Decoupling for ecological sustainability : A categorisation and review of research literature

Vaden, T.; Lähde, Ville; Majava, A.; Jarvensivu, P.; Toivanen, T. ...

2020-10

Elsevier Ltd.

http://hdl.handle.net/10138/345840

Vaden, T, Lähde, V, Majava, A, Jarvensivu, P, Toivanen, T, Hakala, E & Eronen, J T 2020, 'Decoupling for ecological sustainability : A categorisation and review of research literature', Environmental Science & Policy, vol. 112, pp. 236-244. https://doi.org/10.1016/j.envsci.2020.06.016

Author Version

Vadén, T., Lähde, V., Majava, A., Järvensivu, P., Toivanen, T., Hakala, E., **Eronen, J.T.** 2020. Decoupling for ecological sustainability: A categorisation and review of research literature. Environmental Science & Policy 112, 236-244.

Decoupling for ecological sustainability: a categorisation and review of research literature

ABSTRACT

The idea of decoupling "environmental bads" from "economic goods" has been proposed as a path towards sustainability by organizations such as the OECD and UN. Scientific consensus reports on environmental impacts (e.g., greenhouse gas emissions) and resource use give an indication of the kind of decoupling needed for ecological sustainability: global, absolute, fast-enough and long-enough. This goal gives grounds for a categorisation of the different kinds of decoupling, with regard to their relevance. We conducted a survey of recent (1990- 2019) research on decoupling on Web of Science and reviewed the results in the research according to the categorisation. The reviewed 179 articles contain evidence of absolute impact decoupling, especially between CO2 (and SOX) emissions and evidence on geographically limited (national level) cases of absolute decoupling of land and blue water use from GDP, but not of economy-wide resource decoupling, neither on national nor international scales. Evidence of the needed absolute global fast-enough decoupling is missing.

Keywords: decoupling, economy, resources, sustainability, GDP

1. Introduction

The concept of "decoupling" is used to refer to the end of the correlation between increased economic production and decreased environmental quality (IRP 2011). On this abstract level, the term intends to name a phenomenon where, contrary to the majority of past experience, economic growth happens without concomitant growth in use of material resources or negative environmental impact (IRP 2017, 23). The concept is especially necessary for policy-making that, first, sees economic growth necessary or desirable, and, second, accepts that current levels of material use and environmental damage caused by the economy are unsustainable. If economic growth is to continue, it has to be disconnected from increasing use of materials and increasing environmental impact (OECD 2001, UNEP 2011). In this context, the possibility of decoupling can be used as an argument when one wants to encourage economic growth while acknowledging past or current unsustainable development caused by the economy (Jackson & Victor 2019; Hickel & Kallis 2019).

To investigate decoupling empirically, one needs to operationalise both the growth of the economy, and the growth of resource use and environmental impact. These operationalisations carry ambiguities, both conceptual and pragmatic. Just to take one example, the size and growth of the economy is most often represented by gross domestic product, GDP. While well established and widely used, as a measure of the economy GDP is also contested, both for theoretical and practical reasons (van den Bergh 2009, Costanza et al. 2014), especially if GDP is used as a proxy of well-being, as, e.g., by UNEP (2011, 2). Likewise, the relationship between an environmental metric, such as ecological footprint, to what one is supposedly measuring, i.e., environmental damage, can be problematic or even misleading (Giampietro & Saltelli 2014).

The abstract use of the term "decoupling" covers a range of empirical phenomena, that vary widely, e.g., in their duration, pace, geographical reach, economic significance and kind. For instance, research has discussed decoupling in terms of material use (resource decoupling) and negative environmental impact (impact decoupling). However, these two kinds of decoupling are not connected in a straightforward fashion: resource decoupling can exist in the presence of increased negative environmental impact, and vice versa. Furthermore, phenomena such as material efficiency (Schandl et al. 2016), tertiarisation (increased share of the so-called immaterial, such as service sectors of the economy, Heiskanen & Jalas 2000, Fix 2019) and financialisation (increased share of the financial sector of the economy, Kovacic et al. 2017) may all lead to decoupling, but their economic and physical causes and effects are quite different. Consequently, mismatches may occur, e.g., when it is thought that evidence of one kind of decoupling (say, impact decoupling in a particular geographical area during a specific period of time) is taken to support the possibility of another kind of decoupling entirely (say, absolute continuous resource decoupling on an international scale); an example of such a mismatch would be enlisting evidence of decoupling CO2 emissions from economic growth in support of ambitious circular economy goals.

Conceptual criticisms towards presenting decoupling as a key strategy have been put forward from several perspectives, including the field of sustainability studies (see, e.g., Kopnina & Shoreman-Ouimet 2015, Kerschner & O'Neill 2015) and economic models that are not dependent on economic growth, such as steady-state economy and degrowth (see, e.g., Washington & Tomey 2016, Victor 2010). Often the conceptual criticism against the need for decoupling (for instance, in terms of alternative conceptualisations of economy) is connected with a sceptical view of the empirical possibility of achieving sufficient decoupling (e.g., Jackson 2009). The point of such scepticism is not that environmental impact, such as CO2 emissions or the use of natural resources should not diminish, quite the contrary (Jackson 2009, 75). Rather, these alternative views emphasise that the success of an economy in creating well-being and resilience is not dependent on economic growth defined in terms of GDP, and should also be evaluated via other means (Jackson 2009, Victor 2010). Proposed alternative indicators include the Index of Sustainable Economic Welfare (ISEW, Daly & Cobb 1989) and the Genuine Progress Indicator (GPI, Cobb et al. 1995, for a discussion on indicators see O'Neill 2012).

These criticisms are underpinned by the view that human economy is a subsystem of the planetary ecosystem and needs to be studied as such, as is done, e.g., in the discipline of ecological economics (Costanza 1989). According to this approach, economies are limited by the biophysical constraints set by the ecosystem(s) they are embedded in, including limits set by thermodynamics, forming a boundary to what to what can be achieved through technological innovation, especially with regard to the use of energy (Daly 1991, Georgescu-Roegen 1971).

In steady-state economics (see Daly 2014, 1991), the idea is to identify an optimum size of the economy, beyond which futher growth is not desidable, because the environmental impact of such growth outweighs its benefits (therefore the extra growth is also sometimes called ”uneconomic” growth, Daly 2014). Proponents of degrowth emphasise the objective of de-growing the economy within ecologically sustainable limits while at the same time increasing human wellbeing as defined in non-GDP terms (Latouche 2009, Kallis et al. 2018). Thus, the point of degrowth is not only a quantitative downscaling, but also a qualitative change in the goals of the economy. Along these lines, studies have, e.g., concentrated on how a good life for seven billion people would be possible within planetary boundaries (O'Neill et al. 2018), where the definition of a safe and just operating space for human economies combines the concept of planetary boundaries (Steffen et al. 2015, Rockström et al. 2009) with the concept of social boundaries (Raworth 2012, 2017).

The point with regard to decoupling from these alternative conceptualisations is that GDP and the concomitant environmental impact may both diminish, without endangering the well-being economies create, thus undermining the necessity of decoupling that follows from the pursuit of economic growth combined with unsustainable environmental impact. The alternative conceptualisations do not advocate reduced GDP for its own sake (not even degrowth, despite ist name, see Kallis et al. 2018); rather the priority is ecological and social sustainability, and reduced GDP is a secondary effect. Given the priority of sustainability, whether GDP growth happens or not is indifferent, a view that can also be called agrowth (van den Bergh 2017).

While our goal in this review is not to engage in this wider debate, we would like to note that the current moment of the COVID-19 pandemic in early 2020 has changed the tone of discussion about environmental resources and economic growth. On one hand, the actions taken by governments the world over have been seen indicating that massive emergency measures with deep economic consequences have become more possible also with regard to environmental crises. On the other hand, the negative economic, psychological and political consequences of the emergency measures have been seen as potential hurdles for more intensive climate and environmental governance (see, e.g., the discussion in Hepburn et al. 2020).

Changes in the infrastructure and practices of production and consumption are crucial for decoupling. This perspective underlines a crucial difference between the crises caused by the COVID-19 pandemic and the ongoing environmental and resource crises. The latter unfold slowly; even the feared climate tipping points (Lenton 2011, Lenton et al. 2019) are crawling processes in comparison with a long-lasting pandemic. Slow crises cannot be overcome by declaring a martial law or a state of exception, after which things can return to normal. In view of the climate crisis, reports like IPCC (2018) urge deep systemic transformations of societies. Slow environmental and resource crises necessitate an abiding, generational process of social transformation. For instance, in order to mitigate climate change, it is not enough to set the target of carbon neutrality by the middle of the century: net negative emissions are needed for decades in order to bring the CO2 concentrations to a level that avoids catastrophic long-term changes. This is why creating troublesome path dependencies (see, e.g., Vadén et al. 2019 and references therein for a case study) have to be avoided – for example, one has to avoid investing in technological infrastructures that block further change. Emergency measures, on the other hand, tend to lack the long view. Consequently, the question of whether decoupling offers realistic paths toward a more sustainable future is perhaps even more important now when discussions about how to get the economy back on track after the pandemic are prevalent.[1]

Here we present an analytical categorization of different kinds of decoupling and apply the categorization in a survey of recent research. The categorization relies on distinctions along the material, economic, geographic and temporal aspects of phenomena of decoupling. Thus, we are not primarily engaged in a theoretical discussion, but rather proposing a possible path through the conceptual thicket towards a more immediate practical aim: answering the question of how well existing research supports the idea that decoupling is bringing about global ecological sustainability. The choice of the focus on ecological sustainability is motivated by the history of the concept of decoupling. In policy contexts it has been introduced with the goal of ecological sustainability in mind (OECD 2001, UNEP 2011).

The categorization makes it possible to assess the relationships between different kinds of decoupling, and ranks them in view of the goal. The purpose of the review of research literature is, first, to illustrate the use of the categorization and, second, to read out what kind of evidence the literature presents in view of the chosen goal. Consequently, we are not investigating how decoupling has been studied. Instead, we are interested in what recent research has said about the existence of the phenomena of decoupling within the categories. We take the claims of the

1 For example, governments are likely to mobilise significant spending to reinvigorate their economies. In a new study, forthcoming in the Oxford Review of Economic Policy (Hepburn et al. 2020), the authors asked 230 leading economists to rate different stimulus policies according to speed of implementation, long-term economic benefit and climate impact, ranging from positive to negative. The respondents, including academics, senior G20 finance ministry and central bank officials, gave some of their highest ratings for climate benefit and economic outcomes to “green” measures including clean energy investment and building retrofits.

occurrence of decoupling in the articles at face value (noting on methodology only with regard to obvious common-sensical limitations).

Next, in section 2, we describe the framework and data for our survey. In section 3, we will categorise different kinds of decoupling with the focus on ecological sustainability. The survey of research literature is presented in section 4, before a brief discussion on the results in section 5.

2. Framework and data

Our investigation relies on three elements. The first is the choice of the focus for our categorisation and therefore also the review: ecological sustainability. The second is the categorisation itself and the third is the literature survey that are described below respectively.

The first element, the choice of ecological sustainability as the goal, is based on two grounds. As noted above, achieving sufficient levels of decoupling has been introduced as a way towards sustainability (OECD 2001, UNEP 2011). Furthermore, recent scientific consensus reports (IPCC 2011, 2018, IRP 2017) give quantitative estimates of what kind of environmental goals have to be achieved, at a minimum, both in terms of impacts (greenhouse gas (GHG) emissions) and resource use. Whatever the level of economic growth, decoupling has to be such that the levels of GHG gas emissions and resource use established as maximums for the safe continuation of current civilizations are not exceeded (see also Rockström et al 2009).

The second element, the categorisation, is based on the distinctions presented in literature on decoupling, and on reasoning about the relationships between different kinds of decoupling, given the goal of ecological sustainability. Distinctions between impact and resource decoupling, and relative and absolute decoupling are a staple in the literature (UNEP 2011). The axes of geographical, economic and temporal differences are derived from research literature. The reasoning leading to the categorisation is presented in section 3.

The third element, the bibliometric survey was conducted in two phases. Both surveys were done using a Boolean search in Web of Science. The survey structure was: terms “decoupling”, “economic” and “environment” appear in the Title or Topic (Topic includes search within Title, Abstract, Author Keywords, and Keywords Plus®). We restricted the search for period between years 1990–2019. The first survey was done on March 5th, 2019. The survey returned a total of 423 articles. As we were looking for empirical evidence, we left out of scope articles presenting scenarios, models and extrapolations, and articles presenting deeper analyses of previously presented empirical material.[2] Out of the 423 articles 282 were out of scope, which left 141 articles to be reviewed. In order to complete the results for 2019, a second survey with the same parameters was conducted on January 2nd, 2020 and the search included the rest of 2019. It returned a total of 78 articles, out of which 35 were out of scope (3 articles from conference proceedings were not found and 3 articles were duplicates with first survey), which left 37 articles to be reviewed. In total 179 articles were reviewed.[3] Figure 1 displays the survey articles by year. A large number (88 out of 179, i.e., ca. 49 percent) of the articles concern only China or an area in China.

2 One article was left out as it was written in Hungarian which none of the authors can read.

3 A systematic survey like this leaves out articles that would be relevant for the topic and that we are aware of, such as some of the articles mentioned in Parrique et al (2019); however to the best of our knowledge including those articles would not have changed the central outcomes of this paper.

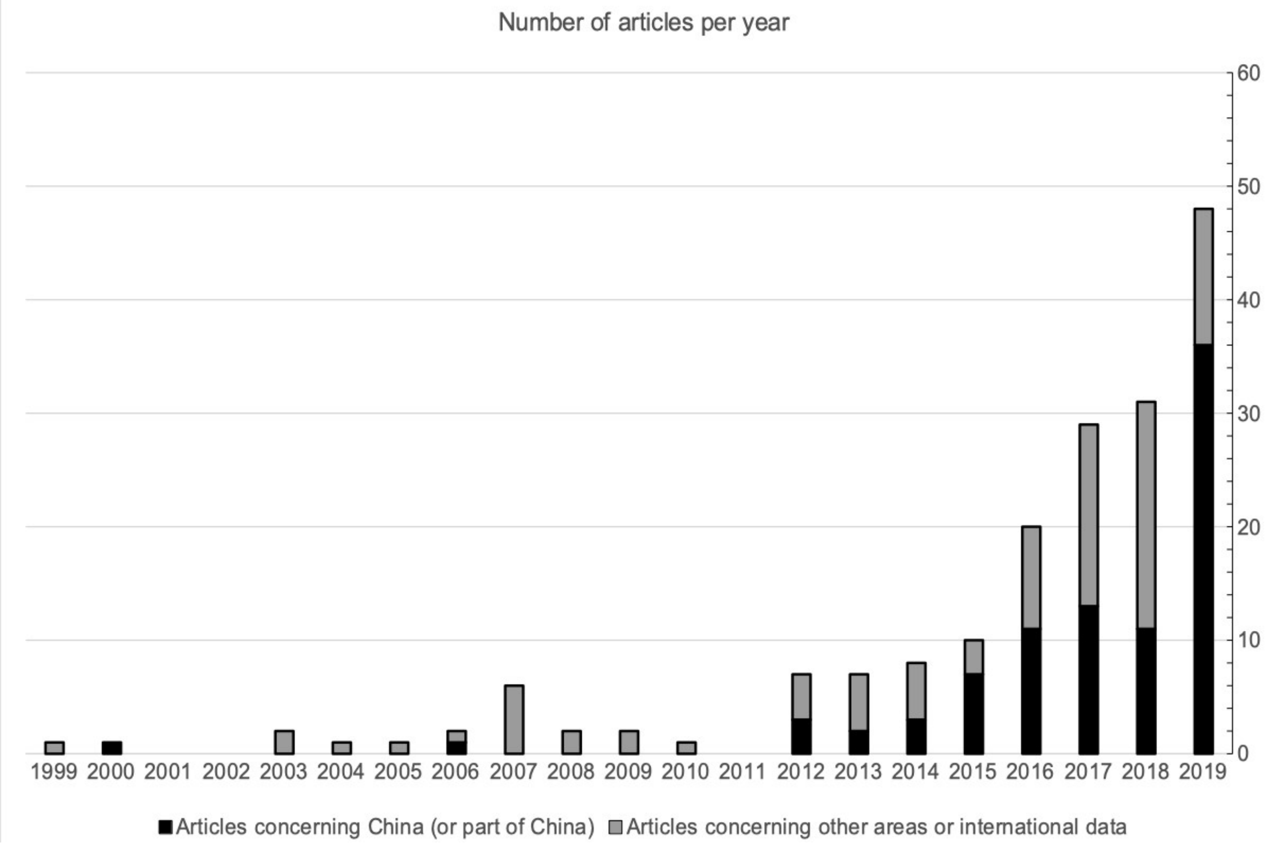

Figure 1. Survey article numbers by year, separated to articles that study only China or areas in China, and articles studying other areas or international data (possibly including China).

We read the 179 articles for the evidence of decoupling that they presented. The reading of the evidence, and its presentation in Appendix, was formed on categorisation and analysis of the different empirical phenomena of decoupling and their relationships presented in section 3. The categorisation is based on existing distinctions in research literature, and intends to present the categories systematically along a few axes (size and location of geographical area, economic sector, time, type of decoupling). Also, based on recent scientific consensus reports, we present in section 3 a brief argument why attention to the more difficult types of decoupling is of special significance to discussions of ecological sustainability. The categorisation is intended as a tool for clarifying the relevance of empirical evidence for decoupling.

Section 4 discusses the results of the survey, with particular emphasis on research results that point towards the kind of absolute and wide-enough (both in terms of geography and the analysis of the economy-environment nexus) decoupling that is a minimal requirement for ecological sustainability.

3. Categorising Decoupling

As noted above, decoupling the growth of economy can be discussed in terms of resource use (resource decoupling) or environmental impact (impact decoupling). For brevity, in the following we will use the term ”decoupling” to refer to both resource and impact decoupling, and make the distinction explicit in cases where it is relevant.

An important conceptual distinction to be made is between absolute (strong) and relative (weak) decoupling. Relative decoupling means that economic growth is faster than the growth of environmental damage or resource use, even though the latter may still be growing. Absolute decoupling, in turn, means that the economy is growing while the amount of resource use and/or environmental impact is decreasing.

For the purposes of the review of empirical evidence, below, it is good to note that relative decoupling does not necessarily lead to absolute decoupling. Relative decoupling due to, for instance, increased material efficiency, may continue for long periods of time without ever turning into absolute decoupling. Relative decoupling is, by definition, connected to increased impacts and/or resource use, so in order to evaluate the pertinence of evidence of relative decoupling it is necessary to investigate what are the structural reasons for the relative decoupling, and find out if they are such that they can continue and intensify into absolute decoupling. For our survey, we concentrated on evidence of absolute decoupling.

The first empirical axis which we use for categorization is geography. In empirical research, decoupling is discussed on various geographical scales, from the regional and national up to the global level. First, it is obvious that decoupling on a limited geographical scale, such as a local region, is easier than on a wider geographical scale, such as a nation. For instance, a local region can diminish its use of chemical fertilisers, if it can buy foodstuffs with enough nutrients from outside the region, thus decoupling fertiliser use from GDP. However, when the wider context is taken into account, such decoupling may prove to be nonexistent.

Second, local decoupling does not necessarily entail global decoupling. In fact, local decoupling may co-exist or even depend on recoupling happening outside the local area. Modern economies are widely interconnected and receive many material and immaterial goods from outside their geographical borders. Consequently, research literature has noted that several observations of decoupling become problematic when outsourcing and trade are taken into account (Bithas & Kalimeris 2018, Schandl et al 2017, Krausmann et al 2017, Schaffartzik et al 2014, Wiedmann et al 2015). Geographical scale has been widely discussed, e.g., in the case of CO2 emissions, where accounting on the basis of production and consumption within a given geographical area often give quite different numbers in areas of heavy imports or exports (Sanye-Mengual et al 2019, Palm et al 2019, Tukker et al 2016).

The second empirical axis for categorization is time. In several studies, periods of decoupling are followed by periods of no decoupling or even recoupling (see, for instance, Zhang & Wang 2013, discussed below). Again, it is obvious that making decoupling a continuous phenomenon is harder than achieving decoupling for a limited period of time, as continuous decoupling entails permanent changes in structures of production. For example, periods of decoupling have in certain areas of the world coincided with periods of economic downturns, and ended when economic growth has again picked up more speed (Sanye-Mengual et al 2019, Shao et al 2017, Krausmann et al 2017).

The importance of temporal scale is illustrated by an example of increased granularity. Zhang & Wang (2013) study decoupling between CO2 emissions and GDP in Jiangsu province, China: within the period of 1995 to 2009, the CO2 emissions in the province rose with an average annual growth rate of 7.54 percent. As the average growth rate of GDP within the province was 12.6 percent, as a whole the period represents relative decoupling (Zhang & Wang 2013, 240). However, by increasing granularity, years 1996 to 1997 and 2000 to 2001 represent strong decoupling and years 2003 to 2005 recoupling (expansive negative decoupling) (Zhang & Wang 2013, 241). As the example shows, only long-enough periods of analysis provide reliable information on prevailing trends.

The third axis for categorization is the economy itself. Decoupling can be studied within one economic sector, or spanning many sectors, or across the whole economy. One of the problems widely discussed with relation to sectoral decoupling is the phenomenon of rebound or so-called Jevons' paradox. For instance, when energy efficiency is increased in a given sector (thus potentially decoupling energy use from economic growth), the result is sometimes increased energy use in other sectors (Sorrell 2009, Magee & Devezas 2017). This means that empirical evidence of decoupling in a given sector of the economy has to be analysed against the background of what is happening in other sectors, and thus against potential rebound. Achieving cross-sectoral or economy-wide decoupling is harder than decoupling in one sector, as the phenomenon of rebound illustrates.

Reports of impact decoupling are more abundant than reports of resource decoupling (see below in section 4). The reason is easy to see. Resource decoupling is typically discussed in terms of indicators like Domestic Material Consumption (DMC), Total Material Requirement (TMR), Material Footprint (MF) and so on. These indicators combine information on a wide range of material resources. Despite their shortcomings, combined indicators capture a large portion of the "metabolism" of an economy. In contrast, studies of impact decoupling typically report the decoupling between one environmental indicator, such as CO2 or SO2 emissions, and the economy. This reflects a difference in how easy it is to achieve resource decoupling in comparison to impact decoupling. An economy may relatively easily replace a harmful substance, such as ozone-depleting CFC gases, and thus be absolutely decoupled from the specific impact. Indeed, such a decoupling may be achieved by increased material use, if the use of the replacement demand more resources, such as energy. In contrast, a decrease in resource use, whether in terms of DMC or TMR or something similar, demands a wider-reaching change in the functioning of the economy (such as increased energy and material efficiency, tertiarisation, etc.).

In the case of impact decoupling it is expedient to investigate whether the impact being decoupled (such as a type of GHG emission) is a good proxy for what is happening in the environment-economy nexus more generally. Below, we find that by far the most studied phenomenon of decoupling in our survey is that between CO2 emissions and GDP. Due to the urgency and importance of climate change, data on this kind of decoupling is essential. Furthermore, climate models and their carbon budgets, such as presented by, e.g., the IPCC (2018), give a quantified goal for the needed absolute decline in GHG emissions, expressed in terms of CO2 equivalents. However, decoupling CO2 emissions from GDP can very well coexist with unsustainable environmental impacts and resource use, as several of the studies in the survey illustrate.

In sum, sectoral, temporally and geographically limited decoupling is easier to achieve than economy-wide, continuous and global decoupling (see Table 1 for summary). Likewise, relative decoupling is easier to achieve than absolute decoupling. More importantly, sectoral, temporally limited and geographically limited cases of decoupling can exist in the presence of or even depend on no decoupling or even recoupling outside the analysed sector, time or geographical area. This can happen, for example, through creating and maintaining an international division of production where a developed country is decoupling certain sector by moving the production to less developed countries (Bithas & Kalimeris 2017, Wiedmann et al 2015). Thus evaluating the relevance of these kinds of cases for the larger, abstract claim of decoupling as a policy goal should proceed with careful analysis, taking into account the limits of the cases, and phenomena like outsourcing, trade and rebound.

	Easier	*Harder*
Kind of decoupling	Relative	Absolute
Economic scope	Sectoral	Economy-wide
Timescale	Limited timescale	Longer timescale
Geographical scope	Geographically limited	Global

Table 1. Dimensions of decoupling: easier and harder.

Decoupling is a measure of ecological efficiency, not one of sustainability: even an absolutely decoupled economy can transgress planetary boundaries either through its impacts or its resource use. This brings in yet another dimension: the question of what kind of decoupling is needed or would be sufficient for ecological sustainability globally. While any kind of decline in the growth of material use or environmental impact is ecologically welcome, we also know that decline in growth is, for many cases, not enough. On the impact side, we know, for instance, that in order for the climate to stay within a safe operating space for human societies, the growth of global CO2 emissions needs not only to stop but actually to decrease and become negative (IPCC 2018). Thus, here, absolute continuous global economy-wide impact decoupling is necessary. Likewise, the global aggregate of current use of material resources is unsustainable (IRP 2017). Here, too, absolute global economy-wide resource decoupling is needed, until the level of resource use decreases to a sustainable level. Even if these kinds of absolute, global and economy-wide decoupling are harder to achieve than, say, cases of sectoral impact decoupling, they should receive the closest attention, as they are the goals necessary for ecological sustainability. In sum, this means that empirically the evidence for the harder types of decoupling is also more pertinent for the ecological goals.

Moreover, as climate change threatens to pass the tipping points after which efforts of mitigation become harder (Lenton 2011, Lenton et al. 2019), the decoupling of CO2 emissions from economic growth has to be *sufficiently fast* (Parrique et al 2019). According to current scientific understanding, there is a limited window of opportunity for the needed absolute and global decoupling of CO2 emissions; any amount of relative or local decoupling within the timeframe is not enough (IPCC 2018). In addition, rapid mitigation measures (e.g. replacing fossil fuel infrastructure with renewable energy solutions) might also cause significant resource pressures and environmental impacts (e.g., biodiversity loss, threats to ecosystems, IPCC 2011), highlighting the need for an economy-wide perspective that takes into account various types of impact and resource use.

As there is a possible disconnect between cases of relative and absolute, temporally limited and continuous, geographically limited and global, sector-specific and economy-wide decoupling, attention is needed to cases that clearly point towards the ecologically necessary goals of absolute, global, economy-wide, long-enough and fast-enough decoupling. It is with this goal in mind that we review the articles of the survey, below.

4. Results and discussion

In the following we present results from the bibliometric review and more general observations on the empirical evidence. In the Appendix, the reviewed articles are listed year by year. For each article, we list the geographical scale of its analysis (local, national, international, global), whether the analysis concerns one economic sector, several sectors or the economy as a whole, and the analysed period of time, if applicable. The main result read out of every article is what kind of decoupling (relative or absolute) it presents evidence of, and which are the analysed economic and environmental metrics. (In addition, separate sheets in the Appendix provide listings of articles presenting evidence of absolute decoupling, both impact and resource decoupling).

Evidence of decoupling	No decoupling	Relative decoupling	Absolute decoupling
	8	170	97
Geographical scale	Local or national	International	Global
	123	50	7
Economic scope	One sector	Several sectors	Economy-wide
	56	7	116

Table 2. Kinds of decoupling mentioned in reviewed articles. (Note: The table only indicates the number in each category: the number of articles on the rows and the columns of the table do not tally with total number of articles, as one article may present evidence in several or none of the different categories).

Out of the 179 reviewed articles, 8 report no evidence of decoupling in their analysis (see Table 2 for summary). Out of these 8, five analyse a limited geographical area (India, Turkey, ASEAN countries, China, Switzerland)[4] and report no decoupling. Three out of the eight deserve further

4 Gokarakonda et al (2019) find increased material-use intensity in construction in India between 2011–2016. Lise (2006) finds no decoupling between carbon emissions and economic growth in Turkey in 1980–2003. Chontanawat (2019), Jaligot & Chenal (2018) and Cohen et al (2019) are borderline cases that could also have been categorised otherwise. Chontanawat (2019) and Jaligot & Chenal (2018) focus on finding an Environmental Kuznets Curve (EKC) in their data (on CO2 emissions in ASEAN countries and municipal solid waste in Vaud, Switzerland, respectively), and report that no EKC is evident and also do not report finding decoupling, although their data may

attention: two (Bithas & Kalimeris 2018, Schandl et al 2017) because they concern global material flows, and one (Moreau & Vuille 2018) as the article makes a pertinent methdological contribution to how decoupling is studied.

Bithas and Kalimeris (2018) analyse global decoupling through data on DMC and GDP. They argue that such analyses should use GDP per capita rather than aggregate national GDP as the economic indicator, as GDP per capita represents the ultimate outcome of the economy. Using the GDP per capita data, they conclude:

> "Our estimates suggest that the dependence of global economic growth on natural resources has increased by over 60% in the last 110 years (1900–2009), contrasting with the prevailing decoupling estimates which suggest a reduction by 63%. We find that the actual decoupling, which began in the mid-1970s in post-industrial economies, is counterbalanced by the intensified resource intensity of several developing economies." (2018, 338)

A similar geographical change in locations of production and concomitant more intense global material use is observed by Schandl et al (2017). They find (2017, 827) an increase in material intensity, i.e., recoupling of material use after 2000:

> "Material efficiency, the amount of primary materials required per unit of economic activity, has declined since around 2000 because of a shift of global production from very material-efficient economies to less-efficient ones. This global trend of recoupling economic activity

---

contain periods of relative decoupling. Similarly, Cohen et al (2019, 19) report "little evidence" of decoupling between GDP and GHG emissions in China on the national level, but their data on the disaggregated provincial level contains periods of decoupling. As these three papers do not report decoupling with regard to the focus of their study, we have categorised them so. Including them in the category of articles presenting evidence on decoupling would have been possible; in our view, the choice matters little with regard to the focus of our presentation.

> with material use, driven by industrialization and urbanization in the global South, most notably Asia, has negative impacts on a suite of environmental and social issues [...].”

Moreau and Vuille’s (2018) study on decoupling between energy consumption and economic growth in Switzerland is an example of a deeper study that shows how earlier reports of decoupling turn out to be too optimistic. They use national energy accounts and national and multiregional input-output tables in order to compose a methodology for comparing national energy intensity with energy intensity adjusted for energy embedded in imports, and also include the effects of sectoral change, such as tertiarization (increasing role of the service sector) of the economy. They find that tertiarization is increasing energy efficiency domestically and deindustrialization is shifting energy use abroad, thus resulting in decreased national energy intensity. However, as energy intensity outside Switzerland is lower than inside, deindustrialisation, together with structural changes in trade, has resulted in increased embodied energy use: "In Switzerland the energy embodied in imports has increased by 80% between 2001 and 2011” (2018, 61). In sum, Moreau and Vuille conclude (2018, 61):

> ”Thus, energy intensity, as conventionally measured, provides a deceptive image of decoupling energy consumption from economic growth. […] In particular, Switzerland does not exhibit the degree of decoupling reported by official statistics. Rather, it has converted part of its final energy consumption into embodied energy in imports, thus giving the illusion of decoupling.”

Out of the reviewed articles, 170 present evidence of (at least) relative decoupling and 97 articles evidence of absolute decoupling. As noted above, absolute decoupling is the minimum requirement for ecological sustainability (and every case of absolute decoupling is also a case of relative decoupling). Therefore, in the following, we will concentrate on those 97 articles (see Figure 2 for details).

A majority of the articles presenting cases of absolute decoupling use GDP as the metric for economic growth, 80 out of 97. The other metrics used include metrics of sectoral productivity (agricultural, energy and industrial production, production in the construction sector), household expenditure, per capita income, road traffic volume and urbanization (see Appendix for details).

The most common case of absolute decoupling reported (50 articles) is between CO2 emissions and economic growth. It is important to notice, that none of these 50 studies explicitly study the possible effect that trade and outsourcing have on national emission and GDP accounts. This substantially diminishes their potential thrust as evidence for absolute global decoupling, since, as several articles in the group, including Juknys, Liobikiene, and Dagiliute (2016, 283) point out: “[...] the displacement of environmental pressure through trade may partially contribute to the course of these positive decoupling trends."

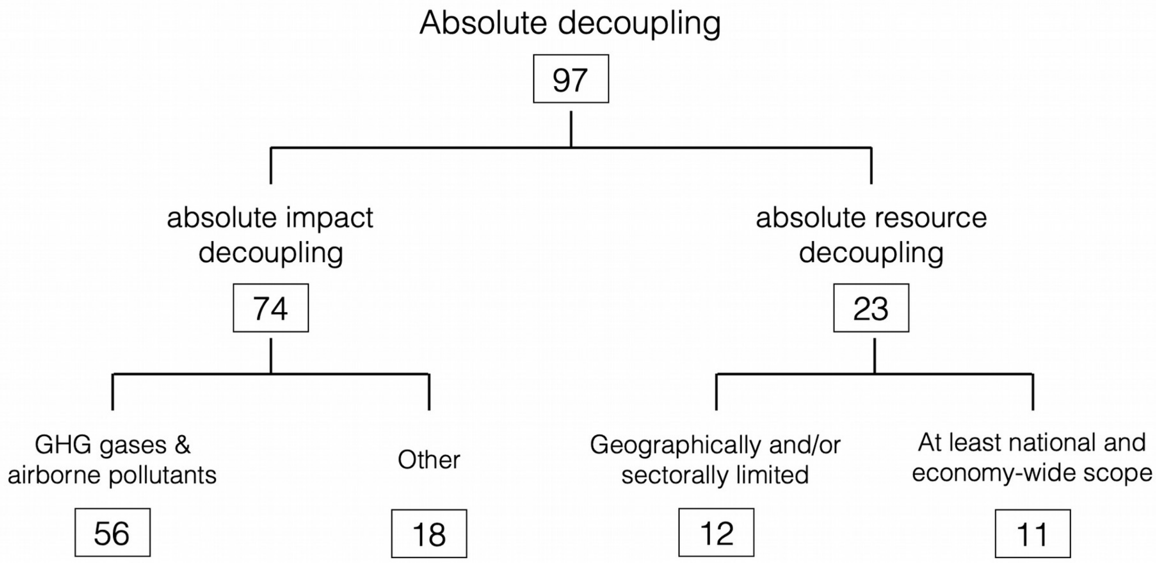

Figure 2. Articles presenting evidence of absolute decoupling.

Altogether 74 articles report some form of absolute impact decoupling (including 56 articles reporting absolute decoupling of CO2 emissions, carbon intensity, other GHG gasses or airborne pollution). The other reported environmental impacts decoupled from GDP growth include: solid waste, soot, marine pollution, and other types of pollution and combined ecological indicators (such as ecological footprint, EF, see Szigeti, Toth and Szabo 2017). In addition, one article reports absolute decoupling between amount of road transport and GDP (Alises, Vassallo, and Guzman 2014) and another between energy used in road transport and the productivity of road transport (Lin, Rogers and Lu 2007).

In order for evidence of absolute impact decoupling to constitute support for the kind of decoupling needed for ecological sustainability, it needs to fulfil two conditions. First, the environmental metric or metrics used have to be such that they function as a reliable proxy for the state and sustainability of the environment, in general. Second, the economic and geographical scope of the evidence need to be wide enough, so that impact and material flows in global economy can be included, to a reasonable extent. Among the 74 articles on absolute impact decoupling, no article fulfils these two conditions at the same time. Individual impact metrics, such as CO2 or SO2 emissions, are not comprehensive enough to function as proxies for the whole of environmental sustainability. A group of six articles (Van Caneghem et al. 2010, Wang et al. 2019, Sanye-Mengual et al. 2019, Szlavik & Sebastyen Szep 2017, Naqvi & Zwickl 2017, Liang & al 2014) use a selection of several environmental indicators thus capturing a more inclusive picture of the state of the environment. However, three of those are limited to restricted geographical areas (van Caneghem et al. (2010) considers Flanders, Wang et al (2019) Chizou, China, and Liang et al (2014) China) or report decoupling only on a limited number of the chosen indicators (Szlavik & Sebastyen Szep 2017, Naqvi & Zwickl 2017; the results by Sanye-Mengual et al. 2019, will be discussed below). The study by Szigeti, Toth and Szabo (2017) reports absolute decoupling between EF and GDP in 30 percent of studied 139 countries, when comparing data for two years, 1999 and 2009. However, the methodological problems, mentioned above, inherent in the EF as a metric for ecological impact are highlighted by the fact that Szigeti, Toth and Szabo (2017, 115) also conclude that their data indicate that the total environmental load between the years 1999 and 2009 increased by 12 percent.

Altogether 23 articles in the survey report some kind of absolute resource decoupling. Out of these five are local studies (concerning provinces or cities in China), nine concern only one economic sector (such as agriculture or the textile industry) and one several selected economic sectors in China, leaving only 11 articles that discuss absolute resource decoupling on an economy-wide basis and at least national geographic scale (Scasny, Kovanda, and Hak 2004; Kovanda, Hak, and Janacek 2008; Wang el al 2013; Wang et al 2018; Palm et al 2019; Wood et al 2018; Kraussman et al 2017; Steinberger et al 2013; Bringezu et al 2004; Sanye- Mengual et al 2019, Chovancova & Vavrek

2019). As these are, then, the articles in the survey that discuss (resource) indicators that give a wider picture of the economy than individual impact metrics and are the widest in reach when it comes to economic and geographical scale, we will look at all of them more closely.

Two (Scasny, Kovanda, and Hak 2004; Kovanda, Hak, and Janacek 2008) out of the ten report absolute decoupling between Eurostat-standardised economy-wide material flows (EW-MFI) and GDP in the Czech Republic for some years during the 1990's. As the authors point out, the decoupling is largely a result of a large decrease in coal mining and use and increase in the proportion of the service sector after the Velvet Revolution (1991–1993). In a similar way, Chovancova and Vavrek (2019) observe years of absolute decoupling between energy use and GDP in Hungary, Slovakia, Poland and the Czech Republic during the years 1991-2015. Chovancova and Vavrek (2019, 163) note that in addition to increased energy efficiency and the introduction of carbon-free energy sources also discontinuation of inefficient industry contributed to the decoupling. They also remind (2018, 164) that their country-level data does not account for the possible off-shoring of energy intensive production.

Sanye-Mengual et al (2019) use a life-cycle assessment (LCA) to evaluate the impacts of consumption in the EU, including both the territorial impacts and the embodied impacts in imports and exports. Their consumption footprint (CF) indicator sums together domestic footprint and import footprint and subtracts from this the export footprint. They find (Sanye-Mengual et al 2019, 7) that the CF has absolutely decoupled from GDP in 2005-2014.

Likewise, using domestic extraction (DE) and DMC, they find absolute resource decoupling, although with considerable variance and a clear effect from the economic downturn after 2008: "DE increased until 2007, drastically decreased between 2008 and 2010, as a result from the economic crisis, and presented an irregular decrease during the last period (2011– 2014). In this sense, the DE had a relative decoupling until 2007 and an absolute decoupling for the rest of the period, apart from years of DE increase (e.g., 2011)" (2019, 8).

Wang et al (2013) and Wang et al (2018) report comparative analyses between BRICS and OECD countries; China and Russia on the BRICS side and Japan and US on the OECD side in Wang et al (2013), and China, Russia and India on the BRICS side and Japan, US and Australia on the OECD side in Wang et al (2018). Wang et al (2018) report that in Japan biomass, non-metallic minerals and metal ore (as parts of DMC) use are all absolutely decoupled from GDP; however using the Material Footprint (MF) indicator, only biomass and non-metallic minerals are absolutely decoupled. For the US, Wang et al (2018) report an absolute decoupling between DMC and GDP, but find only relative decoupling between MF and GDP. The study by Wang et al. (2018) does not account for the possible effect of trade on the observed decoupling, nor does it specify the sources for the DMC, MF and GDP data used.

Palm et al (2019) use a multiregional input-output (MRIO) model in order to capture the resources needed for Swedish consumption also outside its borders. This is crucial since as Palm et al (2019, 634) point out, for example, more than 80 percent of the water use resulting from Swedish consumption fell outside Sweden. Palm et al (2019) address both impact and resource decoupling, analysing indicators for emissions of greenhouse gases, sulphur dioxide, nitrogen oxides, and particulate matter (impact side) and land use, materials consumption, and blue water consumption (resource side). In addition to absolute impact decoupling between CO2 and other emissions and GDP, Palm et al (2019, 643) find an absolute decoupling between land use and blue water use and GDP after 2010 although materials consumption remained relatively stable. However, they point out that "The recorded decoupling is, however, not long enough to say whether it is an established pattern or a temporary stabilisation." (2019, 643)

Wood et al (2018), Kraussman et al (2017), Steinberger et al (2013) and Bringezu et al (2004) present studies based on wide international data on material flows and economic performance. Bringezu et al (2004) report an absolute decoupling between total material requirement and GDP in Czech Republic, Germany and the US. All three cases are explained by one-time structural changes, rather than a deeper-seated trend towards decoupling. In the case of the US, Bringezu et al (2004, 113) write: “In the first case, TMR of the United States declined as a result of continued and successful policy measures to reduce erosion in agriculture.” As for the Czech Republic and Germany, the reason is the one already noted above, as reported by Scasny, Kovanda, and Hak (2004) and Kovanda, Hak, and Janacek (2008): “the collapse of the centrally planned economy and went along with the shift from lignite to other energy sources.” (Bringezu et al. 2004, 113)

Steinberger et al (2013) analyse DMC and CO2 data against GDP for 39 countries, representing both industrialised and developing/emerging economies. They find absolute decoupling between material use and economic growth in Germany, the Netherlands and the United Kingdom (2013, 4). In the case of Germany, they find, in addition to the above- mentioned factor of a decline in polluting industry in the former GDR and changes in energy composition both in the former GDR and in Western Germany, that a decline in construction minerals contributed to the decoupling. In the UK, the decoupling is “mostly due to the decline of the manufacturing and construction sectors, with much of these activities being displaced overseas, as evidenced by the growth in its consumption-based emissions.” (2013, 4). The latter is in contrast to Germany, where consumption-based emissions are declining. Thus Germany emerges as the most promising case, where absolute decoupling of material use is seen in combination of a decline in consumption-based CO2 emissions. However, the overall conclusion by Steinberger et al (2013, 9) is that the Environmental Kuznets Curve hypothesis, according to which environmental bads increase until a turning point at some high-enough level of GDP, and decline thereafter, does not hold: “There is no empirical evidence for decarbonization or dematerialization at higher economic growth rates or incomes.” (2013, 9). The relative or absolute decoupling between CO2 emissions and GDP, observed in tens of the reviewed articles, is an outlier in Steinberger et al’s (2013, 9) conclusion: “EKC-like behaviour, indicating a slowing down of environmental resource use at higher incomes, is only seen for the carbon emissions of the mature economies in our sample, and we observe nothing consistent with an actual decline at higher incomes."

Krausmann et al (2017) find examples of absolute resource decoupling, but also explicitly note that these findings are nullified when trade is taken into account. They summarise:

> "Empirical evidence for continuous absolute decoupling is rare. The only countries that have apparently achieved absolute decoupling of their material consumption from economic growth throughout longer phases are a few high-income importing economies such as Japan and the United Kingdom. Once their material consumption and intensity indicators are corrected for international trade, the success in decoupling, however, vanishes." (2017, 661)

Wood et al (2018) is especially interesting, as it is based on the use EXIOBASE3, a global MRIO model compiled explicitly to investigate the role of international trade in relation to resource efficiency. Thus they address the problem mentioned above and by Kraussman et al (2017), that evidence of decoupling on a national level is possibly undermined by the role of trade. Woods et al (2018) calculate both production and consumption based indices for greenhouse gas emissions, energy use, material use, water consumption, and land use for the period of 1995–2011. To quote from their conclusion:

> "On a global scale, achievements in resource efficiency, which are characterized by either absolute or strong relative decoupling from GDP, have been limited. [...] Material use has shown the strongest increase, from 8.3 to 11.3 tonnes/capita (+36%), outstripping growth in GDP. We also see an equal growth of GHG emissions to emissions-relevant energy use, [...]. Land and water resources, which are more directly subject to natural constraints, have increased the least, with blue water consumption rising from 190 to 200 cubic meters/capita, and the total surface area of land used for productive purposes showing a reduction of 0.3

> hectares/capita [...] It is the only indicator that presented (small) absolute decoupling from GDP."

In sum, although the studies on the resource-economy connection by Wood et al (2018), Kraussman et al (2017), Steinberger et al (2013) and Bringezu et al (2004) report evidence of absolute decoupling on national/country level, these examples are in each case explained by specific economic and political factors, rather than by a general trend towards decoupling in the wider economic network the countries take part in. Examples of national level absolute resource decoupling, such as the absolute decoupling between land and blue water use in Sweden reported by Palm et al (2019, 643) are encouraging (but see Ventner et al (2016) for qualifications on results concerning evidence of decreasing land use in wealthy countries). However, the general thrust from studies like Wood et al. (2018) and Krausmann (2017) is that when trade and consumption-based indicators are taken into account the recent (post- 2000) global trend is a *recoupling* of material use and GDP. Notably, none of the reviewed articles presents evidence for global, economy-wide absolute decoupling, either with regard to environmental impacts or resource use.

5. Conclusion

We found that 170 articles presented cases of relative decoupling and 97 articles cased of absolute decoupling. Out of the 97 cases of absolute decoupling, 74 articles concern impact decoupling and 23 concern absolute resource decoupling. Out of these 23 we concentrated on eleven articles that present evidence of economy-wide and at least national level absolute resource decoupling. We found that none of those articles claimed robust evidence of international and continuous absolute resource decoupling, not to speak of sufficiently fast global absolute resource decoupling. This result in no way undermines the importance of the environmentally desirable outcomes, such as national level absolute decoupling between land and blue water use, reported in the articles in the survey. However, it points out that with regard to the goal of ecological sustainability, the empirical evidence on decoupling is thin.

Together the categorisation and the survey of research literature suggest that the (abstract) notion of decoupling needs qualification and precision when used in policy discussions. The notion is (empirically) so weakly founded that we agree with Antal & van den Bergh's (2014, 7) conclusion: "decoupling as a main or single strategy to combine economic and environmental aims should be judged as taking a very large risk with our common future." This also means that more attention should be given to conceptualisations of economy that do not rely on economic growth as the key route towards ecological sustainability and human wellbeing.

The research literature in our review tells of the historical situation up to date, and the evidence does not suggest that decoupling towards ecological sustainability is happening at a global (or even regional) scale. The literature finds evidence of impact decoupling, especially between GHG emissions (such as COX and SOX emissions) in wealthy countries for certain periods of time, but not of economy-wide resource decoupling, least of all on the international and global scale. Quite the opposite: there is evidence of increased material intensity and re-coupling (Schandl et al 2017, Woods et al 2018).

In view of this, it seems that the claim that the economy can grow while at the same time the "environmental bads" diminish needs further support from sources other than empirical research literature. The claim needs to be supported by detailed and concrete plans of structural change that delineate how the future will be different from the past. Otherwise the onus of the claim will rest on the abstract possibility of decoupling; an abstract possibility that no empirical evidence can disprove but that in the absence of robust empirical evidence or detailed and concrete plans rests, in part, on faith.

Funding: This research has been funded by the Kone Foundation and the Strategic Research Council at the Academy of Finland (University of Helsinki 312623/312663).

LITERATURE

Alises, A., Vassallo, J.M., Guzman, A.F., 2014. Road freight transport decoupling: A comparative analysis between the United Kingdom and Spain. Transport Policy. 32(0). https://doi.org/10.1016/j.tranpol.2014.01.013

Antal, M., Van Den Bergh, J.C.J.M. 2014. Green growth and climate change: conceptual and empirical considerations. Climate Policy 16(2), 165-177. http://doi.org/10.1080/14693062.2014.992003

Bithas, K. and Kalimeris, P., 2018. Unmasking Decoupling: Redefining the Resource Intensity of the Economy. Science of The Total Environment. 619–620, 338–51. https://doi.org/10.1016/j.scitotenv.2017.11.061

Bringezu, S., Schutz, H., Steger, S., Baudisch, J. 2004. International comparison of resource use and its relation to economic growth - The development of total material requirement, direct material inputs and hidden flows and the structure of TMR. Ecological Economics. 51(1–2), 97-124. https://doi.org/10.1016/j.ecolecon.2004.04.010

Chontanawat, J., 2019. Driving Forces of Energy-Related CO2 Emissions Based on Expanded IPAT Decomposition Analysis: Evidence from ASEAN and Four Selected Countries. Energies. 12. https://doi.org/10.3390/en12040764

Chovancová, J., Vavrek, R., 2019. Decoupling Analysis of Energy Consumption and Economic Growth of V4 Countries. Problemu ekorozwoju – Problems of sustainable development.14(1), 159-165.

Cobb, C., Halstead, T., and Rowe, J. 1995. The Genuine Progress Indicator: Summary of Data and Methodology. Redefining Progress, Washington DC.

Cohen, G., Jalles, J. T., Loungani, P., Marto, R., & Wang, G., 2018. Decoupling of emissions and GDP: Evidence from aggregate and provincial Chinese data. Energy Economics. https://doi.org/10.1016/j.eneco.2018.03.030

Costanza, R., 1989. What is ecological economics? Ecological Economics. 1, 1–7. https://doi:10.1016/0921-8009(89)90020-7

Costanza, R., Kubiszewski, I., Giovannini, E., H. Lovins, H., McGlade, J., Pickett, K.E., Ragnarsdóttir, K.V., Roberts, D., De Vogli, R., Wilkinson, R., 2014. Development: Time to leave GDP behind. Nature. 505, 283–285.

Daly, H., 2014. From Uneconomic Growth to a Steady-State Economy. Advances in Ecological Economics. Edward Elgar, Cheltenham. https://doi.org/10.4337/9781783479979

Daly, H., 1991. Steady-state economics. Island Press, Washington.

Daly, H. & Cobb, J., 1989. For The Common Good. Beacon Press, Boston, MA.

Fix, B. 2019. Dematerialization Through Services: Evaluating the Evidence. Biophysical Economics and Resource Quality. 4 (6). https://doi.org/10.1007/s41247-019-0054-y

Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge, MA.

Giampietro, M., Saltelli A., 2014.Footprint to nowhere. Ecological Indicators. 46, 610–621.

Gokarakonda, S., Shrestha, S., Caleb, P. R., Rathi, V., Jain, R., Thomas, S., Topp, K., & Niazi, Z., 2018. Decoupling in India's building construction sector: trends, technologies and policies. Building Research & Information, 1–17. https://doi.org/10.1080/09613218.2018.1490054

Heiskanen, E., Jalas, M., 2000. Dematerialization through services.A review and evaluation of the debate. Tech. rep., Finnish Ministry of the Environment, Helsinki.

Hepburn, C., O'Callaghan, B., Stern, N., Stiglitz, J., and Zenghelis, D., 2020. Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? Oxford Smith School of Enterprise and the Environment. Working Paper No. 20-02. (to appear in Oxford Review of Economic Policy 36) https://www.smithschool.ox.ac.uk/publications/wpapers/workingpaper20-02.pdf

Hickel, J., & Kallis, G., 2019. Is Green Growth Possible? New Political Economy. https://doi.org/10.1080/13563467.2019.1598964

IPCC, 2011. Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change- mitigation/

IPCC, 2018. V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) Summary for Policymakers. In: Global warming of 1.5°C. Geneva: World Meteorological Organization 2018. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf

IRP 2017. S. Bringezu, A. Ramaswami, H. Schandl, M. O'Brien, R. Pelton, J. Acquatella, E. Ayuk, A. Chiu, R. Flanegin, J. Fry, S. Giljum, S. Hashimoto, S. Hellweg, K. Hosking, Y. Hu, M. Lenzen, M. Lieber, S. Lutter, A. Miatto, A. Singh Nagpure, M. Obersteiner, L. van Oers, S. Pfister, P. Pichler, A. Russell, L. Spini, H. Tanikawa, E. van der Voet, H. Weisz, J. West, A. Wiijkman, B. Zhu, and R. Zivy. Assessing global resource use: A systems approach to resource efficiency and pollution reduction. Nairobi, Kenya: International Resource Panel, United Nations Environment Programme. http://www.resourcepanel.org/reports/assessing- global-resource-use

Jackson, T., 2009. Prosperity Without Growth. Economics for A Finite Planet. Earthscan, London.

Jackson, T. & Victor, P., 2019. Unraveling the claims for (and against) green growth. Science. 366(6468), 950-951. https://doi.org/10.1126/science.aay0749

Jaligot, R., & Chenal, J., 2018. Decoupling municipal solid waste generation and economic growth in the canton of Vaud, Switzerland. Resources, Conservation and Recycling. 130, 260–266. https://doi.org/10.1016/j.resconrec.2017.12.014

Juknys, R., Liobikiene, G., Dagiliute, R., 2017. Sustainability of Economic Growth and Convergence in Regions of Different Developmental Stages. Sustainable Development. 25(4), 276-287. https://doi.org/10.1002/sd.1652

Kallis, G., Kostakis, V., Lange, S., Muraca, B., Paulson, S., and Schmelzer, M., 2018. Research On Degrowth. Annual Review of Environment and Resources. 43(1), 291-316.

Kerschner, C., & O´Neill, D. W., 2015. Economic Growth and Sustainability. In: Kopnina, H., & Shoreman-Ouimet, E. (eds.). Sustainability. Key Issues. Routledge, London. 243-276.

Kopnina, H., & Shoreman-Ouimet, E., (eds.) 2015. Sustainability. Key Issues. Routledge, London.

Kovacic, Z., Spano, M., Lo Piano, S. and Sorman, A.H. 2017. Finance, energy and the decoupling: an empirical study. Journal of Evolutionary Economics. 28, 565–590. http://doi.org/10.1007/s00191-017-0514-8

Kovanda, J., Hak, T., Janacek, J., 2008. Economy-wide material flow indicators in the Czech Republic: trends, decoupling analysis and uncertainties. International Journal of Environment and Pollution. 35(1). https://doi.org/10.1504/IJEP.2008.021129

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., Haberl H., 2017. Global in-use material stocks in the 20th century. Proceedings of the National Academy of Sciences. 114(8), 1880-1885. https://doi.org/10.1073/pnas.1613773114

Latouche, S. 2009. Farewell to Growth. Polity, Cambridge.

Lenton, T. 2011. Early warning of climate tipping points. Nature Climate Change. 1, 201– 209. https://doi.org/10.1038/nclimate1143

Lenton, T., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., Schellnhuber, H., 2019. Climate tipping points — too risky to bet against. Nature. 575, 592- 595. https://doi.org/10.1038/d41586-019-03595-0

Liang, S. Liu, Z., Crawford-Brown, D., Wang, Y., Xu, M., Decoupling Analysis and Socioeconomic Drivers of Environmental Pressure in China. Environmental Science and Technology. 48(2), 1103-1113. https://doi.org/10.1021/es4042429

Lin, S.J., Rogers, P., Lu, I.J., 2007. Decoupling effects among energy use, economic growth and CO2 emission from the transportation sector. WIT Transactions on Ecology and the Environment. 105. https://doi.org/10.2495/ESUS070231

Lise, W., 2006. Decomposition of CO2 emissions over 1980–2003 in Turkey. Energy Policy, 34(14), 1841–1852. https://doi.org/10.1016/j.enpol.2004.12.021

Magee, C., Devezas, T., 2017. A simple extension of dematerialization theory: Incorporation of technical progress and the rebound effect. Technological Forecasting and Social Change. 117, 196–205, https://doi.org/10.1016/j.techfore.2016.12.001

Moreau, V., & Vuille, F., 2018. Decoupling energy use and economic growth: Counter evidence from structural effects and embodied energy in trade. Applied Energy. 215, 54-62. https://doi.org/10.1016/j.apenergy.2018.01.044

Naqvi, A., Zwickl, K., 2017. Fifty shades of green: Revisiting decoupling by economic sectors and air pollutants. Ecological Economics. 133, 111-126. https://doi.org/10.1016/j.ecolecon.2016.09.017

OECD, 2001. OECD Environmental Strategy for the First decade of the 21st Century. http://www.oecd.org/environment/indicators-modelling-outlooks/1863539.pdf

O'Neill, D.W., Fanning, A.L., Lamb, W.F., & Steinberg, J.K., 2018. A good life for all within planetary boundaries. Nature Sustainability. 1, 88–95. https://doi.org/10.1038/s41893-018-0021-4

O'Neill, D.W., 2012. Measuring progress in the degrowth transition to a steady state economy. Ecological Economics. 84, 221-231. https://doi.org/10.1016/j.ecolecon.2011.05.020

Palm, V., Wood, R., Berglund, M., Dawkins, E., Finnveden, G., Schmidt, S., Steinbach, N., 2019. Environmental pressures from Swedish consumption - A hybrid multi-regional input- output approach. Journal of Cleaner Production. 228, 634-644. https://doi.org/10.1016/j.jclepro.2019.04.181

Parrique T., Barth J., Briens F., C. Kerschner, Kraus-Polk A., Kuokkanen A., Spangenberg J.H., 2019. Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability. European Environmental Bureau. https://eeb.org/library/decoupling-debunked/

Raworth, K., 2012. Safe and Just Space for Humanity: Can We Live Within the Doughnut? Oxfam, Oxford.

Raworth, K. 2017. Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist. Random House, London.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, III, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B.H., Liverman, D., Richardson, K., Crutzen, C., Foley. J.

2009. A safe operating space for humanity. Nature. 461, 472-475. https://doi.org/10.1038/461472a

Sanye-Mengual, E., Secchi, M,; Corrado, S., Beylot, A., Sala, S. 2019. Assessing the decoupling of economic growth from environmental impacts in the European Union: A consumption-based approach. Journal of Cleaner Production. 236(117535). https://doi.org/10.1016/j.jclepro.2019.07.010

Scasny, M., Kovanda, J., Hak, T., 2003. Material flow accounts, balances and derived indicators for the Czech Republic during the 1990s: results and recommendations for methodological improvements. Ecological Economics. 45(1), 41-57. https://doi.org/10.1016/ S0921-8009(02)00260-4

Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N. and Krausmann, F. 2014. The global metabolic transition: Regional patterns and trends of global material flows, 1950– 2010. Global Environmental Change. 26, 87-97. http://doi.org/10.1016/j.gloenvcha.2014.03.013

Schandl, H., Hatfield-Dodd, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M. and Owen, A. 2016. Decoupling Global Environmental Pressure and Economic Growth. Journal of Cleaner Production. 132, 45–56. http://doi.org/10.1016/j.jclepro.2015.06.100

Shao, Q., Schaffartzik, A. Mayer, A. and Krausmann, F. 2017. The high 'price' of dematerialization: A dynamic panel data analysis of material use and economic recession. Journal of Cleaner Production. 167, 120–132. http://doi.org/10.1016/j.jclepro.2017.08.158

Sorrel, S., 2009. Jevons' paradox revisited: the evidence for backfire from improved energy efficiency. Energy Policy. 37, 1456–1469, https://doi.org/10.1016/j.enpol.2008.12.003

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M. & Biggs, R., 2015. Planetary boundaries: guiding human development on a changing planet. Science 347. https://doi.org/10.1126/science.1259855

Steinberger, J.K., Krausmann, F., Getzner, M., Schandl, H., West, J., 2013. Development and Dematerialization: An International Study. PLoS ONE. 8(10), e70385. https://doi.org/10.1371/journal.pone.0070385

Szigeti, C., Toth, G., Szabo, D.R., 2017. Decoupling – shifts in ecological footprint intensity of nations in the last decade. Ecological Indicators. 72, 111–117. http://dx.doi.org/10.1016/j.ecolind.2016.07.034

Szlavik, J., Sebestyen Szep, T., 2017. Delinking of Energy Consumption and Economic Growth in the Visegrad Group. Geographia Technica. 12(2), 139-149. https://doi.org/0.21163/GT_2017.122.12

Tukker, A., Bulavskayaa, T., Giljum, S., de Koning, A., Lutter, S., Simas, M., Stadler, K., Wood, R. 2016. Environmental and resource footprints in a global context: Europe's structural deficit in resource endowments. Global Environmental Change. 40, 171–181. https://doi.org/10.1016/j.gloenvcha.2016.07.002

UNEP, 2011. M. Fischer-Kowalski, M. Swilling, E.U. von Weizsäcker, Y. Ren, Y. Moriguchi, W. Crane, F. Krausmann, N. Eisenmenger, S. Giljum, P. Hennicke, P. Romero Lankao, A. Siriban Manalang, and S. Sewerin. Decoupling natural resource use and environmental impacts from economic growth. A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme. http://resourcepanel.org/reports/decoupling-natural-resource-use-and-environmental-impacts- economic-growth

Vadén, T. , Majava, A. , Toivanen, T. Järvensivu, P. , Hakala, E. , Eronen, J.T., 2019. To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland. Energy Research & Social Science. 58, 1-11. https://doi.org/10.1016/j.erss.2019.101270

van den Bergh J.C., 2017. A third option for climate policy within potential limits to growth. Nature Climate Change. 7(2), 107–12. https://doi.org/10.1038/NCLIMATE3113 van den Bergh, J.C., 2009. The GDP paradox. Journal of Economic Psychology. 30(2), 117- 135. https://doi.org/10.1016/j.joep.2008.12.001.

Van Caneghem, J., Block, C.. Van Hooste, H., and Vandecasteele, C. 2010. Eco-efficiency trends of the Flemish industry: decoupling of environmental impact from economic growth. Journal of Cleaner Production. 18(14), 1349-1357. https://doi.org/10.1016/j.jclepro.2010.05.019

Venter, O., Sanderson, E., Magrach, A. et al. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications. 7(12558). https://doi.org/10.1038/ncomms12558

Victor, P., 2010. Questioning economic growth. Nature. 468, 370–371. https://doi.org/10.1038/468370a

Wang, L., Li, L., Cheng, K., Pan, G., 2019. Comprehensive evaluation of environmental footprints of regional crop production: A case study of Chizhou City, China Ecological Economics. 164(106360). https://doi.org/10.1016/j.ecolecon.2019.106360

Wang, H., Zhao, S., Wei, Y., Yue, Q., Du, T., 2018. Measuring the Decoupling Progress in Developed and Developing Countries. Proceedings of the 8th International Conference on Management and Computer Science (ICMCS 2018). https://doi.org/10.2991/icmcs- 18.2018.77

Wang, H., Hashimoto, S., Yue, Q., Moriguchi, Y., Lu, Z., 2013. Decoupling Analysis of Four Selected Countries: China, Russia, Japan, and the United States during 2000-2007 Journal of Industrial Ecology. 17(4). https://doi.org/10.1111/jiec.12005

Washington, H., & Tomey, P., 2016. A Future Beyond Growth. Towards a Steady-State Economy. Routledge, London.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proceedings of the National Academy of Sciences. 112(20), 6271–6276. https://doi.org/10.1073/pnas.1220362110

Wood, R., Stadler, K., Simas M., Bulavskaya, T., Giljum, S., Lutter, S., and Tukker, A. 2018. Growth in Environmental Footprints and Environmental Impacts Embodied in Trade. Resource Efficiency Indicators from EXIOBASE3. Journal of Industrial Ecology. http://dx.doi.org/10.1111/jiec.12735

Zhang, M., Wang, W.,Decouple indicators on the CO2 emission-economic growth linkage: The Jiangsu Province case. Ecological Indicators. 32, 239-244. https://doi.org/10.1016/j.ecolind.2013.03.033