RESOURCE EFFICIENCY: TRENDS AND THE POTENTIAL OF CIRCULAR ECONOMY

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Abstract
Global resource use is still increasingly leading to far-reaching environmental impacts. Resource efficiency is now recognized worldwide as a environmental goal. While global resource productivity increased until 2000, it has been declining since then. This means that the global economy today needs more resources per unit of GDP than in 2000. A shift from efficient economies to less efficient economies in recent years explains this phenomenon. But how can this trend be stopped? From an national perspective, technological solutions will not be enough. Today efficiency – or rather productivity – is linked to the existing linear production and consumption system. A holistic change of the system is needed, such as structural changes in consumption patterns and a move from linear to circular resource flows. This contribution illuminates the trends, possibilities and potentials of resource efficiency. In order to identify the most efficient approaches for saving resources, possibilities corresponding to the steps of a value chain are discussed.

1. Introduction

An increase in resource efficiency and a reduction in the overall use of natural resources is a key priority to be tackled in future. For global policy, resource efficiency is one of the most important issues, especially since the United Nations adopted the 2030 Agenda for Sustainable Development in 2015, along with a set of 17 Sustainable Development Goals.

Human life requires natural resources. Resources as a holisitic concept includes all natural inputs into our economy to produce products and services. These include the biotic and the abiotic raw materials, the physical space, the environmental media, the flowing resources as well as all living organisms in their diversity. This paper is focused on material resources. The main categories of material resources are often defined as fossil fuels, biomass, metals and non-metals. Next to water and land use, material resource use is the most reported and quantified use, usually measured in tonnes.

Global resource extraction has accelerated, especially in the last 50 years (Steffen et al, 2004). In 2017 global abiotic and biotic material extraction reached an amount of 92 billion tonnes and thus reached “more than three times the amount that was used in 1970” (Bringezu et al. 2017, see also

Lutter, Giljum & Gözet 2018[1]). At the same time, average use is unevenly distributed. European or North-American inhabitants consume five to ten times more resources than inhabitants in India or Africa. Still, resoure use is predicted to increase. The most important reasons for this are population growth, rising living standards and the transformation of developing countries.

Resource extraction leads to far-reaching environmental impacts. Growing extraction combined with inefficient use have led to the fact that planetary limits have already been exceeded in the environmental impact categories of climate change, loss of biosphere integrity, land-system change and biogeochemical cycles (phoshporus and nitrogen; Steffen et al. 2015, Rockström et al. 2009). Next to environmental pollution there are two more problem areas that are closly interconnected - security of supply in the face of scarce resources as well as distribution reliability. Discussion of these problem areas dominates the overall environmental debate and has led to the demand for a more economical and efficient use of natural resources. By reducing consumption, conflicts can be mitigated, reserves extended and environmental impacts reduced. Thus, in order to solve these problems, resource efficiency is now recognized worldwide as a environmental goal. In line with policy objectives, resource efficiency denotes “allowing the economy to create more with less, delivering greater value with less input, using resources in a sustainable way and minimising their impacts on the environment” (COM(2015), Closing the loop - An EU action plan for the Circular Economy). In many countries the term resource efficiency is still undefined or used synonymously with the terms “decoupling” or “sustainable use of resources”. In general, resource efficiency can be defined by means of the following formula:

$$Resource\ efficiency = \frac{Value\ (product, function,\ functional\ unit)}{Expenditure\ (input\ of\ natural\ resources)}$$

Resource productivity, defined as the ratio of gross domestic product (GDP) to domestic material consumption (DMC), is used as an indicator of resource efficiency. When applying this indicator, it must be taken into account that it measures imports only by their own weight. A shift in resource-intensive inputs of upstream chains abroad thus falsely leads to the impression of an increase in productivity.

However, in developing policy strategies, it is important to distinguish between increasing resource efficiency at the business and national level. In the first case, the aim is to save material in the production or manufacturing process through technological improvements, i.e. to provide the same or an equivalent product or service with less use of resources or the use of different resources. Increasing the national efficiency of resources, on the other hand, means achieving the same or a higher added value with less use of resources. The goal must be to achieve an absolute decoupling of resource consumption from economic growth, i.e. an overall reduction in resource consumption.

Thus, from an national perspective, technological solutions are not enough. Productivity is linked to the existing linear production and consumption system. A holistic change of the system is needed, such as structural changes in consumption patterns and a move from linear to circular resource flows. Next to dematerialization (savings, reduction of material and energy use), rematerilization (reuse, remanufacturing and re-cycling) strategies are needed in any move towards a circular economy. In the following, based on current trends in resource efficiency, approaches for increasing resource efficiency are discussed.

2. Trends in Resource efficiency

Global resource consumption expressed in Domestic material consumption (DMC) or Raw material

[1] http://www.materialflows.net/global-trends-of-material-use/

consumption (RMC) is constantly increasing (see Figure 1**Fehler! Verweisquelle konnte nicht gefunden werden.**). Consumption has more than tripled since 1970. Since 2003 there has also been a further significant increase in material resource extraction, mainly due to a strong increase in non-metallic minerals. Minerals play a core role in meeting the demand for ongoing infrastructural improvements in energy, transport and construction work globally. In Asia, in particular, the demand for resources has grown strongly in recent years, e.g. due to the rapid industrialisation of countries such as China (Krausman et al. 2018, Lutter et al. 2018, Schandl et al. 2017). Still, there is a large gap between living standards in North America and Europe and all other world regions. For example, the DMC in the European Union (EU-28) in 2015 was 13.8 tonnes per capita, whereas in Africa the DMC reached 4.8 tonnes per capita (Lutter et al. 2018). However, resource productivity in the European Union is constantly increasing, measured by the DMC in relation to GDP (Eurostat 2018, Figure 2). Moreover, some countries with a lower Human development Index (HDI) also show higher productivity (Schandl et al. 2017). Nevertheless, globally a decline in resource efficiency has been evident since 2000. This means that the global economy today needs more resources per unit of GDP than in 2000. Schandl et al. (2017) show a correlation between the decline in resource efficiency and a shift from efficient economies to less efficient economies in recent years in explaining this phenomenon.

As mentioned above, by using the DMC as an indicator, resource-intensive inputs from upstream chains are not taken into account. Thus, as Wiedmann et al. (2015) note "with some countries increasingly supplying primary resources for industrial development in other countries, means the burden of raw material extraction is shifting. The DMC shifts with it, as reflected in increasing DMC values for exporting countries, mostly developing countries." In contrast to the DMC, the RMC or "Material Footprint" (MF) takes into account the inputs of the upstream chains according to the real use or point of consumption. Therefore, the RMC or MF should be used as a complementary indicator to the DMC to identify shifts due to trade, as called for by the UN in its Sustainable Development Goal 12, subgoal 12.2. The German Resource Efficiency Programme II (Progress II[2]), for example, is already implementing this request. In addition to the RMC indicator, the German Resource Efficiency Programme II also includes the RMI (Raw Material Input) indicator, which includes expenditure on exports.

A recently published study by Dittrich et al. (2018) examined the future development of these two indicators and the related resource efficiency and resource productivity for Germany. In two scenarios it is shown that already in one trend scenario a considerable decline in the macroeconomic primary raw material consumption is to be expected. Significant here is the switch to renewable energies, but efficiency efforts through material substitution, more efficient use of raw materials or recycling (especially in the case of minerals) also have a major impact. Nevertheless, as in the second scenario, which contains technically ambitious but feasible changes, a further increase in resource productivity can be derived. Based on such trends, the political objective in Germany to increase resource efficiency by 1.3% per year by 2030 will not only be achieved, but exceeded, reaching approximately 1.8% per year. According to Dittrich et al. (2018), the RMC will reach 950 to 1,097 Mio. tonnes in 2030, which is approximately 12 to 14 tonnes per capita (for comparison, in 2014 the RMC per capita was 16 tonnes according to DESTATIS 2018).

Wiedmann et al. (2015) conclude from the existing data that the RMC per capita or MF in the industrialized countries will remain between 20 and 30 tonnes per capita and year. However, these data is well above the threshold of 5 to 8 tonnes that should be achieved for sustainable development (Bringezu 2009, Lettenmeier, Liedtke & Rohn 2014). In addition, the RMC of developing countries will continue to rise with rising living standards.

Schandl et al. (2017) conclude "that additional effort in public policy and financing and changes in

[2]https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/progress_ii_broschuere_bf.pdf

investment toward green sectors are required to improve material use efficiency substantially in the coming decades and to make space for development in low-income regions of the world”. If no changes are achieved through policy strategies, there will be a further severe increase in resource consumption by 2050, with the associated environmental impacts. Next to a global solution, results of a comprehensive modelling process which, in separate scenarios, illustrate a global solution, a European solo effort utilizing predominantly market-based instruments and the effects of committed behaviour on the part of civil society in the European Union (EU) show that the EU can make a considerable contribution to sustainable development on its own (Meyer, Distelkamp & Beringer 2015).

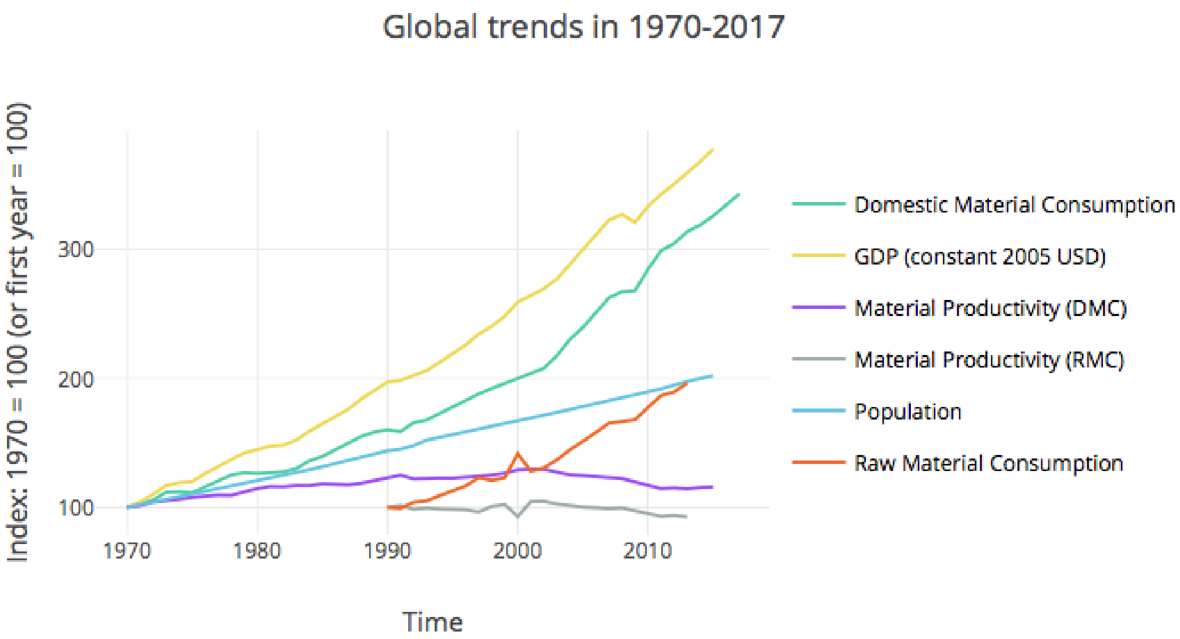

Figure 1: Global trends (Lutter, S., Giljum, S., Gözet, B. 2018; Vienna University of Economics and Business (WU Vienna) – Institute for Ecological Economics, http://www.materialflows.net/decoupling-material-use-and-economic-performance/)

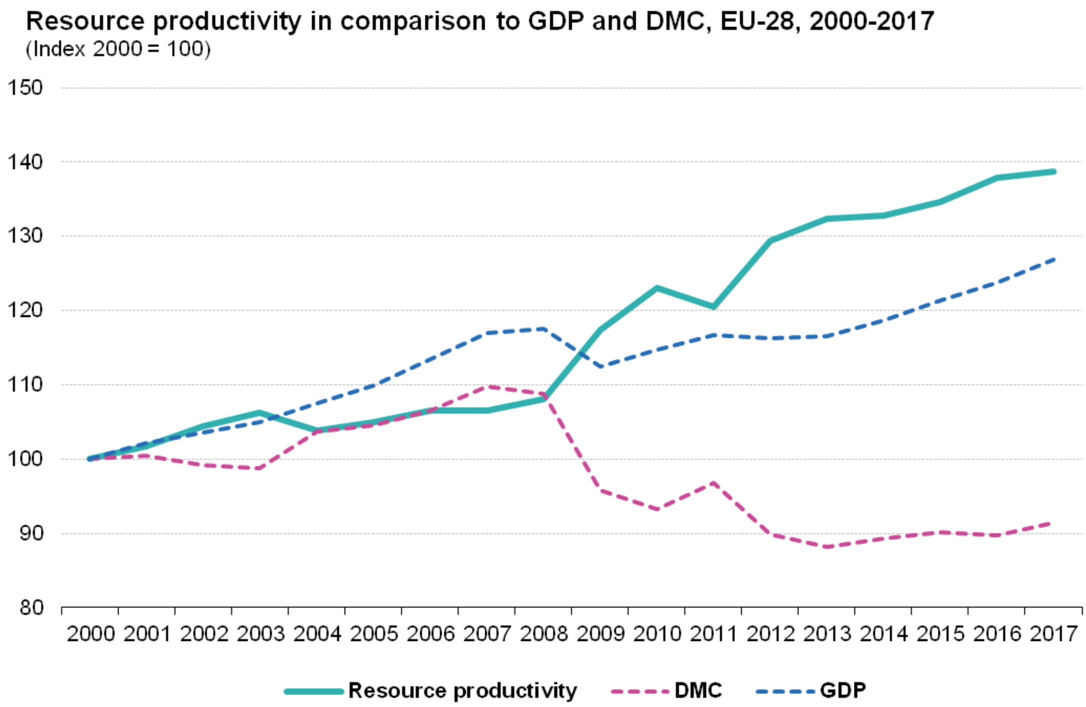

Figure 2: Resource productivity, GDP and DMC of EU-28 from 2000 to 2017 (Eurostat 2018).

3. Influencing factors for increasing resource efficiency

A comprehensive strategy for increasing resource efficiency should be to implement a circular economy that is as complete as possible. For this purpose, a reduced amount of resources should be moved between use and treatment/recovery stages with the least possible losses. In the following, the boundary conditions and potentials for an increase in efficiency along the value chain is examined, according to Faulstich et al. (2013). The extraction of raw materials is followed by the production of basic materials from which goods and services are produced. The user behaviour and the demand has a decisive influence on the type and scope of production and thus also on the upstream and downstream stages of the chain. Waste or no longer required goods are "disposed of".

Resource extraction

In principle, it is possible to increase efficiency in the extraction of raw materials. However, it can be assumed that the concentrations of useful materials will decrease, contamination will increase, larger quantities of overburden will have to be removed or the raw materials will have to be mined from ever greater depths underground. This will further increase the effort of extraction. The efficiency, especially of abiotic resources, will continue to decline, above all in terms of total material requirement. Due to the unchangeable boundary conditions, resource efficiency can best be improved by mining or cultivating fewer raw materials.

Production of primary material

With regard to the production of primary materials in relation to abiotic resources, resource efficiency depends mainly on technical innovations. Through continuous improvements of processes and procedures, a continuous reduction in the specific effort is normally achieved. However, there are natural limits to the use of materials in stoichiometry with respect to both the relevant reaction equations and the thermodynamic equilibriums. In a technically optimized production process, only incremental improvements close to these limits are possible. Noticeable increases in efficiency could therefore only be achieved by substituting other materials.

Production of Goods

There is great potential for increasing material efficiency in the manufacture of goods. At this stage of the value chain, not only incremental improvements and optimizations but also efficiency "leaps" can be achieved. Initially, material efficiency can be increased by optimizing the design or construction of products or by optimizing production processes (reduction of waste, in-house recycling). Where possible, fewer scarce, environmentally unproblematic or renewable resources should be used as materials. However, radical improvements are to be expected, in particular, through innovations that lead to a new design of products and processes and provide certain functionalities of products in a way that requires fewer resources. In addition, by focusing on the value of the products which can also be achieved, for example, through services coupled with new business models, improvements can be achieved. But even the concentration on exclusively technological innovations can already lead to a considerable increase in productivity, as Diettrich et al. 2018 showed.

Many such measures go hand in hand with cost savings for producers and thus improve the competitiveness of manufacturers. Resource efficiency in the production process must therefore be a central and fundamental component of efficiency strategies and must hence inform the promotional measures of federal national support.

Use of Goods

Not only are efforts aimed at the production of raw materials and goods crucial to realizing a resource-light society. In order to secure prosperity with low resource consumption, there must be a shift away from the consumption of resource-intensive goods and services towards resource-light patterns of use. Today, depending on individual lifestyle, it is primarily activity in the areas of housing, nutrition, mobility and holiday travel that dominates the consumption of resources by private households in industrialised countries (Greiff et al. 2017, Buhl et al. 2017). Reversing well-established trends represents a major challenge for politics and society. For this, next to efficiency, sustainability strategies incorporating conceptions of consistency and sufficiency will play key roles.

According to the sustainability strategies “Efficiency, Concictency and Sufficiency” the following aspects must be kept in mind considering the use of goods.

Efficiency:
- Increasing the intensity of use of products through leasing systems
- Extension of service life with regard to technical and design aspects

Consistency:
- Leasing turns the repair and recyclability of products into valuable product features
- Use of renewable energies
- Use of recycable products
- Reuse and Repair of prodructs

Sufficiency
- Shift in demand patterns towards consumption of less material-intensive goods or services, e.g. shifting demand from resource-intensive categories such as food, transport and clothing towards health and education can improve environmental impact by a factor of 2 (Tukker et al. 2006)
- Supporting life satisfaction decoupled from resource consumption
- Development of products and services with transformative design

In principle, measures are necessary to limit the so-called rebound effect within certain limits. This effect describes the fact that percentage savings are achieved in the system through an increase in total production or through increased consumption. These savings can be partially or completely compensated for elsewhere and therefore not be reflected in declining absolute consumption. Positive effects through savings at the stage of production of goods or due to changes in consumer behaviour can be reduced or cancelled by the rebound effect. Without countermeasures, efficiency gains can lead to an overall increase in resource consumption.

End-of-Life Management
The disposal system deals with the long-term retention of materials in the system after their use. However, there is a clear demarcation of the emissions into different environmental compartments, which are to be regarded as a material levy, because the deposited substances are in principle available for recovery. Although the absolute effort may initially be higher compared to the extraction of raw materials for low-concentration and possibly contaminated waste, it can be assumed that the specific effort will decrease. On the one hand, conditions are constantly improving as a result of efficiency increases in processing technology. On the other hand, the elimination of environmentally problematic substances from the goods produced, as called for in the concept for a substance-related environmental policy, also contributes in the long term to an increase in efficiency.

The recovery of materials from the anthropogenic system - from the in-use stocks - is an essential aspect of end-of-life treatment. Krausmann et al. (2018) show that the sociometabolic metabolism “has changed from a throughput system in which materials are used shortly after extraction to a system in which materials accumulate in stocks”. These in-use stocks mainly consist of non-metallic minerals, at 95%, while metals only amount to a mere 3.3%. Furthermore, these results show that a return of the resource to the environment takes place with a large time lag. Krausmann et al. (2018)

show "while in 1900 wastes and emissions still amounted to 94% of all inflows, this share went down to only 65% in 2015". Since the significant increase in resource extraction since 2003, absolute domestic processed output (DPO) has also increased significantly. Thus, a total of 28% of all waste streams since 1900 were generated between 2002 and 2015 alone. These results also lead to the conclusion that an absolute reduction in the use of resources is necessary in order to be able to comply with the planetary limits in the long term. A key factor here is the establishment of a circular economy. For the waste management industry this means that in addition to avoiding outputs and wastes through reuse, re-engineering and ultimately recycling, the use of materials from existing landfills should also be focused on.

4. Conclusions

After many years of urgent reference to the issue of resource use and following comprehensive investigations by science and environmental organisations into both this question as well as into the question of energy and raw material supply, this issue has finally been taken up for discussion in politics, industry, science and society at large. A large number of countries have introduced targets to increase resource productivity. For example, in Europe resource efficiency was a key element in the development of the "EUROPE 2020" strategy (European Commission 2010). The "Roadmap to a resource efficient Europe" sets out how the European economy is to be transformed into a sustainable economy (European Commission 2011). In addition to these strategies, achieving the sustainable development goals (SDGs) will be based on an efficient use and management of resources.

As several publications show, resource efficiency can be achieved by means of a wide range of strategies. Because of the tendency towards increasing quantities of overburden and the purpose of primary raw material supply, the mining of raw materials offers hardly any approaches for a noticeable reduction in the material input. Efficiency enhancements in the production of raw materials are close to stoichiometric or thermodynamic limitations. Due to largely optimized processes in a highly developed society, these improvements will be limited. Considerable potential, on the other hand, can be tapped by leaps in efficiency in the fields of goods and services or by targeted changes in consumption and demand patterns.

To the extent that such instruments take effect and bring about tangible changes, the vision of a genuine circular economy, in which the majority of material movements take place between the production of raw materials and the production of goods, also becomes more tangible. The integration of waste management into a comprehensive resource policy is therefore indispensable. The reversal of material flows from landfill into the production of raw materials and goods could make its contribution in this way and supplement the conventional mining of raw materials. To achieve this, the link between waste management and resource efficiency policies must be intensified. If the energy required for recovery processes were to be provided from renewable sources, a far-reaching convergence towards sustainability would have been achieved in terms of resource use.

5. Literature

Bringezu, Stefan, Anu Ramaswani, Heinz Schandl, Meghan O'Brien, Rylie Pelton, et al. „ASSESSING GLOBAL RESOURCE USE. A Systems Approach to Resource Efficiency and Pollution Reduction." United Nations Environment Programme, 2017. URL: http://www.resourcepanel.org/sites/default/files/documents/document/media/assessing_global_resource_use_amended_130318.pdf. (last request Sept 2018)

Bringezu, Stefan. „Visions of a sustainable resource use“. In Sustainable Resource Management: global trends, visions and policies. Sheffield, UK, 2009. http://www.greenleaf-publishing.com/productdetail.kmod?productid=3467.
Buhl, Johannes, Christa Liedtke, und Katrin Bienge. „How Much Environment Do Humans Need? Evidence from an Integrated Online User Application Linking Natural Resource Use and Subjective Well-Being in Germany“. Resources 6, Nr. 4 (2017): 67. https://doi.org/10.3390/resources6040067.
European Commission (2010). EUROPE 2020. In: A Strategy for Smart, Sustainable and Inclusive Growth, (Brussels).
European Commission (2011): A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. 2011. COM(2011) 21, Brussels.
European Commission (2015): Closing the loop - An EU action plan for the Circular Economy. COM (2015) 614. Brussels.
EUROSTAT (2018): Resource productivity statistics. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php/Resource_productivity_statistics#Resource_productivity_of_the_EU-28_and_across_Member_States_over_time (last request Sept 2018)
Dittrich, M., Kämper, C., Ludmann, S., Ewers, B., Giegrich, J., Sartorius, C., Hummen, T., Marscheider-Weisemann, F., Schoer, K. (2018): Strukturelle und produktionstechnische Determinanten der Ressourceneffizienz: Untersuchung von Pfadabhängigkeiten, strukturellen Effekten und technischen Potenzialen auf die zukünftige Entwicklung der Rohstoffproduktivität (DeteRess). UBA Texte 29/2918. Umweltbundesamt: Dessau. URL: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2018-04-11_texte_29-2018_deteress.pdf (last request Sept 2018).
Faulstich, M., Kögelmeier, M., Leipprand, A., Mocker, M. (2013): Strategies for increased Resource Efficiency. In: Angrick, M., Burger, A., Lehmann, H. (Editors) (2013): Factor X: Re-source-Designing the Recycling Society. Springer: Heidelberg.
Greiff, K., Teubler, J., Baedeker, C. Liedtke, C., Rohn, H. (2017): Material and Carbon Footprint of household activities. In Keyson, D. V., Guerra-Santin, O., Lockton, D. (Eds.): Living Labs. Design and Assessment of Sustainable Living. Springe, Heidelberg.
Krausmann, Fridolin, Christian Lauk, Willi Haas, und Dominik Wiedenhofer. „From resource extraction to outflows of wastes and emissions (2018): The socioeconomic metabolism of the global economy, 1900–2015“. Global Environmental Change 52 (2018): 131–40. https://doi.org/10.1016/j.gloenvcha.2018.07.003.
Lettenmeier, Michael, Christa Liedtke, und Holger Rohn (2014). „Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland“. Resources 3, Nr. 3 (2014): 488–515. https://doi.org/10.3390/resources3030488.
Lutter, Stephan, Stefan Giljum, und Burcu Gözet (2018): The Materialflow Analysis Portal. Data Visualisation Centre. Vienna University of Economics and Business (WU Vienna) – Institute for Ecological Economics, Vienna. http://www.materialflows.net/visualisation-centre/. (last request: Sept 2018)
Meyer, B., Distelkamp, M., Beringer, T. (2015): Report about integrated scenario interpretation.
Deliverable 3.7a of the POLFREE project. www.polfree.eu
Rockstrom, Johan, Will Steffen, Kevin Noone, Asa Persson, F. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton, u. a. (2009): „A safe operating space for humanity“. Nature 461, Nr. 7263 (2009): 472–75. https://doi.org/10.1038/461472a.
Schandl, Heinz, Marina Fischer-Kowalski, James West, Stefan Giljum, Monika Dittrich, Nina Eisenmenger, Arne Geschke, u. a. (2ß17): „Global Material Flows and Resource Productivity: Forty Years of Evidence“. Journal of Industrial Ecology 22, Nr. 4 (2017) 827–38. https://doi.org/10.1111/jiec.12626.
W. Steffen, A. Sanderson, P.D. Tyson, J. Jäger, P.A. Matson, B. Moore III, F. Oldfield, K. Richardson, H.J. Schellnhuber, B.L. Turner, R.J. Wasson (2004): Global Change and the Earth System: A Planet Under Pressure” (2004), published by Springer-Verlag, Berlin Heidelberg New York. ISBN 3-540-40800-2
Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E. Cornell, Ingo Fetzer, Elena M. Bennett, Reinette Biggs, u. a.(2015): „Planetary boundaries: Guiding human development on a changing planet“. Science 347, Nr. 6223 (2015). https://doi.org/10.1126/science.1259855.
Tukker, Arnold, und Bart Jansen (2006): „Environmental Impacts of Products: A Detailed Review of Studies“. Journal of Industrial Ecology 10, Nr. 3 (2006): 159–82. https://doi.org/10.1162/jiec.2006.10.3.159.
Wiedmann, Thomas O., Heinz Schandl, Manfred Lenzen, Daniel Moran, Sangwon Suh, James West, und Keiichiro Kanemoto (2015): „The material footprint of nations“. Proceedings of the National Academy of Sciences 112, Nr. 20 (19. Mai 2015): 6271. https://doi.org/10.1073/pnas.1220362110.