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"Living well, within the limits of our planet"? Measuring Europe's growing external footprint

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The title of this report refers to the title of the new EU Environment Action Programme, adopted in 2013: "Living Well within the Limits of Our Planet".

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ABSTRACT

This report applies the planetary boundaries framework to Europe, in particular addressing Europe’s new environmental goal of “living well within the limits of our planet”. It quantifies the impacts of European consumption patterns within Europe (internal footprints) and outside of Europe (external footprints, as caused by consumption of imported products). For all boundaries considered in this report, Europe’s total (internal plus external) footprints per-capita are higher than global average, and also exceed the allowable per-capita footprints if the planetary boundaries were equally allocated among the 7 billion inhabitants of planet Earth. The external footprints are often larger than the internal footprints. The evidence of growing externalization of Europe’s environmental footprints, or export of environmental problems, provides important guidance for sustainable production and consumption as well as for more coherent European environmental, trade, economic and other policies. For the planetary boundaries to also provide guidance on the formulation of local environmental sustainability boundaries, they need to be further integrated with context-specific information.

An earlier version of this report was prepared for the European Environment Agency (EEA), as input to their stakeholder workshops in preparation of Europe’s State of the Environment Report (SOER) 2015 and as a background paper for the new EU Environment Action Programme.

ABBREVIATIONS

DPSIR	Drivers, Pressures, State, Impact, Response
EEA	European Environment Agency
EU	European Union
GDP	Gross domestic product
MRIO	Multi-Regional Input-Output (see below)

NOTES ON TERMINOLOGY

Footprint: Often refers to total resource use or emissions associated with an entity's consumption, irrespective of the local context (e.g. vulnerability). This report emphasizes the importance of local context for the translation of pressures (e.g. water or land use) into actual impacts (e.g. loss of terrestrial carbon storage or biodiversity), but it synthesizes mostly available literature data on resource use or emissions. Internal or direct or territorial or production-based footprints materialize within a country or region, external or indirect footprints outside. Consumption-based footprints account for internal plus external pressures or impacts on the environment, as caused by the total consumption including that of imported products.

MRIO or Multi-Regional Input-Output analysis traces financial flows or - in its extended form - also physical commodities through the full supply chain from primary production to the final consumer. In combination with production data and related resource use or emissions it enables the calculation of external footprints.

Virtual water or virtual land imports associated with imported commodities quantify the amount of water or land used for the production of these commodities in the exporting country (note that some authors also use the same term for the amount of water or land saved in the importing country, which is not necessarily identical with the former)

See also the explanations of different concepts of environmental boundaries in section 1.2.

CONTENTS

FIGURES

1. INTRODUCTION

Human pressures and impacts on natural resources and ecosystems, or "environmental footprints", keep growing, due to population and economic development and changing consumption patterns (Hoekstra et al. 2014). This development is part of the so-called great acceleration of the Anthropocene (Hibbard et al. 2007, Steffen et al. 2007). There are signs that some critical thresholds in resource use, emissions/loads of pollutants and environmental degradation are being approached – or even transgressed – either locally or globally (UNEP 2012, WWF 2012).

Some of the underlying processes – how pressures translate into impacts, and the critical thresholds – are reasonably well understood and substantiated; for example stratospheric ozone depletion and ocean acidification (Montreal Protocol 1987, Douglass 2010, Schubert et al. 2006). Similarly, in the case of climate change, the relationship between atmospheric carbon dioxide concentration and temperature increase is in principle understood (IPCC 2007, IPCC 2014) and a critical threshold (of about 2° Celsius warming) has been defined (WBGU 1995). In these cases, boundaries have generally been set at a safe distance from the thresholds beyond which potentially critical impacts are anticipated, delineating a "safe operating space".

Other processes, impacts and critical thresholds are less certain, and proposed boundaries delimiting the "safe operating space" have to be based on expert judgment, at least until they can be further specified scientifically (e.g. Persson et al. 2013). In addition, the consequences of going outside these boundaries are not always well understood. Resilience theory postulates that ecological, social and social-ecological systems could undergo non-linear, often abrupt and possibly irreversible changes (termed regime shifts) once critical thresholds are passed, and that they may be even less resilient in their new states (Scheffer et al. 2001, Folke et al. 2004, Biggs et al. 2009).

Given the uncertainties about i) the environmental thresholds and what constitute safe operating spaces, ii) the current status of various systems with respect to these spaces, and iii) the consequences of going outside them, the precautionary principle advises early action in order to reduce anthropogenic pressures and so minimize risks. Taking climate change as an example, it would be unwise to delay mitigation and adaptation actions until all of the uncertainties are resolved (and the full impacts of climate change can be felt), because by that point the changes will be almost irreversible due to the high inertia of the climate system. Instead, so-called adaptive management principles (see e.g. Pahl-Wostl 2007) suggest acting on the existing knowledge, adjusting management interventions whenever new information becomes available, and clearly communicating uncertainties at all times. It also has to be clear that the available scientific knowledge requires interpretation, and that normative decisions must be made to minimize risks.

1.1 "Living well, within the limits of our planet"

The European Union's new Environment Action Programme is titled "Living Well, within the Limits of our Planet" (European Commission 2013). It sets out the following vision for Europe's future:

In 2050, we live well, within the planet's ecological limits. Our prosperity and healthy environment stem from an innovative, circular economy where nothing is wasted and where natural resources are managed sustainably, and biodiversity is protected, valued and restored in ways that enhance our society's resilience. Our low-carbon growth has long been decoupled from resource use, setting the pace for a safe and sustainable global society.

This builds on the earlier Roadmap to a Resource Efficient Europe's (European Commission 2011) calls for the EU economy "to grow in a way that respects resource constraints and planetary boundaries".

In order to start to determine to whether Europe is today "living within the limits of our planet", and how progress towards this vision might be measured, this study attempts to quantify the contribution of European consumption to total environmental pressures and associated transgressions of environmental boundaries, both within Europe and beyond its borders. It does so by determining Europe's consumption-based (i.e. internal plus external) footprints and comparing these to the available tentative global environmental boundaries. Moreover, the report compares European per capita footprints with those of other world regions and global averages. Finally, given the fact that industrialized countries are increasingly externalizing their environmental pressures (Bruckner et al. 2012), this study provides evidence that this process has become a measure "to protect, conserve and enhance the EU's natural capital" (a goal of the new EU Environmental Action Program).

To capture the full impacts of European consumption on all European and external production regions, this study relies primarily on supply chain or multi-regional input-output (MRIO) analyses (see Wiedmann 2009), presenting material, carbon, water, land and biodiversity footprints. To define globally meaningful environmental boundaries, the report starts from the planetary boundaries framework (Rockström et al. 2009), downscaling, interpreting and applying these boundaries to Europe. With that it aims to inform a broad range of European policies (not only environmental, but also e.g. trade and economic policies) about the consequences of Europe's increasing externalization of environmental footprints.

1.2 Environmental boundaries concepts

The idea of environmental boundaries, which delimit the safe operating space of the human enterprise, is not entirely new. Earlier concepts for specifying such boundaries include:

carrying capacity, *limits to growth*, *tolerable windows/impact guardrails*, *critical loads*, *and safe minimum standards.* Some of these earlier concepts of environmental boundaries are still used in scientific literature and policy-making. They also provide building blocks or reference for the planetary boundaries framework, categorizing different types of boundary. These various concepts, along with the planetary boundaries framework, are briefly described below.

Carrying capacity (see e.g. Daily et al. 1992) refers to resource limitations to population growth. Examples of resources that could limit population growth include water, land, minerals, and biodiversity. The concept entails consumption levels and resource-use efficiencies as determinants of maximum sustainable population numbers under given resource limitations.

Limits to growth (see e.g. Meadows et al. 1972, 2004) are also resource limitations, but go further than carrying capacity by recognizing systemic links and dynamics. They represent one of the first attempts to identify boundaries at global level for the use of non-renewable resources and persistent pollution, although without specifying these boundaries in detail or addressing what might occur when they are transgressed.

The *tolerable windows/guardrails* approach (see WBGU 1995; Bruckner et al. 2003) determines pathways or manoeuvering space that would avoid dangerous climate change. It is based on normative principles or constraints: "preservation of the Creation" and "prevention of excessive economic costs". This approach is operationalized by setting normative "impact guardrails": climate impacts considered intolerable by stakeholders, and maximum tolerable costs (e.g. 5% of global GDP). Both maximum temperature and a maximum rate of temperature change have been identified for keeping adaptation costs within "tolerable windows".

The *critical loads* concept, which was developed in the context of the United Nations Economic Commission for Europe (UNECE) convention on Long-Range Transboundary Air Pollution (LRTAP) and has been later used in EU air pollution regulation, aims at avoiding deleterious effects at regional level. These effects are region-specific. Critical loads are quantitative estimates of an exposure level to one or more pollutants, below which significant harmful effects on specified sensitive elements of the environment do not occur (Spranger 2004). Note that this definition contains normative elements, e.g. when defining "harmful effects".

Safe Minimum Standards (Ciriacy Wantrup 1952, Bishop 1978, Crowards 1998) is a more precise interpretation of the precautionary principle and has been applied to different environmental issues such as habitats for endangered species or water quality requirements. They specify a level below which a certain ecosystem service or resource should not fall, in order to minimize maximum possible social losses connected with avoidable irreversibilities. (Context-specific) thresholds and non-linear responses are integral part of the safe minimum standards approach.

The *planetary boundaries* have been designed as a "dashboard" (Cornell 2014), presenting in condensed form the available evidence of human activities pushing the Earth system beyond Holocene-like desirable stable conditions, and clarifying the existence of environmental limitations on allowable resource use, emissions into the environment and environmental degradation at global level. The planetary boundaries, as the latest of these boundary concepts, include traits from all of the above precursor concepts (see references to the respective concepts for each of the environmental boundaries described in chapter 3.1), e.g. the precautionary principle under uncertainty and normative boundary assumptions. Like carrying capacity, the planetary boundaries framework recognizes the dynamics of thresholds, e.g. when the resource base is shrinking due to resource degradation. It postulates thresholds and discontinuities as in the tolerable windows/guardrails approach, but covers a more comprehensive set of Earth system processes. Going beyond region-specific approaches such as the critical loads or safe minimum standards, the planetary boundaries identify aggregate global boundaries and global parameters for these.

Rockström et al. (2009) argue that enough is known by now about the Earth system functioning ("the planet's life support systems", Daily et al. 1992) and the biophysical processes which determine its self-regulating capacity, that the delineation of a "safe operating space" and associated environmental boundaries at planetary scale would be justified. These planetary boundaries are mostly expressed as limits of acceptable deviation from the natural state. Transgression of any of these planetary boundaries, also through simultaneous transgression of multiple local boundaries, may lead to shifts of components of the Earth system into new states ("regime shifts"), with potentially deleterious consequences for humans. Rockström et al. (2009) identified nine challenges or boundaries, seven of which could be quantified with respective control variables (e.g., atmospheric CO_2 concentration for climate change) and specific boundary values for these control variables (e.g., 350 ppm CO_2). Boundaries were determined at what was considered to be a "safe distance" from the estimated critical thresholds or dangerous levels, using the best available science and precautionary principles.

These boundaries are not static. They may shift through pressures, interactions and feedbacks within the Earth system and among the planetary boundaries themselves, and also through interactions with smaller-scale boundaries and underlying pressures (see e.g. Estes et al. 2011). For example, changes in climate, in atmospheric CO_2 concentration, in aerosol loading or in land cover can alter the hydrological cycle. This may subsequently increase or decrease water availability, with implications for the water boundary (which specifies the maximum acceptable level of human water consumption). As global environmental change progresses further, boundaries are also likely to change.

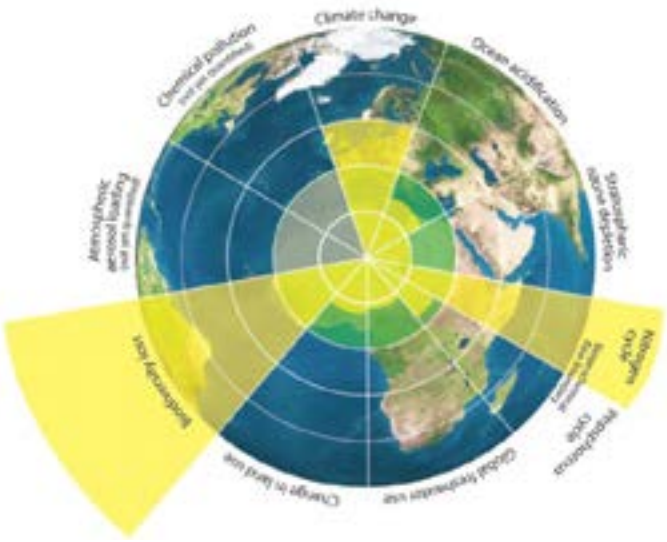

Figure 1: Planetary boundaries, showing some already being transgressed

Source: Nykvist et al. 2013

More scientific research is required (and underway) to better quantify the planetary boundaries and their interactions, in order to understand the consequences of their transgression for the functioning of the Earth system and to interpret, translate and downscale them for specific contexts (Persson et al. 2013).

2. PLANETARY BOUNDARIES AS A GUIDE FOR SUSTAINABLE PRODUCTION AND CONSUMPTION IN EUROPE

This report uses the planetary boundaries as an initial reference for maximum global resource use and emissions, to eventually guide sustainable consumption and production. While the planetary boundaries, the latest concept of environmental boundaries (as described in section 1.2), were conceived primarily as a scientific framework, they also have implications also for policy-making. This report seeks to interpret planetary boundaries for the European context in two directions:

1. How do European per capita footprints compare to an equal allocation across the 7 billion inhabitants of planet Earth of the maximum allowable global use of natural resources and allowable emissions, as specified by the planetary boundaries? This interpretation is quantitatively analyzed for a number of environmental footprints in section 2.1.

2. How could the planetary boundaries be downscaled to specific contexts within Europe, in order to derive environmental boundaries of sustainable resource use or emissions? This interpretation is attempted in section 2.2.

A third interpretation or implication of the planetary boundaries framework may also become relevant for Europe: feedbacks from approaching or transgressing planetary boundaries elsewhere in the world may reduce Europe's own "operating space", for example when it comes to impacts of global climate change, or increasing global commodity prices, or conflict and migration as a result of, e.g., overuse of land or water. This third interpretation is not addressed in this report.

The first interpretation requires an important distinction between, on the one hand, *internal*, *production-based* or direct or *territorial pressures* on environmental boundaries within Europe, through resource use or emissions within European territory; and, on the other hand, *external* or

indirect pressures on environmental boundaries, which include all emissions, resource depletion etc. linked to European consumption, whether they take place in Europe or elsewhere (e.g. in raw material producers and exporters of manufactured goods), transmitted via trade[1] or foreign direct investment.

Both, internal and external pressures and impacts or footprints as caused by European consumption are quantified and compared in section 2.1.

The different planetary boundaries need to be interpreted somewhat differently, given that they address different parts of the "DPSIR" (Drivers, Pressures, State, Impact, Response) sequence (see Nykvist et al. 2013). The water, land and, to some extent, biodiversity and phosphorus boundaries can be interpreted as resource or supply-side limitations, suggesting that a certain level of resource use should not be exceeded (see the concepts of "carrying capacity" or "limits to growth" in section 1.2). In contrast, the climate (CO_2), nitrogen, chemical pollution, atmospheric aerosols, ocean acidification and, to some extent, phosphorus boundaries are "critical load" limitations (see section 1.2), suggesting that certain emission levels should not be exceeded. (Note that phosphorus shows supply-side as well as critical loads limitations.) The biodiversity boundary may also be interpreted as a "safe minimum standards" limitation (see section 1.2), suggesting that ecosystems and their services should not be degraded below a certain level.

Beyond these differences, most of the boundaries also need to account in specific ways for local context. For example, a land boundary that specifies maximum cropland extent (or minimum forest extent) may need to have different threshold values depending on forests types and other ecosystems and their vulnerabilities, agro-ecological conditions, agricultural practices etc. Strictly speaking, the contributions of European consumption to the transgression of planetary boundaries can only be compared in a consistent manner with that of other regions for truly global boundaries, such as climate/CO_2, ozone or ocean acidification. For those boundaries, all emissions contribute to a common global pool, irrespective of the local context in the originating region. For all other planetary boundaries which are composed of aggregates of multiple local pressures – e.g. the sum of all local water or land uses – context matters and equal per capita allocations of the total allowable resource use or emissions are somewhat problematic. The planetary boundaries are being revised, in part to try to address this problem; for example, the revised planetary land boundary is being changed to differentiate between boreal, temperate and tropical forests and to specify different levels of minimum forest cover depending on the role which the respective forest type plays in the functioning of the Earth system.

Quantifying internal or territorial pressures on environmental boundaries (e.g. land and water use within Europe) is relatively straightforward. However, it is more difficult to quantify the external pressures that European consumption places on environmental boundaries in other regions. The latter require a full understanding of global supply chains, and associated resource uses or emissions of each intermediate processing step, as well as the conversion factors from one step in the supply chain to the next. Only by adding up internal and external pressures (and subtracting from the internal pressures the contributions of export production), can Europe's total pressures on environmental and planetary boundaries, its "consumption-based footprints", be calculated.

2.1 Europe's pressure on global environmental boundaries

Europe's self-sufficiency levels or import dependencies for specific commodities may serve as initial rough indicators of the relative importance of internal vs external pressures caused by European consumption. For example, von Witzke et al. (2011) and Hoff et al. (2014) calculate European net virtual land and virtual water imports by combining bi-national trade statistics with specific land and

[1] Examples include imports of livestock feed, e.g. soy from South America, or exports of waste products, e.g. old ships sent to South Asia for breaking.

water use efficiencies in the importing and exporting countries. However, a rigorous assessment of external (and eventually total) pressures as caused by European consumption has to go beyond bi-national trade flows, and undertake a detailed analysis of supply chains.[2] The few available studies to date have used so-called multi-regional input-output analysis, with a comprehensive accounting procedure for all imports and exports and resource inputs or emissions along the international supply chains (see e.g. Hoff et al. 2013).

Materials

Wiedmann et al. (2013) have calculated consumption-based material footprints for European and other countries. The term "materials" in this case covers different categories such as metal ores, fossil fuels, construction materials and biomass. The bars in Figure 2 depict national consumption-based demands for these materials or total footprints[3] relative to the global average value of 10.4 tons (black line). Europe's trends in internal and total material footprints are compared in Figure 3 to economic development (GDP).

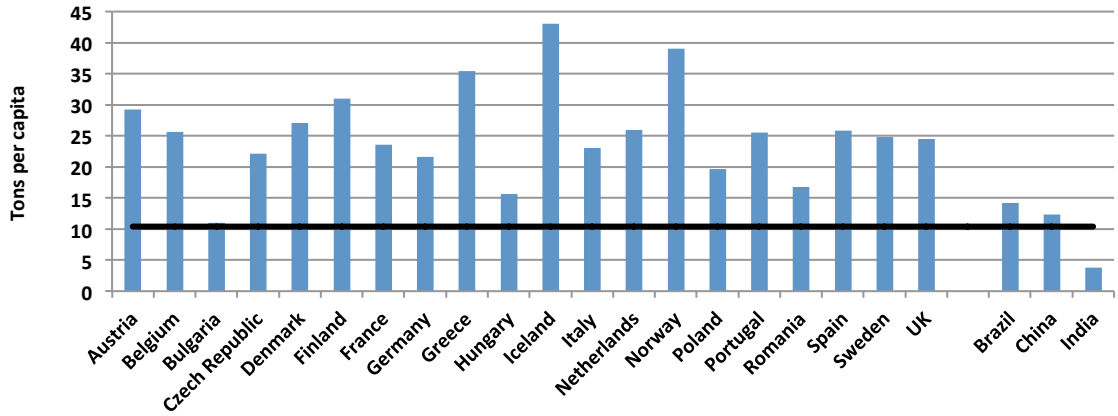

Figure 2: Consumption-based material footprints of 20 EU member states, 2008, compared with 3 major emerging economies and global average

Source: data from Wiedmann et al. 2013

Unlike other types of footprint, no planetary boundary has been defined yet against which such material footprints could be compared. However, this analysis still demonstrates that the often-claimed decoupling of Europe's resource use (and emissions) from its economic development – here represented by GDP – is in fact rather a shift of the demands and associated pressures to other regions, i.e. a shift from internal to external footprints or a "discounting [of environmental costs] over distance" (Daily et al. 1992). The other examples for climate, water, land and biodiversity presented below tell the same story of strong externalization of Europe's environmental pressures and impacts. For the following categories (climate, water, land, and biodiversity) Europe's internal and external pressures as calculated by MRIO are compared to the respective planetary boundary.

[2] A comprehensive analysis of external footprints would need to account also for local vulnerabilities in the producing and exporting regions. This has been attempted to some extent e.g. by Ridoutt et al. (2010) and Lenzen et al. (2013), when accounting in their water footprint analyses for (blue) water scarcity in the exporting regions. But that aspect of context-specific vulnerabilities to resource use or emissions is not addressed in this report.

[3] The term "footprint" is used here and in the following citations rather loosely. Instead of its original meaning of an "impact on the ground" it stands for a certain quantity of resource use or emissions.

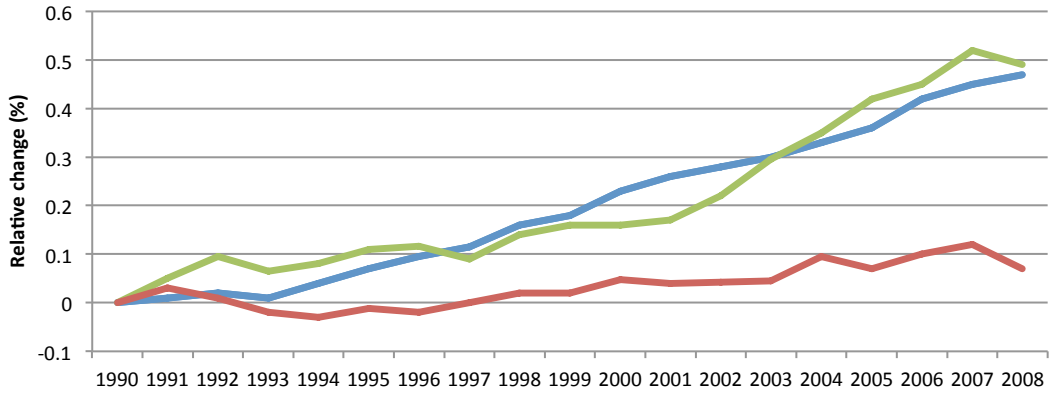

Figure 3: Trends in Europe's internal (red) and consumption-based material footprints (green), and GDP (blue)

Note: "Europe" here aggregates the 27 member states of the EU in 2012.

Source: data from Wiedmann et al. 2013

Climate

The underlying risks associated with transgressing the planetary boundary on climate change (a critical loads boundary) are related to extreme events, regional losses of water supplies, agricultural productivity and biomes, sea level rise, etc. The boundary has been set at 350 ppm atmospheric CO_2 concentration, or 1 watt per m^2 of additional radiative forcing compared to pre-industrial levels, which should keep global warming below 2°C (Rockström et al. 2009a).

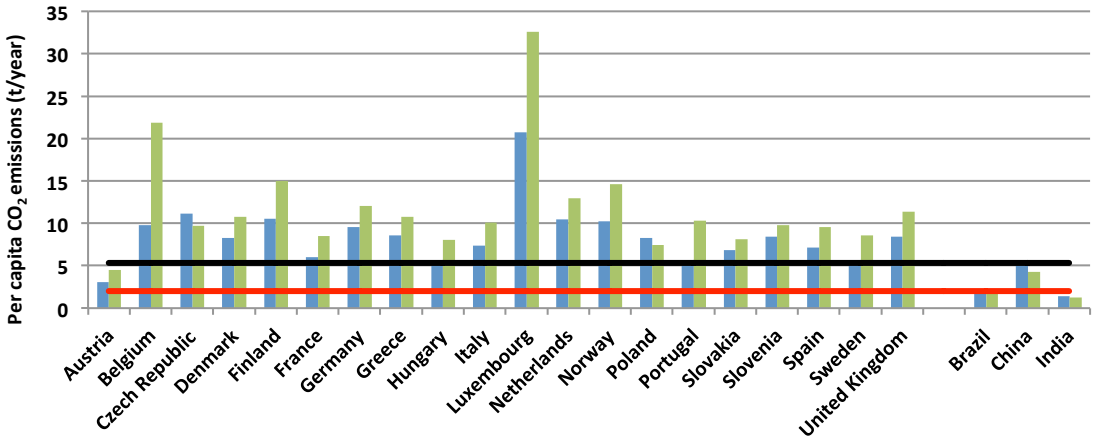

Figure 4: Per-capita territorial and consumption-based CO_2 emissions of 20 EU member states and global average, compared with 3 major emerging economies and equal per capita allocation boundary

Blue bars = territorial emissions; green bars = consumption-based emissions; black line = global average; red line = equal per capita emissions allocation to stay within boundary.

Sources: Nykvist et al. (2013), CDIAC (2012), Peters et al. (2011).

Equal per capita allocations to all inhabitants of the planet Earth of this truly global boundary (not depending on local context) would translate to allowable annual CO_2 emissions of 2 tons per capita (Nykvist et al. 2013). Figure 4 shows that emissions in all European countries are far beyond that boundary (red line) and also above the actual global average of 5.3 tons (black line). This is true for

internal emissions (blue bars), but even more so for consumption-based emissions (green bars). This planetary boundary is already exceeded globally by more than 100%.

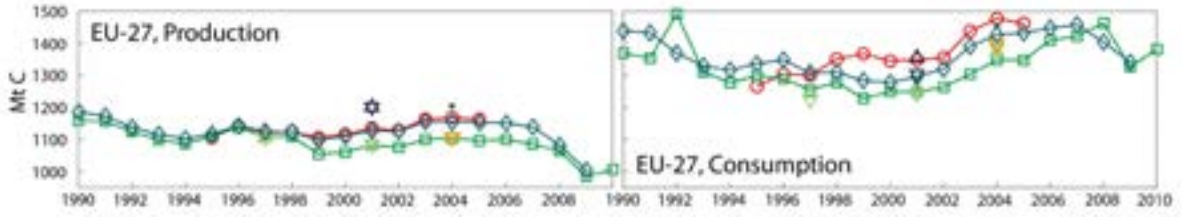

Figure 5: Trends in EU's production-based (territorial) vs consumption-based CO_2 emissions, 1990–2010

Note: The figure compares several global models of CO_2 emissions embodied in traded goods and services. See Peters et al. (2011) for more detail about sources and methods.

Source: Peters et al. 2011.

Figure 5 shows trends. While Europe's territorial CO_2 emissions (left) have been decreasing over the past two decades, consumption-based emissions have been more or less stable or even grown during some periods (right). This is another indication of the growing externalization of Europe's environmental pressures and footprints.

Water

The underlying risks associated with transgressing the planetary boundary on water (a resource boundary) are related to losses of aquatic, and possibly also terrestrial, ecosystems and biodiversity (see e.g. MA 2005, Pastor et al. 2013), as well as disruptions of the hydrological cycle and subsequently the climate system (Douglas et al. 2009, Marengo et al. 2009). While the latter of these risks may affect the functioning of the Earth system, the former are more context-specific and locally relevant.

An equal per capita allocation of the original planetary boundary (maximum total consumptive blue water use of 4000 km^3 per year, according to Rockström et al. 2009a) would translate to an allowable annual blue water use of 570 m^3 per capita per year (Nykvist et al. 2013). (Blue water is fresh surface and ground water.) Figure 6 shows that most European national internal water use and all consumption-based water use exceeds this boundary (red line) and even more so the global average blue water use of 150 m^3 per capita per year (black line).

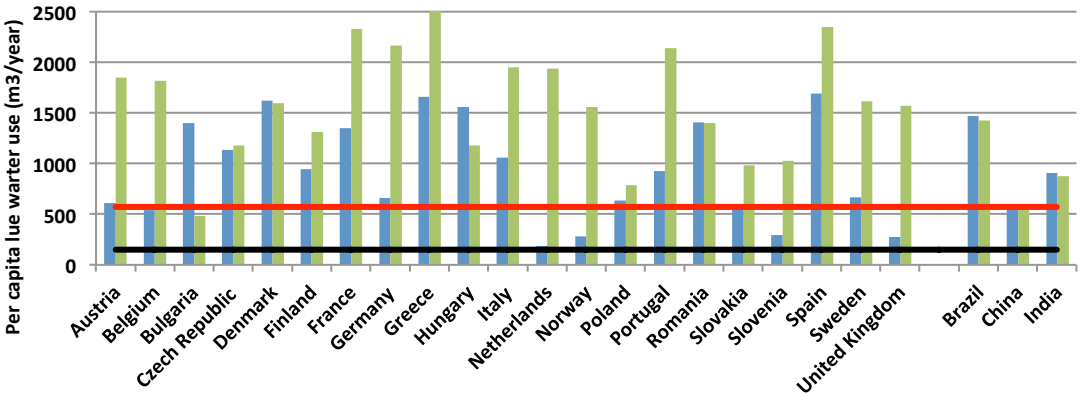

Figure 6: Per capita blue water use of 20 EU member states, compared with 3 major emerging economies, global average and boundary

Blue bars = territorial use; green bars = consumption-based use; black line = global average; red line = equal per capita resource use allocation to stay within boundary.

Source: Lenzen et al. 2013

The externalization beyond national boundaries of pressures on water resources has been growing rapidly: total virtual water associated with traded goods has doubled over the past two decades (Dalin et al. 2012), while total water withdrawals and consumptive use have only grown by about one-third during that period (Waha et al. 2013). Europe, with its rapidly growing agricultural net agricultural imports (von Witzke et al. 2011), is in line with this trend.

An equal per capita allocation of water use according to the original planetary boundary is only of limited practical and policy value, because it does not account for differences in local context. For that reason Lenzen et al. (2013) have begun to include contextual information in their global water footprint analysis by weighing virtual water exports with the respective national level of water scarcity (expressed by the ratio of withdrawals to available renewable resources) in the exporting region. They find, for example, that Germany, being number 19 globally in terms of consumption-based water use, moves up to number 5 in terms of consumption-based water use originating from water-scarce countries. Nykvist et al. (2013) also suggest including water scarcity when defining context-specific downscaled water boundaries, for example by limiting allowable consumptive water use to 40% of available renewable resources. Further suggestions for context-specific local water boundaries are discussed in section 2.2

Land

The underlying risks associated with transgressing the planetary boundary on land (a resource boundary), i.e. transforming more than 15% of total ice-free land into cropland, are related to the loss of carbon storage and changes in land albedo (risks to the climate system; Luyssaert et al. 2014), and loss of moisture recycling (risks to water supply)[4] and of terrestrial ecosystems and biodiversity (Foley et al. 2005). While all of these pose risks to the functioning of the Earth system, they are strongly context-specific, depending on the type of biome, land cover, vulnerability to change and other local parameters.

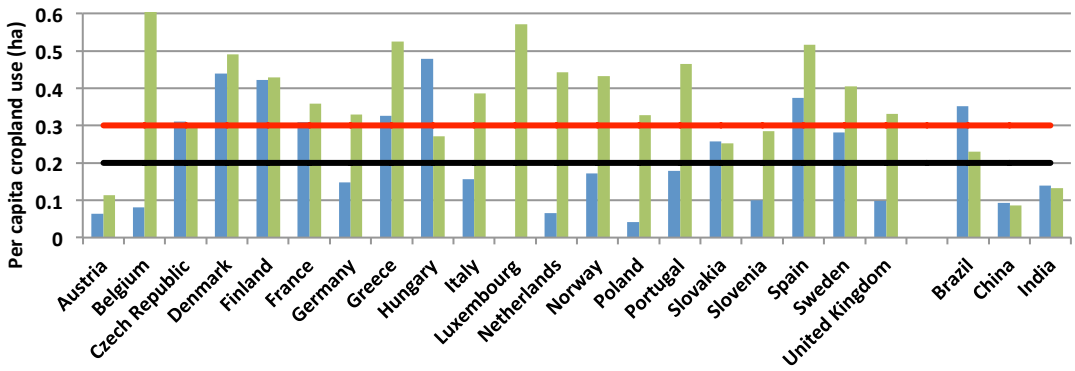

Figure 7: Per capita (crop)land use in 2004 of 20 EU member states, compared with 3 major emerging economies, global average and boundary

Blue bars = territorial use; green bars = consumption-based use; black line = global average (based on incomplete list of countries); red line = equal per capita resource use allocation to stay within boundary.

Sources: FAOSTAT; Bruckner et al. (2012); Nykvist et al. 2013

An equal per capita allocation of land use according to the original planetary boundary (according to Rockström et al. 2009a) would translate into per capita cropland use of 0.3 hectares, or alternatively

[4] Moisture recycling is the re-evaporation or transpiration of precipitation from land surfaces, so it becomes atmospheric moisture again, which feeds new precipitation further downwind (Savenije 1995; Keys et al. 2012).

limiting each nation's cropland area to 15% of its total land (Nykvist et al. 2013). According to the ongoing revision of this planetary boundary, a minimum of 85% of the natural forest cover would have to be maintained in tropical and boreal regions and 50% in temperate regions.

Figure 7 shows that only a few European countries exceed the uniform per capita allocation of 0.3 ha per capita (red line) on their territory (blue bars; largely as a result of their high land productivity), but most do so when their external land use is considered. Europe's high total consumption-based land use (green bars), high also relative to the global average per capita land use of 0.2 ha per capita (black line), and according to one calculation makes the EU15 the largest net importer of total virtual land, importing in total 4 times more than, e.g., China, which has a more than three times larger population than the EU15 (Lugschitz et al. 2011).

The externalization of pressures on land has been growing rapidly: Europe's net virtual land imports with agricultural commodities increased between 2000 and 2008 from about 25 to 35 million ha (excluding grassland), an area equivalent to the size of Germany (von Witzke et al. 2011). More detailed decomposition of the EU food sector confirms this trend of decreasing territorial agricultural land use, at the cost of increasing external land use and increasing net virtual land imports (Kastner 2014). As in the case of water, equal per-capita allocation of the land boundary is of limited practical and policy value, given the need for context-specific sustainability boundaries. A starting point for defining context-specific land boundaries is provided by the ongoing revision of this planetary boundary. This revision specifies different minimum fractions of land cover for different types of forest (tropical, temperate, boreal), according to their relative importance in the climate system and Earth system functioning.

Further suggestions for context-specific local land boundaries are discussed in section 2.2.

Biodiversity loss

The underlying risks associated with transgressing the planetary boundary on biodiversity loss (a safe minimum standards boundary) are related to increasing vulnerability to disturbances and shocks, and loss of the respective ecosystem functions and services. Cardinale et al. (2012) also find that biodiversity is positively correlated with natural resource productivity, so that the transgression of the biodiversity boundary is likely to affect biocapacity and to also interact with the water and land boundaries.

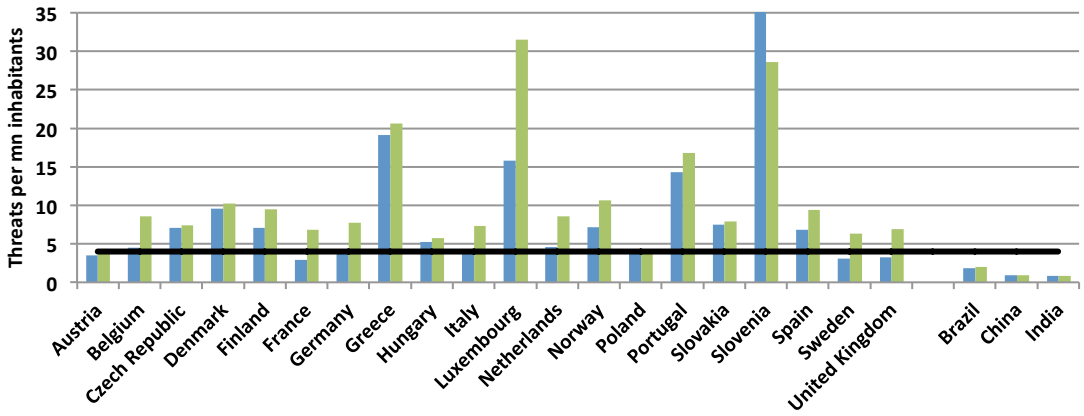

Figure 8: Threats to red listed/protected species per million inhabitants in 20 EU member states, compared with 3 major emerging economies and global average

Blue bars = from production-based pressures; green bars = from consumption-based pressures; black line = global average (based on incomplete list of countries).

Sources: Lenzen et al. 2012, Nykvist et al. 2013.

Lenzen et al. (2012) calculated the threats to biodiversity from internal or territorial pressures vs. those from consumption-based pressures (Figure 8), by linking the production of certain export commodities to risks for red list species. This analysis gives the same message for biodiversity as for the other planetary boundaries: most European countries exceed by far global per capita averages, in particular when accounting for consumption-based pressures, as calculated via MRIO analysis.

Here a direct comparison to the planetary boundary of 10 extinctions per million species per year, or 1% of the natural rate (according to Rockström et al. 2009a) is not possible.

Further suggestions for context-specific local biodiversity boundaries are discussed in section 2.2.

Biogeochemical cycles: phosphorus and nitrogen

The underlying risks associated with transgressing the planetary boundaries on phosphorus (P) and nitrogen (N) (with both being critical loads boundaries, but P also a resource boundary) are related to acidification, eutrophication and anoxia of terrestrial, aquatic and marine systems (Carpenter et al. 2011). These are primarily local risks with indirect effects on the functioning of the Earth system, and the potential, but uncertain risk for larger global anoxic events. In the case of phosphorus, there is an additional important global resource limitation with implications for global food security (see e.g. Cordell et al. 2011 on the "peak phosphate debate").

An equal per capita allocation of the planetary P boundary (11 Mt per year inflow into oceans or 10 times the natural background weathering of P, according to Rockström et al. 2009 a) would translate to about 1.5 kg P per capita per year, and of the N boundary (35 Mt N per year synthetic nitrogen fixation, according to Rockström et al. 2009a) to about 5 kg N per capita per year. Most European countries significantly exceed these per capita values on their territories (Nykvist et al. 2013). Unlike the boundaries presented above, no analysis of external total P and N emissions resulting from total consumption of countries is available yet. Liu et al. (2012) provide an indication of the externalization of environmental pressures in terms of P and N emissions. They show increasing water pollution levels for most P and N compounds in some regions that are producers for export to Europe (e.g. China), while European levels are generally declining.

Other planetary boundaries are only briefly listed below, because there is no full analysis available yet. In particular, there is no analysis of full consumption-based pressures or there is no need for distinguishing between internal and external pressures for those boundaries that are truly global (all emissions contributing to a common global pool).

Stratospheric ozone depletion

The underlying risks associated with transgressing this (safe minimum standards) boundary are related to damages to human health and ecosystems from increased UV radiation (Lloyd 1993, Smith et al. 1992).

While this truly global boundary (set to 5% below the pre-industrial O_3 level of 276 DU, according to Rockström et al. 2009a) was transgressed in the 1980s, trends since then have been reversed and average ozone layer thickness is gradually building up (Douglass 2010). Following the Montreal Protocol, Europe's consumption of controlled (ozone-depleting) substances has been reduced to zero; however, there still seems to be some import, processing and export of those substances by the EU (EEA 2013).

Ocean acidification

The underlying risks associated with transgressing this (critical loads) boundary are related to threats to marine biodiversity including coral reefs and loss of marine carbon sinks (Schubert et al. 2006).

This truly global boundary (80% of pre-industrial aragonite saturation state, according to Rockström et al. 2009a) is closely linked to climate change and hence similar issues of interpretation, translation and downscaling for the European context apply as discussed for the climate boundary.

Chemical pollution

The underlying risks associated with transgressing this (critical loads) boundary are related to adverse effects on human and environmental health as well as impacts on vital earth system processes (UNEP 2013, Persson et al. 2013). Rockström et al. (2009a) does not specify a boundary for chemical pollution, but Persson et al. (2013) have subsequently developed a global approach for identifying critical chemicals that pose threats to a chemical pollution planetary boundary. They identify the following three criteria: i) a disruptive effect on a vital Earth system process, ii) the disruptive effect becomes a problem at the planetary scale, and iii) it cannot be readily reversed. Persistence of a chemical, extent of its emissions and long-range transport can all contribute to the transgression of the planetary boundary on chemical pollution. A context-specific downscaling of such a boundary (yet to be developed) might also take into account the technical remediation/clean up capacity of the respective region.

Atmospheric aerosol loading

The underlying risks associated with transgressing this (critical loads) boundary are related to the interference with the climate system, including potential disruption of monsoon systems – posing threats to the functioning of the Earth system – and human health and potentially food security effects. However, the complexity and spatio-temporal variability of different particles, sources, and impacts make it currently impossible to define a planetary boundary.

2.2 Developing context-specific boundaries for Europe

The planetary boundaries framework was not in the first place constructed to derive local, national or regional environmental boundaries, and hence it does not take into account context-specific resource scarcities, critical loads and specific environmental vulnerabilities. The fact that Europe's landscapes have been changed so much from their original "natural" state makes it even more difficult than for many other regions to downscale and apply the planetary boundaries, which have largely been defined as allowable deviations from an assumed natural state. Below are some initial suggestions for taking into account the specific local context when developing boundaries of sustainable resource use or emissions for Europe.

Water

As mentioned in section 2.1, Lenzen et al. (2013) have begun to include contextual information in their global footprint analysis by weighing virtual water exports with the respective national level of (blue) water scarcity – in this instance, the ratio of water withdrawals to available renewable resources.

A next step in context-specific definition of environmental water boundaries is to constrain allowable withdrawals within the water requirements of aquatic ecosystems (so-called environmental flows). Pastor et al. (2013) have classified river basins in different world regions according to their flow regimes (e.g. monthly low and high flows) and calculated typical environmental flow requirements per flow regime for the world's river basins. Gerten et al. (2013) have used these environmental flow requirements per river basin to calculate a new bottom-up planetary water boundary, arriving at a stricter boundary of about 2800 km^3 per year compared to Rockström et al. 2009a.

Further definition of context-specific environmental water boundaries in Europe also needs to account for water quality constraints. Eventually, water boundaries also need to address the so-called green

water: soil water used by natural and agricultural vegetation and its interactions with other, in particular land, boundaries. Rockström et al. (2009b) claim, for example, that about 90% of natural green water flows are required to sustain critical ecosystem services.

Land

As mentioned in section 2.1, the current revision of the planetary land boundary begins to address land use/land cover context. It does so by specifying different minimum fractions of forest cover to be maintained for tropical, temperate and boreal systems, according to their relative importance in the climate system and for Earth system functioning.

However, the definition of context-specific environmental land boundaries for Europe needs to take into account several additional criteria. These include, for example, the local vulnerability of landscapes to degradation, and the services provided by and required from the original and current ecosystems respectively (local services such as water and food provisioning including pollination, but also global services such as carbon sequestration, albedo and moisture recycling), as well as biodiversity and its importance and vulnerability (e.g. to fragmentation). Eventually, environmental boundaries for land use need to specify allowable land use intensities, e.g., in terms of cropping, grazing and forestry, as well as land to be protected in a close-to-nature state, in close coordination with other environmental boundaries.

Biodiversity loss

As mentioned in section 2.1, the original planetary biodiversity boundary of 10 extinctions per million species per year, or 1% of the natural rate, is not very helpful for defining context-specific environmental boundaries at local, national or regional scale, nor is it of practical use for policy making. For that, a better understanding of local biodiversity, critical species, natural extinction rates, and vulnerabilities to and consequences of biodiversity loss would be required. Lenzen et al. (2012), for example, take a first step towards that end by relating local red-listed and protected species to the effects of export production and their global MRIO trade analysis (see Figure 7).

Furthermore, the definition of boundaries of biodiversity loss in Europe needs to account for additional criteria such as previous extinction history and time lags between pressures and extinction of species (see Dullinger et al. 2013). Links to other boundaries – e.g. the land boundary – need to be elaborated. An example is Aichi biodiversity target 11 (Strategic Plan for Biodiversity 2011-2020, Convention on Biological Diversity), which requires 17% of land area to be protected. This illustrates the ultimate goal of establishing interlinked (systemic) environmental boundaries for Europe, informed by multi-criteria trade-off analysis (see discussion on multi-functional landscapes by, e.g., Phalan et al. 2011 or Tscharnke et al. 2012).

Phosphorous and nitrogen

Critical loads boundaries, e.g. the proposed limit of 160 mg P per m^3 of river discharge (Carpenter et al. 2011) or maximum nitrate concentrations in groundwater, are more promising avenues for eventually deriving context-specific environmental boundaries and evidence for policy-making in Europe, compared to a simplistic downscaling of the original planetary boundaries. In order to fully account for local context, additional sustainability criteria need to be developed. One approach is to include specific nutrient retention capacities of soils, landscapes and water sheds and their vulnerabilities to eutrophication or acidification.

Analogously to the above examples of planetary boundaries for water, land, biodiversity, phosphorous and nitrogen, relevant parameters could probably also be identified for some of the other planetary boundaries for meaningful application of the framework to specific contexts within Europe and to guide policy-making. However, these may eventually only very vaguely be related to the original

planetary boundaries. Accordingly, the planetary boundaries provide only very indirect policy guidance along this line of their interpretation for Europe.

2.3 Uncertainties and open issues

A number of uncertainties and open issues have been identified in sections 2.1 (Europe's internal and external contributions to transgressing global environmental boundaries) and 2.2 (developing context-specific environmental boundaries within Europe, consistent with the planetary boundaries):

- Neither the current planetary boundaries nor their temporal dynamics have been fully specified yet. Impacts of boundary transgression may lag behind the actual transgression (see e.g. Dullinger et al. 2013), and the consequences of these transgressions are not yet understood well. This is particularly true for the loss of biodiversity.
- Interactions and positive or negative feedbacks among planetary boundaries have not been explored yet, but need to be accounted for when applying the planetary boundary framework in European policy-making.
- Many of the requirements for specifying local context – as described in section 2.2 – simply cannot be met with the current state-of-the-art in science. Any boundary setting must hence be provisional and therefore subject to revision. For many European environmental indicators, such as material flow or energy efficiency, critical thresholds have not been defined yet, complicating the application of the planetary boundaries framework to European policy making further.

The interpretation of the planetary boundaries as presented in section 2.1 – European internal and external contributions to transgressing global environmental boundaries – provides important information for European policy-making, in particular the objective of "living well, within the limits of our planet". However, the interpretation of the planetary boundaries via downscaling to context-specific environmental boundaries within Europe (as in section 2.2) seems to be of limited value to European policy-making.

3. RELEVANCE OF THE PLANETARY BOUNDARIES FOR EUROPEAN POLICY-MAKING

While the planetary boundaries were not originally developed to support policy-making, there are some implications for better-targeted environmental indicators and goals, in support of consistent multi-level and cross-sectoral policy-making in Europe, and for achieving the goal of "living well, within the limits of our planet". This section identifies and discusses key areas of concern for policy-making, summarized as knowledge gaps, policy gaps, and implementation gaps.

These "gaps" – between what is needed and the level of current knowledge, policy targets and performance – are illustrated in Figure 9 below. On the left in the figure is the environmental or planetary boundary, with the "safe space" being the green area to the left of the boundary (PB). To the right of the boundary are first the relevant policy goals and targets (which are in many cases outside the safe space, resulting in "policy gaps"). While the EU has set several goals that lie within the boundaries for its own territory, boundaries may still be transgressed either due to internal implementation gaps or, even more so, through the externalization of Europe's environmental pressures and footprints. In Figure 9, "actual performance (territorial)" and "actual performance (consumptive)" indicate the two implementation gaps responsible for these boundary transgressions. Finally, a "knowledge gap" (which is not directly indicated in the figure), can be viewed as introducing uncertainty about where the specific points are (or should be) on the line. Current knowledge is insufficient all along the line of Figure 9. Note that not all gaps depicted in Figure 9 necessarily exist for all boundaries.

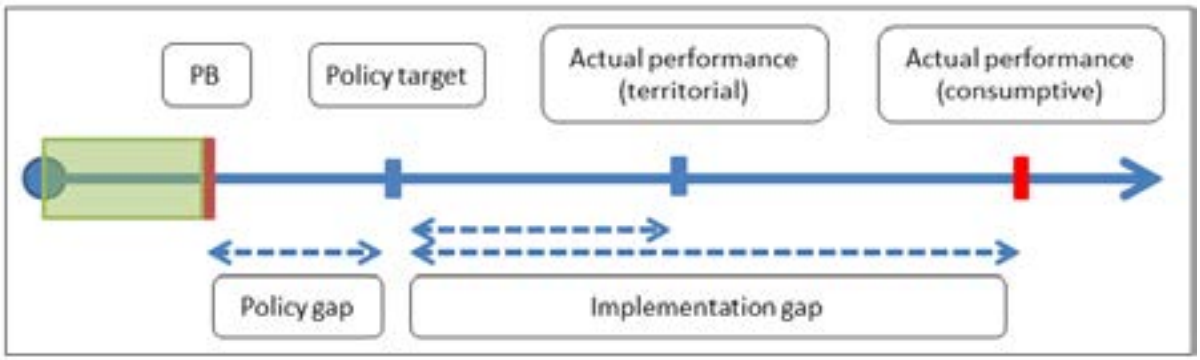

Figure 9: Policy gaps and internal and external implementation gaps

Source: Adapted from Nykvist et al. 2013 in their application of the planetary boundaries framework to the European context.

Knowledge gaps: The metrics used within the EU to measure environmental performance and progress do not necessarily correspond with the scope/location of the problem. As illustrated in this report, even as Europe manages to reduce environmental pressures and improve resource use efficiency within its borders, some of this improvement comes through exporting negative externalities. While these environmental pressures may be reasonably well understood in Europe, the external pressures are more challenging to accurately quantify. The change in geographical context may generate different kinds of interactions, with unexpected feedbacks in Europe via supply chain disruptions, social/political instability, or unexpected pressures on global environmental boundaries. The challenge is similar at the level of global boundaries, where the key thresholds in non-linear processes or interactions between the different boundaries are not known. Here, more scientific research is needed to fill out important – and also policy-relevant – gaps in both detailed knowledge and in how the systems interact.

Policy gaps: Figure 9 illustrates how goals and policies might fall short of what is known to be needed, given current knowledge, to stay within environmental boundaries. This is one type of problem to which the EU dedicated considerable energy and effort, and as a result, has achieved significant improvements. Important gaps do remain, as illustrated in ways in which the modesty of the recent reforms of the Common Agricultural Policy leaves the policy falling short of many of the goals identified in discussions leading up the reform (Carson 2013). The even more difficult challenge, however, is getting policy leverage on indirect or external pressures outside of Europe's borders. Many of the commonly available tools are imprecise (product standards), are difficult to agree upon and enforce (international conventions), and may conflict with other priorities of either the EU or of the countries in which the activities are taking place (employment opportunities, economic development, reducing poverty).

Implementation gaps: While this type of shortfall can be interpreted in simple terms as the gap between policies and plans made and results delivered, it can also be a function of insufficient knowledge of the nature or causes of the problem, leading to policies that when implemented are effective at changing the intended parameters, but do not solve the underlying problem. Implementation and achieving intended aims may also be frustrated by incompatibilities between policies in different sectors, which may have been designed to achieve conflicting or mutually incompatible aims. One example of how to identify leverage points in such instances is the work analyzing policy (in)coherence. Research on environmental policy in EU shows that policy visions are often coherent with regard to societal and environmental targets, but study of actual policy implementation reveals large discrepancies and incoherence between policy sectors (Nilsson et al. 2012). Shortfalls in implementation can also be caused by the challenges inherent in enforcing the changes in practice required by new policies, the time and resources required to retool existing

infrastructure, and the need to overcome various types of opposition, as identified in the research on major societal changes in response to environmental or comparable challenges (for example, Spargaren and Mol 1992; Schnaiburg and Pellow 2002; Loorbach 2007; York et al. 2010).

4. CONCLUSIONS

This report demonstrates that Europe's per capita environmental footprints are significantly larger than global averages, in particular when externalized pressures associated with Europe's imports for local consumption are taken into account. This also illustrates in a new way the principle of common-but-differentiated responsibilities for planetary stewardship. Responsibilities for better stewardship in this case are related to countries' internal and external environmental footprints. This has important implications for Europe's consumption and trade patterns, and for policies and measures to address those, such as the proposed new European Environment Action Programme.

Implications for Europe to reduce its internal, external and total footprints are not limited to environmental policies (which primarily address internal footprints) but also include, for example, agricultural, industry, economic, trade and development cooperation policies and the coherence among these. For example, the principle of the Roadmap to a Resource-Efficient Europe of "no net land take by 2050 ***in*** the EU" with planetary stewardship in mind would need to be reformulated to "no net land take by 2050 ***by*** the EU". Sweden is a forerunner in this respect,already having adopted a "generational goal" of not increasing environmental problems beyond its borders, i.e. of not exporting environmental problems (Nykvist et al. 2013).

Coherence between internal and external European policies towards better planetary stewardship is also important as a positive example, in view of the fact that Europe's share of global consumption is shrinking as the rapidly growing middle class in other parts of the world adopt resource-intensive lifestyles and consumption patterns similar to those of Europe. The growing external environmental pressures of Europe itself also suggest a need for closer cooperation, in particular with less-developed (exporter) countries. Transfer of knowledge and technology can help to increase resource use efficiencies and to reduce emission intensities globally, and eventually also to reduce Europe's external footprints. Such cooperation could promote sustainable intensification (Godfray et al. 2010) and support true decoupling of economic development from environmental footprints. Within Europe, better information of customers also about external footprints can support sustainable production and consumption patterns.

The planetary boundaries framework provides some guidance on the allowable total footprints and the European contribution to these. However, it was not designed to address local and regional sustainability concerns, and hence alone cannot guide EU efforts towards sustainability. Therefore, on the research side there is a clear need to adapt and downscale the planetary boundaries and to develop analytical tools for determining sustainability boundaries across scales, resources and sectors, which account for context-specific resource limitations, critical loads and environmental vulnerabilities. Interactions between and among environmental boundaries and different policies and their coherence need to be addressed, e.g. via multi-criteria analyses and multi-stakeholder platforms.

The "boundaries" perspective should be broadened to also include opportunities (see e.g. DeFries et al. 2012) as arising from interactions among boundaries (e.g. the potential positive effects of carbon fertilization with higher atmospheric CO_2 concentration, and resulting improvements in land and water resource use efficiency), or from technological progress, lifestyle changes or other factors. Eventually, environmental boundaries such as those proposed by Rockström et al. (2009a) also need to be integrated with socio-economic boundaries, as previously attempted by Raworth (2012) or currently through the development of Sustainable Development Goals, see e.g. Weitz et al. (2014).

To conclude, Europe is externalizing a large and growing part of its environmental footprints, which runs counter to Europe's objective of "living well within the limits of our planet". The planetary boundaries framework offers useful guidance for more sustainable production and consumption patterns, but it cannot be used yet to specify in detail local and regional sustainability boundaries and the required measures to meet those. For that it will be necessary to further elaborate context-specific criteria that can be the basis for developing policy-oriented sustainability boundaries across scales and regions.

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