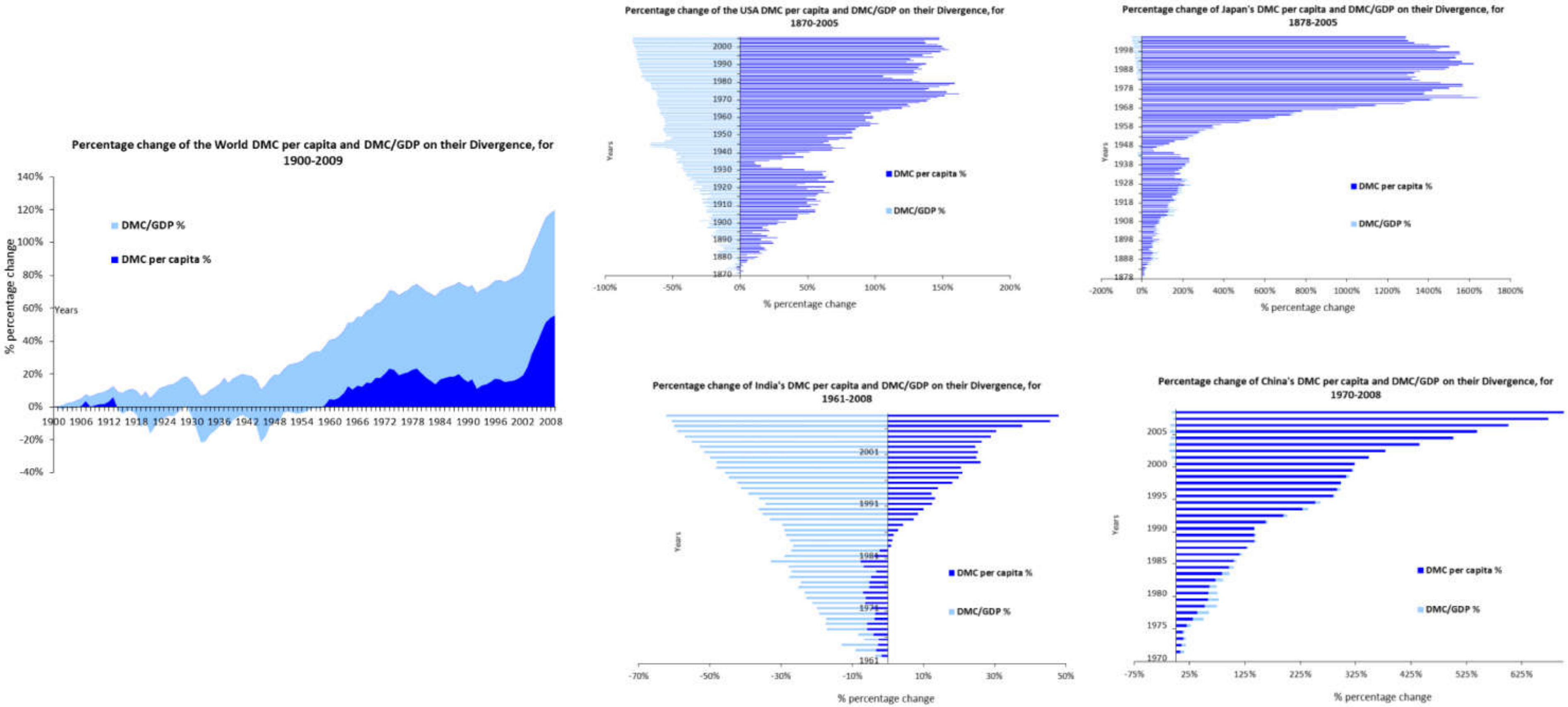

Figure 3. Divergence between the percentage change of per capita resource use (DMC per capita%) and resources required to produce one unit of GDP [DMC/GDP)%]: the global level, the United States, Japan, China, and India.

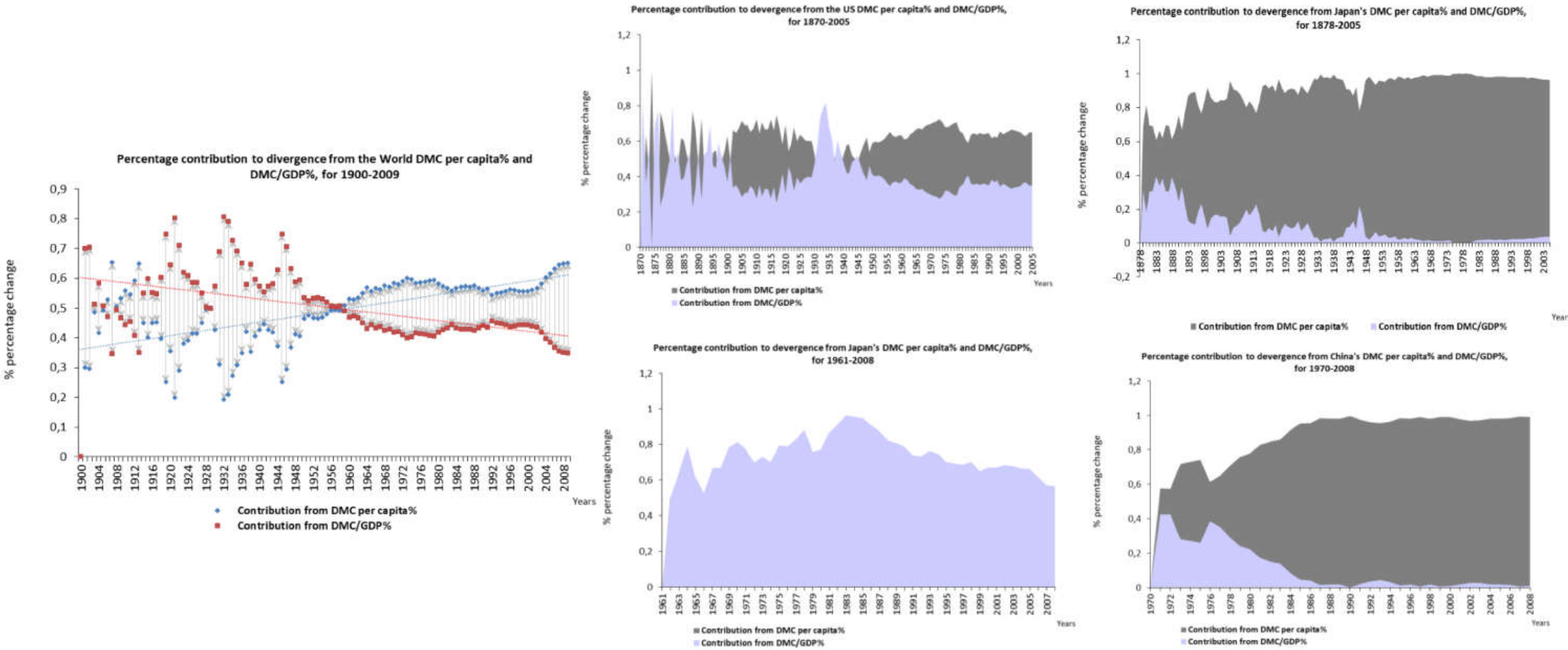

Figure 4. The percentage contribution of the % change of the per capita resource use (DMC per capita %) and % change in the resources required to produce one unit of GDP [(DMC/GDP)%] to their Divergence: the global level, the United States, Japan, China, and India.

4. Discussion and Conclusions

The present study proposes novel composite divergence indicators, by using core MFA indicators, in order to empirically investigate essential aspects of the resource–economy link. By using long run datasets for the global and four national levels (the USA, Japan, China, India), we try to shed light into a fundamental contradiction of two opposite dynamics: the continuous and unprecedented increase in total and per capita resources use signaling natural resources depletion and environmental degradation and the continuous declining of Material Intensity, signaling the significant technological improvement in resource productivity and efficiency.

The results of our study indicate the complexity of economy–nature interactions [38,39]. The efficiency of resource use has indeed increased as clearly depicted by the declining trends of the MI of the economy. With more technological advances, there are opportunities for further increasing the efficiency of using natural resources in the production process, to mitigate or even reduce environmental impacts [27], and thus to promote sustainability and circular economy policies [10,40]. On the other hand, gains in the efficiency have been offset by the increasing demand for basic goods from an increasing population [29,41], as well as by growing per capita consumption of goods, including luxury goods, by an increasing percentage of the population [42]. The United Nations recently projected a tripling of the global use of resources by 2050 [9]. This "coupling" trend suggests an increasing dependency of the economy on resources. In this context, there exist increasing challenges for sustainable development and resources management worldwide. The realization of actual decoupling between growth and resources should be advocated by the trends of "per capita" and total resources use. This is not the case under the prevailing status of the economy, society, and geopolitical relations. Enabling actual decoupling requires a new era of resources management, orientation of economic policies, as well as geopolitical relations which should focus on collaboration and "knowhow" transfer to the so-called developing world.

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