IntRESS exploring options for global resource use

Developing targets for global material use

Working paper

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Contents

List of figures

Abbreviations

DMC	Domestic Material Consumption
DMC_{abiot}	Domestic Abiotic Material Consumption
DMI	Domestioc Material Input
DG Environment	Directorate-General for the Environment
EMC	Environmentally Weighted Material Consumption
EU	European Union
EUROSTAT	Statistical Office of the European Union
EW-MFA	Economy-wide Material Flow Analysis
GDP	Gross Domestic Product
GHG	Green House Gases
$GLU_{cropland}$	Global Cropland Land-Use
GWP	Global Warming Potential
HANPP	Human Appropriation of Net Primary Production
LCA	Life Cycle Assessment
MFA	Material Flow Accounting (and Analysis)
OECD	Organization for Economic Cooperation and Development
TMC	Total Material Consumption
TMC_{abiot}	Total Abiotic Material Consumption
TMR	Total Material Requirement
UBA	German Federal Environment Agency
UNEP	United Nations Environment Programme

1 Introduction

Increasing resource efficiency as a means to achieve an overall decoupling of resource use and the environmental, but also social and economic impacts of resource use from economic growth and higher well-being has reached the highest levels of European as well as global socio-economic and environmental policy agendas. In its “Roadmap to a resource-efficient Europe” (European Commission, 2011) the European Commission calls not only for a measurement of resource use and an increase in resource efficiency, but also identifies the need for target setting as a means to evaluate progress towards the overarching policy goals.

The IntRESS project initiated by the German Federal Environment Agency (UBA) and funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety develops new insights, options and recommendations for international sustainable resource use policies through engaging the scientific community and relevant stakeholders. This should further strengthen the profile of resource efficiency and sustainable resource use issues on the European and international policy agenda.

The project will discuss and develop science-based suggestions for international targets on sustainable resource use and focuses on the following key questions: How can one derive internationally accepted, qualitative and quantitative 2050-targets for sustainable resource use in the categories raw materials, water, and land use? How can scientific insights on planetary boundaries and social and economic concerns best be taken into account in such targets? What types of indicators could be most suitable to measure progress towards potential 2050-targets for sustainable resource use?

Regardless of the growing consciousness and scientific knowledge about the necessity of fostering resource efficient production technologies and resource-saving consumption patterns, the extraction of raw material is steadily increasing. Binding policy measures defining clear thresholds are still missing for most material categories. In this paper a comprehensive approach for deriving targets on sustainable material use will be developed. The suggested approach was presented to and discussed by an expert panel in a workshop held in Berlin in January 2015. The authors want to thank Raimund Bleischwitz, Maria Amélia Enríquez, Aldo Femia, Michael Golde, Andreas Hauser, Pawel Kazmierczyk, Jan Kosmol, Fridolin Krausmann, Michael Lettenmeier, Alexa Lutzenberger, Christopher Manstein und Anke Schaffartzik for their valuable contributions.

In IntRESS working paper 2.1, „Perspectives and Assumptions for setting resource targets“ and working paper 2.2. “Towards a scientific framework for resource targets revisited”, a general framework was developed to be applied to all resource categories concerned for the derivation of resource targets: materials, water and land. The framework builds upon Rockström's concept of "planetary boundaries" (Chapter 2) while suggesting further differentiations of the boundaries which are considered to be of special importance for the derivation of resource targets. The latter are subject to Chapter 3. In chapter 4 of this paper, we suggest a comprehensive approach towards setting resource targets on materials. The annex to this paper summarizes the concepts and indicators that are considered feasible for the derivation of resource targets.

Primary material resources can be disaggregated into four resource categories, following the EUROSTAT (2013) definition:

1. Biomass
2. Metal ores
3. Non-metallic minerals
4. Fossil energy materials/carriers

This disaggregation will be the point of departure for the development of resource targets on materials. Material Flow Analysis and Accounting (MFA) provides the framework for measuring abiotic and biotic material flows. Since the extraction of biotic resources is directly linked to land coverage and land conversion, a strong interaction with the category of land will have to be kept in mind when deriving targets on land use.

The following box comprises the most important indicators used in the discussion on material use.

Domestic Material Consumption (DMC): measures all materials used within an economic system, *excluding indirect flows*. DMC is calculated by subtracting direct exports from DMI.

Domestic Material Input (DMI): comprises all materials with economic value which are directly used in production and consumption activities. DMI equals the sum of domestic extraction and direct imports.

materials / material resources: comprises biotic materials/biomass (from agriculture, forestry, fishery and hunting as well as biomass products) and abiotic material resources (metal ores and metal products; non-metallic minerals and mineral products; fossil energy materials/carriers used for energetic and non-energetic purposes) that are used in production processes or for energy production.

(natural) resources: Natural assets (raw materials) that can be used for (economic) production or consumption. Includes materials, water and land.

Raw Material Consumption (RMC): next to domestic extraction, the RMC indicator comprises imports expressed or converted into their raw material equivalents (RME), i.e. into equivalents of domestic extractions that have been induced in the rest of the world to produce the respective good. RMC is calculated by subtracting the RME of exports from RMI.

Raw Material Input (RMI): adds the used part of the raw material equivalents (RME) of imports to DMI.

Total Material Consumption (TMC): next to RMC, TMC includes also the unused extraction related to RMEs of both imports and exports**.** TMC equals TMR minus exports and their "hidden" flows.

Total Material Requirement (TMR): adds to RMI the unused domestic extraction (UDE) and the unused extraction related to the RMEs of imports. TMR is thus the most comprehensive material input indicator, comprising all input flows.

Unused extraction: refers to the materials that are extracted from the environment without the intention of using them. It comprises soil and rock excavation during constructions, the overburden from mining and quarrying, unused parts of felling in forestry, unused by-catch in fishery, unused parts of the straw harvest in agriculture or natural gas flared or vented.

Box 1: Definition of key terms and terminological usage (alphabetical order), based on EUROSTAT 2001 and 2013.

2 Rockström's concept and challenges for deriving thresholds on materials

Threshold-related concepts and indicators have been developed to measure the extraction and consumption of biotic resources, such as the Ecological Footprint (cf. Rees/Wackernagel 1994), the Human Appropriation of Net Primary Production/HANPP indicator (cf. Haberl 1997), the Water Footprint or Water Exploitation Index (WEI). The establishment of politically justifiable thresholds for the use of abiotic materials is still a challenging task. So far, only in the case of greenhouse gas emissions a clear global threshold of a maximum of 2°C temperature increase has been identified and translated into a maximum "allowance" of GHG emissions at the country level.

The idea of limiting material resource use arose already at the very beginning of the scientific discussion on sustainable resource use (cf. Schmidt-Bleek 1992). Primary energy and its sustainable utilization are targeted by the scientific community since more than 20 years. However, our analysis (see the results of work package 1 of the IntRESS project) shows that very little has so far been published in scientific literature that actually provides evidence-based concepts to derive targets for a sustainable material use. Different concepts such as Factor 4, Factor 5 (von Weizsäcker 1995, 2010) or Factor 10 (Schmidt-Bleek 1992, 2014) address a reduced extraction of raw materials. Although there is an ongoing discussion on these concepts, their derivation is still a major challange. Schmidt-Bleek derived his reduction goal based on the precautionary principle and finds that global environmental pressure can be measured by global material extraction and needs to be reduced in order not to transgress planetary boundaries. Taking into account the argument of equity and "fair share", all countries with a consumption level per capita above global average have to reduce their consumption up to a factor 10 or 90% (Schmidt-Bleek 1992).

The publication of Rockström and his colleagues (2009) is the most widely discussed recent work linking the environmental impacts of resource use to global thresholds, suggesting planetary boundaries to those Earth system processes where scientific evidence allows to.

2.1 Rockström's concept of "planetary boundaries"

In 2009, Johan Rockström and colleagues proposed a framework of "planetary boundaries" developed to define a "safe operating space for humanity", in which human activity must stay in order to sustain the Earth's life-supporting systems and thus enable sustainable development of societies (Röckström et al. 2009). The planetary boundaries define a 'safe' global level for three consequences of human interference into nature: (i) for the depletion of non-renewable fossil resources, (ii) the use of the living biosphere, including the exploitation of ecosystems (input perspective), protection of diversity and consumption of renewable resources, as well as (iii) the Earth's capacity to absorb waste, including carbon, nitrogen, phosphorus and chemicals (output perspective). Rockström et al. determined nine Earth system processes that are of crucial importance to prevent unacceptable environmental change on a global scale: climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, biogeochemical flows of phosphorus and nitrogen, global freshwater use, land-system change, biodiversity loss and chemical pollution.

For some of the boundaries, specific threshold values were established, namely for climate change, stratospheric ozone depletion, and global freshwater use. For others, thresholds are likely or very likely (ocean acidification, biogeochemical flows of P and interference with P cycles, land-system change, rate of biodiversity loss) whereas different probabilities at different scales exist. For atmospheric aerosol loading, global N cycles and chemical pollution there is no knowledge on the existence of threshold behaviour on a global level after all. On the other hand, the Earth system processes of climate change, biodiversity loss and the influx of nitrogen due to anthropogenic activity have already passed the acceptable limit within a safe operating space, seriously affecting ecological sub-systems and societies (ibid.).

As described in the IntRESS working paper 2.1. "Perspectives and assumptions for setting resource targets", two main entry points for the discussion on resource targets can be identified with regard to environmental perspectives: the input side, i.e. the environmental impacts of resource extraction, and the output side considering the limited absorption capacities of global ecosystems for waste and emissions arising from natural resource use. Material Flow Accountings (MFAs) ideally look at both material input and output as far as the system functioning of non-renewable resources is concerned. Rockström et al. also take on both an input and an output perspective on the issue of setting global thresholds on resource use. Nevertheless, they rather focus on the scale of human action in general in relation to the Earth's biocapacity, similar to the

Ecological Footprint. They aim at an essential understanding of large-scale Earth system processes and the role of thresholds, within the framework of social-ecological resilience at regional to global scales (ibid.).

For the resource categories land and water, Rockström et al. propose two planetary boundaries that target at the use of the resource itself (global freshwater use and change in land use).

Planetary Boundary (Rockström et al.)	**Drivers and/or pressures of material use**	**Control variable (Rockström et al.)**	**Threshold behaviour and proposed value (Rockström et al.)**
Climate change	GHG emissions (due to combustion of fossil energy carriers/material)	Atmospheric CO_2 concentration, ppm; Energy imbalance at Earth's surface, W m^{-2}	*Multiple sub-system thresholds* Atmospheric CO_2 concentration: <350 ppm (range 350-550 ppm); Energy imbalances: +1 W m^{-2} (+1.0 W m^{-2}-+1.5 W m^{-2})
Stratospheric ozone depletion (extra-polar)	Emissions of ozone-depleting substances (such as CFCs, halons, etc.)	Stratospheric O_3 concentration in the atmosphere, on a regional basis	*Threshold well established* <5% reduction from pre-industrial level of 290 DU (range 5%-10%)
Ocean acidification	GHG emissions	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite (Ω_{arag})	*Threshold likely* Sustain ≥80% of the pre-industrial aragonite saturation state of mean surface ocean, including natural diel and seasonal variability (range ≥80%-≥70%)
Biogeochemical flows; inference with P and N cycles	Phosphor influx due to agricultural activities; Biomass extraction	P: inflow of phosphorous to ocean, (increase compared to natural background weathering) N: amount of N_2 removed from atmosphere for human use, Mt N yr^{-1}	*High probability of threshold* P: <10x (10x-100x) *Global threshold behaviour unknown* N: limit industrial and agricultural fixation of N_2 to 35 Mt N yr-1, which is ~25% of the total amount of N_2 fixed per annum naturally by terrestrial ecosystems (range 25%-35%)
Rate of biodiversity loss	GHG emissions; Biomass extraction; Land use; Nitrogen deposition	Extinction rate, extinctions per million species per year (E/MSY)	*Thresholds likely at local and regional scales* <10 E/MSY (10-100 E/MSY)
Chemical pollution	Emissions of chemical substances, due to extraction and processing of abiotic materials	Emissions or concentrations of persistent organic pollutants, plastics, endocrine disruptors, heavy metals, and nuclear wastes.	*Large-scale thresholds unknown* *Threshold value to be determined*

Atmospheric aerosol loading	Emissions of aerosols, due to burning of fossil materials and biomass	Overall particulate concentration in the atmosphere, on a regional basis	*Global threshold behaviour unknown*

Table 1: Relation between material use and Rockström et al.'s planetary boundaries.

All the seven remaining planetary boundaries are linked to material extraction and use. Rockström et al. do not explicitly draw a connection between material use and environmental impacts. In Table 1 the relation between Rockström et al.'s planetary boundaries and material use is described. We find that materials use is primarily concerned as pressures in terms of GHG emissions, chemical pollution, aerosols and ozone-depleting emissions, driven by the burning of fossil energy materials and biomass, during the processing of abiotic materials or the use of products of fossil origin.

Looking at the boundaries defined by Rockström et al., the scientific evidence for a global threshold behavior is quite different. For three major physical circulation systems of the planet – climate, stratosphere and ocean systems – global scale thresholds are established or, in the case of ocean acidification, at least very likely. At the same time, the system processes of climate change, loss of biodiversity and the anthropogenic nitrogen influx have already exceeded the acceptable limit of a safe operating space and serious negative impacts on ecological subsystems can already be observed at least at regional levels.

For the congestion of the global biochemical cycles of nitrogen and phosphorus it is known that agricultural activities are the main drivers, e.g. through the excessive use of phosphate-based fertilizers, pesticides and excessive livestock farming, thus fossil energy materials are indirectly concerned. Also unsustainable rates of biomass extraction (e.g. forest harvesting for commercial reasons or conversion into cropland) further trigger the excess of this planetary boundary.

Burning fossil energy carriers as well as biomass (coal, dung, forests, crop waste, etc) produce aerosols (soot, sulphates and other particles). The global concentration of the atmospheric aerosol loading has doubled since pre-industrial times. However, impacts are highly variable. Some aerosols cause cooling, reflecting radiative forcing (like sulphates), while others are known to cause global warming (black carbon etc). Since the global balance of these heating and cooling effects are still unclear, the threshold behaviour for this potential planetary boundary has not been defined by Rockström and his colleagues. (Pearce 2010)

2.2 Challenges and obstacles to target derivation on materials use

One challenge for deriving resource targets on material resources based on Rockström et al's concept lies within the great heterogeneity of this resource category, comprising both renewable and non-renewable resources and very different material compositions. As Rockström and colleagues have noted themselves (EEAC/BMU 2014), another main challenge is the fact that many environmental impacts have not yet been scientifically evaluated and quantified in a sufficient way in order to formulate evidence-based targets or threshold values. To date, only few international agreements exist. For fossil energy materials impact assessments are internationally recognized and counter-measures to reduce those negative impacts initiated.[1]

The obvious impacts related to materials are the emissions produced in the use phase (of the final product). For materials applied in a product, impacts are related to the product and not the material resource itself anymore (cf. Schmidt-Bleek 1992; UNEP 2013). Apart from fossil energy materials, there is still a knowledge gap on the environmental impacts of extraction, processing of all other materials and especially those attributed to the final use phase (i.e. concerning ecotoxicity but also human health risks). As described above, for some planetary boundaries the question if there is threshold behaviour on global or regional level after all cannot be answered yet. Another epistemological challenge is the yet unknown dimension of the interaction between the nine planetary boundaries (Rockström e al. 2009).

3 Criteria for deriving resource targets on materials

3.1 Beyond Rockström

Referring to the concept of planetary boundaries for target derivation on materials implies the difficulty of "translating" the boundaries into thresholds for materials use. In the case of global climate change, Rockström et al. propose using atmospheric CO_2 concentration and radiative forcing as control variables, limiting CO_2 emissions to 350 parts per million (ppm) and radiative forcing at 1 Watt per square meter (W/m^2) (with a current level of 1.6 W/m^2). CO_2 concentration serves as a proxy for radiative forcing[2]. Both thresholds represent very restrictive boundaries. Given that in 2007 CO_2 concentration level were at 387ppm, this would require removing CO_2 from the atmosphere.

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[1] The Kyoto Protocol sets the threshold of total global temperature increase by 2°C above pre-

[2] Radiative forcing is mainly triggered by CO_2 emissions as well as methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) 12 and 11, and 15 other minor halogenated gases. (ibid.)

(Umpfenbach/Tan 2013) Derived from a precautionary principle, they provide a high probability that the 2°C guardrail can be respected and risks of non-linear, abrupt and irreversible Earth system responses related to other thresholds minimized. (Rockström et al., 2009)

Apart from the climate change boundary, the definition of limits and proxy indicators for all other planetary boundaries is more complex, mainly due to incomplete information on the interrelation of different environmental pressures on a global level.

A commonly accepted framework for the implementation of targets and thresholds for material resource use[3] would have to take various aspects into account that are not directly addressed by Rockström et al's concept of the safe operating space. The political discussion and scientific literature on resource use and environmental impacts comprises further reference points for the quantitative and qualitative refinement of planetary boundaries. Data can be drawn from the different MFA- and environmental accounting methods in order to allow an evidence-based formulation of targets for sustainable use of materials. The possible differentiations of global resource targets presented in this working paper stem from the scientific discussion of the planetary boundaries themselves as well as the conclusions drawn from IntRESS working paper 2.2.

3.2 Multi-scale dimension, geographical variety and socio-economic aspects

The complexity provoked by the multi-level and multi-scale dimension of Rockström et al.'s planetary boundaries is an inherent problem of the concept for the purpose of defining resource targets on materials. Spatial dimensions of the concerned sub-system, its geographical location and the state or vulnerability of the concerned sub-system need to be considered in deriving targets on material use.

Eco-systems affected by global scale processes show varying degrees of sensitivity to changes on a sub-Earth system scale. This is why the planetary boundaries proposed address different scales, aiming at complying with all known thresholds at local and regional sub-system scale in the foreseeable future. (Rockström et al. 2009)

Rockström et al. determine three systemic processes with already identified boundary character of global scale. Climate change is associated with at least

[3] Material (resource) use here comprises processing of the raw materials, beneficiation processes, the conversion into energy or semi-finished goods and final products (production perspective). The final consumption of the products is also included if not referred to separately.

nine “tipping elements” such as the Amazonian rainforest, Indian Monsoon, El Niño-Southern Oscillation (ENSO) in the Southern Pacific, the Arctic Summer sea-ice etc. Those natural phenomena show different sensitivity to human-induced temperature change or radiation forcing – the two control variables of climate change – and have different key impacts on regional to global level. (Lenton et al. 2008) The geographical location determines the vulnerability of a sub-system, so that the consequences of more and more frequently occurring strong rains, floods and tidal waves, draughts, extreme heat, etc. have different impacts e.g. on river delta, a Pacific island, or in high mountain regions. These disasters connected to changing climate conditions on a global scale need to lead to both, limiting the use of greenhouse gases emitting industrial and agricultural activities, i.e. abiotic material use, as well as risk and vulnerability assessments, disaster prevention and the integration of long-term adaption measures into national and regional sustainable development strategies. (IFRC et al.2012)

All other identified Earth system processes are aggregated from local or regional scale with different degrees of uncertainty of the time point of reaching a threshold on global scale. Direct economic activities such as harvesting, mining or fossil fuel extraction often lead to severe environmental pressure on local or regional level. For instance: the combustion of fossil fuels leads to extreme levels of particulate matter in many Chinese urban mega-metropolis; the extraction of raw oil in Nigeria contaminates since decades the fertile soils and ground water in the Niger Delta. If the infrastructure or technology of a extraction site is outdated (like in the Nigerian case), if the raw material is very difficult to access, almost depleted or its concentration in the rock material very low, the negative social and environmental impacts as well as the economic value (including external costs) of persistent extraction often become disproportional to its desired outcome (which is usually economic profit). Examples are the shale gas extraction in Canada or the planned oil drilling in the Arctic shell. In such cases, when internal and external costs exceed the revenue from resource extraction and processing, the establishment of local or regional threshold values for the use of abiotic resources is regarded necessary, if the functioning of the concerned eco-system shall be upheld without compromising social justice.

Unsustainable material use also affects other planetary boundaries, such as biodiversity loss. Rockström et al. consider thresholds to be likely at local and regional scales for biodiversity loss, while its role on global scale is not yet fully understood. This boundary might be suited to propose limits on the extraction of biotic material or limits for land and water use for crop growing on local and regional level. For instance, if data on the extinction rate per year is available and the causal connection to human interference can be proven, this could provide enough reason for setting limits on the amount of commercial timber harvesting (or the forest converted into plantations of oil palm trees, etc.).

3.3 Disaggregation of material categories vs. bulk definition

Regarding the assessment of environmental impacts, Bringezu has a different approach than Rockström and his colleagues. Bringezu postulates that not the specific environmental impact of using a primary resource is at the forefront, as it is the case for several processes analyzed by Rockström (e.g. acidification, etc.), but the system turnover of relevant material flows is quantified. In this case, the chemical composition and the emissions and pressures related to the production of the material are not important. It would thus not be necessary to draw a distinction between the material composition of different kinds of energy, metals or minerals, but only between those broad definitions of resource categories (Bringezu 2014, 53).

This view is derived from Friedrich Schmidt-Bleek's (1992, 1997, 2009, 2014) oberservation that human impacts on ecological equilibria are subject to fundamental limitations of awareness, cognition and knowledge and in line with Nordhaus et al.'s (2012) notion of "non-treshold 'boundaries'". Targets of this kind are based on the concept of a precautionary principle, considering all material extractions in one way or another as disturbing these equilibria in ways that might sooner or later affect human life and economic activities in very negative ways.

The counterargument is that the formulation of targets based on such broad material indicators has to be further differentiated in order to consider the widely differing environmental impacts of abiotic material use. A clear relationship between the use of non-renewable raw materials and environmental impacts cannot be drawn, thus complicating the derivation of limits on resource use.

A number of planetary boundaries are affected by the emissions produced by the use of fossil fuels, for instance. Although it cannot be neglected that the extraction and processing of raw materials produces damages to the environment such as the pollution of water, air, and soil, the causal chain is of such complexity, that no linear relationship between the amount of metal used, for instance, and a certain boundary phenomenon related to the impacts of metal use, can be proven.

The impact on the output side depends on several factors, such as the deployment of technologies regarding the processing of raw materials and the avoidance of emissions (e.g. filters).

3.4 Used and unused extraction

The category of used materials is defined as the amount of extracted resources, which enters the economic system for further processing or direct consumption. All used materials are transformed within the economic system. Unused extraction on the other hand refers to materials that never enter the economic system. It comprises overburden and parting materials from mining, by-catch from fishing, wood and agricultural harvesting losses, as well as soil excavation and dredged materials from construction activities. (SERI and WU 2014)

Bringezu (2014) identifies “Big Three” environmental pressures of global scale for which there are corresponding headline indicators: the Global Warming Potential (GWP) indicator, the Global Land-Use ($GLU_{cropland}$) indicator[4] and Total (abiotic) material consumption (TMC_{abiot}). Mineral extraction is considered by Bringezu to play a key role for systemic environmental pressures. While Bringezu suggests accounting for biomass through indicators related to land use, the IntRESS team decided to include biomass into the materials category as explained in Chapter 1. (Bringezu 2014, 51f)

Total material consumption (TMC) is a consumption indicator based on the input indicator total material requirement (TMR), representing the final demand of an economy, while excluding the exports and their corresponding material requirements. TMC includes unused extraction and therefore can be interpreted as a generic pressure indicator, as mentioned above. It measures the system turnover of major flows of materials and thus depicts the subsequent environmental impacts according to the system’s dimension.

When targets for materials use are concerned, it is important account for unused extraction. Depending on the type of material, the technology applied and the conditions of the extraction site, the ratio between used and unused extraction varies considerable. For some abiotic materials like precious metals, rare earths, and fossil energy carriers the masses removed during extraction amount for a multiple of the weight of the used materials. In other cases, sand, gravel or iron ore for instance, the amount of materials extracted is almost identical to the used material.

Bringezu assumed that there is no difference between the environmental impacts associated with the excavation for the construction of infrastructure and the extraction of other used abiotic materials, which is why unused extraction and has to be accounted for (Bringezu 2014, 58). Ekins et al. also postulates that the damage on nature produced by material extraction “closely correlates” with its weight. Transport, distribution and conversion as well as beneficiation processes of material resources would directly correlate with the amount of energy required and the emissions produced as well as other impacts like detraction of biodiversity or noise generation. (Ekins et al. 2009)

3.5 Direct vs. indirect material flows

[4] The GWP measures GHG emissions and other emissions related to the combustion of fossil fuels and agriculture, the $GLU_{cropland}$ measures the (change of) global cropland.

Closely related to the notion of used versus unused extraction is the distinction between direct and indirect material flows. Direct flows refer to the actual weight of the products and thus do not take into account the life-cycle dimension of production chains. Indirect flows indicate all materials that have been required for manufacturing (up-stream material requirements) and comprise both used and unused materials. Used up-stream material requirements of traded products should be expressed in Raw Material Equivalents (RMEs), which express the amounts of used primary extracted materials required along the whole production chain of an imported or exported product. (SERI and WU 2014)

Especially for the setting of global threshold values, the relation between the resources used by a nation (or one economic sector) and international flows of material resources in form of goods should not be overlooked. Global trade causes the movement of large amounts of material also in processed form, without adequately recording the exported, imported or possibly re-exported resources contained in the products.

Attributing the resources to the respective country of origin is not possible using the DMC indicator, which does not account for indirect material flows[5]. By importing resource-intensive goods and outsourcing resource-intensive production processes, a national economy can improve its environmental performance. However, both practices do not reduce environmental impacts on a global level but merely shift the burden to another country or region, usually to those already confronted with socioeconomic problems or high ecological vulnerability.

3.6 Temporal differentiation

The time period in which materials are extracted can also be relevant for the quantities that can be extracted and consumed without negative effects on the carrying capacities of the local sub-system and even on global scale.

For biomass extraction, a temporal differentiation that goes further than yearly extraction amounts is rather comprehensible. According to specific geographic-climatic conditions or the amounts available, harvesting periods or rain or dry seasons should be considered as limiting factors (e.g. fishing grounds vary according to the time of year). It is useful for biotic material to differentiate the threshold values not only per year, but also regarding agricultural seasons. Also indirect negative environmental impacts due to the use of abiotic materials, like

[5] EUROSTAT (2001) further differentiates between materials that are extracted from the national environment but not actually used by the economy, so-called „domestic hidden flows“ (such as mining overburden or soil excavation during construction) and „foreign hidden flows“, that is upstream resource requirements associated to imported products (such as the mining overburden arising abroad when raw materials are imported).

air pollution stemming from the combustion of fossil fuels, can be curbed by reducing the upper limits for certain time periods, like cases in great urban agglomerations in Asia exemplify regularly in periods of extreme heat.

For his planetary boundaries, Rockström differentiates between “control variables” and “slow variables”, affecting the limit value behaviour of the considered processes (Rockström et al. 2009). Only for three Earth system processes it was possible to define the exact time point of reaching the tipping point which leads to the transgression of the boundary level.

For the slow variables, it would be useful to specify the time periods more precisely. Statistical data collection mostly relies on the calendar year as time dimension. Accordingly, resource extraction is indicated per year. Nevertheless, to what extent a further differentiation will be possible within the scope of this project is not clear.

3.7 Absolute vs. relative formulation of targets

Quantifying absolute material use of socio-economic units in absolute physical amounts is important in times of resource scarcities, limited access to resources, import dependencies and increased competitiveness due to improved resource productivity (BIO IS et al. 2012). However, limiting target setting to absolute material flows would oversee the great socio-economic and geographical variety at national, regional and local scale. From a purely environmental perspective, targets could be set relative to natural flows like non-anthropogenic erosion or observable phenomena like the decrease of coral reefs, the melting of glaciers or the orders of magnitude of “human bioturbation” (cf. Zalasiewicz et al. 2014).

However, targets on material use must take into account the criteria of equity and global “fair share” so targets and thresholds should be set corresponding to the socio-economic situation of a country. National economic structures, the amount of materials extracted and consumed and the distribution of raw material deposits varies considerably. However, setting thresholds on a national scale relative to GDP cannot capture the whole picture, it has to be further evaluated which indicators are suitable to reflect the very different realities faced by each country, e.g. extractive compared to non-extractive countries, countries faces by high environmental vulnerability etc.

4 Suggestion for a comprehensive approach on setting material targets

Global threshold values can be derived from Rockström et al.'s values for those planetary boundaries identified which show a clear threshold behaviour and are influenced (directly or indirectly) by the use of abiotic materials – i.e. climate change, ocean acidification and stratospheric ozone depletion. However, as mentioned earlier, translating threshold values for these planetary boundaries into concrete targets for the different material categories in absolute terms is a challenging task. A source of uncertainty in deriving resource targets on materials on a global level is the lacking data availability for many non-OECD countries. Even more difficult for quantifying materials use is the knowledge gap on long-term environmental impacts of the usage of certain abiotic materials and especially their behaviour in interaction with one another.

4.1 Derivation of a framework for setting global targets on materials

Rockström et al. estimated the quantitative evolution of their control variables of the planetary boundaries from the pre-industrial level to the present. They found that two planetary boundaries were already transgressed decades ago[6]: the rate for human interference with the global nitrogen cycle transgressed the current boundary of 35 Mt per year already before the 1970s and the climate boundary was approached and transgressed during the 1980s. (Rockström et al. 2009)

The basis of our approach builds on Rockström's idea of a "safe operating space for humanity" which provides the framework within which the functioning of the Earth system and its ecological sub-systems as well as societies is not at jeopardy. It can also be seen as based on Weterings' and Opschoor's (1994) concept of "environmental space".

To operationalize the "safe operating space" in the aforementioned sense, the questions we asked were

- How much materials can be used in order to restore and maintain the equilibrium between the Earth's carrying/regenerative capacity and human activity, without sacrificing the functioning of the Earth system? and
- When was the point in time (or time period) where the Earth's system was still in equilibrium (when no boundaries where transgressed or the ecological balance was not in jeopardy)?

We argue that reduction factors and targets on extraction, production and consumption of material resources should aim at the amounts of materials that can be used without resulting in severe environmental impacts on a global level,

[6] The boundary of biodiversity loss (extinction rate: 10 million species per year) does not imply that a boundary has actually been passed as there is no aggregate data on biodiversity loss over long time periods, but implies that the current level of loss of species will lead to a collapse of the functioning of ecosystems. (Rockström et al. 2009)

thus restoring the state of the Earth system when it was still considered a 'safe' space.

Scientific literature on environmental history (Pfister 2010) and ecological economics (Krausmann et al. 2009) allow for the determination of a time period in which the "significant turning point from a slow-going to a rapid loss of sustainability" (Pfister 2010, 93) happened. The period after World War II and especially from the 1950s onwards was characterized by exponential growth rates in the production of many raw materials and energy. In 1992, Pfister called this the "1950s syndrome", stating that „the decline in the price of fossil fuel since the 1950s, seen in relation to the price of labor and capital, was the most significant cause of the wasteful consumption of raw materials and energy, and the resulting excessive environmental stress" (ibid, 92)[7]. This was the time of the emergence of a society of mass production and consumption. Alternatively, this period was also called the stage of "The Great Acceleration" (Hibbard et al. 2007).

Krausmann et al. (2009) draw similar conclusions from their quantification of global materials extraction for the past century, based on the conceptual and methodological principles of EW-MFA. Analysing data and estimations for the period of 1900 to 2005, the authors found that total material extraction increased by a factor 8 during this time. The strongest increase was found for construction minerals which grew by a factor 34, metal ores and industrial minerals by a factor 27 and biomass extraction 3.6-fold. Krausmann et al. accounted for domestic extraction (DE)[8] under the assumption that on a global level the amount of resources extracted equals the amount of resources used as international trade equals out for different domestic consumption levels (DE=DMC).

[7] Later, responding to some critiques, he broadened the concept by the issue of high-input agriculture.
[8] Domestic extraction corresponds to what is known for domestic extraction used (DEU).

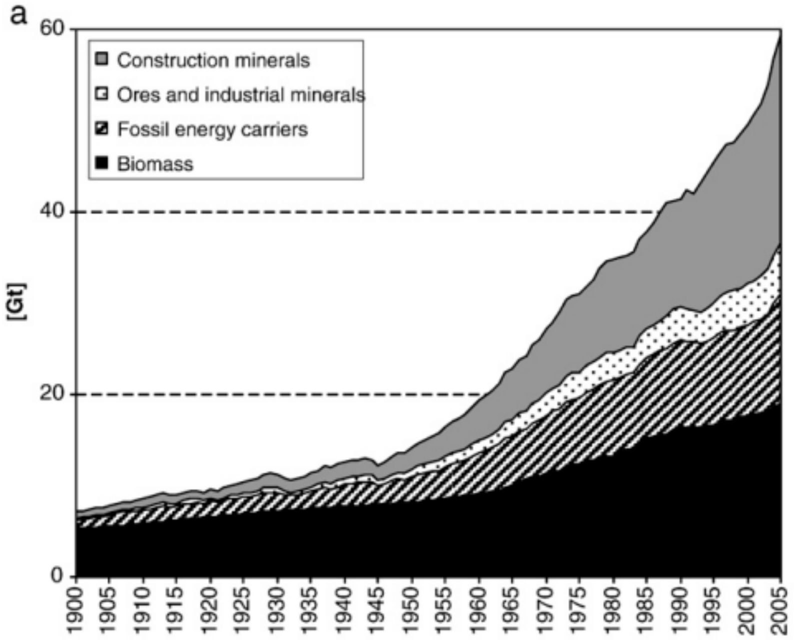

Figure 1: Materials use (DMC = DE) by material types in the period 1900 to 2005: total materials use in Giga tons (Gt) per year (Krausmann et al. 2009, 4)

In accordance with the findings of Pfister, these numbers show a period of uninterrupted and rapid growth of materials use which started after WWII and lasted until the oil crises in 1973. In 1970, 27.3 billion tonnes of materials were used, of which 11.5 billion (roughly 40%) were biomass. The average growth of overall DMC until 1973 was 3.3%. The use of fossil energy carriers grew by 4.5% in this period, metal ores, industrial and construction minerals even about 6%. These growth rates exceeded by far population growth, leading to an unprecedented increase in the rate of materials used per capita, the so-called "metabolic rate", of more than 50%, the use of non-renewable minerals even by 340%. Biomass extraction (without unused extraction) has been growing at a much lower rate (1.52% between 1945 and 1973) compared to abiotic materials (more than 5%) but continued to rise at a moderate pace until 2005 while growth rates for non-renewable materials dropped by almost 50% after the oil crises 1973 (Krausmann et al. 2009).

Despite some natural environmental fluctuations (rainfall patterns, vegetation distribution, nitrogen cycling, etc), Earth has remained within the Holocene stability domain over more than 10.000 years. The resilience of the planet has kept it within the range of variation with key biogeochemical and atmospheric parameters fluctuating within a relatively narrow range. (Rockström et al. 2009) Undoubtedly, the almost exponential growth of total material extraction from the 1950s onwards resulted in a significant increase in human pressure on ecological systems. Although there are controversial opinions on the beginning of the so-called "Anthropocene", the evidence about the relative anthropogenic impact such as the growing human influence on land use, ecosystems, biodiversity, species extinction, climate change etc. had grown exponentially between the 1950s and early 1970s. In line with this argumentation, the concept of the Ecological Footprint timed the first emergence of the so-called "ecological overshoot"[9] on a global level in the early 1970s (Pfister 2010; Wackernagel et al. 2002).

The disequilibrium between human demand for resources, especially for fossil fuels and materials, and the capacity of the ecosystem to sustain itself, was finally perceived on a greater scale by the international community, national governments and civil society in the early 1970s. Several organisations dedicated to the conservation of nature and the protection of species already endangered by human activity were founded, such as the World Wildlife Fund (WWF) in 1961, and Greenpeace in 1971. In 1972, the United Nations Conference on the Human Environment was held and the United Nations Environment Programm (UNEP) was created. In the same year, the European Union started their first Environment Action Programme. The Club of Rome already stressed the relation between economic and population growth, resource exploitation and environmental degradation publishing "The Limits to Growth" in 1972.

4.2 Approaching target derivation and first target suggestions

1970 as base year for target derivation

Following the above outlined arguments, we postulate that the relationship between human demand for natural resources and the capacity of the ecosystem to produce biotic materials and to absorb waste materials got out of balance at the latest around the year 1970. Therefore, we propose to look at the year 1970 for determining thresholds on materials use. In accordance with Rockström et al's notion of the "safe operation space", we suggest to look at 1970 as the latest point of time of a safe operating space for humanity.

Looking at recent year's statistics and future estimations on global material consumption underline the necessity to put a limit to the growing material use as witnessed before 1973. In 2008, global used extraction of materials amounted for approximately 68 billion tonnes of raw materials. Another 40 percent[10] or 44 billion tonnes of unused extraction add up to 112 billion tonnes of global total material extraction. Excavated soil for infrastructure building and

[9] Global overshoot occurs when humanity's demand on nature exceeds the biosphere's supply, or regenerative capacity. Such overshoot leads to a depletion of Earth's life supporting natural capital and a build up of waste. Local overshoot occurs when a population's demand on an ecosystem exceeds the capacity of that ecosystem to regenerate the consumed resources.
[10] The data quality of unused extraction is generally poor as the majority of countries average values are extrapolated in order to estimate unused extractions. Lutter et al. 2014 estimated unused domestic extraction (UDE) by multiplying used extraction with factors expressing amounts of unused materials per used materials (in tonne/tonne). The resulting conversion factors may be national, average continental or world average factors, depending on data availability.

soil erosion due to agricultural activity is not included in these flows of unused extraction (SERI/WU 2014)[11]. If world economy continues to grow at the current pace (the "business-as-usual" scenario) and assuming that developing and emerging countries would reach the same consumption levels as rich countries have today, global material use could be as high as 160 billion tonnes by 2030 and rough estimates illustrate that by 2050 humanity would even require around 180 billion tonnes of materials (ibid., 66) as Figure 2 illustrates. Thus, business as usual is not an option. Clearly, there is no way around reducing the total consumption of abiotic materials worldwide.

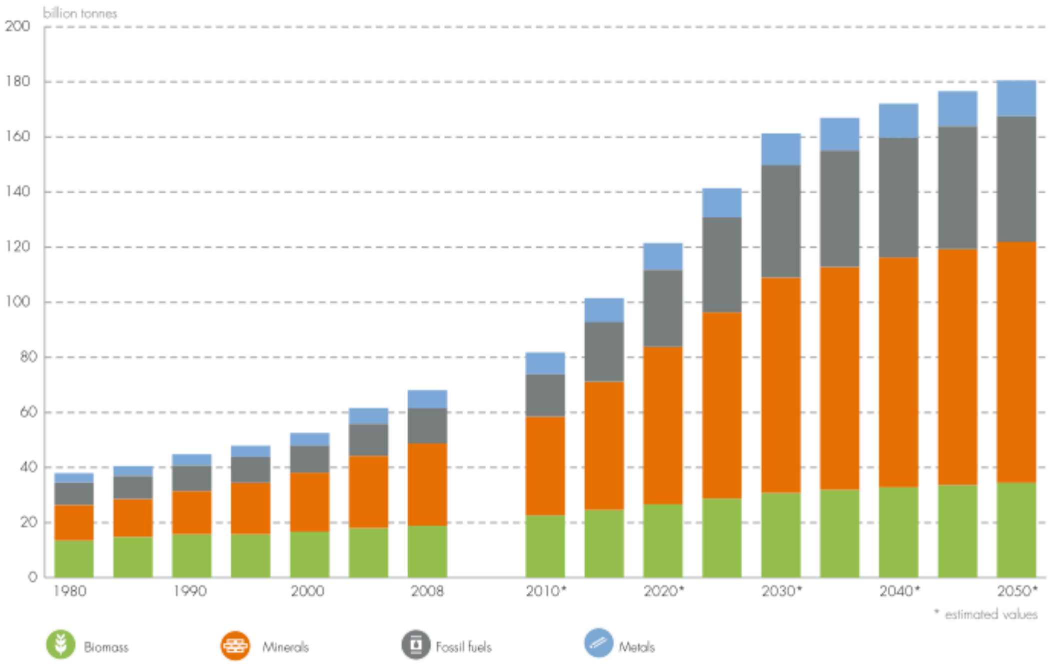

Figure 2: Global material consumption 1980-2008 and estimations until 2050 (Dittrich et al. 2012)

[11] This estimation of global material flows in 2008 by SERI / WU (2014) are slightly higher than those of Krausmann et al. 2009 (66.8 billion); At the same time, Krausmann et al. observe a steeper trend of growth for the time period 1980 to 2008: 2.28% as compared to 1.55% average annual growth. This is mainly due to a different estimation procedure for the category of construction minerals (cf. Krausmann et al. 2009, 3)

Estimations by Bringezu (2014) show an even worse picture. He postulates that today twice to triple as many materials are extracted and remain unused globally than the used material extraction of itself. In 2000, only for building infrastructure, an estimated 40 to 50 billion tonnes of soil and earth were being excavated worldwide but not counted as unused extraction. Another 25 to 50 billion tonnes of eroded soil due to agriculture add up to 145 to 180 billion tonnes of primary material extracted from the global environment in 2000 (Bringezu 2014).

General considerations for target derivation

TMC as headline indicator

On a global scale, total material extraction equals total material consumption, as trade equals out. In the different assessments of material flow indicators for the derivation of global resource targets, RMC and TMC are considered analogically. In their manifesto, the European Resource Efficiency Platform (EREP) encouraged the regular use of RMC for EU economic activities, to provide insights and raise public awareness on the global effects of EU production and consumption (European Commission 2013). For target derivation, both RMC and TMC have been suggested, but certainly are to be favoured over DMC. The authors propose to use the TMC indicator for global material use targets. TMC provides a more comprehensive picture than RMC by including also the unused parts associated to the imported products.

Dittrich et al. (2012) assumed that the overall scale of industrial metabolism rather than toxicities of specific substances are the determining environmental factors. This is in line with Bringezu's argumentation (2014). Even though there is no simple one-to-one relation between aggregate materials use and environmental deterioration, the size and composition of materials serve as a proxy for environmental pressures resulting from human activities. (Krausmann et al. 2009) Thus, we find that TMC is best suited to derive general targets within the framework of Rockström et al's planetary boundaries-approach. This does not mean that other indicators such as DMC or EMC (Environmentally Weighted Material Consumption) may not serve to complement TMC, especially as long as data availability on unused extraction is poor for most countries.

Differentiate used and unused extraction

In 2005, global average material consumption measured in DMC amounted to about 10.2 tonnes per capita, whereas when TMC is concerned, material use amounted for at least 16.5 tonnes per capita on global average. These numbers show that hidden flows associated with domestic consumption do matter. They can reduce the economic gains achieved by higher resource productivity. Unused extraction needs to be reduced in order to reduce overall amounts of material extracted.[12] The ratio of unused to used extraction varies considerably

[12] Ten countries are responsible for almost 75% of total unused extraction worldwide: United States of America, Australia, China, India, Russian Federation, South Africa, Germany, Indonesia, Canada

among the material categories. While for construction minerals like sand, gravel and limestone volumes of unused extraction are low (in OECD countries less than 10 percent), the ratio is very large for fossil fuel carriers and most metal ores. TMC of fossil energy carriers, for instance, is significantly higher than DMC, however depending on the fossil fuel mix of a country (coal mining produces a lot more unused extraction than oil or gas extraction). Since DMC is based on mine output rather than metal output, also the type of metal influences the ratio of used to unused extraction. (OECD 2015) The volume and quality of natural resource stocks, trade activities, and production and consumption patterns of countries may require looking at both the volumes of used and unused material extraction to result in meaningful targets on material extraction and consumption. Toxicity of tailings and other waste material produced in ore mining (especially concerning lead, uranium and other toxic heavy metals) is subject to many studies and could in the future also be considered when limits for unused materials are to be defined.

Formulate sub-targets for disaggregated abiotic materials

Closely related to these considerations on used and unused extraction is the disaggregating of the category of abiotic materials into fossil energy carriers, industrial minerals, construction minerals and metal ores is considered necessary by the authors from a long-term perspective. A direct relation between the aggregate material use and environmental deterioration is difficult to establish due to their great variability. Further research is needed in this field in order to provide correlations between the use of a certain material and the associated environmental impact. However, for some categories the overall volume of material flows serves to indicate the impact on the surrounding environment. Iron and copper, for instance, cause the largest amounts of excavated materials on a global level. The amount of non-target material generated in iron ore extraction is relatively small with a metal content of 1:3-4. For metals like nickel, zink and lead, the unused materials generated are 20-30 times greater, for precious metals like gold and platinum more than 200-300 times (OECD 2015). The quantity of overburden from ore mining activities also depends on the type of extraction technology, difficult accessibility of the metal-containing ores and the local properties of the metal deposit. (SERI and Dittrich 2014)

Derive targets for biotic and abiotic material extraction separately

We also suggest that in a long term perspective, targets should be formulated for biotic and abiotic materials separately taking into account the increasing demand for biomass, e.g. as a substitute for fossil energy carriers, and the growing demand for food crops due to the rapid population growth. The environmental impacts associated with a rapidly increasing demand for biotic materials such as large-scale land use change, the loss of biodiversity and ecosystem instability could be limited by targets specifically looking at the use of biotic materials.

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and Chile amount for 32.8 out of 44 billion tonnes of unused extraction in 2008 (SERI and Dittrich 2014).

In agricultural production systems, large quantities of agricultural residues are generated which do not enter into economic activity. Although the residues are often being used for energy production (biogas), forage and bio-fuels, large amounts still remain unused as their further processing is not considered profitable enough. Although for the functioning of an ecosystem biomass residues are important as in the case of forests, it is estimated that up to 45% of forestry residues occur in wood logging, an unnecessary high proportion. Likely, the by-catch in marine fishery amounts to one fourth of global biomass extraction from fishery, endangering the local food chain of many marine species (Jölli/Giljum 2005). However, detailed data on unused biomass extraction is still scarce and further research is needed to enable clear sub-targets on this materials category.

Suggested target values

Global target: Total material consumption limited to 45 bn tonnes

With regard to the environmental perspective, Dittrich et al. 2012 suggested that global resource extraction should be frozen at the level of 1992 or 50 billion tonnes (base year 2008) of global material consumption.[13] In this derivation, however, unused extraction was not yet included. The importance of accounting for both used and unused material flows was stressed repeatedly. We assume that unused extraction on an aggregate level adds at least an estimated 40 to 60% to the used material, with an increasing trend towards 2050. The ratio of unused to used extraction will increase further due lower contents in material deposits, lower mass concentration in ores, more difficult accessibility and its non-regenerative nature of abiotic materials.

When referring to material extraction in 1970, we propose to set the limit for global material consumption at 45 billion tonnes TMC with unused extraction included. Global materials extraction should not exceed this order of magnitude in order not to overexploit the Earth and leave the safe operating space. On a global scale, this would mean an overall reduction by 65 percent referring to today's material consumption, while considered still a conservative target. This implies significant changes in the level of economic activity based on non-renewable resources and a significant advancement from known and future technologies, especially in high income/highly industrialized countries.

Per-capita target: 5 tonnes based on TMC, to be complemented by socio-economic indicators

Formulating a per-capita target based on the absolute target of 45 billion tonnes TMC would lead to a maximum of 5 tonnes per-capita of material use with a world population of nine billion people in 2050. Schmidt-Bleek's (2009) suggestion of a global per capita threshold value of 6 tons of raw materials (including unused extraction) is even less drastically. Lettenmeier et al.'s (2014)

[13] Other authors chose 2000 (Bringezu / Schütz 2014) or 2005 (BIO et al. 2012) as reference years for reasons of data availability and robustness, simplicity or harmonization. However, between 2000 and 2008 used extraction increased significantly (by 27%), mainly due to growth dynamics in East Asia (particularly China), India and Brasil, which is why 2008 is considered to reflect a more accurate picture of "today's" global resource use.

suggestion of a material footprint of a maximum of 8 tonnes per person, meaning a factor 5-reduction of the Finnish household consumption (or 80%), would still not be enough to reach the 5 tonnes-per-capita target.

Between 1980 and 2008, domestic material consumption per capita increased from 8.5 to 10.2 tonnes on global average. In 2008, Australia including Oceania consumed 36 tonnes per capita, North America 27 tonnes, in Europe an average 15 tonnes, and in Latin America 13 tonnes. Asian per-capita consumption was still below global average with 9 tonnes. In Africa, material consumption per capita was 5 tonnes in 2008. (Dittrich et al. 2013) These numbers show that a reduction of domestic material consumption would have to range between 50 and 90 percent in order to reach the 5 tonnes-goal among all countries.
These number also illustrate that an absolute global per-capita threshold value not only urges highly industrialized or high income countries to reduce their use of resources, it would also limit total material consumption for emerging countries and even some developing countries and thus hinder socio-economic development. Therefore, in order to comply with the equity criterion of sustainable development, global material use should be related to the socio-economic situation of a country. Low income countries should be allowed to use more resources for a specified period of time (e.g. until 2050) in order to "catch up" and enable a sustainable development of their economy and society.[14] The upcoming 'horizontal paper' will deal with this issue in more detail.

Further sub-targets

Separate sub-target for sand and gravel

Within the subgroup of construction minerals sand and gravel requires special attention. The importance of this material in terms of environmental impact as well as the socio-economic consequences of unlimited and unsustainable sand mining is highly underestimated or ignored on the international discourse on resource use. Sand and gravel are the main components in the production of cement for concrete, the construction material used in two thirds of all buildings worldwide, and asphalt production. More than 200 industries rely on sand as a resource, making it the second most important resource after water and accounting for the largest volume of solid material extracted globally. Between 1980 and 2008 global extraction and use of sand and gravel grew by 187%, limestone grew by 171% (Dittrich et al. 2012). In 2012, 25 to 30 billion tonnes of sand and gravel were used globally only for building construction. Sand demand for land reclamation projects (e.g. in Singapore and Qatar), shoreline sanitation (also for touristic reasons), road building and other industries add up to a conservative estimation of a yearly extraction of 40 billion tonnes of sand aggregates (UNEP GEAS 2014). Sand mining in international sea waters is not

[14] In this context resource productivity indicators such as GDP/RMC or GDP/TMC could also be useful. To be discussed.

subject to limitations as its deposits seem endless. However, illegal mining activities in national waters (especially in South East Asia) is taking place mostly unhindered, causing major impacts on the concerned ecosystems (coastal, river and land erosion, biodiversity loss etc.). We thus suggest formulating a specific target on sand extraction, in line with UNEP's recommendation to regulate and monitor sand extraction in both national and international waters (ibid.). Although reliable data is only available for recent years (Krausmann et al. 2009) it can be assumed that quantities demanded by emerging economies, especially China and in South East Asia, will be growing steadily. As sand and gravel can be assumed to amount for almost half of total used material extraction, a reduction target similar to that of (abiotic) materials in general is regarded necessary. Thus, a per capita-target relative to land area on the one hand and GDP on the other hand can give additional insights.

Derive targets for certain critical materials

Some specific biotic and abiotic materials might need special consideration from a socio-economic point of view. Raw materials such as rare earths, for instance, are becoming a more and more important resource for the renewable energy sector (e.g. wind turbines, batteries), electric mobility and electronic devices in general, demand for them will grow further in the future. Their use has been growing rapidly and minable deposits are limited and concentrated in only a few world regions. Their criticality mainly refers to their importance for the economic development, while at risk of supply disruption. Other biotic materials like cotton, fish, forestry products, cocoa, sugar, palm oil, soybeans, etc. are critical due to high volatility of yields and prices. Targets could also be oriented on other benchmarks such as market shares of commodities produced under internationally recognized sustainability standards (e.g. MSC, PRSPO project, UTZ Certified, FSC, Roundtables on Responsible Soy/RTRS and Responsible Palm Oil/RSPO, etc.) instead of purely absolute material flows. While economic aspects seem to be predominant for the above mentioned materials, they certainly are of major importance from an environmental perspective as their production is usually linked to large scale land use change and use of fertilizers etc. with the associated impacts on biodiversity, biogeochemical flows and climate change.

Consideration of material stocks and secondary materials

Two other aspects that have not been addressed in particular in this paper but should be considered in target derivation are the role of stocks for the limitation of material resources use and the role of secondary materials. Targets such as no net additions to stock could complement those based on mere material flows analyses. A modelling approach that draws the relationship between material use and stock accumulation, estimating global material stocks in infrastructures, buildings and durable goods from 1900 until today could deliver data for the dynamic of material stocks and material flows (cf. Wiedenhofer et al. 2014). Although not issued in this paper, another mid-term targets could consider balancing the extraction of primary materials and the use of recycled material. As a long-term perspective, targeting the gradual substitution of virgin materials (e.g. aluminium, plastic, etc.) by enforcing the circular economy should be on the international agenda.

5 Conclusion

The approach suggested in this paper combines the broader picture of human interference in the Earth's biosphere as depicted by Rockström and his collegues, with the actual dimensions of humanity's use of material resources using the data offered by material flow accountings. Biotic and especially abiotic materials appear in Rockström et al.'s concept primarily as pressures, in terms of GHG emissions, chemical pollution, aerosol and ozone-depleting emissions. Energy production and the processing of abiotic material resources (for industrial and agricultural purposes) as well as the extraction and burning of biomass are the drivers that lead to the transgression of many planetary boundaries and thus jeopardizing humanity's safe operating space.

In order to derive internationally accepted, qualitative and quantitative targets reduction factors on material use, the shares of CO_2 emissions of the overall atmospheric CO_2 concentration produced by biomass extraction and burning, the use of fossil energy carriers, metal ores, industrial and construction minerals would have to be quantified. The respective shares, combined with MFA data on global material flows measured in Total Material Consumption (TMC) can provide the basis for the formulation of limits and targets on a global scale at least for some material categories. This "translation work" has still to be done for most materials.

Other aspects also need to be considered, as this report aimed to outline. Although global targets are needed for the large-scale systemic processes identified by Rockström et al. and limits in terms of absolute material extraction on a global scale are needed for further target derivations, a distinction of local or regional level pressures have to be undertaken where necessary, i.e. where geographical exposition, climate issues etc. play a major role for the dimension of the environmental degradation. For the future, other indicators such as the Environmentally Weighted Material Consumption (EMC)[15] could also be considered when the assessment of environmental impacts in terms of individual impact categories is concerned. It was not the aim of this paper though to assess its suitability to complement MFA data analysis for the derivation of material targets. Finally, equity considerations lead to the necessity to derive separate targets for high-consuming industrialized countries, emerging high-consuming countries and developing countries that are still consuming only small shares of the global material consumption. This relationship is at the core

[15] The environmentally weighted material consumption (EMC) indicator is not an accounting approach, but an aggregate of separate assessments, using data of material flows and life-cycle wide emission inventories as well as environmental impacts of different materials. It combines a set of specific impact indicators which are then aggregated using weighting factors. It covers impacts independent from absorption capacities, so called midpoint indicators such as human toxicity and eco-toxicity of certain materials or issues of ozone depletion, eutrophication, acidification, etc. (van der Voet et al., 2009)

of another IntRESS working paper, drawing the “horizontal line” between the three resource categories as well as taking into account the socio-economic perspective of resource use targets.

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