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Planetary boundaries: Challenges for science, civil society and politics

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Planetary boundaries: Challenges for science, civil society and politics

Final report

by

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Kurzbeschreibung

Das Konzept der Planetaren Grenzen wurde 2009 durch eine internationale Forschergruppe um Johan Rockström formuliert und 2015 durch Will Steffen und weitere Wissenschaftlerinnen und Wissenschaftler überarbeitet und aktualisiert (Rockström et al. 2009; Steffen et al. 2015b). Das Konzept entstand vor dem Hintergrund des Zeitalters des Anthropozäns, das verbunden ist mit einem schnell wachsenden Druck auf die Umwelt und immer stärkerer Degradation und Verknappung von globalen Umweltgütern und einer möglichen Gefährdung der Funktionen des Erdsystems. Die Belastung der globalen Umwelt und Ökosysteme durch den Menschen hat ein Ausmaß erreicht, bei dem plötzliche nicht-lineare systemische Veränderungen nicht mehr auszuschließen sind.

Das UFOPLAN-Vorhaben ‚Planetare Grenzen – Anforderungen an die Wissenschaft, Zivilgesellschaft und Politik' (FKZ 3714 100 0) setzt an der Herausforderung der Operationalisierung des Konzeptes der Planetaren Grenzen an. Ziel war es, die Anforderungen, die das Konzept an Politik, Wissenschaft, Zivilgesellschaft und Wirtschaft stellt, zu analysieren und entsprechend konkrete Informationen für die politische Umsetzung des Konzepts bereitzustellen. Dafür wurden Querschnittspapiere erstellt, die sich mit Themen beschäftigen, die für diverse politische Prozesse von Bedeutung sind – wie bspw. das kommunikative Potenzial des Konzepts, Risiken bei Grenzüberschreitung und der Methodologie zur Operationisierung. Außerdem wurden Papiere zu politischen Fokusthemen erarbeitet, die sich mit der Frage auseinandersetzen, in welcher Weise das Konzept der Planetaren Grenzen an einzelnen Stellen der Umweltpolitik sinnvoll eingesetzt werden kann, bspw. bei der Erarbeitung einer nationalen Stickstoffstrategie sowie des Integrierten Umweltprogramms 2030.

Wichtige nächste Schritte für die Operationalisierung des Konzeptes stellen u.a. eine stärkere Aufnahme der Planetaren Grenzen in Nachhaltigkeitsstrategien sowie die Ausrichtung der Wissenschaftsförderung auf die integrierte Weiterentwicklung des Konzeptes dar.

Abstract

The planetary boundaries concept was formulated in 2009 by an international research group led by Johan Rockström, and revised in 2015 by Will Steffen and colleagues (Rockström et al. 2009; Steffen et al. 2015b). The concept emerged against the background of the Anthropocene – a period of time associated with rapidly growing environmental pressures, and increasing degradation and scarcity of global environmental resources, which intensifies risks for the stability and functioning of the Earth system. The human burden on the global environment and ecosystems has reached a level where sudden non-linear systemic changes can no longer be ruled out.

The UFOPLAN project 'Planetary Boundaries – Challenges for Science, Civil Society and Politics' (FKZ 3714 100 0) addresses the challenge of operationalizing the planetary boundaries concept. The project analyzes the requirements that the concept places on politics, science, civil society and business, with the aim of informing the political implementation of the concept. In addition to cross-sectional papers that deal with topics of significance for various political processes (e.g., the potential for environmental communication, risks associated with transgressing boundaries and a methodology for operationalization), political focus topics were addressed. The political focus topics address questions of how the planetary boundaries concept can be applied to specific environmental policymaking areas (e.g., the formulation of a national nitrogen strategy and the Integrated Environmental Programme 2030).

Important next steps for the operationalization of the concept include the stronger inclusion of planetary boundaries in sustainability strategies and a reorientation of science funding toward the integrated development of the concept.

Table of Contents

List of Figures 8

List of Tables 11

List of abbreviations 13

Kurzzusammenfassung 15

Summary 16

Ausführliche Zusammenfassung 17

Detailed summary 46

1 Cross cutting issues 73

1.1 Das Konzept der Planetaren Grenzen – Chance für nachhaltige Entwicklung, Perspektiven für eine integrative Umwelt- und Nachhaltigkeitspolitik 73

1.1.1 Einleitung 73

1.1.2 Übersicht über die Planetaren Grenzen 73

1.1.3 Weiterentwicklung der Planetaren Grenzen seit 2009 77

1.1.4 Nationale (und regionale) Anwendungen des Planetare Grenzen-Konzepts 81

1.1.4.1 Schweden 82

1.1.4.2 Schweiz 82

1.1.4.3 Europa 82

1.1.4.4 Südafrika 82

1.1.4.5 China 82

1.1.5 WBGU-Politikpapier (2014) und DIE Current Column (2015) 83

1.2 Planetary Boundaries: current status, trends, risks, criticality – what do we know, and what do we need to know? 84

1.2.1 Introduction 84

1.2.2 Boundaries 87

1.2.2.1 Climate change 87

1.2.2.2 Ocean acidification 91

1.2.2.3 Stratospheric ozone depletion 94

1.2.2.4 Biosphere integrity 96

1.2.2.5 Land-system change 100

1.2.2.6 Biogeochemical flows, N and P 103

1.2.2.7 Freshwater use 107

1.2.2.8 Atmospheric aerosol loading 111

1.2.2.9 Novel entities 112

1.2.3 Systems view, synthesis and conclusions, bringing the boundaries together 114

1.2.3.1 Comparison of the different boundaries 114

1.2.3.2 Systemic interactions and feedbacks between different boundaries and their role in Earth system dynamics 115

1.2.3.3 Key concerns 115

1.2.3.4 Ways forward, making the planetary boundaries work and co-generating the required knowledge for sustainability transitions 116

1.2.4 Annex 117

1.2.4.1 Glossary 117

1.2.4.2 Expert interview procedure and interview questions 120

1.2.4.3 Trend projections, description of procedure 120

1.3 Environmental policy-making in the Anthropocene 121

1.3.1 Introduction 121

1.3.2 Charting the human-nature relationship from pre-industrial times to the Anthropocene 122

1.3.2.1 Human-nature relationship over time: pre-modern Europe and the rise of the scientific revolution 122

1.3.2.2 Human-nature relationship in the Anthropocene 125

1.3.3 The Anthropocene: exploring different interpretations 126

1.3.3.1 The Anthropocene – Open for interpretation 127

1.3.3.2 Three Anthropocene interpretations 129

1.3.4 The Anthropocene: implications for environmental policy-making in a safe operating space according to each interpretation 134

1.4 Operationalization of the planetary boundaries: ways forward and first results for Germany and the EU 144

1.4.1 The planetary boundaries framework 147

1.4.2 Operationalization of the planetary boundaries – a methodology 151

1.4.3 Initial exploration and illustration of this methodology for Germany and the EU 161

1.4.4 Conclusion 171

1.5 The communicative potential of the planetary boundaries concept 171

1.5.1 Introduction: communicating planetary boundaries 171

1.5.2 Planetary Boundaries: communicative strengths 174

1.5.3 Tracing the German planetary boundaries discourse: realising the communication gap 175

1.5.4 Understanding the communication gap: communicative weaknesses of the planetary boundaries framework 180

1.5.5 Planetary boundaries: messages 183

1.5.6 Understanding the planetary boundaries framework potential: communicative functions 186

1.5.7 Understanding the planetary boundaries framework potential: target audiences 189

1.5.8 Exploiting the planetary boundaries framework potential: closing the communication gap ... 194
1.5.9 Visual language ... 195
1.5.10 Narratives and the planetary boundaries framework ... 198
1.5.11 Annex ... 203
1.6 The Planetary boundaries as social boundaries: re-framing the doughnut ... 212
1.6.1 Introduction: planetary and social boundaries ... 212
1.6.2 Combining planetary and social boundaries: understanding the debate ... 213
1.6.3 Combining planetary and social boundaries: the Doughnut Approach ... 218
1.6.4 Re-framing the debate on planetary and social boundaries ... 226
1.6.5 Where are we heading? Applying socially re-framed planetary boundaries ... 236
1.6.6 Annex ... 240
1.7 Planetary Boundaries and Burden Sharing ... 242
1.7.1 Introduction: planetary boundaries and global ecological justice ... 242
1.7.2 Global ecological justice and burden sharing: definitions ... 242
1.7.3 Planetary boundaries and global ecological justice & burder sharing: science discourse ... 243
1.7.4 Planetary boundaries and global ecological justice & burden sharing: German governmental discourse ... 245
1.7.5 Planetary boundaries and distributive justice: further potential ... 249
1.7.5.1 Principles of distributive justice for planetary boundaries burden sharing 250
1.7.5.2 Planetary boundaries and "fittingness" of distributive justice principles 250
1.7.6 Conclusion and recommendations ... 252
1.7.7 Annex ... 253
1.7.7.1 Documents, science discourse 253
1.7.7.2 Documents, governmental discourse 257
2 Focus issues ... 260
2.1 Entry points ... 260
2.1.1 Planetary boundaries and resource efficiency: pathways for a sustainable future? (workshop summary) ... 260
2.1.2 Thesenpapier: Möglichkeiten und Grenzen des Konzepts der Planetaren Grenzen für die nationale Umwelt- und Nachhaltigkeitspolitik: Integriertes Umweltprogramm und Implementierung der Agenda 2030 (Fachdialog) ... 262
2.1.2.1 Hintergrund 262
2.1.2.2 Rolle der Planetaren Grenzen in der Agenda 2030 und der Neufassung der Deutschen Nachhaltigkeitsstrategie 267
2.1.2.3 Rolle der Planetaren Grenzen im Integrierten Umweltprogramm 2030 (IUP) 268
2.1.2.4 Möglichkeiten der Operationalisierung der Planetaren Grenzen 269

2.1.2.5 Kommunikationspotenzial der Planetaren Grenzen 271

2.1.2.6 Sozio-ökonomische Anschlussfähigkeit der Planetaren Grenzen 272

2.2 Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie 273

2.2.1 Einleitung 276

2.2.2 Die Planetaren Leitplanken und Möglichkeiten des Herunterskalierens auf die nationale Ebene 279

2.2.3 Verwendbarkeit vorhandener Grenzwerte und der Planetary Boundary als Grundlage für die Bestimmung integrierter nationaler Stickstoffziele 286

2.2.4 Übersicht über relevante Modelle zur Unterstützung integrierter N-Umweltziele 289

2.2.5 Darstellung der Stärken und Schwächen des PB-Konzeptes im Hinblick auf Stickstoff-bezogene nationale Umweltziele 291

2.2.6 Handlungsempfehlungen für eine nationale Stickstoffstrategie 293

3 Ways Forward 301

3.1 Next steps for the political sector 301

3.1.1 Objectives 301

3.1.2 Next steps 302

3.2 Next steps for the scientific community 303

3.2.1 Planetary boundary simulators 305

3.2.2 SDG pathways 305

3.2.3 Socio-ecological complexity 305

3.2.4 Implementation research 306

3.2.5 Orders and ontologies 306

3.2.6 Procedural actions 306

3.3 Next steps for the private sector 307

3.3.1 Added value 307

3.3.2 Next steps 307

4 References 309

List of Figures[1]

Abbildung 1: Planetare Grenzen 17
Abbildung 2: Drei Deutungen des Anthropozäns und Einordnung der Planetaren Grenzen....................23
Abbildung 3: Vergleich der Planetaren Grenzen hinsichtlich des Konsenses für die Notwendigkeit der Grenze 30
Abbildung 4: Vergleich der Planetaren Grenzen hinsichtlich der Unsicherheit des Grenzwertes....................30
Abbildung 5: Vergleich der Planetaren Grenzen hinsichtlich der Reversibilität der Überschreitung der Grenzen und hierdurch bedingter Auswirkungen 30
Abbildung 6: Vergleich einiger Planetarer Grenzen hinsichtlich der Zeitskala der Auswirkungen von Überschreitungen 30
Abbildung 7: Kommunikationsfunktionen des Konzepts....................35
Abbildung 8: Sozialentwicklung, 1880-2010 37
Figure 9: Planetary Boundaries....................46
Figure 10: Three interpretations of the Anthropocene and the classification of planetary boundaries....................52
Figure 11: Comparison of the planetary boundaries with regard to the consensus for the necessity of the boundary....................58
Figure 12: Comparison of the planetary boundaries with regard to the uncertainty of the boundary value 58
Figure 13: Comparison of the planetary boundaries with regard to the reversibility of the crossing of boundaries and the resulting impacts58
Figure 14: Comparison of some planetary boundaries with respect to the time scale of the effects of exceedances 58
Figure 15: Communication functions of the concept 60
Figure 16: Social development, 1880-2010 66
Abbildung 17: Gegenwärtiger Status der Kontrollvariablen 79
Abbildung 18: Wechselwirkungen zwischen Planetaren Grenzen....................80
Figure 19 The planetary boundaries....................85
Figure 20: annual CO_2 emissions according to the different SSPs....................88
Figure 21: GHG emissions in Germany in million tons CO_2equiv....................89
Figure 22: Burning embers diagram for climate change, indicating the different risk levels (colors) for the different exposure units for any given warming level 90

[1] In diesem Abschlussbericht werden sowohl deutsch- als auch englischsprachige Querschnitts- und Fokuspapiere veröffentlicht. Die Abbildungen und Tabellen wurden einheitlich für den gesamten Bericht durchnummiert und je nach Sprache des Papieres deutsch- oder englischsprachig bezeichnet.

Figure 23: Time-series of surface ocean aragonite saturation globally..............92

Figure 24: Aragonite saturation for the Sargasso Sea in the North Atlantic Ocean and ocean acidification boundary 92

Figure 25: Risks for marine species impacted by ocean acidification 93

Figure 26: Trend in annual minimum ozone concentration, with slight recovery beginning after the year 2000 95

Figure 27: Stratospheric ozone under different representative concentration pathways (blue: RCP 2.6, light blue: RCP 4.5, orange: RCP 6.0, red: RCP 8.5)...95

Figure 28: Projected net change in local richness from 1500 to 2095 98

Figure 29: Trends in aggregated abundance of different bird species in different landscapes and relative to the nationally defined target..................98

Figure 30: Forest area Germany in km^2 101

Figure 31: Historic trends and future scenarios of % global forest cover, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015)...............102

Figure 32: German production- based agricultural N-balance (excess N in kg per ha), 70 kg is the goal specified in the German Sustainable Development Strategy...105

Figure 33: Historic trends and future scenarios of global P-delivery to surface waters, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015)..106

Figure 34: Historic trends and future scenarios of global consumptive freshwater (blue water) use, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015) 109

Figure 35: Water withdrawals in billion m^3 in Germany, for public water supply, mining and manufacturing industry, production of electricity and agriculture (1991-2013)..109

Figure 36: Comparison of boundaries in terms of consensus about the need for a planetary boundary 114

Figure 37: Comparison of boundaries in terms of uncertainty around the boundary value...115

Figure 38: Comparison of boundaries in terms of the reversibility of boundary transgression and resulting impacts 115

Figure 39: Comparison of boundaries in terms of timescale of impacts from boundary transgression 115

Figure 40: Anthropocene Interpretations, the Earth system and planetary boundaries...134

Figure 41: The Planetary Boundaries and their transgression status (Steffen et al. 2015a) 150

Figure 42: Production-based vs. consumption-based perspective (after Wilting et al. 2015) ... 157
Figure 43: Co-development within a safe and just space as delimited by environmental and socio-economic sustainability criteria, from Leach et al. (2013) ... 160
Figure 44: Actual environmental performance vs. PB and safe operating space, from Hoff et al. 2014 ... 161
Figure 45: Stylized emission reduction pathways for different world regions, from Den Elzen et al. (2003) ... 164
Figure 46: Annual per capita CO_2 emissions (blue: production-based, green: consumption-based), from Hoff et al. (2014). Black line: global average per capita CO_2 emissions, red line: allowable per-capita emissions according to Nykvist et al. (2013), CDIAC (2012) ... 166
Figure 47: Comparison of Europe's consumption-based, production-based and historical contribution to total CO_2 emissions – Europe is shown in blue (orange: China, green: US, purple: India, grey: all others), GCP (2015) ... 166
Figure 48: Europe's per-capita cropland use, from Hoff et al. 2014 ... 169
Figure 49: The planetary boundaries (Source: Steffen et al. 2015a) ... 172
Figure 50: Core and additional Messages of the Planetary Boundaries Framework ... 184
Figure 51: Communicative Functions ... 187
Figure 52: Number of Citations of Rockström et al. 2009 in Nature grouped by Research Areas (Source: Web of Science) ... 190
Figure 53: Revised illustration based on Steffen et al. 2015a ... 196
Figure 54: Revised Illustration with arrows building on Steffen et al. 2015a and Rockström et al. 2009 ... 197
Figure 55: Planetary Boundaries Interaction (own illustration; building on Friedrich 2013) ... 197
Figure 56: Biosphere integrity and interactions (Source: Steffen et al. 2015a) 198
Figure 57: Environmental space concept (Spangenberg 2002: 298); image annotation by Spangenberg 2002 ... 217
Figure 58: Raworth's doughnut (Raworth 2012: 4) ... 219
Figure 59: The updated doughnut (Raworth 2017b) ... 221
Figure 60: The Great Acceleration: socio-economic trends (Steffen et al. 2011b: 851) ... 227
Figure 61: Updated Illustration; socio-economic trends (Steffen et al. 2015b: 86) ... 228
Figure 62: Snapshot from Human Development Report 2016, showing regional trends in HDI values (UNDP 2016) ... 230
Figure 63: Trends in global well-being (1880-2010) ... 230

Figure 64: Publications by actor (in absolute numbers, search results for "planetary boundaries" and "Planetare Grenzen")........................246

Figure 65: Number of in-text occurrence of "justice" references in documents which mention "planetary boundaries" and "Planetare Grenzen" or synonyms (absolute numbers) 247

Figure 66: Comparison between planetary boundaries and justice, number of publications 248

Figure 67: Trends in publications on planetary boundaries and justice in the German governmental discourse 249

Abbildung 68: Schema des Zusammenwirkens naturwissenschaftlicher Analyse und normativer Festlegungen in der Diskussion um die Bewahrung eines Holozän-artigen Erdsystemzustands im Anthropozän. 264

Abbildung 69: Gesellschaftliche Megatrends verändern erdsystemare Zustandsgrößen und damit das gesamte Erdsystem (blaue Linie, Abweichung vom horizontalen Naturzustand des Holozän) 265

Abbildung 70: Vereinfachte Illustration verschiedener potenzieller selbststabilisierender Zustände des Erdsystems 266

Abbildung 71: Zwei illustrative Fälle für die Festlegung planetarer Grenzen..........267

Abbildung 72: Wirkung des Konzepts der planetaren Belastungsgrenzen auf die zwei im internationalen Diskurs dominanten Wissenschaftsrichtungen der Erdsystemanalyse und der Makroökonomie des Globalen Wandels. 273

Abbildung 73: Kritikalität der gegenwärtigen biologischen Fixierung und Düngeranwendung von Stickstoff auf Ackerflächen, gemäß einheitlich flächenbezogen herunterskalierter N-PB. NB: der Begriff „application" wird hier ungenau verwendet. 282

Figure 74: The position of planetary boundaries research between climate-oriented Earth system science and implementation oriented sustainable development SDG research...303

Figure 75: A Planetary Boundaries Science Roadmap (system understanding and system governance)...304

List of Tables

Tabelle 1: Factsheets zu den einzelnen Planetaren Grenzen.............................27

Tabelle 2: Die neun Planetaren Grenzen, ihre Unsicherheitsbereiche und ihr derzeitiger Status...80

Table 3: Climate change factsheet 87

Table 4: Ocean acidification factsheet 91

Table 5: Stratospheric ozone depletion factsheet 94

Table 6: Biosphere integrity factsheet 96

Table 7: Land system change factsheet...100

Table 8: Biogeochemical flows factsheet 103
Table 9: Freshwater use factsheet 107
Table 10: Atmospheric aerosol loading factsheet 111
Table 11: Novel entities factsheet 112
Table 12: Anthropocene Interpretations.. 128
Table 13: Core aspects of three Anthropocene interpretations 133

List of abbreviations

BMFSFJ	Bundesministerium für Familie, Senioren, Frauen und Jugend (Federal Ministry for Family Affairs, Senior Citizens, Women and Youth)
AA	Auswärtiges Amt (Ministry of Foreign Affairs)
BfN	Bundesamt für Naturschutz (Federal Agency for Nature Conservation)
BMAS	Bundesministeriums für Arbeit und Soziales (Federal Ministry of Labour and Social Affairs)
BMBF	Bundesministeriums für Bildung und Forschung (Federal Ministry of Education and Research)
BMEL	Bundesministerium für Ernährung und Landwirtschaft (Federal Ministry of Food and Agriculture)
BMF	Bundesfinanzministerium (Federal Ministry of Finance)
BMG	Bundesministerium für Gesundheit (Federal Ministry of Health)
BMI	Bundesministerium des Innern, für Bau und Heimat (Federal Ministry of the Interior, Building and Community)
BMJV	Bundesministeriums der Justiz und für Verbraucherschutz (Federal Ministry of Justice and Consumer Protection)
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur (Federal Ministry of Transport and Digital Infrastructure)
BMWI	Bundesministeriums für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry of Economic Cooperation and Development)
BUND	Bund für Umwelt und Naturschutz Deutschland (German Federation for the Environment and Nature Conservation)
ESDN	European Sustainable Development Network (Europäisches Nachhaltigkeitsnetzwerk)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change (Zwischenstaatlicher Ausschuss für Klimaänderungen)
N-boundary	Nitrogen Planetary Boundary (Planetare Stickstoffgrenze)

PB	Planetary Boundary (Planetare Grenze)
PBnE	Parlamentarische Beirat für nachhaltige Entwicklung (Parliamentary Advisory Council on Sustainable Development)
P-boundary	Phosphorus Planetary Boundary (Planetare Phosphorgrenze)
PG	Planetare Grenze (Planetary Boundary)
RCP	Representative Concentration Pathway (Repräsentativer Konzentrationspfad)
RNE	Rat für Nachhaltige Entwicklung (German Council for Sustainable Development)
SDGs	Sustainable Development Goals (Ziele Nachhaltiger Entwicklung)
SRU	Sachverständigenrat für Umweltfragen (German Advisory Council on the Environment)
SSPs	Shared Socioeconomic Pathways (sozioökonomische Pfade)
UBA	Umweltbundesamt (German Environment Agency)
UNDP	United Nations Development Programme (Entwicklungsprogramm der Vereinten Nationen)
UNEP	United Nations Environment Programme (Umweltprogramm der Vereinten Nationen)
WGBU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)

Kurzzusammenfassung

Das Konzept der „Planetaren Grenzen"[2] wurde 2009 durch eine internationale Forschergruppe um Johan Rockström formuliert und 2015 durch Will Steffen und weitere Wissenschaftlerinnen und Wissenschaftler überarbeitet und aktualisiert (Rockström et al. 2009; Steffen et al. 2015b). Das Konzept entstand vor dem Hintergrund des Zeitalters des Anthropozäns, das verbunden ist mit einem schnell wachsenden Druck auf die Umwelt, einer immer stärkeren Degradation und Verknappung von globalen Umweltgütern und einer möglichen Gefährdung der Funktionen des Erdsystems. Die Belastung der globalen Umwelt und der Ökosysteme durch den Menschen hat ein Ausmaß erreicht, bei dem plötzliche nicht-lineare systemische Veränderungen nicht mehr auszuschließen sind. Die Wirtschafts- und Konsumaktivitäten des Menschen untergraben die Kapazitäten des Erdsystems, sich selbst zu regulieren, weil die Pufferkapazität und Regenerationsfähigkeit der Umweltmedien missachtet und die natürlichen Ressourcen übernutzt werden. Insgesamt entsteht die Gefahr, so genannte *tipping points* (Kipp-Punkte) anzustoßen, die die Ökosysteme und damit letztlich auch sozial-ökologische Systeme dauerhaft aus ihrem bisherigen Gleichgewicht zu bringen oder die Resilienz des Erdsystems durch graduellen Wandel zu beeinträchtigen.

Die wichtigste Herausforderung für die weitere Bearbeitung des Konzeptes der Planetaren Grenzen stellen, neben der wissenschaftliche Weiterentwicklung die Übersetzung, Operationalisierung, Nutzbarmachung, Herunterskalierung und Anwendung des Konzepts dar – bspw. hin zu konkreten Umwelt- und Nachhaltigkeitszielen. Das UFOPLAN-Vorhaben ‚Planetare Grenzen – Anforderungen an die Wissenschaft, Zivilgesellschaft und Politik' (FKZ 3714 100 0) setzt an dieser Herausforderung an und untersucht die Stärken, Schwächen sowie Chancen und Risisken des Konzeptes. Ziel war es, die Anforderungen, die das Konzept an Politik, Wissenschaft, Zivilgesellschaft und Wirtschaft stellt, zu analysieren und entsprechend konkrete Informationen für die politische Umsetzung des Konzepts bereitzustellen.

Dafür wurden Querschnittspapiere und Fokuspapiere erarbeitet. Querschnittspapiere beschäftigten sich mit Themen, die für diverse politische Prozesse von Bedeutung sind. Gegenstand der unterschiedlichen Querschnittspapiere stellen die Einführung in das Konzept der Planetaren Grenzen, die Analyse des Wissensstandes zu Risiken bei Grenzüberschreitung sowie die Analyse des Konzeptes des ‚Anthropozäns' dar. Weitere Querschnittspapiere beschäftigten sich mit der Operationalisierung der Planetaren Grenzen, der Analyse des Zusammenspiels sozialer und planetarer Grenzen, dem Zusammenhang mit Burden Sharing sowie der Untersuchung des Umweltkommunkationspotenzials. Die Fokuspapiere setzen sich mit der Frage auseinander, in welcher Weise das Konzept der Planetaren Grenzen in der Umweltpolitik sinnvoll eingesetzt werden kann. Schwerpunkte waren die Unterstützung einer nationalen integrierten Stickstoffstrategie sowie des Integrierten Umweltprogramms 2030.

Nächste Schritte für die Operationalisierung des Konzeptes wurden im Frühjahr 2017 auf einer zweitägigen Konferenz diskutiert. Im Bereich der Politik stellen wichtige nächste Schritte unter anderem die stärkere Aufnahme der Planetaren Grenzen in Nachhaltigkeitsstrategien dar. Auf wissenschaftlicher Ebene sollte künftige Wissenschaftsförderung stärker auf die integrierte Weiterentwicklung und Operationalisierung des Konzepts ausgerichtet werden. Im Bereich der Wirtschaft umfassen wichtige weitere Schritte die Mitwirkung von Unternehmen an der Entwicklung von Methoden für die Herunterskalierung und Anwendung des Konzepts auf Unternehmensebene sowie die Analyse von unternehmensbezogenen Nachhaltigkeitsstandards und ihre Verknüpfung mit den Planetaren Grenzen.

[2] Der Begriff «planetary boundaries» kann unterschiedlich übersetzt werden, bspw. mit «Planetare (Belastungs-)Grenzen», «Planetarische (Belastungs-)Grenzen» oder «Planetare Leitplanken». Nachfolgend wird «planetary boundaries» durchgängig mit «Planetare Grenzen» übersetzt (mit Ausnahme des Kapitels 2.2, das bereits als UBA-Text 75/2017 veröffentlicht wurde; für dieses Kapitel wurde die dort verwendete Übersetzung mit «Planetare Leitplanke» übernommen).

Summary

The planetary boundaries concept was formulated in 2009 by an international research group led by Johan Rockström, and revised in 2015 by Will Steffen and colleagues (Rockström et al. 2009; Steffen et al. 2015b). The concept emerged against the background of the Anthropocene – a period of time associated with rapidly growing environmental pressures, and increasing degradation and scarcity of global environmental resources, which intensifies risks for the stability and functioning of the Earth system. The human burden on the global environment and ecosystems has reached a level where sudden non-linear systemic changes can no longer be ruled out. Economic and consumer activities disregard the buffer and regenerative capacities of environmental compartments, and overuse natural resources, undermining the capacity of Earth's system to self-regulate. Overall, there is a risk of weakening the resilience of the Earth system either through gradual change or by triggering so-called tipping points, which would permanently disrupt global ecosystems and ultimately social-ecological systems.

The most important challenge to the further development of the planetary boundaries concept – in addition to deepening the scientific foundations of the concept – is the development, translation, operationalization, utilization, downscaling and application of the concept in order to establish concrete environmental and sustainability goals. The UFOPLAN project 'Planetary Boundaries – Challenges for Science, Civil Society and Politics' (FKZ 3714 100 0) addresses the challenge of operationalizing the planetary boundaries concept. The project examines the strengths, weaknesses, opportunities and risks of the concept, and analyzes the requirements the concept places on politics, science, civil society and business, with the aim of informing the political implementation of the concept.

Individual papers address crosscutting issues and political focus topics. The papers on crosscutting issues introduce the planetary boundaries concept, analyze possible risks associated with crossing the nine boundaries, address the concept's relationship to the concept of the Anthropocene, explore ways to operationalize the concept, examine the interplay between social and planetary boundaries, consider the implications for burden sharing, and investigate the potential of the concept for environmental communication. The political focus topic papers deal with the question of how the planetary boundaries concept can be applied to specific areas of environmental policymaking. Among other things, the political focus topic papers aim to support the formulation of a national integrated nitrogen strategy and the Integrated Environmental Programme 2030.

Next steps for the operationalization of the concept were discussed at a two-day conference in spring 2017 and subsequently elaborated. In the field of politics, important next steps include the further integration of the planetary boundaries concept in sustainability strategies. At the scientific level, future science funding should be directed more toward integrated development and operationalization. In the economic domain, important next steps include engaging businesses in the development of methods for downscaling and application of the concept at the company level, and the analysis of business sustainability standards and their linkages to planetary boundaries.

Ausführliche Zusammenfassung

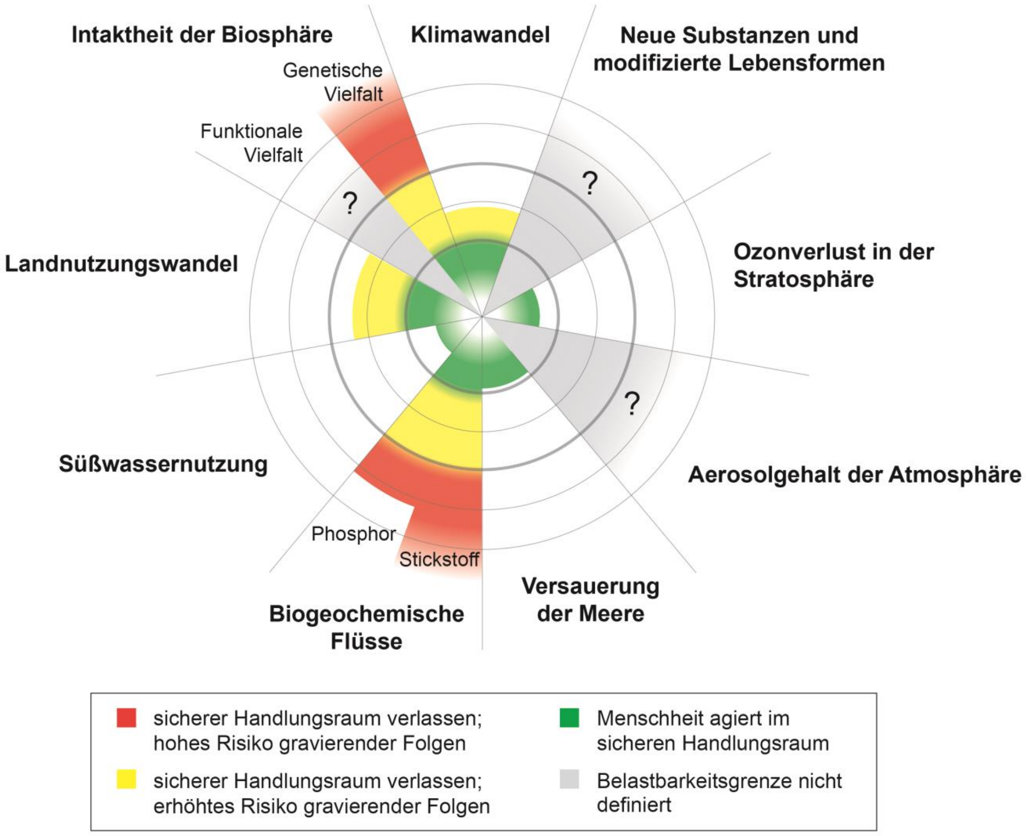
Ausgangsstellung

Das Konzept der „Planetaren Grenzen“[3] wurde 2009 durch eine internationale Forschergruppe um Johan Rockström formuliert und 2015 durch Will Steffen und weitere Wissenschaftlerinnen und Wissenschaftler überarbeitet und aktualisiert (Rockström et al. 2009; Steffen et al. 2015b). Das Konzept entstand vor dem Hintergrund des Zeitalters des Anthropozäns, das verbunden ist mit einem schnell wachsenden Druck auf die Umwelt, einer immer stärkeren Degradation und Verknappung von globalen Umweltgütern und einer möglichen Gefährdung der Funktionen des Erdsystems. Die Belastung der globalen Umwelt und der Ökosysteme durch den Menschen hat ein Ausmaß erreicht, bei dem plötzliche nicht-lineare systemische Veränderungen nicht mehr auszuschließen sind. Die Wirtschafts- und Konsumaktivitäten des Menschen untergraben die Kapazitäten des Erdsystems, sich selbst zu regulieren, weil die Pufferkapazität und Regenerationsfähigkeit der Umweltmedien missachtet und die natürlichen Ressourcen übernutzt werden. Insgesamt entsteht die Gefahr, so genannte *tipping points* (Kipp-Punkte) anzustoßen, die die Ökosysteme und damit letztlich auch sozial-ökologische Systeme dauerhaft aus ihrem bisherigen Gleichgewicht bringen, oder die Resilienz des Erdsystems durch graduellen Wandel zu beeinträchtigen.

Aufbauend auf Vorläufer- und verwandten Konzepten wie „Limits to Growth“, „Carrying Capacity“, „Critical Loads“, „Tolerable Windows“, dem Leitplankenansatz des WBGU, dem Vorsorgeprinzip sowie auf der Erdsystem- und Resilienzforschung definiert das Konzept einen globalen nachhaltigen Entwicklungsraum (*safe operating space*) und identifiziert neun Prozesse, die zentral für die Stabilität des Erdsystems sind. Dazu zählen der Klimawandel, die Versauerung der Meere, der Ozonverlust in der Stratosphäre, die Intaktheit der Biosphäre, der Landnutzungswandel, die Süßwassernutzung, biogeochemische Kreisläufe (Stickstoff- und Phosphorkreisläufe), der Aerosolgehalt der Atmosphäre und die Einbringung neuer Substanzen und modifizierter Lebensformen. Für eine Mehrzahl dieser Prozesse quantifiziert das Konzept sichere Abstände (Grenzen) zu Bereichen mit erhöhtem und hohem Risiko für gravierende Folgen. Wie Abbildung 1 illustriert, sind nach der aktualisierten Darstellung von Steffen et al. (2015a) vier der planetaren Grenzen bereits überschritten (Klimawandel, Biosphäre, biogeochemische Kreisläufe, Landnutzungswandel).

[3] Der Begriff «planetary boundaries» kann unterschiedlich übersetzt werden, bspw. mit «Planetare (Belastungs-)Grenzen», «Planetarische (Belastungs-)Grenzen» oder «Planetare Leitplanken». Nachfolgend wird «planetary boundaries» durchgängig mit «Planetare Grenzen» übersetzt (mit Ausnahme des Kapitels 2.2, das bereits als UBA-Text 75/2017 veröffentlicht wurde; für dieses Kapitel wurde die dort verwendete Übersetzung mit «Planetare Leitplanke» übernommen).

Abbildung 1: Planetare Grenzen



Quelle: angepasst und übersetzt nach Steffen et al. 2015a

Seit der Veröffentlichung der Publikation „Safe operating space for humanity“ (Rockström et al. 2009) ist das Konzept der „Planetaren Grenzen“ auf großes Interesse, aber auch auf Kritik gestoßen. Während es primär als wissenschaftliches Konzept der Erdsystemwissenschaft entwickelt wurde, ist die Anwendbarkeit des Konzepts in der Politik als Leitlinie für eine nachhaltige Entwicklung vielfach diskutiert worden, mit einem weiten Spektrum unterschiedlicher Einschätzungen dazu. Die Autoren des Konzeptes (bspw. Will Steffen, Johan Rockström etc.) betonen, dass es keinen politischen Masterplan darstelle, sondern in erster Linie einen wissenschaftlichen Ansatz für einen globalen Aktionsrahmen biete.

Kritisiert wird unter anderem, dass die planetaren Grenzen mit großen Unsicherheiten – auch hinsichtlich ihrer Dynamik – behaftet seien und ihre Kritikalität zu wenig belegt sei (also in welchem Umfang durch die Übertretung der Grenzen und Umweltdegradation nachhaltige Entwicklung gefährdet sein wird; vgl. Montoya et al. 2017). Außerdem wird angemerkt, dass die Kipp-Punkte der planetaren Grenzen möglicherweise nicht existierten – oder zumindest nicht an den genannten Punkten –, dass die vorgeschlagenen Kontrollvariablen der planetaren Grenzen nicht ausreichten und dass die komplexen Wechselwirkungen zwischen den betreffenden Umweltsektoren, die durch die planetaren Grenzen repräsentiert werden (und die daraus resultierenden *systemic thresholds*), nicht genügend beachtet worden seien. Weiterhin wird kritisiert, dass möglicherweise nicht alle genannten Grenzen Relevanz für das Erdsystem hätten, sondern sich lediglich auf lokale, kontext-spezifische Prozesse bezögen (vgl. bspw. Nordhaus et al. 2012). Aus sozial- bzw. politikwissenschaftlicher Perspektive wurde unter anderem angemerkt, dass das Konzept falsche kommunikative Signale senden könne: dass es nämlich einerseits kommuniziere, dass noch Raum bis zur Grenzüberschreitung bestehe (unterhalb der Grenze), und andererseits, dass einige Grenzen sowieso schon überschritten seien (Schlesinger 2009). So könnten sich einerseits Inaktivität und andererseits Fatalismus einstellen (vgl. Brook und Bradshaw 2013).

Das Konzept hat das Potenzial, globale Umweltprobleme in ihrer Gesamtheit (holistisch) leicht fassbar zu illustrieren, was Anschlussfähigkeit ermöglicht und gesellschaftlichen Rückhalt für politische Entscheidungen schaffen kann. Jedoch bedarf es noch einiger Forschungs- und Übersetzungsarbeit, um die bisher entwickelten Annahmen zu konkretisieren (und in nationale und regionale Politik zu übersetzen) und genauere Kenntnisse (bspw. zum Herunterskalieren oder zu den Wechselwirkungen der einzelnen planetaren Grenzen) zu erhalten.

Die wichtigsten Herausforderungen für die planetaren Grenzen sind erstens die wissenschaftliche Weiterentwicklung des Konzepts und zweitens die Übersetzung, Operationalisierung, Nutzbarmachung, Herunterskalierung und Anwendung des Konzepts – bspw. hin zu konkreten Umwelt- und Nachhaltigkeitszielen. Diese Herausforderungen sind von Wissenschaft, Politik, Privatsektor und Zivilgesellschaft gemeinsam anzugehen, weil nur durch den Austausch dieser Akteure sichergestellt wird, dass das Planetare-Grenzen-Konzept auch für zentrale Bereiche der Gesellschaft anwendbar wird.

Ziele des Vorhabens und Beschreibung des Projektverlaufs

An der zweiten zentralen Herausforderung – der Operationalisierung – setzt das UFOPLAN-Vorhaben „Planetare Grenzen – Anforderungen an die Wissenschaft, Zivilgesellschaft und Politik“ (FKZ 3714 100 0) an. adelphi, das Potsdam Institut für Klimafolgenforschung und das Stockholm Environment Institute untersuchten im Auftrag des Umweltbundesamtes und des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit die Stärken und Schwächen sowie Chancen und Risiken des Konzeptes für die Bereiche Wissenschaft, Gesellschaft, Politik und Wirtschaft. Ziel des Projektes war es, die Anforderungen, die das Konzept an Politik, Wissenschaft, Zivilgesellschaft und Wirtschaft stellt, zu analysieren und entsprechend konkrete Informationen für die politische Umsetzung des Konzepts bereitzustellen. Hierfür wurden durch das Projekt Inputs in Form von Inputpapieren in den laufenden politischen Prozess gespiegelt, um die Umsetzung des Konzepts zu unterstützen. Unterziele des Vorhabens waren (1) die Bestandsaufnahme zur Konzeptentwicklung der „Planetaren Grenzen“ und deren Quantifizierung, (2) die Auswertung für die nationale politische Praxis (z. B. integriertes Umweltprogramm, integrierte Stickstoffstrategie), (3) eine Fortführung des Dialogprozesses zu den planetaren Grenzen (Fachdialoge, Vernetzungstreffen, Abschlusskonferenz) sowie (4) die Entwicklung von Handlungs- und Forschungsempfehlungen für Politik und Wissenschaft.

Im Projektverlauf wurde das ursprünglich in einzelne Arbeitspakete strukturierte Vorhaben modifiziert, um den oben skizzierten Zielen des Vorhabens Rechnung zu tragen. Die Arbeiten wurden hierfür stärker verschränkt (grundlegende Fragen und Anwendungsfragen, naturwissenschaftliche und sozialwissenschaftliche Zugänge); konkreter Output war die Erstellung von Papieren zu Querschnittsthemen und Fokusthemen.

Querschnittspapiere beschäftigen sich mit Themen, die für diverse politische Prozesse von Bedeutung sind. Inhaltlich handelt es sich hierbei sowohl um eher naturwissenschaftlich ausgerichtete Fragestellungen als auch um eher sozialwissenschaftlich geprägte Themen. Schwerpunkte dieser Querschnittsthemen waren:

- Eine Einführung in das Thema „Planetare Grenzen“ und die Charakterisierung des Konzepts
- Die Darstellung des Wissensstands zu Dynamiken, Trendsund Risiken, die mit den Planetaren Grenzen verbunden sind;
- Die vertiefte Analyse des Konzepts des Anthropozäns als „Hintergrund“ und Prämisse der planetaren Grenzen

- Die Operationalisierung der planetaren Grenzen (im Sinne der Herunterskalierung auf handlungsrelevante Skalen) und die Verknüpfung des Konzepts mit der Analyse konsumbasierter Verlagerungseffekte
- Die Analyse des Zusammenspiels sozialer und planetarer Grenzen
- Den Zusammenhang mit Burden Sharing
- Die Untersuchung des Umweltkommunikationspotenzials der planetaren Grenzen

Neben den Querschnittspapieren wurden Papiere zu politischen Fokusthemen erstellt. Diese Papiere setzten sich aus unterschiedlichen Perspektiven damit auseinander, in welcher Weise das Konzept der „Planetaren Grenzen“ an einzelnen Stellen der Umweltpolitik sinnvoll eingesetzt werden kann. Schwerpunkte waren unter anderem die Unterstützung der Formulierung einer nationalen integrierten Stickstoffstrategie sowie des Integrierten Umweltprogramms 2030.

Nachfolgend werden die Inhalte und Ergebnisse der einzelnen Querschnittspapiere sowie einzelner Fokuspapiere zusammengefasst. Da die einzelnen Papiere als für sich stehend konzipiert wurden (mit jeweils eigener Einleitung, Analyse und Schlussteil), werden sie jeweils einzeln dargestellt. Sich wiederholende Aspekte (bspw. aus den jeweiligen Einleitungen der Querschnittspapiere) werden nur einmal erläutert.

Querschnittsfragen: Übergeordnete, politikrelevante Fragestellungen

Das Konzept der Planetaren Grenzen – Chance für nachhaltige Entwicklung, Perspektiven für eine integrative Umwelt- und Nachhaltigkeitspolitik

Das Papier charakterisiert das Konzept der „Planetaren Grenzen“, skizziert Weiterentwicklungen und diskutiert nationale und regionale Anwendungen (siehe Kapitel 1.1). Es ist konzipiert als Einführung in das Konzept, richtet sich an einen weiteren Interessentenkreis und ist teilweise in Form von Thesen strukturiert. Nachfolgend werden zentrale Punkte des Papieres hervorgehoben.

Das Konzept der „Planetaren Grenzen“ fasst insgesamt den Stand der Wissenschaft zu großmaßstäbigen Umweltgrenzen zusammen und versucht anhand von Leitplanken einen globalen nachhaltigen Entwicklungsraum (safe operating space) zu definieren. Dies geschieht mithilfe von Kontrollvariablen für die neun Umweltkompartimente bzw. -prozesse zu Klima, Biosphäre, Land, Wasser, biogeochemischen Kreisläufen, Ozeanen, stratosphärischem Ozon, Aerosolen und neuartigen Substanzen. Die Reduktion dieser komplexen Prozesse auf einzelne, gut kommunizierbare Kontrollvariablen, analog dem Zwei-Grad-Ziel, hat zu einer raschen Aufnahme des Konzepts in Politik und gesellschaftliche Diskurse geführt. So nehmen international z. B. das High Level Panel on Global Sustainability sowie das 7. Umweltaktionsprogramm der EU auf die planetaren Grenzen Bezug. Auf nationaler Ebene sind die planetaren Grenzen z. B. in das Integrierte Umweltprogramm 2030 (IUP) sowie in die Deutsche Nachhaltigkeitsstrategie eingegangen.

Die folgenden Grundprinzipien charakterisieren die planetaren Grenzen:

- Für die planetaren Grenzen ist der historische Klima- und Erdsystemzustand (das Holozän) die Referenz.
- Das wissenschaftliche Konzept der „Planetaren Grenzen“ weist auf die Risiken hin, die mit einem Verlassen des bisherigen Holozän-Zustands verbunden sind.
- Die neun planetaren Grenzen betreffen physikalische, chemische und biologische Prozesse des Erdsystems.
- Die planetaren Grenzen erweitern die Global-Change-Debatte über das Klimathema hinaus.
- Die planetaren Grenzen beschreiben den Zustandsraum des Erdsystems, in welchem nachhaltige Entwicklung möglich ist.

- Planetare Grenzen basieren auf dem Vorsorgeprinzip.
- Planetare Grenzen stellen (erd-)systemische Grenzen dar. Einige der planetaren Grenzen sind bereits überschritten.
- Die Folgen der Überschreitungen der einzelnen planetaren Grenzen sind noch nicht vollständig bekannt.
- Die planetaren Grenzen werden zunehmend räumlich explizit und auf der Ebene der handelnden Akteure, v. a. von Staaten, dargestellt.
- Innerhalb der planetaren Grenzen gibt es erhebliche Chancen für Transformationen.
- Das Konzept der „Planetaren Grenzen" hat Implikationen für die Gerechtigkeits- und Nachhaltigkeitsdebatte.
- Die wissenschaftliche Weiterentwicklung der planetaren Grenzen konzentriert sich auf deren globale Quantifizierung und regionale Anwendung.

Weiterentwicklungen der planetaren Grenzen von der ersten Publikation (Rockström et al. 2009) zu der Revision von 2015 (Steffen et al. a) umfassen z. B.:

- Die *rate of biodiversity loss* (Grad des Biodiversitätsverlustes) wurde zu *change in biosphere integrity* (Veränderung der Intaktheit der Biosphäre), wobei zusätzlich der Indikator *biodiversity intactness index* (Index der Intaktheit der Biosphäre) eingeführt wurde.
- *Nitrogen & phosphorus cycle* (Stickstoff- und Phosphorkreislauf) wurde zu *biogeochemical flows* (biogeochemische Flüsse), worunter auch (bislang noch nicht quantifizierte) Grenzen für andere Elemente wie Silizium fallen; für Stickstoff (N) und Phosphor (P) wurden zusätzlich zu den globalen Grenzwerten auch regionale eingeführt.
- Für *land system change* (Wandel der Landsysteme) wurde der Indikator „Maximal möglicher Anteil von Ackerland an der Gesamtlandfläche" zu „Mindestens zu erhaltender Waldanteil" geändert und letzterer räumlich bzw. nach Biomen differenziert (tropische, temperate, boreale Wälder).
- Die planetare Grenze für *freshwater use* (Süßwassernutzung) wird jetzt zusätzlich für jedes Flusseinzugsgebiet einzeln bestimmt, basierend auf dem Wasserbedarf aquatischer Ökosysteme (*environmental flow requirements*) und daraus der global aggregierte Wert berechnet (*bottom-up construction of the planetary boundary*, d. h. Entwicklung der planetaren Grenze aus lokalen bzw. regionalen Grenzen).
- Für *atmospheric aerosols* (Aerosolgehalt der Atmosphäre) wurde erstmals ein Grenzwert (*atmospheric optical depth* 0.25) festgelegt, allerdings nur für eine Region (South Asia Monsoon).
- *Chemical pollution* (2009) (Verschmutzung mit Chemikalien) wurde *zu introduction of novel entities*, wobei diese planetare Grenze jetzt weiter gefasst wird und auch *modified life-forms* umfasst (Einführung neuer Substanzen und modifizierter Lebensformen); hier wurden drei Kriterien für kritische Substanzen (Persistenz, Mobilität über Skalen hinweg mit entsprechend weiter Verbreitung, potenzielle Auswirkungen auf wichtige Prozesse des Erdsystems oder seiner Sub-Systeme) definiert, allerdings noch keine Indikatoren oder Grenzwerte bestimmt.
- In der zentralen Grafik, dem „Planetare-Grenzen-Kreis" (siehe Abbildung 1), wurde ein zusätzlicher gelber Bereich für erhöhtes Risiko eingeführt, sodass sich der derzeitige Status einiger planetarer Grenzen verändert hat.
- Zwei planetare Grenzen, die für Klimawandel und die für Änderungen der Biosphärenintegrität, werden jetzt als *core boundaries* (Kerngrenzen) mit besonderer Bedeutung für die Funktionsfähigkeit des Erdsystems herausgehoben; sie stellen die am stärksten systemischen planetaren Grenzen dar und interagieren mit allen anderen Grenzen.

Was die Folgen der Überschreitung von Grenzwerten betrifft, so wird jetzt differenzierter dargestellt, dass nicht alle Überschreitungen der Grenzen zu abrupten Reaktionen (regime shifts) führen müssen, sondern auch moderate bzw. kontinuierliche Reaktionen erfolgen können. Auch ist inzwischen klar, dass nicht alle Überschreitungen globale Dimensionen haben, sondern z. B. die für Wasser und Land eher lokalen bis regionalen Charakter haben. Die kumulativen Folgen vielfacher lokaler Grenzwertüberschreitungen stellen allerdings wiederum ein Risiko für die Funktionsfähigkeit des Erdsystems dar.

Durch eine beginnende räumliche Differenzierung und räumlich explizite Darstellung der planetaren Grenzen (downscaling) wird der räumlichen Heterogenität von Umweltzuständen und der Sensitivität gegenüber den zugrundeliegenden Prozessen Rechnung getragen. Damit wird auch die Integrierbarkeit in lokale Umweltziele und die Operationalisierbarkeit und Anschlussfähigkeit der planetaren Grenzen an nationale Prozesse verbessert. Ein solches downscaling ist für einzelne Grenzen wie Wasser und Land und für Länder bzw. Regionen schon erfolgt.

Für Schweden sind die planetaren Grenzen für die Quantifizierung des sogenannten generational goal angewendet worden. Für die Schweiz konnte eine rasch wachsende Externalisierung der Umweltauswirkungen (und damit des Drucks auf die Grenzen) aufgrund von schweizerischen Konsummustern und entsprechenden Importen festgestellt werden. Für Europa konnte gezeigt werden, dass die Pro-Kopf-Werte der Umweltauswirkungen weit über dem globalen Mittel und über den aus den planetary boundaries errechneten zulässigen Pro-Kopf-Grenzwerten liegen und dass sich die Umweltauswirkungen europäischer Konsummuster zunehmend in andere Weltregionen verlagern.

Für Südafrika ist ein nationales „Barometer“ entwickelt worden, welches die Nachhaltigkeit der Entwicklung in Hinblick auf einen safe and just space misst, also bereits versucht, biophysikalische Umweltziele und sozio-ökonomische Entwicklungsziele zu integrieren. Für China ist das Konzept ebenfalls um sozio-ökonomische Grenzen erweitert und auf ländliche Gemeinden in den Provinzen Yunnan und Anhui angewendet worden.

Environmental Policy-Making in the Anthropocene

Das Querschnittspapier „Environmental Policy-Making in the Anthropocene“ (siehe Kapitel 1.3) beschäftigt sich mit den Auswirkungen unterschiedlicher Anthropozän-Verständnisse auf die Umweltpolitik. Es analysiert aus sozial- bzw. geisteswissenschaftlicher Perspektive drei (im Diskurs präsente) Interpretationen des „Anthropozäns“. Im Fokus stehen dabei (1) Implikationen für das Selbstverständnis, die Rolle und Aufgaben deutscher Umweltpolitik, (2) für Politikinstrumente, Institutionalisierung und internationale Zusammenarbeit der Umweltpolitik sowie (3) für den Gestaltungsanspruch der Umweltpolitik und (politischer) Risiken und Chancen, welche die jeweilige Interpretation mit sich bringt.

Ausgangspunkt der Analyse ist eine kursorische Darstellung unterschiedlicher Mensch-Natur-Interaktionen sowie von Naturverständnissen von der vorindustriellen Zeit bis heute. Drei unterschiedliche Dichotomien von „Natur“ werden identifiziert:

- Instrumenteller vs. intrinsischer Wert der Natur: Natur als Mittel zum Zweck (als Instrument) vs. inhärenter Wert der Natur (ästhetischer oder spiritueller Wert der Natur)
- Dualismus vs. Holismus: Natur und Mensch sind ontologisch getrennt (z. B. durch die dem Menschen inhärente Vernunft) vs. Mensch als untrennbarer Teil der Natur (Menschen als Tiere)
- Animismus vs. Materialismus: nicht-menschliche Entitäten wie Flüsse oder Seen haben eine „Seele“ oder einen „Geist“ vs. Natur besteht ausschließlich aus Materie

Auf Grundlage dieses Rasters sowie der zuvor erfolgten kursorischen Darstellung der Mensch-Natur-Interaktionen lassen sich die planetaren Grenzen einordnen. Im Konzept der „Planetaren Grenzen" finden sich spezifische Ausprägungen der zuvor skizzierten Mensch-Natur-Interaktionen bzw. auch spezifische Ausprägungen der drei Dichotomien wieder: Die Idee einer Verantwortungs- und Führungsrolle des Menschen gegenüber der Natur, wie sie sich teils auch in der christlichen Tradition wiederfindet scheint auch in der Diskussion um Planetare Grenzen auf;

- Die Idee einer Verantwortungs- und Führungsrolle des Menschen gegenüber der Natur, wie sie sich teils auch in der christlichen Tradition wiederfindet, scheint auch in der Diskussion um planetare Grenzen auf.
- Die Idee einer Natur, die menschlichen Interessen dient (instrumenteller Wert), wird auch im Konzept der „Planetaren Grenzen" impliziert – sie dienen einer nachhaltigen menschlichen Entwicklung innerhalb eines durch Gesellschaften bzw. in Arbeitsteilung durch Wissenschaftlerinnen und Wissenschaftler definierten sicheren Handlungsraumes.
- Die Idee einer organischen und holistischen Natur findet sich auch im Konzept der „Planetaren Grenzen" wieder: So werden die Interaktionen zwischen einzelnen Erdsystemprozessen stark betont.
- Die materialistische Tendenz des Konzepts der „Planetaren Grenzen" kann als starke Abgrenzung zum Animismus verstanden werden.
- Der Fokus auf Empirismus als Basis für Fortschritt, wie er grundlegend für die Epoche der wissenschaftlichen Revolutionen ist, liegt auch dem Anspruch der planetaren Grenzen zugrunde, wissenschaftlich quantifizierte Grenzwerte bereitzustellen.

Im Anschluss hieran wird das Konzept des „Anthropozäns" als interpretationsoffen charakterisiert. Es ist nicht primär als Ausfluss einer Diskussion innerhalb der Disziplin der Geologie zu verstehen, sondern hat vielmehr politische, moralische, kulturelle und sogar metaphysische Konnotationen und ist als Konzept auch außerhalb der Disziplin der Geologie geprägt worden. Erst durch die wachsende Popularität beschäftigten sich auch Geologen mit der Idee einer neuen, durch Menschen geprägten Epoche. So ergeben sich ganz unterschiedliche Verständnisse des Anthropozäns, das beispielsweise als „ökologische Katastrophe", „Ausdruck der Moderne", „Angriff auf Menschenrechte" oder auch „Konsumentenexzess" gedeutet wird (übersetzt nach Autin 2016: 5).

Aufbauend auf und in Modifikation von drei durch Will Steffen identifizierten „philosophischen Ansätzen" einer Reaktion auf das Anthropozän werden im Querschnittspapier drei mögliche Interpretationen des Anthropozäns vorgestellt. Diese betrachten das Anthropozän einmal aus natur-bewahrender Perspektive (Mensch als Bewahrer), aus Sicht einer stärker naturgestaltenden Interpretation (Mensch als Gärtner) sowie einer stark natur-verändernden und -kontrollierenden Perspektive (Mensch als Erdingenieur).

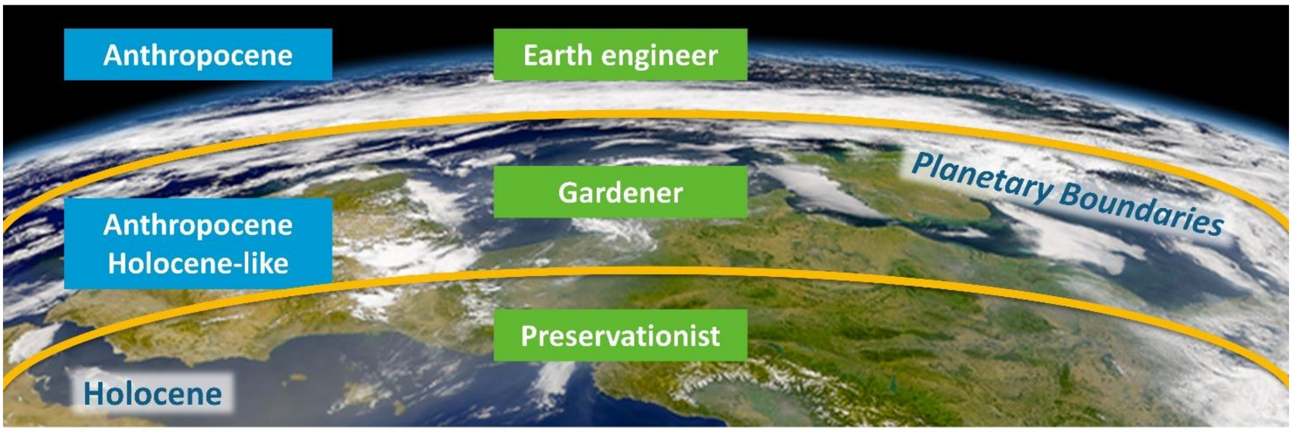
Aus bewahrender Perspektive wird das Anthropozän als „Fremdkörper" wahrgenommen, der zu korrigieren ist. „Natur" wird in dieser Deutung holistisch verstanden; sie ist nicht nur Objekt menschlichen Handelns, sondern eigenständiges Subjekt, das heißt eine Entität, die zu achten ist. Im Anthropozän missachten wir aber diese Natur konsequent und in immer stärkerem Maße. Gleichzeitig entstehen Risiken für uns Menschen, da wir uns fortschreitend unsere Lebensgrundlagen entziehen. Um aus dem Anthropozän wieder in das Holozän zu gelangen, müssen wir im Sinne dieser Deutung unseren Einfluss auf die Natur umfassend einschränken und der Natur wieder wesentlich mehr Raum ohne menschlichen Einfluss lassen. Leitprinzipien sollten Suffizienz sowie eine Rückbesinnung auf die belebte Natur werden.

Aus Perspektive der stärker naturgestaltenden Interpretation („Gärtner-Interpretation") bietet das Anthropozän sowohl Risiken als auch Chancen. Wir sind jetzt zwar in einem Zustand der Mensch-Natur-Interaktion, in dem wir die Natur so stark beeinflussen, dass der Begriff des „Anthropozäns“ gerechtfertigt ist. Aber wir können dieses Anthropozän auch so beeinflussen, dass es „gut“ wird, indem wir versuchen, es nach Art des Holozäns auszugestalten. Hierfür müssen wir die planetaren Grenzen der Erde achten, unsere Gesellschaften innerhalb dieser Grenzen transformieren und insgesamt zu einem klug sachwaltenden Gärtner werden.

Aus einer stark naturgestaltenden und –kontrollierenden Perspektive ist die Natur ein reines Instrument für unseren Wohlstand und Fortschritt. Als Erdingenieure manipulieren wir die Erde schon sehr lange; der Menschheit gelang es hierdurch, vormalig existierende ökologische Grenzen zu verschieben, indem Technologien und menschliche Organisationsformen so eingesetzt wurden, dass beispielsweise die Agrarproduktion erhöht wurde. Wir sind nicht einfach der Natur ausgesetzt, sondern durch unsere Vernunft und Innovationsgabe von ihr abgesetzt. Hieraus folgt, dass wir unsere technischen Fähigkeiten zur Beherrschung der Erde weiter perfektionieren müssen und die Entwicklung des Anthropozäns insgesamt weiter vorantreiben sollten. Das Projekt einer Rückkehr zum Holozän ist insgesamt abzulehnen.

Diese drei Deutungen des Anthropozäns können wiederum in Bezug zum Konzept der „Planetaren Grenzen“ gesetzt werden (siehe Abbildung 2, die wie das Querschnittspapier auf Englisch wiedergegeben wird). Die bewahrende Perspektive („Preservationist“) steht nicht grundsätzlich im Widerspruch zu den planetaren Grenzen; dass Pufferkapazitäten der Erde zu beachten sind, würde auch der Bewahrer mittragen. Gleichzeitig sind die planetaren Grenzen aber nicht weitreichend genug; es reicht nicht aus, das Anthropozän positiv zu transformieren. Vielmehr muss das Experiment der menschlichen Dominanz über die Erde insgesamt abgebrochen werden und die Rückkehr zum Holozän im Vordergrund stehen. Die „Gärtner-Perspektive“ ist mit dem Konzept der „Planetaren Grenzen“ weitgehend kohärent; allerdings lassen die Grenzen grundsätzlich Entwicklungswege innerhalb des sicheren Handlungsraumes offen. Insofern ist die Transformationsperspektive nur eine der möglichen Antworten. Die Perspektive des Erdingenieurs betrachtet die planetaren Grenzen als nicht gewinnbringend, sie können durch menschliches Handeln beständig verschoben werden.

Abbildung 2: Drei Deutungen des Anthropozäns und Einordnung der Planetaren Grenzen



Quelle: Eigene Darstellung, adelphi; Bild der Erde: SeaWiFS Project, NASA/Goddard Space Flight Center, und ORBIMAGE

Aufbauend auf der Charakterisierung der drei Interpretationen werden im nächsten Schritt jeweils Implikationen für die deutsche Umweltpolitik abgeleitet. In der bewahrenden Perspektive adressiert die Umweltpolitik die Treiber des Anthropozäns, insbesondere gesellschaftliche und ökonomische Strukturen, Lebensstile, Werte und Produktionsmuster; Suffizienz wird als allumfassendes Prinzip propagiert und Wirtschaftsaktivitäten möglichst radikal reduziert. Gleichzeitig wird der Naturschutz aufgewertet und die Rückgewinnung der Wildnis (re-wilding) vorangetrieben. Kompromisse und weiche

Lösungen (wie Selbstverpflichtungen), „grünes Wachstum“ oder technologische Lösungen für Umweltprobleme treten vollkommen in den Hintergrund. Auf der institutionellen Seite wird der Naturschutz und diejenigen Referate und Organisationseinheiten, die sich dem Naturschutz verbunden fühlen, stark aufgewertet. International würde die Umweltpolitik sich dafür stark machen, nachholende Entwicklung und Modernisierungsansätze als Entwicklungsmodelle abzulehnen.

In der stärker naturgestaltenden „Gärtner-Perspektive“ widmet sich die Umweltpolitik nachhaltiger Entwicklung innerhalb der planetaren Grenzen. Ihrem Selbstverständnis nach ist Umweltpolitik vernunftgeleitet, und ähnlich wie ein Gärtner durchdringt sie den Gang der Natur und greift behutsam ein, wo es notwendig wird. Um zu dieser Vision eines für lange Zeit früchtetragenden Gartens zu gelangen, bedarf es aber einer Nachhaltigkeits-Transformation unseres Umgangs mit der Natur. Innerhalb der „Gärtner-Interpretation“ des Anthropozäns verändert sich die politische Sprache: Betont werden Möglichkeiten, Vorteile, Innovationen und Lösungen innerhalb des Anthropozäns. Politisch begibt sich die Umweltpolitik innerhalb dieser Interpretation in wesentlich stärkere Nähe zur Wirtschaft. Dahinter steht das Bild einer gesamtgesellschaftlichen Kooperation und eines neuen Gesellschaftsvertrages zwischen allen gesellschaftlichen Akteuren, die sich einer neuen Form des Wirtschaftens und Konsumierens verschreiben.

In der Perspektive des Erdingenieurs wird das Anthropozän nicht abgelehnt, sondern bestärkt. Ökologische Grenzen sind letztlich menschliche Konstrukte; die Erde ist wesentlich resilienter, als in den anderen Perspektiven angenommen wird. Das Selbstverständnis der Umweltpolitik verändert sich hierdurch; im Mittelpunkt steht eine positive, zukunftsbejahende Sicht. Gleichzeitig kann der Planet auch noch wesentlich stärker so modifiziert werden, dass er menschlicher Entwicklung dienlich ist. Dazu zählt, negative Umweltveränderungen zu antizipieren und ihnen durch technologische Lösungen entgegenzuwirken. Durch die Bejahung eines wachsenden Eingriffs in die Natur wird die Umweltpolitik damit selbst zu einer Kraft für das Anthropozän.

Mit allen drei Interpretationen verbinden sich spezifische politische Risiken. Die bewahrende Perspektive beschwört eine erdgeschichtliche Wirklichkeit, die angesichts des immer stärker werdenden Anthropozäns zunehmend verblasst; es erscheint immer unrealistischer, das Holozän „wiederherzustellen“. International erscheint das Modell wenig erfolgsversprechend, stellt es doch das Wirtschaftswachstum grundsätzlich in Frage; einen politischen Konsens hierzu international herzustellen erscheint sehr unwahrscheinlich. Die Sprache der „Gärtner-Perspektive“ kann im politischen Raum auch zu dem Effekt führen, dass unklar wird, warum entschieden transformiert werden soll (wenn es doch im Anthropozän so viele Möglichkeiten gibt). Die Gärtnermetapher verwischt außerdem soziale Ungleichheiten und schwächt Ansätze, welche die Achtung vor der Natur ins Zentrum rücken. Der Erdingenieur steht vor den gleichen starken Risiken wie das Geo-Engineering: Die bisherige Forschung betont hier, dass Nebeneffekte und unerwünschte Langzeitfolgen auftreten können. Außerdem könnten bestehende Bestrebungen zur Bekämpfung von Umweltproblemen hinausgezögert werden, weil auf technologische Lösungen gesetzt wird, die am Ende die Erde doch wieder nach unseren Wünschen umgestalten; technologische Lösungen würden voraussichtlich enorme Geldsummen benötigen, um Veränderungen in großem Maßstab herbeizuführen.

Planetary Boundaries: current status, trends, risks, criticality – what do we know, and what do we need to know?

Das Querschnittspapier “Planetary Boundaries: current status, trends, risks, criticality – what do we know, and what do we need to know?” (siehe 1.2) ist als Hintergrundpapier für das Umweltressort konzipiert. Zielstellung ist es, bisher verfügbare wissenschaftliche Erkenntnisse bezüglich Status, Trends, Risiken und Kritikalität zusammenzustellen und hierauf aufbauend auch Unsicherheiten und Wissenslücken anzuzeigen, die zu beachten sind, wenn politische Aussagen bezüglich des Konzepts und seiner Implikationen getroffen werden. Zielstellung des Papieres war die Sekundärauswertung bestehender Arbeiten und die Darstellung dieser Ergebnisse. Es wurde daher zunächst darauf verzichtet divergierende Forschungsergebnisse hinsichtlich ihrer Plausibilität oder Validität zu bewerten.

Sofern im Rahmen des Umfangs des Papieres möglich – und in Abhängigkeit der Verfügbarkeit der Forscher/-innen - wurden punktuell Wissenschaftler/-innen eingebunden (allerdings fand kein systematischer wissenschaftlicher Review-Prozess statt wie er im Rahmen von wesentlich größer angelegten Prozessen wie den IPCC-Berichten oder auch im Rahmen von wissenschaftlichen Peer-Reviews stattfindet). Für die Analyse von Trends/Dynamiken wurde über die ursprüngliche Zielstellung des Papieres hinausgegangen und in einem ersten Anlauf explorativ Trendprojektionen für einzelne Kontrollvariablen der Grenzen unter Einbeziehung von verfügbaren Zeitreihen-Daten sowie der für die Klimadiskussion entwickelten shared socioeconomic pathways bzw. SSP-Szenarien erstellt. Diese Trendprojektionen sind als Ergänzung zu der ursprünglich anvisierten Zielstellung zu betrachten und haben keinen Review-Prozess durchlaufen. Sie sollten daher auch nicht als abschließendes (Peer-Review-) Ergebnis oder auch als (Neu-)Bewertung der Ergebnisse von Steffen et al. (2015a) betrachtet werden. Ausgangspunkt war hier vielmehr, dass zu dieser spezifischen Fragestellung noch keine Forschungsergebnisse existieren und so zumindest ein „first guess“ erarbeitet werden sollte.

Im Papier wurden für jede der neun Grenzen dargestellt:

- Kontrollvariable, Quantifizierung und Unsicherheiten: Definition der Kontrollvariablen, Quantifizierung der planetaren Grenze, Status gegenüber der quantifizierten Grenze, der Anteil Deutschlands und der EU am Druck auf die Grenze (soweit möglich), Datenverfügbarkeiten, Konsens hinsichtlich der Grenze (Kritikalität, Notwendigkeit einer Grenze, wissenschaftliche Stichhaltigkeit einer Grenze, Position der Grenze)
- Dynamik und Trends: Analyse der Trends und Dynamiken in Bezug auf die Kontrollvariablen der planetaren Grenzen; in den Blick genommen wird die bisherige Entwicklung der Kontrollvariablen, der Status in Bezug auf die planetaren Grenzen (Wurden diese bereits überschritten bzw. wann werden sie unter verschiedenen Trendprojektionen überschritten?); auf Grundlage verschiedener SSP-Szenarien wurden mögliche unterschiedliche Entwicklungspfade abgeleitet; einige dieser Pfade beinhalten die Möglichkeit, innerhalb des sicheren Handlungsraumes zu bleiben oder hierhin zurückzukehren bzw. zeigen Möglichkeiten für Nachhaltigkeitstransformationen an.
- Risiken, Reversibilitäten und Kritikalität: Untersucht wurden biophysikalische und sozio-ökonomische Risiken, die sich mit der Überschreitung einzelner planetarer Grenzen verknüpfen; außerdem wurde die Kritikalität der Grenze abgeschätzt.
- Herunterskalierung und Politikimplikationen: Sofern sich aus der Analyse der einzelnen Grenzen auch Politikimplikationen ergaben, wurden diese einzelnen Informationen zum Herunterskalierungspotenzial der jeweiligen Grenze mit aufgenommen.

Methodisch basierte das Querschnittspapier auf einer Literaturrecherche sowie auf Befragungen von Expertinnen und Experten. In Tabelle 1 werden zusammenfassend die Ergebnisse der Analyse kursorisch dargestellt. Details finden sich in Kapitel 1.2. Die Ergebnisse werden aufgrund der englischen Sprache des Querschnittspapieres auf Englisch wiedergegeben.

Tabelle 1: Factsheets zu den einzelnen Planetaren Grenzen

	Climate Change	Ocean Acidification	Stratospheric Ozone Depletion	Biosphere Integrity	Land-system change
Current global situation	Boundary transgressed in late 1980s	Currently boundary not transgressed	Below boundary, except Antarctica	Boundary transgressed	Boundary transgressed around 1990
Data availability	Very good	Limited	Good	Fragmented	Good
Consensus	Broadly accepted	Broadly accepted	Agreement on criticality of the boundary and the need to reverse ozone depletion	Boundary debated	Broadly accepted
Observed trend	Atmospheric CO_2 concentration increasing; annual emissions currently not increasing	Decreasing aragonite saturation	Ozone concentration has stabilized and/or slightly increased again	Biodiversity loss could not be stopped	Total global forest area keeps decreasing
Scenarios of future trends	Only a few of the RCPs reach net zero emissions by mid of the century	Boundary will be transgressed under all RCPs	Ozone concentration expected to increase further	Biodiversity loss not stopped	Widely diverging scenarios
Teleconnections	Drivers (trade) and impacts (e.g. of deforestation)	effects manifest far away from locations of CO_2 emissions	Locations of production of ozone depleting substances and of their impacts separated by large distance	Externalization of impacts through supply chains but also through climate change	trade related externalization of pressures on forests, hydrological and climatic impacts across large distances
Large scale risks	e.g. extreme events, changes in water availability, changes in (agro-)ecosystems (more details in IPCC 2014a)	Decreasing calcification; negative impacts on marine ecosystems, hatcheries and food security	Impacts on health (skin cancer), plants, biogeochemical cycling	Loss of ecosystem functions, services; impacts on health, economy and loss of resilience of social-ecological systems	Loss of biodiversity and ecosystem services, change in large-scale climate and moisture recycling,

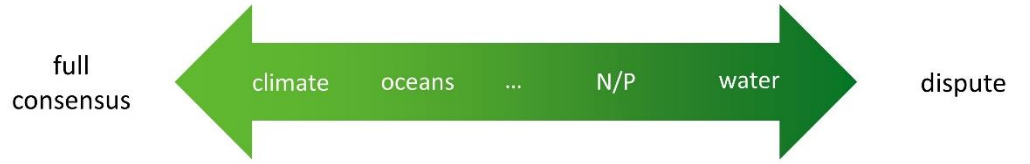
Reversibility, adaptability	CO_2 can remain in atmosphere for centuries, carbon capture potential is limited	reversibility only over extremely long time scales	Fully reversible; adaptability depends on speed of change	Extinct is extinct, species cannot be replaced; poor people depend more strongly on intact biosphere and hence adaptation is more critical	Deforestation difficult to reverse, in particular natural forest are hard to restore
Criticality	High	High	Decreasing	High	High
	Biogeochemical Flows	**Freshwater Use**	**Atmospheric Aerosol Loading**	**Novel entities**	
Current global situation	Boundary transgressed according to Steffen et al. (2015)	Boundary not yet transgressed	Boundary exceeded in south Asia	n.a.	
Data availability	Good	No globally harmonized data on consumptive use available	Global dataset available	n.a.	
Consensus	Medium to low	Low: local to regional scale boundaries seem to be more critical than global boundary	Medium to low	Necessity to include novel entities accepted	
Observed trend	Increase according to Steffen et al. (2015)	Consumptive freshwater use is increasing globally	Spatially and temporally highly variable aerosol loading; growing in some world regions	n.a.	
Scenarios of future trends	Decrease in anthropogenic N-fixation and global P-delivery under all SSP scenarios	Freshwater use increasing under all SSPs	For particulates decreasing under different SSP scenarios	n.a.	

Teleconnections	Some of the N compounds are subject to long distant transports	Drivers and impacts of changes often separated, e.g. via trade and atmospheric moisture transport	Long distant transport in higher altitude	Plastics distributed globally with ocean currents	
Large scale risks	Eutrophication of freshwater bodies coastal eutrophication and subsequent anoxic/dead marine zones, acidification of soils, changes in ecosystems	Impacts on aquatic ecosystems, changes in dilution of pollution, changing green water and atmospheric moisture flows	Global warming, hydrological cycle, air quality, health, crop productivity	n.a. (see e.g. ozone boundary for illustration)	
Reversibility, adaptability	Reversibility moderate if strong measures are taken; adaptability low for poorer communities	Direct effects reversible	Atmospheric aerosol loading is reversible, some of the impacts on human or environmental health not	Some pollutants and also plastics are very persistent, GMOs once released cannot be retrieved	
Criticality	High	Multiple changes in the hydrological cycle and water resources are critical throughout the Earth system	Potentially high (health effects and climate effects)	Potentially very critical	

Quelle: Eigene Darstellung, PIK, adelphi

Insgesamt verdeutlicht die Analyse noch einmal, dass die planetaren Grenzen sich stark voneinander unterscheiden – beispielsweise in Bezug auf den erreichten Konsens hinsichtlich der Notwendigkeit der Grenze, die mit der Grenze verbundenen Unsicherheiten, in Bezug auf die Reversibilität der Grenzüberschreitung bzw. hiermit verbundener Auswirkungen sowie der Zeitskala dieser Auswirkungen. Die nachfolgenden Abbildungen verdeutlichen einige dieser Unterschiede.

Abbildung 3: Vergleich der Planetaren Grenzen hinsichtlich des Konsenses für die Notwendigkeit der Grenze



Quelle: Eigene Darstellung, PIK

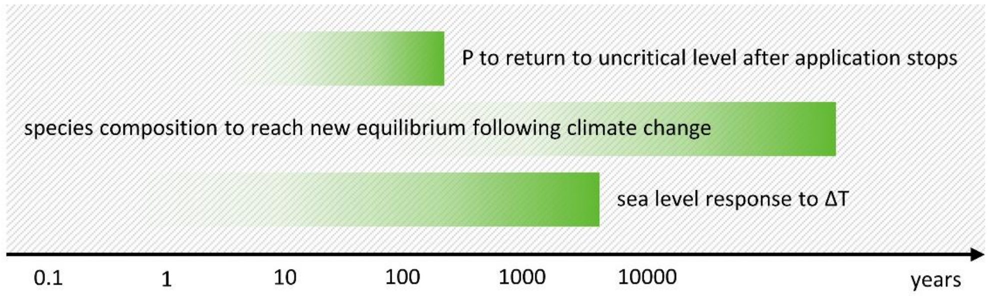
Abbildung 4: Vergleich der Planetaren Grenzen hinsichtlich der Unsicherheit des Grenzwertes

Quelle: Eigene Darstellung, PIK

Abbildung 5: Vergleich der Planetaren Grenzen hinsichtlich der Reversibilität der Überschreitung der Grenzen und hierdurch bedingter Auswirkungen

Quelle: Eigene Darstellung, PIK

Abbildung 6: Vergleich einiger Planetarer Grenzen hinsichtlich der Zeitskala der Auswirkungen von Überschreitungen



Quelle: Eigene Darstellung, PIK

Operationalization of the Planetary Boundaries: Ways Forward and First Results for Germany and the EU

Das Querschnittspapier „Operationalization of the Planetary Boundaries: Ways Forward and First Results for Germany and the EU“ (siehe Kapitel 1.4) stellt Ansätze für eine Methodologie zur Operationalisierung (Herunterskalierung) der planetaren Grenzen dar und exploriert bzw. illustriert diese methodologischen Ansätze für die Klimawandel- und Landnutzungsgrenze. Das Papier richtet sich primär an die Politik, die dargestellten methodischen Ansätze sind aber prinzipiell auch auf andere Akteure übertragbar (unter Einbeziehung des Akteurskontexts).

Die planetaren Grenzen liefern je eine Kontrollvariable pro kritischem Umweltprozess. Die Regionalisierung und Operationalisierung der planetaren Grenzen können helfen, eine globale Umweltperspektive in lokale bzw. nationale Politikprozesse zu integrieren und damit vertikale Politikkohärenz über Skalen hinweg zu fördern. Aufgrund ihrer systemischen Definition kann die Operationalisierung der planetaren Grenzen gleichzeitig auch die horizontale Kohärenz über Sektoren hinweg verbessern.

Vor der Anwendung des Konzepts der „Planetaren Grenzen“ sollte jedoch immer die Frage stehen, wie ein Mehrwert geschaffen werden kann und welches die jeweils relevanten planetaren Grenzen sind. Ziele der Anwendung sowie sinnvoll anwendbare Informationen und der Prozess der Operationalisierung sind auf den jeweiligen Kontext anzupassen. Die Kooperation von Wissenschaftlerinnen und Wissenschaftlern, Politikerinnen und Politikern sowie anderen Stakeholdern erlaubt ein zielorientiertes Herunterskalieren, sodass die planetaren Grenzen als *benchmarks* (Richtwerte) für den erreichten Umweltzustand oder für angestrebte Umweltziele dienen können. Dabei sind immer auch normative Entscheidungen über eine „faire“ Verteilung der globalen Werte auf die einzelnen Länder zu treffen (z. B. durch gleiche Pro-Kopf-Zuteilungen über alle Länder hinweg). Diese Art der Kooperation von Wissenschaft und Anwendung stärkt die Legitimität des Prozesses und sichert gleichzeitig ein evidenzbasiertes Vorgehen.

Nachfrageorientierte Operationalisierung und das Mainstreaming der planetaren Grenzen kann z. B. über Anknüpfungspunkte wie die folgenden Programme und Strategien erfolgen:

- Integriertes Umweltprogramm 2030
- Deutsche Nachhaltigkeitsstrategie und SDG-Implementierung
- Bioökonomiestrategie
- Integrierte Stickstoffstrategie

Solche Programme und Strategien können durch *benchmarking* im Vergleich zu herunterskalierten planetaren Grenzen auf ihre Konsistenz mit globalen Umweltzielen getestet werden. Der systemische Planetare-Grenzen-Ansatz (*dashboard for sustainability*) kann auch helfen, Zielkonflikte zwischen verschiedenen Programmen, Strategien und Umweltzielen zu identifizieren.

Während die einzelnen planetaren Grenzen verschiedene Eigenschaften haben und es entsprechend kein standardisiertes Vorgehen für ihre Anwendung gibt, lassen sich doch einige typische Elemente dafür identifizieren, etwa:

- Das Herunterskalieren der planetaren Grenzen auf die relevante Skala
- Die Berücksichtigung der zeitlichen Dynamik der zugrundeliegenden Prozesse
- Das *benchmarking* des produktionsbasierten Drucks auf den jeweiligen Umweltprozess gegen die herunterskalierte planetare Grenze
- Das *benchmarking* des konsumbasierten Drucks auf den jeweiligen Umweltprozess gegen die herunterskalierte planetare Grenze
- Die Übertragung der Ergebnisse auf relevante Politikstrategien und Programme

Erste Anwendungen der planetaren Grenzen auf den nationalen und europäischen Kontext zeigen, dass es wichtig ist, über den produktionsbasierten bzw. territorialen Ansatz hinauszugehen und externe Umwelteffekte entlang der Handelsketten mitzuberücksichtigen. Erst ein solches konsumbasiertes *benchmarking* gegen die planetaren Grenzen kann den vollen Impakt eines Landes und damit seinen Beitrag zur Überschreitung der planetaren Grenzen erfassen. Zudem kann damit eine räumlich explizite Erfassung des ausgeübten Drucks und der Ressourcennutzung erfolgen, wie sie aus Erdsystemsicht erforderlich ist.

Die Anwendung eines solchen Ansatzes auf den deutschen und europäischen Kontext kann die vertikale und horizontale Politikkohärenz verbessern. Dabei zeigt sich, dass der Pro-Kopf-Beitrag Deutschlands und Europas zur Überschreitung der planetaren Grenzen deutlich über dem globalen Mittel liegt. Für die untersuchten planetaren Grenzen (Klima, Landnutzung, Stickstoff) überschreiten Deutschland und Europa die herunterskalierten planetaren Grenzen – unabhängig davon, ob diese auf globaler Ebene bereits überschritten sind – insbesondere aus konsumbasierter Perspektive. Positive Trends sind auf Europa beschränkt. Die negativen externen Trends über Handelsketten überkompensieren diese positiven Trends. Konsumbasiert hat sich Europas Beitrag zur Überschreitung der planetaren Grenzen in den vergangenen Jahren nicht verringert.

Für einzelne planetare Grenzen ergibt sich folgendes Bild (für Stickstoff ist dies separat im UBA-Text 75/2017 dargestellt; siehe auch Kapitel 2.2):

<u>Klima</u>: Deutsche und europäische Pro-Kopf-CO_2-Emissionen liegen produktionsbasiert um ca. 100 % (Deutschland) bzw. 50-% (EU) über dem globalen Mittel, aus konsumbasierter Perspektive noch deutlich höher. Während produktionsbasiert die CO_2-Emissionen in den letzten zwei bis drei Jahrzehnten abgenommen haben, haben die wachsenden, über Handelsketten externalisierten Emissionen diesen positiven Effekt überkompensiert. Auf EU-Ebene sind die konsumbasierten CO_2-Footprints zurzeit ca. 10-20 % höher als die produktionsbasierten. Je nach gewähltem Klimaziel müssten Deutschlands und Europas Emissionen bis 2030 um ca. 50-90 % reduziert werden, was einer jährlichen Reduktion von 2-5 % seit 1990 entsprechen würde. Die tatsächliche Rate lag in den letzten zwei bis drei Jahrzehnten jedoch nur bei ca. 1 %, sodass für die kommenden Jahre entsprechend höhere jährliche Reduktionsraten von bis zu 10 % erforderlich werden.

<u>Landnutzung</u>: Die planetare Grenze für Landnutzung (Erhalt von ≥75-% der natürlichen Waldbedeckung) ist – je nach Berechnungsart – bislang global kaum oder noch nicht überschritten worden, auf nationaler Ebene in Deutschland (34 % noch erhalten) und auf EU-Ebene (38 % erhalten) jedoch deutlich überschritten, obwohl die Grenze für temperate Wälder durch Steffen et al. sogar niedriger angesetzt wurde (50 %). Die meisten EU-Länder haben über dem globalen Mittel liegende, konsumbasiert meist noch einmal deutlich höhere Land-Footprints. Über die hohen Nettoimporte von landwirtschaftlichen Produkten und Biomasse wird die Landnutzung in starkem Maße externalisiert. Deutschland und Europa nutzen etwa gleich viel Land in anderen Weltregionen wie daheim. Verkleinerungen der landwirtschaftlichen Flächen und Ausweitung von Waldflächen hierzulande werden durch wachsende Importe und Beiträge zur Entwaldung in anderen Weltregionen überkompensiert. Zu beachten ist jedoch, dass ein Herunterskalieren der planetaren Grenze für Land kontextspezifisch erfolgen muss, unter Beachtung von lokalen Nachhaltigkeitskriterien.

The Communicative Potential of the Planetary Boundaries Concept

Das Querschnittspapier „The Communicative Potential of the Planetary Boundaries Concept“ (siehe Kapitel 1.5) skizziert sowohl spezifische kommunikative Herausforderungen als auch Möglichkeiten für die Umweltkommunikation.

In einem ersten Schritt der Analyse werden einzelne kommunikative Stärken des Konzepts herausgearbeitet. Teile der Botschaft des Konzepts sind leicht zu erfassen (unter anderem die begrenzte Tragfähigkeit der Erde). Das Konzept adressiert außerdem einen universellen Personenkreis – die Menschheit – und betrifft eine große Bandbreite unterschiedlicher Aspekte ökologischer Nachhaltigkeit. So kann es für die Kommunikation in unterschiedlichen Umweltdebatten und mit unterschiedlichen Akteuren genutzt werden. Das Konzept bedient sich außerdem verschiedener Metaphern wie die der „großen Beschleunigung" (*great acceleration*) und des „unwirtlichen Planeten" (*inhospitable planet*) und erleichtert so die Erfassung der Kernbotschaften. Schließlich wird das Konzept von einer Gruppe von Wissenschaftlerinnen und Wissenschaftlern getragen und erfährt dadurch Legitimität.

Im zweiten Schritt der Analyse wurde herausgearbeitet, inwieweit das Konzept diese Stärken auch in der öffentlichen Debatte ausspielt. Hierzu wurden 107 Dokumente aus dem Zeitraum 2010 bis 2015 aus der deutschen Zivilgesellschaft, den Bundesministerien, aus Bundestagsdebatten und aus Dokumenten politischer Stiftungen und Parteien zusammengestellt. Außerdem wurde mithilfe einer Analyse der WISO-Datenbank der Mediendiskurs für den Zeitraum 2009 bis 2015 aufgearbeitet. Untersucht wurde, welcher Akteur das Konzept nutzt, wie das Konzept interpretiert wird, für welche Zwecke es eingesetzt wird, welche weiteren Diskurse hiermit verknüpft werden und schließlich welche politischen Mittel durch das Konzept legitimiert werden.

Insgesamt ergab die Analyse:

- Die Nutzungsintensität des Konzepts veränderte sich im gesamten Zeitraum; ab 2011 tauchte das Konzept verstärkt in Debatten auf; Beiträge im Bundestag und der Bundesregierung datieren vor allem aus dem Jahr 2015, während die Bezugnahme auf das Konzept bei anderen Akteuren konstant blieb.
- Verschiedene Bundesministerien bezogen sich auf das Konzept, darunter BMUB, BMZ und BMFSF, außerdem Bundeskanzlerin Angela Merkel und Umweltministerin Barbara Hendricks; politische Stiftungen bezogen das Konzept unter anderem in Bezug auf die Themen Ressourcengerechtigkeit, Ernährungssicherung und Katastrophenvorsorge mit ein; verschiedene zivilgesellschaftliche Akteure berufen sich auf das Konzept, darunter Brot für die Welt, BUND und Germanwatch; in deutschen Medien taucht das Konzept hingegen nur sehr selten auf – in der WISO-Datenbank fanden sich nur 13 Ergebnisse für den Suchbegriff „Planetare Grenzen".
- Das Konzept wurde kontextabhängig sehr unterschiedlich aufgefasst; oft wird es als objektive, wissenschaftliche Darstellung der Risiken, vor denen die Menschheit steht, charakterisiert; dabei wird meist darauf verwiesen, dass das Konzept altbekannte Einsichten noch einmal bestärkt, wie z. B. den zunehmenden Zerfall der Ökosysteme; im Diskurs wurden außerhalb meist sehr selektiv Elemente des Konzepts betont und andere ausgelassen: So findet sich der Aspekt der Interaktion der Grenzen und ihr systemischer Charakter nur selten; wissenschaftliche Unsicherheiten des Konzepts werden unterbetont, ebenso wird teilweise der Unterschied zwischen planetaren Grenzen und Kipp-Punkten vermischt.
- Das Konzept wird für sehr unterschiedliche (argumentative) Zwecke eingesetzt und verknüpft sich hierüber mit den Diskursen zu globalen (Entwicklungs-)Herausforderungen, nachhaltiger Entwicklung und Nachhaltigkeitstransformationen, Klimawandel, Umweltzerstörung und menschlicher Sicherheit, teilweise sogar mit dem Überleben der Menschheit; teilweise wird das Konzept genutzt, um auf globale Krisen hinzuweisen und die Herausforderungen herauszustellen, denen sich die Politik stellen muss; teilweise wird das Konzept auch nur verwendet, um eine starke ökologische Nachhaltigkeit im Diskus zu untermauern oder den globalen Umweltzustand abzubilden.
- Verschiedenste politische Maßnahmen werden im Diskurs vorgeschlagen, um die Einhaltung der Grenzen sicherzustellen. Dazu zählen Maßnahmen in Bezug auf Individuen wie der Wandel von Lebensstilen und Konsum oder hinsichtlich der Transformation des sozio-technischen Regimes, teilweise wird auch die starke Umsetzung der Ziele nachhaltiger Entwicklung (SDGs)

gefordert. Insgesamt werden durch das Konzept nicht einzelne Maßnahmen präjudiziert, sondern das Konzept wird argumentativ an einigen Stellen hinzugezogen – nämlich dort, wo es in bestehenden Debatten nützlich erscheint.

Im Diskurs zeigen sich also auch Lücken zwischen den oft wahrgenommenen kommunikativen Stärken des Konzepts und der Tatsache, dass es teils missverstanden, teils selektiv genutzt wird und bestehende Diskurse weniger abändert als punktuell argumentativ bestärkt. Insbesondere der Wirtschaftssektor wird von dem Konzept noch nicht umfassend erreicht, ebenso die Gesellschaft, wie der Mediendiskurs zeigt. Diese Lücken erklären sich durch einige kommunikative Schwächen des Konzepts. Dazu zählen:

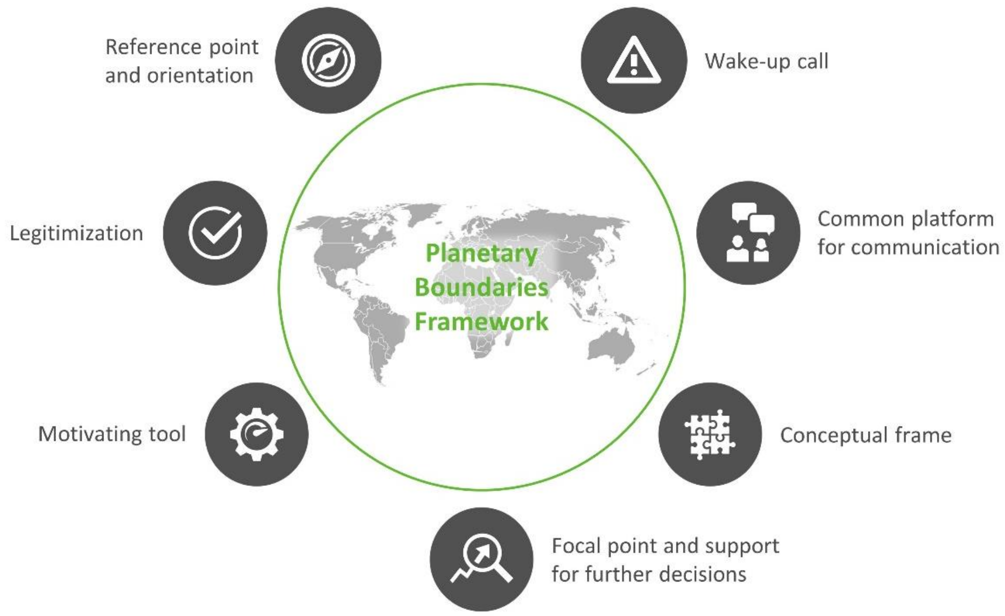
- Die Komplexität des Konzepts, das verschiedenste Botschaften in sich vereint und unterschiedlich gedeutet werden kann
- Der Begriff der „Planetaren Grenzen", der selbst nur Teile des dahinterliegenden Konzeptes erfasst; insbesondere wird der systemische Charakter des Ansatzes durch den Begriff nicht hervorgehoben.
- Die schwache Verankerung des Konzepts in Zeit und Raum; räumlich bezieht sich das Konzept zuerst einmal auf den gesamten Planeten, zeitlich auf Anthropozän und Holozän; hierdurch wird das Konzept weniger zugänglich für Adressaten, da es wenig Bezug zur eigenen Erfahrungswelt hat.
- Die Konsequenzen der Überschreitung von Grenzen und Kipp-Punkten werden im Konzept nicht umfassend beschrieben; so wird bspw. nicht aufgeführt, wer durch Grenzüberschreitung wo in welchem Umfang betroffen sein könnte.
- Die Frage der Entwicklungspfade innerhalb der Grenzen wird durch das Konzept offengelassen; damit wird diese Frage wieder vollständig der politischen Diskussion geöffnet.
- Das Konzept steht in einem Spannungsverhältnis zwischen normativer Grenzsetzung (als Ausdruck des Risikos, das Gesellschaften bereit sind zu tragen) und wissenschaftlicher Forschung.
- Gesellschaftliche Gruppen bzw. gesellschaftliche Wertentscheidungen wurden für die Formulierung der Konzepte von Rockström et al. (2009) und Steffen et al. (2015a) nicht eingebunden (Vertreterinnen und Vertreter der Planetare-Grenzen-Forschungsgemeinschaft betonen aber die Notwendigkeit der Zusammenarbeit und die prinzipielle Offenheit des Konzepts für gesellschaftliche Inputs).
- Die Sprache des Konzepts ist stark technisch; insbesondere Begriffe wie „biogeochemische Kreisläufe", „Kipp-Punkte", „Aerosolgehalt der Atmosphäre" etc. sind noch stärker der Erdsystemwissenschaft verbunden und damit weiten Teilen der Gesellschaft nicht sofort zugänglich.
- In der Konzeption von Rockström et al. (2009) wird teilweise auf eine apokalyptische bzw. dramatisierende Sprache zurückgegriffen; dazu zählt beispielsweise die Bezugnahme auf „Gefahrenzonen", „Gefahren-Levels", „gefährlicher Klimawandel", „planetare Risiken" und „schädliche oder sogar katastrophale" Auswirkungen bei Grenzüberschreitungen.
- Die zentrale Illustration des Konzepts ist teilweise missverständlich oder nicht sofort zugänglich; so sind die grauen Felder und Fragezeichen für den Laien erst einmal nicht selbsterklärend; missverständlich ist auch, dass der Klimawandel gelb, die Ozeanversauerung sogar grün erscheint, obwohl beide von der Weltgemeinschaft als prioritär aufgefasst werden; die Illustration ist außerdem statisch und zeigt die Interaktion zwischen den Grenzen und die Dynamik der Grenzen nicht an.

- Damit zusammenhängend sind auf Basis des Konzepts unterschiedliche Formen der Priorisierung von Grenzen möglich; einerseits durch die Farbgebung und damit durch die in der Kommunikation besonders oft genutzte zentrale Grafik; dann erscheinen die Grenzen der Intaktheit der Biosphäre und der biogeochemischen Flüsse verstärkt in den Blick zu nehmen; andererseits werden durch Steffen et al. (2015) der Klimawandel und die Intaktheit der Biosphäre als Kerngrenzen aufgefasst, nicht aber biogeochemische Kreisläufe.

Im nächsten Schritt werden die kommunikativen Funktionen des Konzepts analysiert und auf einzelne Zielgruppen bezogen. Hierzu werden zuerst Kernbotschaften sowie weitere Botschaften des Konzepts herausgearbeitet. Zu den Kernbotschaften zählen unter anderem, dass die Stabilität des Erdsystems gefährdet ist, dass vier Grenzen überschritten sind und dass das Überschreiten der Grenzen zu abruptem Systemwandel führen kann. Zusätzliche Botschaften sind beispielsweise, dass die Menschheit eine neue geologische Epoche geschaffen hat, die ihren Namen trägt (Anthropozän). Die verschiedenen Botschaften lassen sich thematisch einzelnen Themenbereichen zuordnen, nämlich unter anderem dem Zustand der Umwelt, der Rolle von Gesellschaften und Bürgerinnen und Bürgern in der Umwelt, umweltpolitischen Prinzipien und der Rolle von Umweltpolitik in Politik und Gesellschaft.

Das kommunikative Potenzial kann nicht nur über die verschiedenen Botschaften erfasst werden, die sich damit verbinden, sondern auch über Kommunikationsfunktionen. Sieben Funktionen wurden im Querschnittspapier beschrieben (siehe Abbildung 7). So kann das Konzept als Weckruf fungieren, als Motivationsanreiz (Transformationsmacht des Menschen im Anthropozän), als Referenzpunkt und zur Orientierung (insbesondere durch die Quantifizierungen und die Übersetzung und Operationalisierung auf sub-globale Skalen), als Fokuspunkt und Unterstützung für verschiedene Debatten, bspw. von Transformationsansätzen, als gemeinsame Kommunikationsplattform für den Austausch zwischen verschiedenen Akteuren, als begrifflicher Rahmen für notwendige Bedingungen nachhaltiger Entwicklung sowie als Legitimationstool, bspw. in der Debatte zur Stickstoffminderung.

Abbildung 7: Kommunikationsfunktionen des Konzepts



Quelle: Eigene Darstellung, adelphi

Das Querschnittspapier analysiert außerdem das Potenzial des Konzepts, verschiedene Zielgruppen zu erreichen. In der Wissenschaft wird das Konzept häufig zitiert (bspw. wurde das Ursprungspapier von Rockström et al. 2009 in Ecology & Society 292-mal zitiert und die erste Version in Nature 1.345-mal;

Stand 1. Quartal 2016), vor allem im Bereich der Umweltwissenschaften wurde auf das Konzept Bezug genommen. Bestehende wissenschaftliche Austauschmöglichkeiten bestehen sowohl für die Umwelt(problem)bereiche, die hinter den einzelnen Grenzen stehen (Klimawandel, Bedrohung von Ökosystemen und Biodiversität etc.) und weiteren thematischen Anknüpfungspunkten wie Entwicklungszusammenarbeit, Ressourcenverbrauch, Risiko-Analysen etc.

In der Politik liegt das größte Potenzial des Konzepts in der Kommunikation zwischen einzelnen Regierungsstellen sowie zwischen der Zivilgesellschaft und politischen Stiftungen, die auf die Umweltpolitik Einfluss nehmen. Grund hierfür ist, dass die meisten Kommunikationsfunktionen innerhalb von politischen Prozessen zu verorten sind. In der Wirtschaft wird noch selten auf das Konzept zurückgegriffen, vor allem, weil es einerseits stark nach einer Begrenzung wirtschaftlicher Aktivitäten klingt, andererseits, weil es hinsichtlich der Rolle von Unternehmen unspezifisch bleibt (hierfür ist eine Übersetzungs- bzw. Operationalisierungsleistung notwendig). Einige der Kommunikationsfunktionen bieten auch in der Wirtschaft Ansatzpunkte; hierzu zählen die „Plattform-Funktion" und die „Referenzfunktion" (als konzeptueller Rahmen für die eigene Geschäftstätigkeit). In der Öffentlichkeit wird die Kommunikation durch verschiedene kommunikative Schwächen des Konzepts erschwert (wie bspw. die schwache Verankerung in Raum und Zeit). Die Zielgruppenkommunikation könnte sich direkt an verschiedene gesellschaftliche Milieus wenden und einzelne Botschaften an die Spezifika dieser Gruppen anpassen. Beispielsweise könnte für das „traditionelle Milieu", das Ordnung, Sicherheit, Stabilität und die Bewahrung des Status Quo ins Zentrum setzt, betont werden, dass diese Werte nur durch Achtung der planetaren Grenzen langfristig ermöglicht werden.

Das Konzept sollte sowohl konzeptuell als auch hinsichtlich der Bildsprache weiterentwickelt werden. Wo möglich – und insbesondere in der Kommunikation mit der Öffentlichkeit –, sollte die Konzeptsprache vereinfacht werden; die Öffentlichkeit könnte außerdem über Dialogprogramme und Austausch direkt mit eingebunden werden. Wichtig aus kommunikativer Sicht ist auch die weitere Erforschung und Darstellung der Folgen einer Grenzüberschreitung sowie die weitere Quantifizierung der Grenzen. Auch Narrative könnten eingesetzt werden, welche die Botschaften des Konzepts in leichter zugängliche Erzählungen übertragen.

The Planetary Boundaries as Social Boundaries: Re-framing the doughnut

Das Querschnittspapier „The Planetary Boundaries as social boundaries" (siehe Kapitel1.6) beschäftigt sich mit dem von Kate Raworth formulierten „Doughnut"-Ansatz, welcher die biophysikalischen planetaren Grenzen um soziale Grenzen ergänzt und so einen sicheren und gerechten Raum für nachhaltige Entwicklung konstruiert. Ziel des Papiers ist es, den Raum, der von Raworth erschaffen wird, kritisch zu reflektieren und gleichzeitig das Konzept der „Planetaren Grenzen" aus sozialer Perspektive zu interpretieren.

Ausgangspunkt der Analyse sind verschiedene Konzeptionen sozialer Minimalstandards, wie sie beispielsweise im internationalen Menschenrecht und im Rahmen der SDGs und des UN Global Compact gesetzt werden. Verschiedene Vorgänger des Konzepts von Raworth verbinden ökologische und soziale Nachhaltigkeit mit der Metapher eines Entwicklungsraumes, so die Erklärung von Cocoyoc, der Brundlandt-Bericht und das Umweltraumkonzept (Opschoor und Weterings 1994). Sie teilen verschiedene Annahmen:

- Nachhaltige Entwicklung ist nur unter Integration von sozialen und ökologischen Kriterien möglich.
- Soziales und Ökologie stellen zwei unterschiedliche Bereiche dar, für die jeweils eigene Ziele zu formulieren sind.
- Beide Bereiche können in Form von Grenzen formuliert werden (bspw. Grenzen in Bezug auf Arbeitslohn und Grenzen in Bezug auf Ressourcenverbräuche).

- Umweltraumkonzepte sind kommunikativ vorteilhaft.
- Vermeidungsziele (Grenzen) sind hinreichend für eine nachhaltige Entwicklung; im so aufgespannten Raum gefährdet die Freiheit der Entfaltung nicht die Grenzen als solche.

Das Konzept des „Doughnuts" zeigt einige Stärken. Die sozialen Grenzen sind umfassend legitimiert (abgeleitet von den Rio+20-Einreichungen von Regierungen) und reflektieren Themen, die von vielen als zentrale Entwicklungsherausforderungen begriffen werden. Das Konzept bindet auch Gerechtigkeitsthemen außerhalb der Ökologie ein und füllt so eine Lücke, die von den planetaren Grenzen eröffnet wird. So eignet sich das Konzept auch für den Austausch mit Akteuren der Entwicklungszusammenarbeit.

Gleichzeitig verbinden sich mit dem Konzept einige Schwächen. Durch die beiden Grenzen wird ein Spannungsverhältnis zwischen Ökologie und Gesellschaft erzeugt. Außerdem wird die Illustration der planetaren Grenzen damit überkomplex. Unklar bleibt auch, wie Konflikte zwischen beiden Dimensionen aufzulösen sind. Verschiedene Aspekte sozialer Gerechtigkeit (wie das Recht auf Leben, Freiheit von Folter, Sicherheit) werden durch das Konzept nicht adressiert.

Innerhalb der Planetare-Grenzen-Community ist der Ansatz von Raworth (2012) auf großes Interesse gestoßen, auch im Vorfeld der Verabschiedung der „Agenda 2030" wurde auf das Konzept teilweise Bezug genommen. Gleichzeitig wurden weder der Doughnut-Ansatz noch das Planetare-Grenzen-Konzept in die Ziele nachhaltiger Entwicklung aufgenommen. Das Konzept der „Planetaren Grenzen" bestärkt aus Sicht einiger Kommentatoren und Kommentatorinnen einerseits Ängste in den Entwicklungsländern, dass unter dem Deckmantel des Umweltschutzes durch die Industriestaaten die wirtschaftliche Entwicklung des Globalen Südens untergraben wird. Gleichzeitig erschien es auch unrealistisch, dass das Konzept in Industriestaaten glaubhaft in operationale Schritte überführt werde, also Ressourcen- und Energieverbräuche drastisch gesenkt würden. Insgesamt erschien das Konzept damit als polarisierend und wurde zugunsten anderer Ansätze, wie dem „triple bottom line"–Ansatz, fallengelassen (integrierte ökologische, soziale und wirtschaftliche Entwicklung).

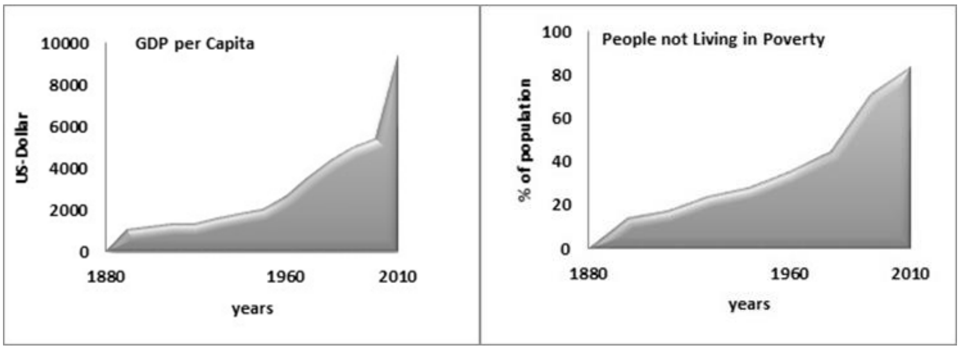
Um die Herausforderungen anzugehen, die aus der Kritik im Vorfeld der Agenda 2030 für nachhaltige Entwicklung (Generalversammlung der Vereinten Nationen 2015) ersichtlich werden, erscheint es sinnvoll, das Konzept der „Planetaren Grenzen" sprachlich zu spezifizieren und anders darzustellen. Dies geschieht teils schon durch Akteure in der Planetare-Grenzen-Community, so Johan Rockström, der von „Wachstum innerhalb der Grenzen" spricht (als Antwort auf die Kritik, dass Konzept sei „Grenzen des Wachstums" in neuem Gewand). Außerdem lässt sich auch Raworths Ansatz hierunter fassen, soziale Grenzen zu den planetaren Grenzen hinzuzufügen (auch als Antwort auf Bedenken, hier werde ökologischer Dominanz gegenüber sozialer Nachhaltigkeit wissenschaftlich Vorschub geleistet).

In Weiterentwicklung dieser Ansätze fokussiert das Querschnittspapier auf das Konzept der „Planetaren Grenzen" selbst. Die These ist, dass die planetaren Grenzen als sozial charakterisiert werden sollten und sich so kein Umweltraum aus sozialen und planetaren Grenzen, sondern ein Kontinuum an sozialen Zielen ergebe, die entlang eines Zeitstrahls angeordnet werden können. Einige der Grenzen beschäftigen sich mit sozialen Zielen, die sofort zu erfüllen sind (soziale Grenzen), andere mit langfristigen Zielen (Stabilität des Erdsystems, planetare Grenzen).

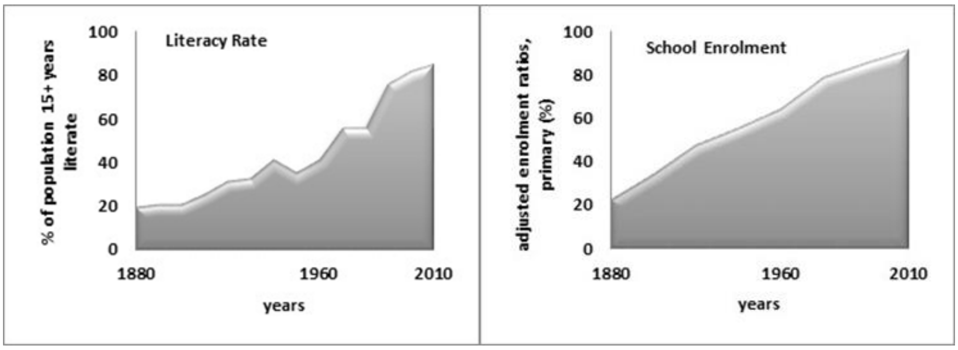
Ausgangspunkt der Analyse sind die beiden Welten, in denen sich Entwicklungs- und Umweltpolitiker/-innen und -wissenschaftler/-innen bewegen. In der ersten Welt werden Umweltzerstörung, Risiken und Katastrophen betont, auf die die Weltgesellschaft zusteuert. Im Konzept der „Planetaren Grenzen" geschieht dies vor allem über die Darstellung des Anthropozäns als Epoche, in der Ressourcenverbräuche und weitere sozio-ökonomische Trends exponentiell steigen und sich so ein immer schneller wachsender Druck auf den Planeten ergibt. Diese Wahrnehmung wird auch in prominenten Analysen des Umweltzustandes geteilt, so im „Millenium Ecosystem Assessment" (Verlust an Ökosystemdienstleistungen), dem GEO-5-Bericht der Vereinten Nationen (UNEP 2012) (bspw. Konsequenzen für Nahrungsmittelsicherheit und Gesundheit) und im letzten Bericht des IPCC (unter anderem auch ökonomische Auswirkungen des Klimawandels). Im Gegensatz hierzu bewegen sich Entwicklungspolitikerinnen und -politiker in einer anderen Welt. Im Fortschrittsbericht zu den MDGs von 2015 (Vereinte Nationen 2015) wird beispielsweise auf die sozialen Fortschritte verwiesen, etwa die Verringerung extremer Armut und von Unterernährung. Auch im Bildungsbereich, bei der Gender-Gleichheit sowie in der Verringerung der Kindersterblichkeit verzeichnet der Bericht Fortschritte. Im „Human Development Report 2016" (UNDP 2016) wird ebenfalls die Verringerung extremer Armut herausgehoben. Die nachfolgenden Grafiken zeigen den Fortschritt in Bezug auf einzelne Dimensionen sozialer Entwicklung.

Abbildung 8: Sozialentwicklung, 1880-2010

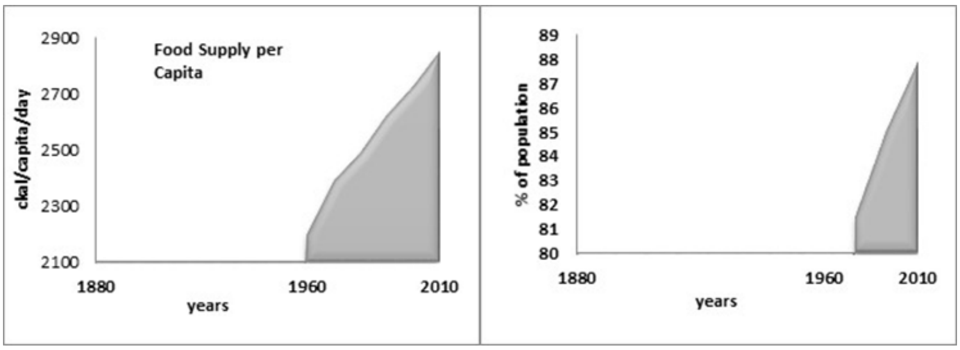
No Poverty



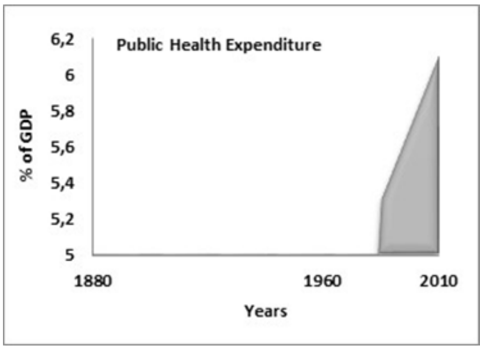
Quality Education

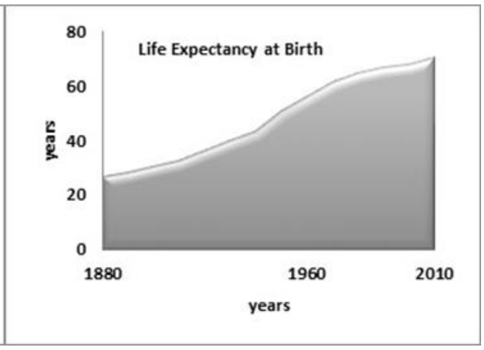


Zero Hunger

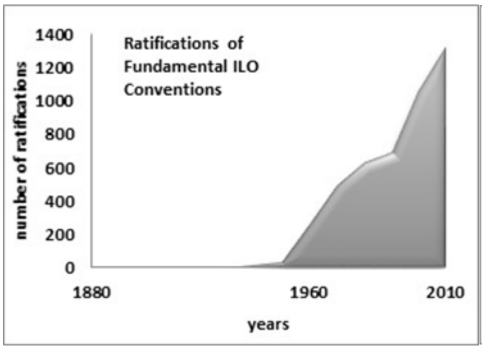


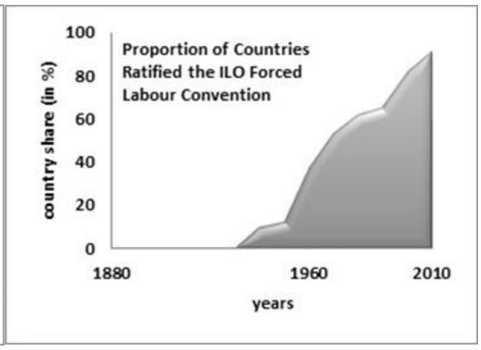
Good Health



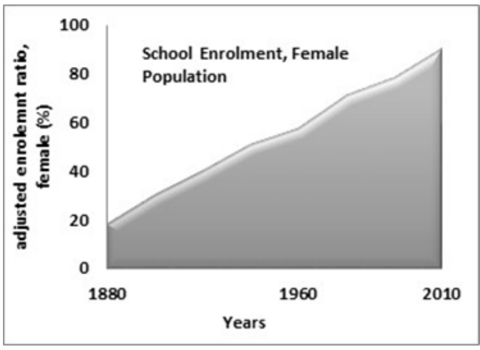


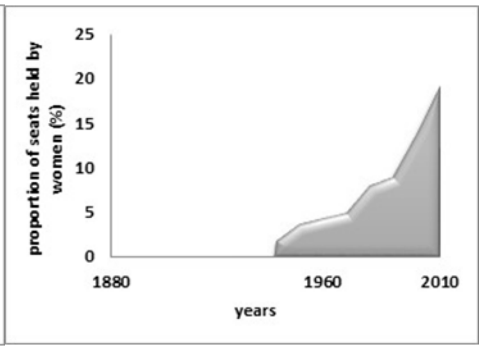
Strong Institutions



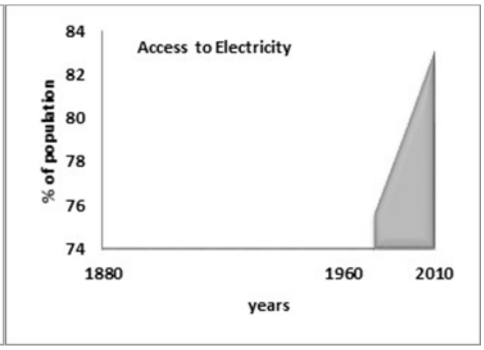


Gender Equality

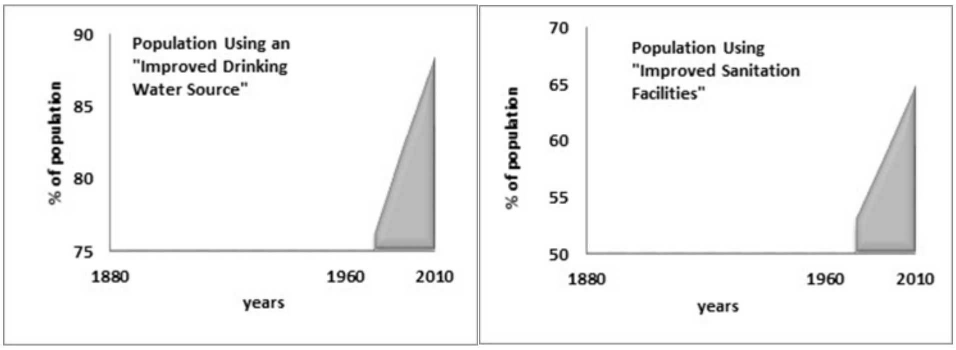




Affordable Energy



Access to Water and Sanitation



Quelle: siehe Kapitel 1.6

Insgesamt entspricht die Kernbotschaft des Konzepts der „Planetaren Grenzen" zu großen Teilen der Kernbotschaft des Konzepts der „Sozialen Grenzen". Über eine wissenschaftlich fundierte Grenzsetzung hinaus implizieren auch diese Grenzen unseres jetzigen Wirtschaftens; sie beinhalten auch eine Bewertung der ökonomischen und sozialen Treiber, die weltweit zu Umweltzerstörung führen. Es wird zwar keine Vorgabe darüber getroffen, welches Wachstumsmodell zu befolgen sei; gleichzeitig wird aber der Weiterführung des bisherigen Modells implizit eine Absage erteilt. Schließlich betont die Forschergruppe, die das Konzept entwickelt, dass die Grenzen sozialen Charakter haben. Die planetaren Grenzen seien damit weniger naturwissenschaftliche Grenzen als tatsächlich auch soziale Grenzen; sie setzen sich das Ziel, menschliche Entwicklung und das Funktionieren unserer Gesellschaften langfristig zu sichern.

Als sozial charakterisierte bzw. umgedeutete planetare Grenzen beinhalten sowohl Chancen als auch Risiken für die Umweltpolitik. So könnte die Umdeutung die Legitimität des Konzepts im Diskurs schwächen, da die normative Seite des Konzepts im Vergleich zur wissenschaftlichen betont wird. Eine große Chance liegt darin, die beiden Welten der Umwelt- und Entwicklungspolitik stärker zusammenzubringen.

Burden-Sharing und Planetare Grenzen (siehe Kapitel 1.7)

Das Papier analysiert die verschiedenen Vorstellungen von Gerechtigkeit, die das Konzept der planetarischen Grenzen hevorruft, und untersucht die Verknüpfung des Burden Sharings (internationale Lastenteilung) mit den Planetaren Grenzen. Dazu definiert das Papier zunächst wesentliche Unterschiede in Bezug auf ökologische Gerechtigkeit und Burden Sharing. Es gibt drei Unterscheidungen, die für die Diskussion des Konzepts der Planetaren Grenzen grundsätzlich nützlich sind:

- Verteilungsgerechtigkeit bezieht sich auf einen Zustand, in dem jedes Referenzobjekt von Gerechtigkeitsüberlegungen (z.B. ein Individuum oder ein Staat) das erhält, was ihm / ihr zusteht (ein bestimmter Nutzen oder eine bestimmte Last oder ein bestimmtes Recht oder eine bestimmte Pflicht) – dies aufgrund eines Verteilungsprinzips wie Gleichheit oder Bedürfnis.
- Korrektive Gerechtigkeit bedeutet, einen ungerechten Zustand zu ändern, der durch Handeln eines Akteurs wie bspw. eines Individuums oder Staates herbeigeführt wurde.
- Die Verfahrensgerechtigkeit verlangt, dass die Art und Weise, wie eine Lastenverteilung formuliert wird, fair ist.

Das Papier befasst sich anschließend mit dem Diskurs in der Wissenschaft, welche das Konzept der Planetaren Grenzen definiert und entwickelt, um zu verstehen, wie die wichtigsten Befürworter des Konzepts dieses mit Fragen der Gerechtigkeit verbinden. Im wissenschaftlichen Diskurs ist die Verteilungsgerechtigkeit ein Hauptthema, das im Hinblick auf faire Anteile am sicheren Handlungsraums diskutiert wird; die korrektive Gerechtigkeit wird derzeit nicht im Zusammenhang mit dem Konzept der

Planetaren Grenzen diskutiert; die Verfahrensgerechtigkeit wird im Hinblick auf die Alloktation fairer Anteile am sicheren Handlungsraum erörtert.

Darüber hinaus wurde der deutsche Regierungsdiskurs analysiert, da das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit einer der Vorreiter des Mainstreaming der Planetaren Grenzen ist und der Diskurs somit ein gutes Beispiel für die Analyse des Zusammenhangs zwischen dem Konzept und Burden Sharing in der Praxis darstellt. Die Analyse zeigt, dass das Konzept tatsächlich verschiedene Interpretationen darüber hervorruft, wie das Konzept der Planetaren Grenzen mit Burden Sharing verbunden ist:

- In einer ersten Perspektive, die im Diskurs sichtbar ist, werden Planetare Grenzen als Vorbedigung der Gerechtigkeit angesehen. Sie werden als Grundlage für die Erreichung anderer sozialer Ziele interpretiert, wie zum Beispiel einer Welt mit weniger gewalttätigen Konflikten, weniger Armut und Würde für alle.
- In einer zweiten Perspektive sind die Planetaren Grenzen mit der Verteilungsgerechtigkeit verknüpft, insbesondere der Verteilung fairer Pro-Kopf-Zugangsrechte zu Ressourcen und die ‚gerechte Verteilung‘ schädlicher Auswirkungen auf die Umwelt (bspw. Treibhausgasemissionen).
- Eine dritte Perspektive verbindet das Konzept der Planetaren Grenzen mit der Verfahrensgerechtigkeit, insbesondere hinsichtlich der normativen Aspekte des Konzepts, wie z.B. der Definition des Risikos, das Gesellschaften bereit sind, zu tragen.

In einem letzten Schritt werden im Papier weitere Potenziale für Burden Sharing und Planetare Grenzen analysiert, um zur Frage beizutragen, was eine Lastenverteilung für jede Planetare Grenze bedeuten könnte. Planetare Grenzen, die für die Anwendung des Prinzips der Verteilungsgerechtigkeit besonders geeignet erscheinen, sind (derzeit) Klimawandel, Biosphärenintegrität, Landsystemänderung, Süßwassernutzung und biogeochemische Flüsse. Verteilungsgerechtigkeitsprinzipien, die für die Grenzen nach erster Analyse am besten geeignet erscheinen, sind das Gleichheits- bzw. Pro-Kopf-Prinzip und das Verantwortungsprinzip (für die Klimagrenze) sowie das vertikale Prinzip und das Recht auf Entwicklung (für alle Planetaren Grenzen). Weitere Forschung sollte die Implikation von Prinzipien der Verteilungsgerechtigkeit auf die jeweiligen Grenzen genauer analysieren, z.B. anhand von Fallstudien.

Fokusfragen: Unterstützung konkreter politischer Prozesse durch das Konzept (siehe Kapitel 2)

Gemäß der Zweiteilung des Vorhabens in Querschnitts- und Fokusthemen wurden im Bereich Fokusthemen für spezifische Fragestellungen des Umweltressorts konkrete Inputpapiere formuliert, die im politischen Prozess einen Mehrwert liefern sollten. Diese waren ursprünglich nicht zur Veröffentlichung vorgesehen und sind dementsprechend nicht als Publikation aufbereitet. Nachfolgend werden die Ergebnisse einzelner Papiere dargestellt, um einen Einblick in die konkrete Operationalisierung im Rahmen des Projektes zu geben. Hierzu zählen ein Thesenpapier, das für einen Fachdialog formuliert wurde, die Zusammenfassung eines internationalen Fachdialogs zum Thema Ressourceneffizienz und Planetare Grenzen sowie Inputpapiere für den Formulierungsprozess des Integrierten Umweltprogrammes 2030 des BMUB und einer nationalen integrierten Stickstoffstrategie. Nachfolgend wird aufgrund der Kürze des Thesenpapiers und der Workshop-Summary nur das Fokuspapier zu Stickstoff aufgeführt.

Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie (siehe Kapitel 2.2)

Die planetaren Grenzen beschreiben einen sicheren Handlungsraum, innerhalb dessen mit hoher Wahrscheinlichkeit die Funktionsfähigkeit des Erdsystems in einer für den Menschen günstigen Konstellation erhalten bleibt. Damit können sie die vertikale Integration einer nationalen Stickstoffstrategie mit globalen Nachhaltigkeitskriterien und Umweltzielen – und damit auch die internationale Kooperation – unterstützen. Für eine solche Operationalisierung und Anwendung der planetaren Grenzen sind die globalen Planetare-Grenzen-Werte herunterzuskalieren, räumlich explizit darzustellen (*downscaling*) und für den jeweiligen Kontext zu übersetzen. Erst dann können sie als Richtwerte (*benchmarks*) dienen, mit denen der nationale Ist-Zustand der Umwelt zu vergleichen ist und nationale Strategien gegebenenfalls entsprechend angepasst werden können (*mainstreaming*).

Die planetare Grenze für Stickstoff wird von Steffen et al. (2015a) mit 63 Millionen Tonnen pro Jahr angegeben. Diese Grenze, die gegenwärtig global um den Faktor 2 überschritten wird, bezieht sich nur auf die beabsichtigte Erzeugung und Freisetzung von reaktivem Stickstoff durch biologische Fixierung und Düngeranwendung. Sie umfasst nicht die unbeabsichtigten Freisetzungen durch Verbrennungsprozesse. Die vorliegende Studie leitet daraus für Deutschland eine Stickstoff-Grenze von 0,5–0,7 Millionen Tonnen pro Jahr ab, je nachdem, ob der globale Wert bezogen auf den Anteil Deutschlands an der globalen Landwirtschaftsfläche oder bezogen auf den Anteil Deutschlands an der Weltbevölkerung herunterskaliert wird. Diesem *benchmark* aus Planetare-Grenzen-Sicht steht ein gegenwärtiger realer Wert von ca. 2,3 Millionen Tonnen gegenüber. Wenn man zusätzlich die Stickstofffreisetzungen berücksichtigt, die Deutschland aufgrund des Konsums und entsprechender Nettoimporte landwirtschaftlicher Produkte im Ausland verursacht (*external footprints*), liegt dieser Wert noch deutlich höher.

Eine solche Anwendung der planetaren Grenze für Stickstoff weist darauf hin, dass die bisherigen – zumeist noch nicht einmal erreichten – deutschen und europäischen Stickstoffziele aus Sicht globaler Nachhaltigkeitskriterien nicht ambitioniert genug sind. So würde z. B. die Einhaltung der EU-Richtlinie über nationale Emissionshöchstmengen (European Environmental Agency 2016) nur zu einer Reduktion des gegenwärtigen Wertes um knapp 0,5 Millionen Tonnen führen. Selbst bei vollständiger Umsetzung der vom Sachverständigenrat für Umweltfragen (SRU) und vom Umweltbundesamt (UBA) geforderten Halbierung des N-Überschusses auf landwirtschaftlichen Flächen würde die auf Deutschland herunterskalierte planetare Grenze für Stickstoff noch immer um ca. 200 % überschritten. Zu ihrer Einhaltung wären zusätzliche Emissionsminderungen in der Landwirtschaft und darüber hinaus (v. a. in den Sektoren Energie, Transport und Industrie) erforderlich.

Eine Erhöhung der Effizienz der Stickstoffnutzung (*nitrogen use efficiency*) auf allen Ebenen und über die gesamte Wertschöpfungskette stellt einen wichtigen Hebel zur Erreichung verschiedener Umwelt- und Nachhaltigkeitsziele dar. Neben der Verminderung der Stickstofffreisetzung in die Umwelt lassen sich zusätzliche Verbesserungen (*co-benefits*) z. B. in Bezug auf Land, Wasser, Energie, Ernährungssicherheit und andere Entwicklungsziele, wie sie in den SDGs benannt sind, erreichen. Durch Erhöhung der Ressourceneffizienz kann der in die Umwelt freigesetzte Anteil des eingesetzten Stickstoffs reduziert werden. Da die planetare Grenze für Stickstoff über maximal zulässige Umweltkonzentrationen definiert ist, kann sie bei erhöhter Ressourceneffizienz höher angesetzt werden.

Entscheidend für die vertikale Integration von deutschen und internationalen Umweltzielen und Nachhaltigkeitskriterien ist der „Dreiklang" aus (1) der Verringerung der Stickstofffreisetzung innerhalb Deutschlands, (2) der Reduktion des (handelsbedingten) deutschen Stickstoff-Footprints im Ausland sowie (3) einer internationalen Kooperation für eine verbesserte Stickstoffnutzung und Ressourceneffizienz in allen Bereichen, z. B. über Investitionen, Entwicklungszusammenarbeit und Wissens- und Technologietransfer. Dieser Dreiklang entspricht auch dem Leitbild der nationalen Implementierung der SDGs innerhalb Deutschlands unter gleichzeitiger Beachtung dieser Ziele auch im Ausland (*implementation in, by and with Germany*). Anknüpfungspunkte für eine verbesserte vertikale Politikkohärenz von national über regional bis global sind z. B. die gemeinsame europäische Agrarpolitik, internationale Handelsabkommen sowie die verschiedenen multilateralen Umweltabkommen.

Aus der Operationalisierung und Anwendung der planetaren Grenzen für Stickstoff für die integrierte nationale Stickstoffstrategie ergeben sich umgekehrt auch Hinweise für die Weiterentwicklung der planetaren Grenze selbst, z. B. in Hinblick auf deren Erweiterung über den Landwirtschaftssektor hinaus. Die Weiterentwicklung der planetaren Grenzen und deren Anwendung muss iterativ und wechselseitig erfolgen. Dazu sollte die Stickstoffstrategie dynamisch weiterentwickelt werden, sodass neues Wissen (z. B. aus der Begleitforschung) kontinuierlich eingepflegt werden kann (*adaptive management*). Entsprechend dem systemischen Charakter des Konzepts und der Komplexität des Stickstoffkreislaufs bedarf dies eines umfassenden Dialogs mit Partnern aus allen relevanten Sektoren, gemäß dem Future-Earth-Prinzip von *co-design & co-production of relevant knowledge*, d. h. in wechselseitiger Abstimmung zwischen Politikerinnen und Politikern, Entscheidungsträgerinnen und Entscheidungsträgern und Wissenschaftlerinnen und Wissenschaftlern.

Fazit und nächste Schritte für die Operationalisierung des Konzepts der Planetaren Grenzen (siehe Kapitel 3)

Auf einer zweitägigen, umfassend angelegten internationalen Konferenz im April 2017 mit 400 Teilnehmern und Teilnehmerinnen in Berlin wurden zentrale Fragen für die Weiterentwicklung und Anwendung des Konzepts der „Planetaren Grenzen“ diskutiert: Wie lässt sich das – international weitgehend anerkannte – Konzept noch besser wissenschaftlich begründen? Wie lässt es sich in der nationalen Umwelt- und Nachhaltigkeitspolitik anwenden? Welche Chancen eröffnet das Konzept für technische, wirtschaftliche und soziale Innovationen, für betriebliches Risiko- und Umweltmanagement, für Umweltbildung und -kommunikation?

Die englischsprachige Konferenz hatte zum Ziel, wichtige Akteurinnen und Akteure einer Nachhaltigkeitstransformation zusammenzubringen, um eine Agenda für die weitere Nutzung des Konzeptes der „Planetaren Grenzen“ in Wissenschaft, Politik, Privatwirtschaft und Zivilgesellschaft zu erarbeiten und so zu einem internationalen Meilenstein für seine Verbreitung, Weiterentwicklung und Anwendung zu werden. Zwei Konferenzthemen standen im Fokus:

- Konferenzthema 1: Wissenschaftlicher Stand der planetaren Grenzen, neueste konzeptuelle Weiterentwicklungen, kritische Aspekte und Defizite sowie zukünftige Forschungsbedarfe, bspw. zur Lage der Grenzen, zu Wechselwirkungen zwischen ihnen sowie zum unterschiedlichen Charakter der Grenzen
- Konferenzthema 2: Stand der Anwendung der Grenzen und ihrer Umsetzung in der Praxis, bspw. für verschiedene geographische Skalen, politische Kontexte und Akteure (Politik, Privatsektor, Zivilgesellschaft). Spezifische Beispiele sind hier nationale Anwendungen des Konzeptes für die EU, Deutschland, die Schweiz, Schweden, Südafrika und China.

Gleichzeitig wurden während der Konferenz Ausgangspunkte, Ziele, neue Netzwerke und nächste Schritte für die weitere Umsetzung und Forschung zu den planetaren Grenzen erarbeitet, präsentiert und im Nachgang in einer Konferenzdokumentation festgehalten. Diese nächsten Schritte (*roadmaps*) werden hier noch einmal aufgeführt.

Nächste Schritte für die Politik (siehe Kapitel 3.1)

Die weitere Umsetzung, Anwendung und Übertragung der planetaren Grenzen erfolgt vor dem Hintergrund einer immer stärkeren Aufnahme in Nachhaltigkeitsstrategien (bspw. im Integrierten Umweltprogramm 2030 in Deutschland). Das Konzept hat Potenzial für Nachhaltigkeits- und Risiko-Governance in der öffentlichen und privaten Sphäre, insbesondere für Politik- und Strategiekohärenz, für die Kommunikation mit Expertinnen und Experten, Stakeholdern und der breiteren Öffentlichkeit, für die Unterstützung der Verhandlung von globalen Zielen für Umweltprobleme und das *mapping* externalisierter Umweltauswirkungen.

Hinsichtlich der weiteren kommunikativen Verknüpfung des Konzeptes ist es zentral, die planetaren Grenzen mit bestehenden sozialen und ökonomischen Diskursen zu verbinden sowie ein kohärentes Narrativ aufzubauen, das die Integrität des Erdsystems als notwendige Bedingung für Würde, Wohlstand und Frieden herausstellt. Auch die Verknüpfung mit dem Anthropozän-Konzept sollte herausgearbeitet werden. Das Konzept sollte als komplementär und unterstützend zu den Zielen der „Agenda 2030“ dargestellt werden. Die planetaren Grenzen sollten flexibel interpretiert werden – diejenigen Parameter des Konzepts, die am stärksten relevant sind für einzelne Räume bzw. Governance-Herausforderungen sollten fokussiert werden, bspw. indem das Konzept mit *footprints* entlang globaler Wertschöpfungsketten oder dem DPSIR-Framework verbunden wird.

Insgesamt sollte der Dialogprozess um das Konzept der „Planetaren Grenzen“ weiter fortgeführt werden, aufbauend auf bisherigen Veranstaltungen. Dazu zählt der Austausch innerhalb der Europäischen Union, bspw. zum achten Umweltaktionsprogramm und dem „2020 State of the Environment Report“, der Umsetzung der „Agenda 2030“, im Rahmen des „European Sustainable Development Network“ (ESDN) und der Europäischen Umweltagentur. Thematisch könnte der weitere Dialog bspw. auf Risiken für Versicherer, Unternehmen, den Finanzsektor bei Grenzüberschreitungen oder auf Innovationen innerhalb des sicheren Handlungsraumes fokussieren.

Politisch sollte das Konzept in die nationale und europäische Umsetzung der „Agenda 2030“ einbezogen werden. Auch sollte das Konzept in verschiedene globale Berichte einfließen – bspw. in den „Global Sustainability Report“ der Vereinten Nationen, in Berichte von UN Environment und den „Global Risk Report“ des World Economic Forums. Es sollten insbesondere solche Maßnahmen betont werden, welche die „hockey stick“-Tendenzen des wachsenden Ressourcenverbrauchs und wachsender Umweltbelastungen reduzieren; dazu zählen insbesondere die Transformation hin zu einer sozial-ökologischen Marktwirtschaft und die weitere Verbreitung alternativer Wohlfahrtsmodelle.

Politikrelevante Forschung sollte sich auf die Governance-Herausforderung fokussieren, die aus dem Konzept entsteht; Strategien und politische Ansätze sollten entwickelt werden, die sicherstellen, dass Gesellschaften in den sicheren Handlungsraum gelangen bzw. dort verbleiben. Weitere Forschung könnte sich mit der Umsetzung und Umsetzungsdefiziten bestehender Strategien und Politikinstrumente beschäftigen.

Nächste Schritte für die Wissenschaft (siehe Kapitel 3.2)

In der Wissenschaft hat das Konzept der „Planetaren Grenzen“ großen Anklang gefunden; gleichzeitig ist die Forschungsgemeinschaft, die sich explizit dem Konzept widmet, noch relativ klein. Die Wissenschaftsförderung ist aktuell noch nicht auf die integrierte Weiterentwicklung und Operationalisierung des Konzepts gerichtet, insbesondere die Modellierung und Daten-Analyse müsste noch stärker auf die praktische Nutzbarmachung des Konzepts fokussieren. Grundsätzlich ist die Forschung zu planetaren Grenzen anzusiedeln zwischen den klimaorientierten Erdsystemwissenschaften und der eher umsetzungsorientierten Forschung (zu den SDGs und im Diskurs der Nachhaltigkeitsforschung). Der Forschung zu planetaren Grenzen kommt hier eine Mittlerrolle zwischen beiden Ebenen zu.

Verschiedene Forschungsbereiche sind für die weitere Entwicklung des Konzepts zentral. Dazu zählt die Realisierung von Modellen, welche planetare Grenzen und ihre Interaktion im Rahmen der Erdsystemdynamik simulieren. Offene Forschungsbereiche betreffen hier unter anderem die Schaffung eines systemischen Ansatzes, in den auch die Intaktheit der Biosphäre einfließt (über das Klima hinaus), die Aufnahme menschlicher Gesellschaften als dynamische biogeochemische Komponenten (Anthropo-Biogeochemie), die Interaktionen zwischen planetaren Grenzen und *teleconnections* sowie Nexus-Forschung (u. a. zu Land-Ozean undLand-Wasser-Energie-Landwirtschaft).

Ein zweiter Forschungsbereich betrifft die Quantifizierung von SDG-Pathways innerhalb der planetaren Grenzen, zum Beispiel die sozio-ökonomische Machbarkeit normativer Pfade, die Quantifizierung von *shared socio-economic pathways*, das *benchmarking* bestehender Entwicklungen gegen die planetaren Grenzen, das Aufzeigen von Synergien und *trade-offs* zwischen den SDG-Zielen und der Aufrechterhaltung des sicheren und gerechten Handlungsraums.

Weitere Forschung sollte sich auch mit sozial-ökologischer Komplexität beschäftigen (hierzu gehört unter anderem Forschung zu den Vorbedingungen des sicheren und gerechten Umweltraumes) und mit der Umsetzung des Konzepts in der Umwelt- und Nachhaltigkeitspolitik und bei Unternehmen (für einzelne Sektoren und Regionen). Hierzu zählt unter anderem die Einbettung des Konzepts in die Entscheidungsfindung, Fragen der Umweltgerechtigkeit, der Kooperation und institutionellen Ausgestaltung und die Verknüpfung des Konzepts mit der Kreislaufwirtschaft und Green Economy.

Weitere Forschung sollte sich auch mit den (politischen und gesellschaftlichen) Ordnungen und Ontologien beschäftigen, die sich mit dem Konzept verbinden. Hierzu zählt die Diskussion der sozio-kulturellen Implikationen des Konzepts, bspw. Fragen der Bildgestaltung und Bildsprache, philosophische und moralische Fragen der Formulierung von planetaren Grenzen und die Rolle von Transformationsnarrativen.

Außerdem sind prozedurale Schritte anzudenken. Beispielsweise könnten regelmäßige Assessments aufbauend auf den planetaren Grenzen konzipiert werden (im Zusammenspiel mit der Evaluation der SDG-Umsetzung), eine Dialogplattform mit Unternehmen und dem Finanzsektor etabliert werden sowie Berichte zu Forschungslücken und Kosten des Nichthandelns erstellt werden. Auch ein internationaler Kreis von Beratern und Beraterinnen könnte das Konzept voranbringen.

Nächste Schritte für die Wirtschaft (siehe Kapitel 3.3)

Einige Unternehmen und Branchen beziehen sich bereits auf das Konzept und haben begonnen, es für ihre operationelle und strategische Planung zu übersetzen und für spezifische Bedarfe zu operationalisieren; insgesamt stehen die Umsetzung und Anwendung aber eher am Anfang. Das Konzept bietet für Unternehmen einen Mehrwert: Einerseits kann es für die Unternehmenskommunikation eingesetzt werden und als Narrativ das Unternehmenshandeln in einen größeren Kontext setzen. Es kann auch intern in Unternehmen genutzt werden, um Risiken auf die Agenda zu setzen, und extern, um die Verpflichtung zu Nachhaltigkeit zu betonen und Konsumentenvertrauen zu schaffen (z. B. in den Bereichen *corporate social responsibility* und *shared value*), wenn glaubhafte Schritte unternommen werden, den Druck auf die Grenzen zu reduzieren. Inhaltlich kann das Konzept als *dashboard* genutzt werden, das wichtige Dimensionen der Nachhaltigkeit (Bedingungen nachhaltiger Entwicklung) gleichzeitig formuliert und betrachtet und Verbindungen zwischen den Dimensionen anzeigt. Für einige der Grenzen liefert das Konzept ein globales Budget bzw. großmaßstäbige und langfristige Performance-Indikatoren.

Nächste Schritte für Unternehmen umfassen (1) die Mitwirkung an der Formulierung von *science-based targets* und an Methodologien für die Herunterskalierung und Anwendung des Konzepts auf der Ebene von Unternehmen und Branchen; außerdem die Analyse von unternehmensbezogenen Nachhaltigkeitsstandards und ihre Verknüpfung mit den planetaren Grenzen sowie die Förderung von *good practices*/Standardsetzern und ersten Anwendern bei Unternehmen, (2) die Unterstützung von Unternehmen bei der Umsetzung, bspw. durch Entwicklung von Narrativen und Argumenten (Geschäftsmodell für Unternehmen) und Erstellung eines Planetary-Boundary-Kompasses (bspw. mit einzelnen Vorreitern und Good-Practice-Beispielen) und (3) die weitere Verbreitung des Konzepts in der Unternehmenswelt, bspw. durch Verknüpfung mit unternehmensnahen Dialogprozessen.

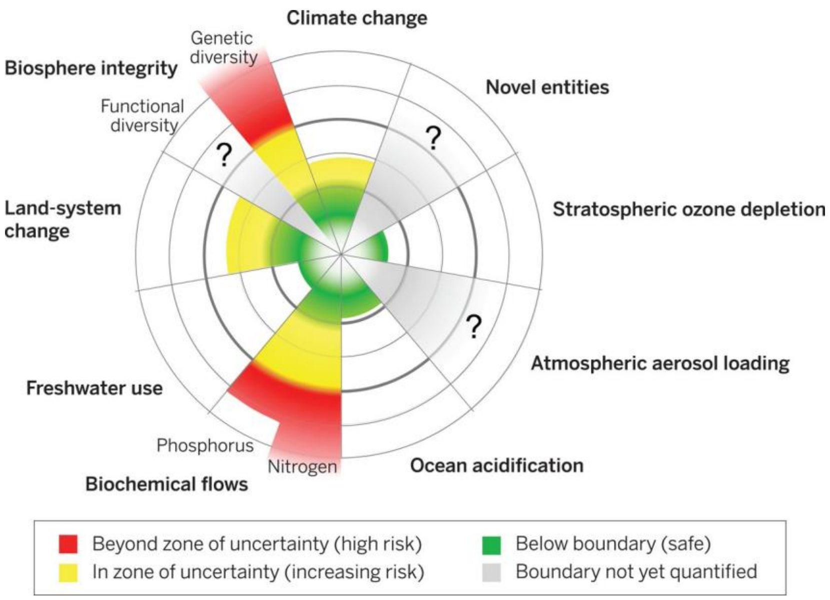
Detailed summary

Starting point

The planetary boundaries concept was formulated in 2009 by an international research group led by Johan Rockström, and revised in 2015 by Will Steffen and colleagues (Rockström et al. 2009; Steffen et al. 2015b). The concept emerged against the background of the Anthropocene – a period of time associated with rapidly growing environmental pressures, and increasing degradation and scarcity of global environmental resources, which intensifies risks for the stability and functioning of the Earth system. The human burden on the global environment and ecosystems has reached a level where sudden non-linear systemic changes can no longer be ruled out. Economic and consumer activities disregard the buffer and regenerative capacities of environmental compartments, and overuse natural resources, undermining the capacity of the Earth system to self-regulate. Overall, there is a danger of weakening the resilience of the Earth system either through gradual change or by triggering so-called tipping points, which would permanently disrupt global ecosystems and ultimately social-ecological systems.

Building on related concepts (e.g., limits to growth, carrying capacity, critical loads and tolerable windows), WBGU's guard rail approach, the precautionary principle, earth system science and resilience research, the concept defines a global "safe operating space" and identifies nine processes that are central to the stability of the Earth system. These nine processes are climate change, ocean acidification, stratospheric ozone depletion, biosphere integrity, land system change, freshwater use, biogeochemical cycles (nitrogen and phosphorus cycles), atmospheric aerosol loading, and novel entities and modified life forms. For the majority of these processes, the concept quantifies safe distances (boundaries) from areas of increased and high risk of serious consequences. According to Steffen et al. (2015a), four of the planetary boundaries (climate change, biosphere integrity, biogeochemical cycles and land system change) have already been crossed (see Figure 9).

Figure 9: Planetary Boundaries



Source: Steffen et al. 2015a

Since the publication of 'Safe Operating Space for Humanity' (Rockström et al. 2009), the planetary boundaries concept has received widespread interest, but also criticism. While it was primarily developed as a scientific concept within earth system science, the applicability of the concept in politics as a guideline for sustainable development has been widely discussed, with a broad spectrum of assessments. The authors of the concept (Johan Rockström et al. and Will Steffen et al.) emphasize that it is primarily a scientific approach to support a global framework for action, not a political master plan.

Among other things, the planetary boundaries have been criticized for their large uncertainties (e.g., with regard to their dynamics) and that their criticality (i.e., the extent to which sustainable development will be endangered by the transgression of boundaries and environmental degradation; cf. Montoya et al. 2017) is not well documented. Furthermore, it has been noted that the tipping points of the planetary boundaries may not exist or at least not at the defined points, that the proposed control variables of the planetary boundaries are insufficient and that the complex interactions between environmental sectors represented by the planetary boundaries (and the resulting systemic thresholds) have been insufficiently considered. It has also been argued that not all of the concept's boundaries may be relevant to the Earth system, but may only refer to local context-specific processes (cf. Nordhaus et al. 2012). From a social and political science perspective, it has been noted that the concept could send a false signal that, on the one hand, there is still space until all boundaries are crossed and, on the other hand, that several boundaries have already been crossed in any case (Schlesinger 2009). This could lead to inactivity on the one hand and fatalism on the other (see Brook and Bradshaw 2013).

The concept has the potential to illustrate global environmental problems in their entirety (i.e., holistically) in an easily comprehensible way, which enables compatibility and can create social support for political decisions. However, additional research is needed to substantiate the assumptions developed so far (and translate them into national and regional policy) and obtain more precise knowledge (e.g., on downscaling planetary boundaries and the interactions between individual planetary boundaries).

The most important challenge to the planetary boundaries concept is the need to deepen the scientific foundations of the concept, and secondly the translation, operationalization, downscaling and application of the concept - e.g. towards concrete environmental and sustainability goals. These challenges must be tackled jointly by science, politics, the private sector and civil society. Only collaboration between all of these sectors will ensure that the planetary boundaries concept is applicable to key areas of society.

Objectives and course of the project

The second central challenge is operationalization, which is tackled by the UFOPLAN project 'Planetary Boundaries – Challenges for Science, Civil Society and Politics' (FKZ 3714 100 0). adelphi, the Potsdam Institute for Climate Impact Research and the Stockholm Environment Institute were commissioned by the German Environment Agency, and Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety to examine the strengths, weaknesses, opportunities and risks of the concept to inform science, society, politics and business. The aim of the project was to analyze the requirements the concept places on politics, science, civil society and business in order to inform the political implementation of the concept. For this purpose, the project provided input – in the form of input papers – into ongoing political processes in order to support the implementation of the concept. The objectives of the project were to (1) describe the state of the art of the conceptual development and quantification of planetary boundaries, (2) analyze the concept's applicability to national policymaking (e.g., integrated environmental program, integrated nitrogen strategy), (3) continue the planetary boundaries dialogue process (through expert dialogue, networking meetings and a final conference), and (4) develop recommendations for politics and science.

In the course of the project, the original structure was modified to account for the objectives outlined above. The work was more closely intertwined with natural and social science approaches. Project outputs include the preparation of papers addressing crosscutting issues and political focus topics.

Crosscutting issues deal with key topics relevant to various political processes. These papers focus on issues that are natural science-oriented and issues that are social science-oriented. The objective of these crosscutting issues papers was to:

- Introduce the topic of planetary boundaries and characterize the concept

- Present the state of knowledge on dynamics, trends and risks associated with planetary boundaries
- Analyze the background concept of the Anthropocene and its relationship to the planetary boundaries concept
- Operationalize the planetary boundaries (in the sense of downscaling the boundaries to the relevant level) and linking the planetary boundaries concept with analysis of consumption-based impacts
- Analyze the interplay between social and planetary boundaries
- Examine interlinkages with burden sharing
- Investigate the potential of the planetary boundaries concept for environmental communication

In addition to crosscutting issues, papers focused on political focus topics. These papers addressed, from a range of different perspectives, the way in which the planetary boundaries concept can be applied to specific areas of environmental policymaking. Among other things, the political focus topics papers aim to support the formulation of a national integrated nitrogen strategy and the Integrated Environmental Programme 2030.

The contents and results of the papers on crosscutting issues and political focus topics are summarized below. Since the individual papers were designed as stand-alone documents (each with its own introduction, analysis and conclusion), they are presented individually. Repeated aspects (e.g., from the respective introductions to the crosscutting issues) are explained only once.

Crosscutting issues: overarching, policy-relevant topics

The Planetary Boundaries Concept – Opportunities for Sustainable Development, Perspectives for Integrated Environmental and Sustainability Policy

The paper 'The Planetary Boundaries Concept – Opportunities for Sustainable Development, Perspectives for Integrated Environmental and Sustainability Policy' characterizes the planetary boundaries concept, outlines further developments, and discusses national and regional applications of the concept (see chapter 1.1). The paper is conceived as an introduction to the planetary boundaries concept. The paper addresses a wider circle of interested parties and is partly structured in the form of theses. The central points of the paper are highlighted in the following section.

The planetary boundaries concept summarizes the state of the art regarding large-scale environmental boundaries and defines a global sustainable development space (a "safe operating space") on the basis of guard rails. This is done with the help of control variables for the nine environmental compartments: climate, biosphere, land, water, biogeochemical cycles, oceans, stratospheric ozone, aerosols and novel entities. The reduction of these complex processes to individual, easily communicable control variables, analogous to the two-degree objective, has enabled the concept to be rapidly incorporated into political and social discourses. Internationally, the High Level Panel on Global Sustainability and the seventh EU Environmental Action Programme have both referenced planetary boundaries. At the national level, the planetary boundaries are incorporated into the Integrated Environmental Programme 2030 (BMUB 2016a) and the German Sustainable Development Strategy (Press and Information Office of the Federal Government 2018).

The planetary boundaries are characterized by the following basic principles:

- The Holocene (Earth's historical climate and system state) establishes the reference point for the planetary boundaries
- The planetary boundaries concept refers to the risks associated with leaving the Holocene state
- The nine planetary boundaries concern the physical, chemical and biological processes of the Earth system
- The planetary boundaries extend the global change debate beyond the climate issue

- The planetary boundaries describe the space within the Earth system in which sustainable development is possible
- The planetary boundaries concept is based on the precautionary principle
- The planetary boundaries represent Earth's systemic boundaries, some of which have already been crossed
- The consequences of transgressing individual planetary boundaries are not yet fully known
- The planetary boundaries are increasingly presented on sub-global scales and at the level of stakeholders, especially states
- Within the planetary boundaries there are considerable opportunities for transformation
- The planetary boundaries concept has implications for justice and sustainability debates
- The scientific development of planetary boundaries focuses on the global quantification and regional application of the concept

The initial definition of the planetary boundaries concept (Rockström et al. 2009) was expanded in 2015 (Steffen et al.). Key revisions include:

- The "rate of biodiversity loss" was changed to "change in biosphere integrity" and an additional indicator "biodiversity intactness index" was introduced
- The "nitrogen and phosphorus cycle" was changed to "biogeochemical flows," which includes (as yet unquantified) limits for other elements (e.g., silicon), while regional limits were introduced in addition to the global limits for nitrogen (N) and phosphorus (P)
- The indicator for "land system change" was changed from "percentage of global land cover converted to cropland" to "area of forested land as a percentage of original forest cover," with the latter indicator differentiated spatially and according to biomes (tropical, temperate, boreal forests)
- The freshwater use boundary is now additionally determined for each river basin individually, based on the water requirements of aquatic ecosystems ("environmental flow requirements"), with the aggregated global value calculated from this ("bottom-up construction of the planetary boundary")
- A boundary value for "atmospheric aerosols" (atmospheric optical depth 0.25) was established for the first time, but only for the South Asia Monsoon region
- "Chemical pollution" was changed to "introduction of novel entities," as the respective planetary boundary has been broadened to include modified life forms, while three criteria for critical substances were defined (persistence, mobility across scales with correspondingly wide distribution, potential effects on important processes of the Earth system or sub-systems), although no indicators or thresholds have yet been determined
- In the central illustration, the planetary boundary circle (see The planetary boundaries concept was formulated in 2009 by an international research group led by Johan Rockström, and revised in 2015 by Will Steffen and colleagues (Rockström et al. 2009; Steffen et al. 2015b). The concept emerged against the background of the Anthropocene – a period of time associated with rapidly growing environmental pressures, and increasing degradation and scarcity of global environmental resources, which intensifies risks for the stability and functioning of the Earth system. The human burden on the global environment and ecosystems has reached a level where sudden non-linear systemic changes can no longer be ruled out. Economic and consumer activities disregard the buffer and regenerative capacities of environmental compartments, and overuse natural resources, undermining the capacity of the Earth system to self-regulate. Overall, there is a danger of weakening the resilience of the Earth system either through gradual change or by triggering so-called tipping points, which would permanently disrupt global ecosystems and ultimately social-ecological systems.

Building on related concepts (e.g., limits to growth, carrying capacity, critical loads and tolerable windows), WBGU's guard rail approach, the precautionary principle, earth system science and resilience research, the concept defines a global "safe operating space" and identifies nine processes that are central to the stability of the Earth system. These nine processes are climate change, ocean acidification, stratospheric ozone depletion, biosphere integrity, land system change, freshwater use, biogeochemical cycles (nitrogen and phosphorus cycles), atmospheric aerosol loading, and novel entities and modified life forms. For the majority of these processes, the concept quantifies safe distances (boundaries) from areas of increased and high risk of serious consequences. According to Steffen et al. (2015a), four of the planetary boundaries (climate change, biosphere integrity, biogeochemical cycles and land system change) have already been crossed (see Figure 9).

- Figure 9), an additional yellow area of increased risk has been introduced, so that the current status of some planetary boundaries has changed
- Two planetary boundaries, climate change and changes in biosphere integrity, have been identified as boundaries of particular significance for the functioning of the Earth system, as these two boundaries interact with all other planetary boundaries

Concerning the consequences of exceeding boundaries, the concept is now more explicit in stating that not all transgressions of boundaries will necessarily lead to abrupt reactions ("regime shifts"), rather moderate or continuous reactions can also occur. Furthermore, the revised concept also makes clear that not all transgressions have global dimensions (e.g., water and land factors have local to regional characters). However, the cumulative consequences of multiple local transgressions of boundaries pose a risk to the functioning of the Earth system.

The spatial heterogeneity and sensitivity of environmental conditions to underlying processes is taken into account by spatial differentiation and the spatially explicit representation of planetary boundaries ("downscaling"). This has improved the integration of the concept into local environmental objectives, operationalizing and connecting the planetary boundaries concept to national processes. Such downscaling has already taken place for individual boundaries (e.g., water and land), and countries and regions.

For Sweden, the planetary boundaries have been used to quantify the so-called generational goal. For Switzerland, the rapid externalization of environmental impacts (and thus of the pressure on the boundaries) due to domestic consumption patterns and corresponding imports has been observed. For Europe, the per capita values of environmental impacts are far above the global average and above the permissible per capita values calculated for the planetary boundaries, while the environmental impacts of European consumption patterns are increasingly shifting to other regions of the world.

For South Africa, a national barometer has been developed, which measures the sustainability of development in terms of a "safe and just space." The barometer attempts to integrate biophysical environmental goals with socioeconomic development goals. For China, the concept has also been extended to socioeconomic boundaries, and applied to rural communities in Yunnan and Anhui provinces.

Environmental Policymaking in the Anthropocene

The crosscutting paper 'Environmental Policymaking in the Anthropocene' (see chapter 1.3) deals with the implications of a range of Anthropocene understandings for environmental policymaking. It analyzes three interpretations of the Anthropocene, which are present in the discourse. The paper discusses the implications of these understandings for German environmental policymaking, policy instruments, institutionalization and international cooperation. The paper also discusses the concept's implications for the legitimacy of environmental policymaking, and the (political) risks and opportunities that each interpretation entails.

The starting point for the analysis is a cursory description of various human-nature interactions and understandings of nature from pre-industrial times to the present. Three different dichotomies of "nature" are identified:

- Instrumental vs intrinsic values of nature: Nature as a means to an end vs inherent aesthetic or spiritual values of nature

- Dualism vs holism: Nature and humans are ontologically separated vs humans as an inseparable part of nature
- Animism vs materialism: Non-human entities (e.g., rivers and lakes) have a "soul" or "spirit" vs nature consists exclusively of matter

The planetary boundaries can be assessed based on these distinctions and the previous cursory representation of human-nature interactions. In the planetary boundaries concept, specific characteristics of human-nature interactions and the three dichotomies can be found:

- The idea of human's guiding role over nature, as partly found in the Christian tradition, reappears in the discussion on planetary boundaries
- The idea of nature serving human interests (instrumental value) is implied in the planetary boundaries concept's framing of sustainable development within a safe operating space
- The idea of an organic and holistic nature can be found in the planetary boundaries concept's emphasis on the interactions between individual earth system processes
- The materialistic tendency of the planetary boundaries concept can be understood as a strong demarcation to animism
- The focus on empiricism as a basis for progress, given empiricism's fundamental contribution to scientific revolutions, is inherent in the claim that the planetary boundaries concept provides quantifiable limits

Subsequently, the concept of the Anthropocene is characterized as open to interpretation. The concept should not primarily be understood as the result of a discussion within the discipline of geology. Rather the concept has much wider political, moral, cultural and even metaphysical connotations, having been shaped by factors outside the discipline of geology. Only since the growth in popularity of the Anthropocene concept have geologists become interested in the idea of a new earth epoch shaped by humans. Thus, quite different understandings of Anthropocene have emerged, including interpretations involving "ecological catastrophe," "expression of modernity," "attack on human rights" or "consumer excess" (Autin 2016: 5).

Building on and modifying three "philosophical approaches" to the Anthropocene identified by Will Steffen, the paper on crosscutting issues presents three possible interpretations of the Anthropocene. The paper examines the Anthropocene from a perspective that preserves nature ("humans as preservationists"), an interpretation that shapes nature more strongly ("humans as gardeners of the earth") and a perspective that modifies nature more strongly ("humans as earth engineers").

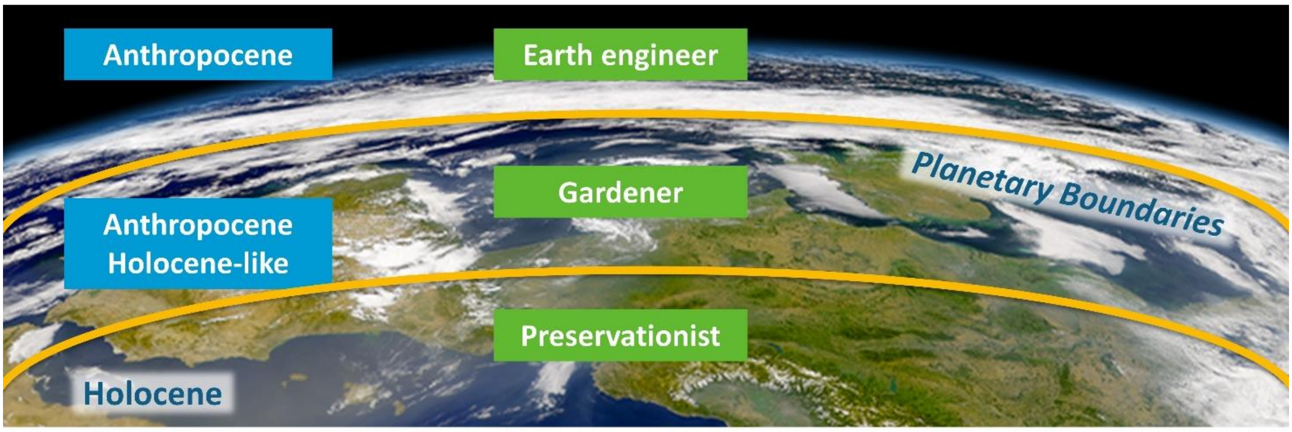
From the preservationist perspective, the Anthropocene is perceived as an object to be corrected. In this interpretation, "nature" is understood holistically; nature is not only an object of human action, but is also an independent subject (i.e., an entity to be respected). In the Anthropocene, however, we consistently and increasingly disregard nature. At the same time, there are risks for humans, as we progressively deprive ourselves of the foundations of our livelihoods. In order to reverse the Anthropocene and return to the Holocene, we must comprehensively limit our influence on nature and eliminate human influence on nature space. The guiding principle of human action should be sufficiency.

From the perspective of humans as gardeners, the Anthropocene presents both risks and opportunities. We are now in a state of human-nature interaction in which we influence nature to such an extent that the concept of a human-dominate epoch is justifiable. However, we can also influence the Anthropocene to make it "good" by trying to shape it to resemble the Holocene. To do this, we must respect planetary boundaries and transform our societies within these boundaries.

From the perspective humans as earth engineers, nature is an instrument for our prosperity and progress. As earth engineers, we have been manipulating Earth for a very long time; humanity has succeeded in shifting previous ecological boundaries by using technologies and human forms of organization in such a way that, for example, agricultural production has increased. We are not simply exposed to nature, but are separated from it by our rationality and ability to innovate. It follows from this that we must continue to perfect our technical capabilities for mastering Earth and should continue to advance the development of the Anthropocene. In this perspective, the aim of returning to the Holocene must be rejected.

These three interpretations of the Anthropocene can in turn be related to the planetary boundaries concept (see Figure 10). The preservationist perspective does not fundamentally exclude planetary boundaries. The fact that Earth's buffer capacities must be taken into account can also be supported from the preservationist perspective. At the same time, however, the planetary boundaries are not far-reaching enough. It is not sufficient to transform the Anthropocene positively. Rather, the experiment of human dominance over Earth must be abandoned and a return to the Holocene must be prioritized. The gardener perspective is largely coherent with the planetary boundaries concept. Though the boundaries leave open how development can be pursued within the safe operating space, with the transition to more sustainable socio-ecological systems only one possible answer. The earth engineer perspective regards the planetary boundaries as flexible, which can be shifted by human action.

Figure 10: Three interpretations of the Anthropocene and the classification of planetary boundaries



Source: from authors, adelphi; image of planet from SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

Based on the characterization of the three interpretations, the next step is to derive implications for German environmental policymaking. From a preservationist perspective, environmental policymaking should address the drivers of the Anthropocene, in particular social and economic structures, lifestyles, values, production patterns; sufficiency is propagated as an all-encompassing principle and economic activities are to be reduced as much as possible. At the same time, nature conservation is to be pursued and "rewilding" supported. Meanwhile, compromises and soft solutions (e.g., voluntary commitments), "green growth," and technological solutions for environmental problems become less important. On the institutional side, organizational units connected to nature conservation become more influential. Internationally, environmental policymaking would strongly reject catch-up and modernization development approaches.

According to the gardener perspective, environmental policymaking is dedicated to sustainable development within the planetary boundaries. According to this perspective, environmental policymaking is guided by rationality, and – like a gardener – modifies the course of nature, intervening carefully where necessary. In order to achieve this vision, our relationship to nature needs to change. With the gardener interpretation of the Anthropocene, political language changes as possibilities, advantages, innovations, solutions to the Anthropocene are emphasized. Within this interpretation, environmental policymaking is closer to the current economic structure than the preservationist perspective. This is due to the gardener perspective's emphasis on cooperation, and a new social contract between all societal actors committed to a new form of economic activity and consumption.

In the earth engineer perspective, the Anthropocene is supported rather than rejected. Ecological boundaries are ultimately human constructs and the Earth is much more resilient than assumed in the other perspectives. This changes environmental policymaking to a more positive view of the future: the planet can be modified to serve human development. This includes anticipating negative environmental change and counteracting it with technological solutions. By affirming our increasing intervention in nature, environmental policymaking becomes a force for the Anthropocene.

All three interpretations are associated with specific political risks. The preservationist perspective evokes a geological reality that increasingly fades away in the face of an ever stronger Anthropocene epoch, as it appears increasingly unrealistic to "restore" the Holocene. Internationally, the model seems unlikely to be successful, since it fundamentally questions economic growth; it seems highly unlikely that a political consensus will be reached internationally. The language of the gardener perspective may also make it harder to explain why a sustainability transition is necessary. The gardener metaphor blurs social inequalities and weakens approaches that focus on respect for nature. Engineering the earth implies the same strong risks as geoengineering. Research to date has stressed that side effects and undesirable long-term effects can occur, and existing efforts to combat environmental problems could be delayed because of the reliance on technological solutions. Technological solutions would likely require substantial financial resources to bring about large-scale change.

Planetary Boundaries: Current Status, Trends, Risks, Criticality – What Do We Know and What Do We Need to Know?

The cross-sectional paper 'Planetary Boundaries: Current Status, Trends, Risks, Criticality – What Do We Know and What Do We Need to Know?' (see chapter 1.2) is intended to be a background paper to the environmental compartments. The paper compiles available scientific findings on the status, trends, risks and criticality of the concept, and indicates uncertainties and gaps in knowledge that need to be taken into account when issuing policy statements on the concept and its implications. The aim of the paper was the analysis of research literature and the presentation of these results. Initially, an evaluation of diverging research results was not undertaken (e.g. regarding plausibility / validity).

As far as possible, within the scope of the paper – and depending on availability – scientists were selectively involved. Though no systematic scientific review process took place, as is the case with much larger processes (e.g., the IPCC reports). For the analysis of trends and dynamics, the authors went beyond the original aim of the paper. In a first attempt, explorative trend projections for individual control variables of the boundaries were generated, taking into account available time series data, and the shared socioeconomic pathways and SSP scenarios developed for the climate discussion. These trend projections are to be regarded as supplementary to the original aim, and have not undergone any peer review process and should not be regarded as a final (peer review) result or a (re-)evaluation of the results of Steffen et al. (2015). The starting point was rather that no research results existed on this specific issue and that a first guess should be made (at the time of exploration).

For each of the planetary boundaries, the paper addressed the following aspects:

- <u>Control variables, quantification and uncertainties:</u> Definition of the control variables, quantification of the planetary boundary, status in relationship to the boundary, (as far as possible) the contribution of Germany and the EU to pressures on the boundary, data availability, and consensus on the boundary (criticality, necessity of a boundary, scientific validity of a boundary, position of the boundary)
- <u>Dynamics and trends:</u> Analysis of the trends and dynamics in relation to the control variables, examination of previous developments of the control variables, the status of control variables in relation to the planetary boundary (if these have already been exceeded or when they will be exceeded under different trend projections), identification of development paths on the basis of different SSP scenarios, analysis of which development paths contain the possibility of

remaining within or returning to the safe operating space, and investigation of possibilities for sustainability transformations

- Risks, reversibilities and criticality: investigation of biophysical and socioeconomic risks associated with crossing planetary boundaries, and assessment of the criticality of the boundaries
- Downscaling and policy implications: if the analysis of a boundary revealed policy implications, this information was included in the downscaling potential of the respective boundary

Methodologically, the paper was based on a literature review and expert interviews. Table 2 summarizes the results of the analysis.

Table 2: Factsheets on the individual planetary boundaries

	Climate Change	Ocean Acidification	Stratospheric Ozone Depletion	Biosphere Integrity	Land System Change
Current global situation	Boundary transgressed in late 1980s	Currently boundary not transgressed	Below boundary, except Antarctica	Boundary transgressed	Boundary transgressed around 1990
Data availability	Very good	Limited	Good	Fragmented	Good
Consensus	Broadly accepted	Broadly accepted	Agreement on criticality of the boundary and the need to reverse ozone depletion	Boundary debated	Broadly accepted
Observed trend	Atmospheric CO_2 concentration increasing; annual emissions currently not increasing	Decreasing aragonite saturation	Ozone concentration has stabilized and/or slightly increased again	Biodiversity loss could not be stopped	Total global forest area keeps decreasing
Scenarios of future trends	Only a few of the RCPs reach net zero emissions by mid of the century	Boundary will be transgressed under all RCPs	Ozone concentration expected to increase further	Biodiversity loss not stopped	Widely diverging scenarios
Teleconnections	Drivers (trade) and impacts (e.g. of deforestation)	effects manifest far away from locations of CO_2 emissions	Locations of production of ozone depleting substances and of their impacts separated by large distance	Externalization of impacts through supply chains but also through climate change	trade related externalization of pressures on forests, hydrological and climatic impacts across large distances
Large scale risks	e.g. extreme events, changes in water availability, changes in (agro-)ecosystems (more details in IPCC 2014a)	Decreasing calcification; negative impacts on marine ecosystems, hatcheries and food security	Impacts on health (skin cancer), plants, biogeochemical cycling	Loss of ecosystem functions, services; impacts on health, economy and loss of resilience of social-ecological systems	Loss of biodiversity and ecosystem services, change in large-scale climate and moisture recycling,

Reversibility, adaptability	CO_2 can remain in atmosphere for centuries, carbon capture potential is limited	reversibility only over extremely long time scales	Fully reversible; adaptability depends on speed of change	Extinct is extinct, species cannot be replaced; poor people depend more strongly on intact biosphere and hence adaptation is more critical	Deforestation difficult to reverse, in particular natural forest are hard to restore
Criticality	High	High	Decreasing	High	High
	Biogeochemical Flows	**Freshwater Use**	**Atmospheric Aerosol Loading**	**Novel entities**	
Current global situation	Boundary transgressed according to Steffen et al. (2015)	Boundary not yet transgressed	Boundary exceeded in south Asia	n.a.	
Data availability	Good	No globally harmonized data on consumptive use available	Global dataset available	n.a.	
Consensus	Medium to low	Low: local to regional scale boundaries seem to be more critical than global boundary	Medium to low	Necessity to include novel entities accepted	
Observed trend	Increase according to Steffen et al. (2015)	Consumptive freshwater use is increasing globally	Spatially and temporally highly variable aerosol loading; growing in some world regions	n.a.	
Scenarios of future trends	Decrease in anthropogenic N-fixation and global P-delivery under all SSP scenarios	Freshwater use increasing under all SSPs	For particulates decreasing under different SSP scenarios	n.a.	

Teleconnections	Some of the N compounds are subject to long distant transports	Drivers and impacts of changes often separated, e.g. via trade and atmospheric moisture transport	Long distant transport in higher altitude	Plastics distributed globally with ocean currents	
Large scale risks	Eutrophication of freshwater bodies coastal eutrophication and subsequent anoxic/dead marine zones, acidification of soils, changes in ecosystems	Impacts on aquatic ecosystems, changes in dilution of pollution, changing green water and atmospheric moisture flows	Global warming, hydrological cycle, air quality, health, crop productivity	n.a. (see e.g. ozone boundary for illustration)	
Reversibility, adaptability	Reversibility moderate if strong measures are taken; adaptability low for poorer communities	Direct effects reversible	Atmospheric aerosol loading is reversible, some of the impacts on human or environmental health not	Some pollutants and also plastics are very persistent, GMOs once released cannot be retrieved	
Criticality	High	Multiple changes in the hydrological cycle and water resources are critical throughout the Earth system	Potentially high (health effects and climate effects)	Potentially very critical	

Source: from authors, PIK, adelphi

Overall, the analysis shows that the planetary boundaries differ greatly from one another, for example, with regard to the consensus reached on the necessity of the boundaries, the uncertainties associated with the boundaries, the reversibility of transgressing the boundaries and associated effects, and the time scale of these effects. The following figures illustrate some of these differences.

Figure 11: Comparison of the planetary boundaries with regard to the consensus for the necessity of the boundary

Source: from authors, PIK

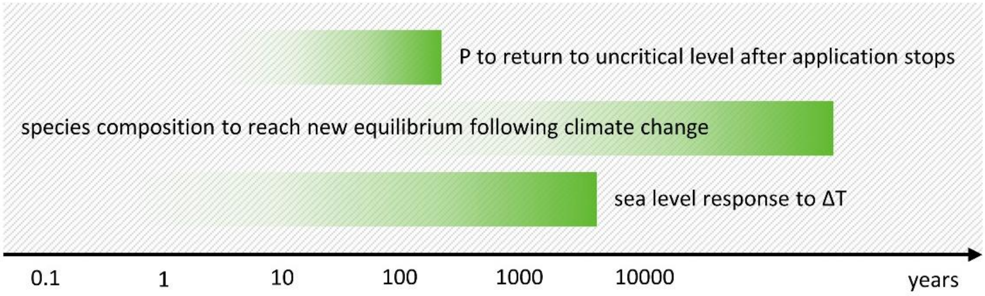
Figure 12: Comparison of the planetary boundaries with regard to the reversibility of the crossing of boundaries and the resulting impacts

Source: from authors, PIK

Figure 13: Comparison of the planetary boundaries with regard to the uncertainty of the boundary value

Source: from authors, PIK

Figure 14: Comparison of some planetary boundaries with respect to the time scale of the effects of transgressing boundaries



Source: from authors, PIK

Operationalization of the Planetary Boundaries: Ways Forward, and First Results for Germany and the EU

The paper 'Operationalization of the Planetary Boundaries: Ways Forward, and First Results for Germany and the EU' (see chapter 1.4) presents approaches to operationalizing planetary boundaries, and explores methodological approaches for the climate change and land use boundaries. The paper is primarily aimed at policymakers, but the methodological approaches presented are in principle relevant to a wider range of actors.

The planetary boundaries provide one control variable per critical environmental process. Regionalization and operationalization of the planetary boundaries can help to integrate a global environmental perspective into local or national policymaking, promoting vertical policy coherence across scales. Due to their systemic definition, the operationalization of planetary boundaries can also improve horizontal coherence across sectors.

Before applying the planetary boundaries concept, however, the question of how added value can be created should be asked and the relevant planetary boundaries should be specified. The objectives of the concept's application, as well as useful information and the process of operationalization have to be adapted to the respective context. The cooperation of scientists, politicians and other stakeholders allows target-oriented downscaling, enabling the planetary boundaries to serve as benchmarks for environmental goals. This will always involve normative decisions regarding the "fair" distribution of global values among individual countries (e.g., through equal per capita allocations across all countries). This kind of cooperation between science and practice strengthens the legitimacy of the process and ensures an evidence-based approach.

Demand-oriented operationalization and mainstreaming of the planetary boundaries can be achieved, for example, through linking the concept to the following programs and strategies:

- Integrated Environmental Programme 2030
- German Sustainable Development Strategy and SDG Implementation
- Bioeconomic Strategy
- Integrated nitrogen strategy

Such programs and strategies can be benchmarked against downscaled planetary boundaries to test their consistency with global environmental goals. The "dashboard for sustainability" can help to identify conflicts of interest between different programs, strategies and environmental objectives.

As the individual planetary boundaries have different properties, there is no standardized procedure for their application. Nevertheless, some typical elements can be identified:

- The downscaling the planetary boundaries to the relevant scale
- The consideration of the temporal dynamics of underlying processes
- The benchmarking of production-based pressure on the respective environmental process against the downscaled planetary boundary
- The benchmarking of the consumption-based pressure on the respective environmental process against the downscaled planetary boundary
- The transfer of results to relevant political strategies and programs

Applications of the planetary boundaries to national and European contexts demonstrates that it is important to go beyond production-based and territorial approaches, and account for external environmental effects along the supply chain. Only consumption-based benchmarking against the planetary boundaries can capture a country's full impact and contribution to crossing planetary boundaries. In addition, a consumption-based perspective can provide a spatially explicit assessment of the pressure exerted and the use of resources, as is necessary from the point of view of the Earth system.

Applying such an approach to the German and European contexts can improve vertical and horizontal policy coherence. This shows that the per capita contribution of Germany and Europe to crossing planetary boundaries is significantly higher than the global average. For the planetary boundaries investigated (climate, land use, nitrogen), Germany and Europe exceed the downscaled planetary boundaries, especially from a consumption-based perspective, regardless of whether the boundaries had already been exceeded at the global level. Positive trends are limited to Europe, while the negative external trends via supply chains more than negate these positive trends. From a consumption-based perspective, Europe's contribution to crossing planetary boundaries has not diminished in recent years.

The outcomes for individual planetary boundaries include (nitrogen is shown separately in UBA text 75/2017; see chapter 2.2):

Climate: Per capita CO_2 emissions are about 100% for Germany and 50% for the EU above the global average on a production basis, and are significantly higher from a consumption-based perspective. While production-based CO_2 emissions have decreased over the last two to three decades, the growing emissions externalized via trade have more than negated this positive effect. At the EU level, consumption-based CO_2 footprints are currently about 10% – 20% higher than production-based CO_2 footprints. Depending on the chosen climate target, Germany and Europe would have to reduce emissions by 50% – 90% by 2030, which would correspond to an annual reduction of 2% – 5% against the basis year 1990. However, the actual rate over the last two to three decades has only been about 1%, so that annual reduction rates of up to 10% will be necessary over the coming years.

Land use: The planetary boundary for land use (conservation of ≥75% of natural forest cover) has been marginally exceeded or is yet to be exceeded globally (depending on the type of calculation), but has been significantly transgressed in Germany (34% still maintained) and at the EU level (38% still maintained), despite the boundary for temperate forests being lowered to 50% by Steffen et al. (2015a). Most EU countries have land footprints that are above the global average and, based on consumption, are usually significantly higher than the global average. The high net imports of agricultural products and biomass externalize land use to a large extent. Germany and Europe use about the same amount of land in other regions of the world as they do domestically. Reductions in agricultural land and the expansion of forest areas in Germany are more than offset by growing imports and contributions to deforestation in other regions of the world. It should be noted, however, that a downscaling of the planetary boundary for each country must be context-specific, taking into account local sustainability criteria.

The Communicative Potential of the Planetary Boundaries Concept

The paper 'The Communicative Potential of the Planetary Boundaries Concept' (see chapter 1.5) outlines communicative challenges and opportunities presented by the planetary boundaries concept for environmental communication.

In a first step of the analysis, individual communicative strengths of the concept are described. Parts of the concept's message are easy to grasp (e.g., the limited carrying capacity of Earth). The concept also addresses a universal group of people (i.e., humanity) and concerns a wide range of different aspects of environmental sustainability. Thus, the concept can be used for communication in different environmental debates and with different actors. The concept also makes use of various metaphors (e.g., the acceleration of environmental pressures and an inhospitable planet) to facilitate the understanding of its core messages. Finally, the concept is supported by a group of scientists, which gives it legitimacy.

In the second step of the analysis, the paper explored the ways in which the concept makes use of these strengths in public debate. To this end, 107 documents from German civil society, federal ministries, Bundestag debates, and political foundations and parties from the period 2010 to 2015 were compiled. In addition, the media discourse between 2009 and 2015 was analyzed with the help of the WISO database. The paper examined which actors referenced the concept, how the concept was interpreted, for what purposes the concept was used, which other discourses were linked to the concept and what political means were legitimated by the concept.

Overall, the analysis showed that:

- The intensity of the use of the concept changed over the analyzed period; the concept increasingly appeared in debates from 2011; contributions in the Bundestag and the federal government date mainly from 2015, while references to the concept remained constant among other actors
- Various federal ministries (e.g., BMUB, BMZ and BMFSF), Chancellor Angela Merkel and Environment Minister Barbara Hendricks referred to the concept; political foundations referred to the concept in relation to issues such as resource justice, food security and disaster prevention; various civil society actors referenced the concept (e.g., Brot für die Welt, BUND and Germanwatch); in German media, however, the concept appeared very rarely – in the WISO database, only 13 results were found for the search term “planetary boundaries”
- The concept was perceived very differently depending on the context; often the concept was characterized as an objective or a scientific representation of the risks facing humanity; it was usually pointed out that the concept reinforces well-known insights (e.g., the increasing decay of ecosystems); outside the discourse, elements of the concept were emphasized very selectively or ignored (e.g., interactions between boundaries); the scientific uncertainties of the concept, and the difference between planetary boundaries and tipping points were underemphasized
- The concept was used for very different (argumentative) purposes, and was linked to discourses on global (development) challenges, sustainable development, sustainability transformations, climate change, environmental degradation, human security and even humanity’s survival; the concept was partially used to highlight global crises and political challenges; the concept was used to reinforce ecological sustainability discourses and to depict the global state of the environment
- Various policy measures were proposed in the discourse to ensure compliance with the boundaries, including measures relating to individuals (e.g., changes in lifestyles and consumption), the transformation of the socio-technical regime and the strong implementation of the Sustainable Development Goals (SDGs); the concept was not used to promote individual measures, but rather was used argumentatively where useful

The discourse reveals gaps between the often perceived communicative strengths of the concept, and that the concept is partly misunderstood, partly selectively used and existing discourses are not so much changed as selectively strengthened by arguments. The media discourse demonstrates that the economic sector, in particular, and society more widely are yet to strongly engage with the concept. These gaps can in part be explained by some of the concept's communicative weaknesses, including:

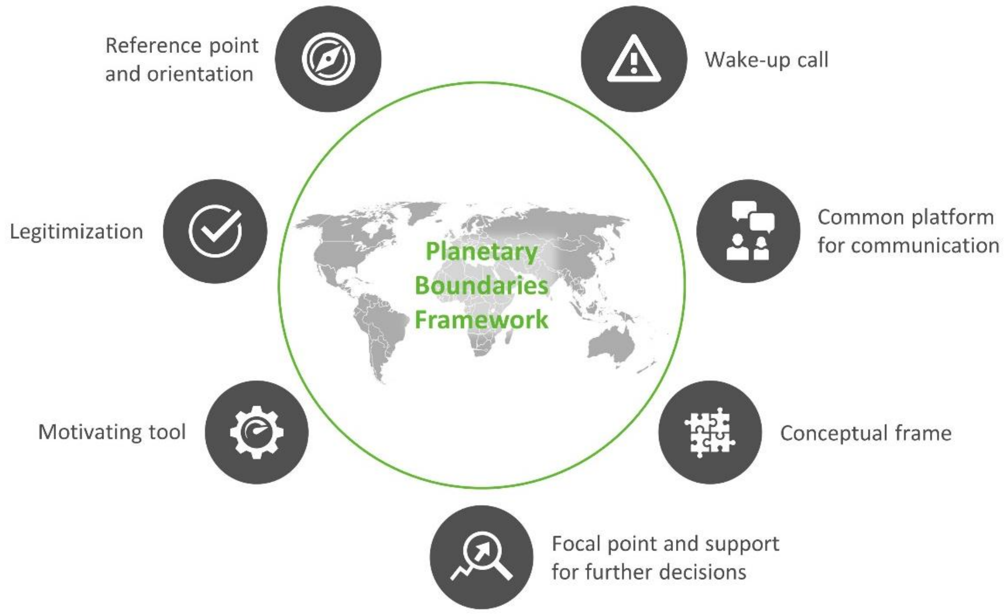
- The complexity of the concept, which unites different messages and can be interpreted in different ways
- The “planetary boundaries” phrase covers only parts of the underlying concept; in particular, the systemic character of the concept is not captured by the phrase
- The weak anchoring of the concept in time and space; the concept spatially refers to the entire planet, and temporally to the Anthropocene and Holocene; this makes the concept less accessible to individuals, since it has little relation to their specific spatial and temporal experience
- The consequences of crossing boundaries and tipping points are not comprehensively described in the concept (e.g., who would be affected by crossing boundaries, where and to what extent)
- The question of developmental paths within the boundaries is left open by the concept; thus, the question is left to political decision-making
- The concept’s relationship between normative boundary setting (as an expression of the risk that societies are willing to bear) and science is tense

- Social groups were not involved in formulating the concept (however, representatives of the planetary boundaries research community emphasize the necessity of cooperation and openness for social inputs)
- The language of the concept is highly technical, especially the terms closely related to earth system science (e.g., biogeochemical cycles, tipping points and aerosol loading) and are therefore not immediately accessible to large sections of society
- Rockström et al. (2009) use dramatizing language to describe the planetary boundaries concept; this includes references to danger zones, danger levels, dangerous climate change, planetary risks and harmful or even catastrophic effects when crossing boundaries
- The central illustration of the concept is sometimes misleading or not immediately accessible (e.g., grey fields and question marks are not self-explanatory to a layperson); it is also misleading that climate change appears yellow, although it is perceived as a priority challenge by the world community; the illustration is also static and does not show the interaction between boundaries and the dynamics of boundaries
- Different forms of prioritization of boundaries are possible: on the one hand, on the basis of the colors of the illustration, the biosphere integrity boundary and the biogeochemical cycles need to be increasingly tackled; on the other hand, Steffen et al. (2015) view climate change and the biosphere integrity as core boundaries, but not biogeochemical cycles

In the next step, the communicative functions of the concept are analyzed and related to target groups. First, the concept's core messages and additional messages are identified. Among the core messages are that the stability of the Earth system is at risk, four boundaries have already been crossed and that transgressing boundaries can lead to abrupt change. An additional message is that humanity has created a new geological epoch (Anthropocene). The various messages can be classified thematically according to individual subject areas, namely the state of the environment, the role of societies and citizens in the environment, principles of environmental policymaking, and the role of politics and society in environmental policymaking.

The communicative potential of the concept can be captured not only by looking at the various messages associated with it, but also by looking at its communication functions. Seven functions were identified (see Figure 15). For example, the concept can function as a wake-up call, a motivating tool (humanity's transformative power in the Anthropocene), and a point of reference and orientation (in particular through quantification and operationalization to sub-global scales). The concept can also be used as a focus point and support for further discussion, such as the development of a new social and economic order, as a common communication platform for exchange between different actors, as a conceptual framework, and as a tool of legitimization.

Figure 15: Communication functions of the concept



Source: from authors, adelphi

The paper also analyzes the potential of the concept to reach different target groups. In science, the concept is often quoted. For example, the original paper by Rockström et al. (2009) was quoted 292 times in Ecology & Society and the first version was quoted 1345 times in Nature (as of first quarter 2016), especially in the field of environmental sciences. Possibilities for exchange exist both for the environmental (problem) areas behind the individual boundaries (e.g., climate change, and threats to ecosystems and biodiversity) and for other thematic links (e.g., development cooperation, resource consumption and risk analyses). The concept has been used as a basis for the exchange of ideas and experience in the field of environmental sciences.

In politics, the greatest potential of the concept lies in communications between individual government agencies, and between civil society and political foundations that influence environmental policymaking. This is because most communication functions can be located within political processes. In business, the concept is still rarely used, since the concept is associated with limiting economic activities and (yet) remains rather unspecific with regard to the role of companies. Some of the communication functions also offer starting points to communicate with companies, including the "platform function" and "reference function" (as a conceptual framework for business activities). In public, communication is hampered by the concept's various communication weaknesses (e.g., the concept's weak anchoring in space and time). Target group communication could directly address different social milieus and adapt individual messages to the specifics of these groups. For example, for the "traditional milieu" – which focuses on order, security, stability and the preservation of the status quo – it could be emphasized that these values can only be achieved in the long run by respecting planetary boundaries.

The concept should be further developed both conceptually and in terms of visual language. Where possible, in particular in communicating with the public, the conceptual language should be simplified; the public could also be directly involved through dialogue programs and exchanges. From a communicative point of view, it is important to further research, quantify boundaries and present the consequences of crossing boundaries. Narratives could also be used to translate the messages of the concept into more accessible narratives.

The Planetary Boundaries as Social Boundaries: Re-framing the Doughnut

The paper 'The Planetary Boundaries as Social Boundaries: Re-framing the Doughnut' (see chapter 1.6) focuses on the "doughnut" approach formulated by Kate Raworth (2012), which complements the biophysical planetary boundaries with social boundaries, constructing a safe and just space for sustainable development. The aim of the paper is to critically reflect on the approach formulated by Raworth and interpret the planetary boundaries concept from a social perspective.

The starting point of the analysis are various minimum social standards, such as established in international human rights law, and within the SDG and the UN Global Compact frameworks. Several predecessors of Raworth's approach combine ecological and social sustainability with the metaphor of a development space, such as the Cocoyoc Declaration, the Brundland Report and the environmental space concept (Opschoor and Weterings 1994). They share several assumptions:

- Sustainable development is only made possible by integrating social and ecological criteria
- Social and environmental issues represent two different areas, each of which requires its own objectives
- Both areas can be sufficiently grasped in the form of boundaries (e.g., wage and resource consumption boundaries)
- Environmental space concepts are communicatively beneficial
- "Avoidance targets" (boundaries) are sufficient for sustainable development; within this defined safe and just space, development does not necessarily endanger boundaries

The doughnut approach exhibits some strengths. The social boundaries are comprehensively legitimized (derived from the Rio+20 government submissions) and reflect issues that many see as key development challenges. The concept also integrates justice issues outside ecology, filling a gap left open by the planetary boundaries. Thus, the safe and just operating space concept is also suitable for exchange with development cooperation actors.

At the same time, the concept is associated with a number of weaknesses. The two boundaries create a tension between ecology and society. In addition, the illustration of the planetary boundaries becomes overly complex. It also remains unclear how conflicts between the two dimensions can be resolved. Various aspects of social justice (e.g., the right to life and security, and freedom from torture) are not addressed by the concept.

Within the planetary boundaries community, the approach of Raworth (2012) has met with widespread interest and, in the run-up to the adoption of the 2030 Agenda for Sustainable Development, several references were made to the concept. At the same time, neither the doughnut approach nor the planetary boundaries concept were included in the SDGs. In the view of some commentators, the planetary boundaries concept reinforces fears within developing countries that the economic development of the Global South will be undermined by industrialized countries under the guise of environmental protection. At the same time, it also seems unrealistic that the concept will be fully implemented in industrialized countries, as to do so would entail drastically reducing resource and energy consumption. Overall, the concept appeared polarizing and was abandoned in favor of other approaches, such as the "triple bottom line approach" (integrated ecological, social and economic development).

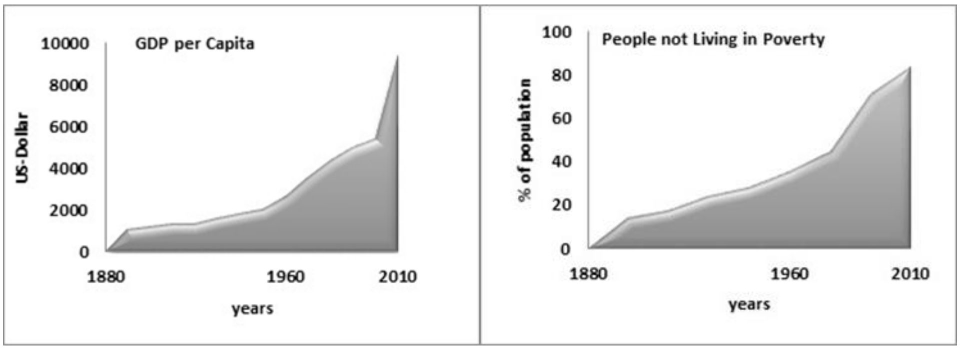
In order to address the challenges that emerge from this criticism in the run-up to the 2030 Agenda (Generalversammlung der Vereinten Nationen 2015), it appears beneficial to specify the language of the planetary boundaries concept and to present it differently. This is being done by actors in the planetary boundaries community. For example, Johan Rockström speaks of "growth within boundaries" (in response to the criticism that the concept is nothing more than "limits of growth" in a new guise). Furthermore, Raworth's approach of adding social boundaries to planetary boundaries can be understood as an attempt to present the concept differently.

In further developing these approaches, the paper focuses on the individual planetary boundaries. The thesis is that planetary boundaries should be characterized as social, and therefore an environmental space of social and planetary boundaries does not emerge, although a continuum of social goals can be arranged along a timeline. Some of the boundaries focus on social goals that are to be fulfilled immediately (e.g., social boundaries), while others focus on long-term goals (e.g., the stability of the Earth system and planetary boundaries).

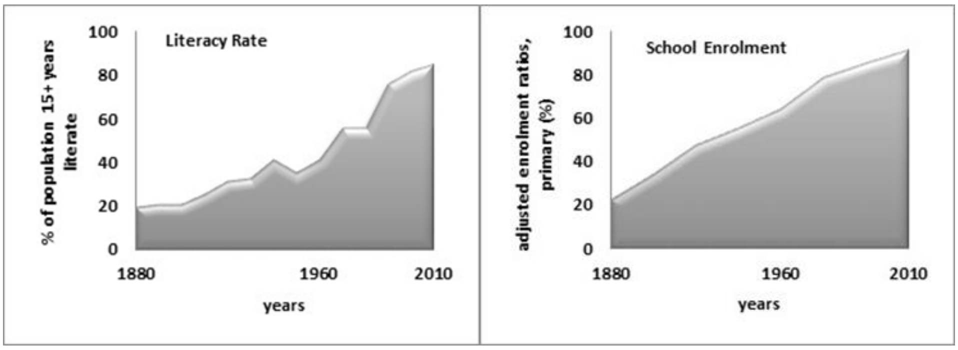
The starting point for the paper's analysis are the separate worlds in which development and environmental policymakers and scientists operate. In one world, environmental degradation, risks and catastrophes are emphasized, which the global society must face. In the planetary boundaries concept, this aspect is primarily highlighted through the representation of the Anthropocene – an epoch characterized by exponential increases in resource consumption and other socioeconomic trends, resulting in growing pressure on the planet. This perception is shared in prominent analyses of the state of the environment, such as the Millennium Ecosystem Assessment (loss of ecosystem services), the GEO 5 report of the United Nations (UNEP 2012) (e.g., consequences for food security and health) and the latest IPCC report (IPPC 2014) (e.g., economic impacts of climate change). In contrast, development policymakers often operate in a different world. The 2015 progress report on the MDGs (United Nations 2015) highlights social progress, including reductions in extreme poverty, malnutrition and child mortality, and improvements in the areas of education and gender equality. The Human Development Report 2016 (UNDP 2016) also highlights reductions in extreme poverty. The following graphs show progress in relation to individual dimensions of social development.

Figure 16: Social development, 1880-2010

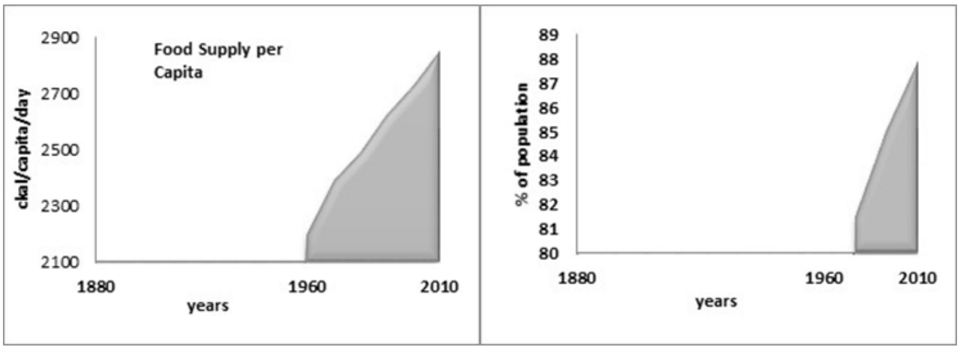
No Poverty



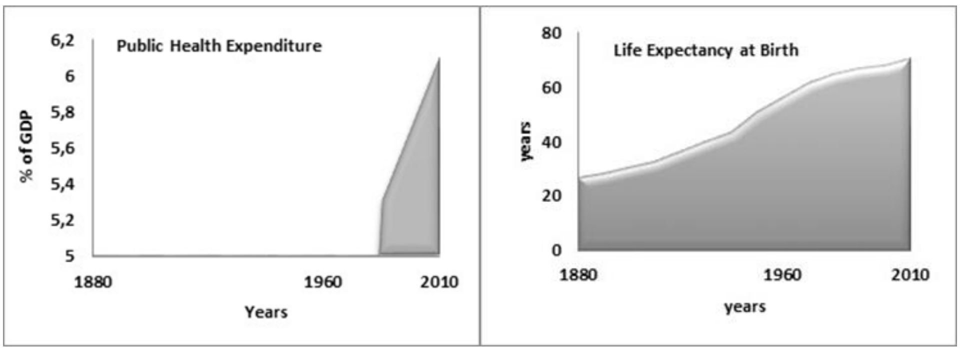
Quality Education



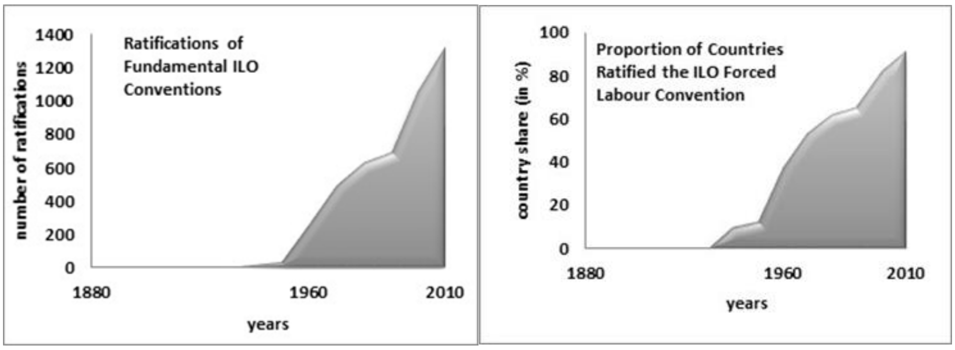
Zero Hunger



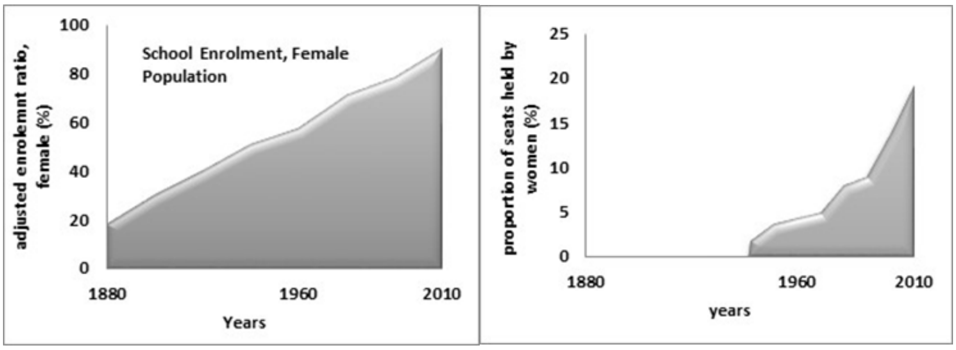
Good Health



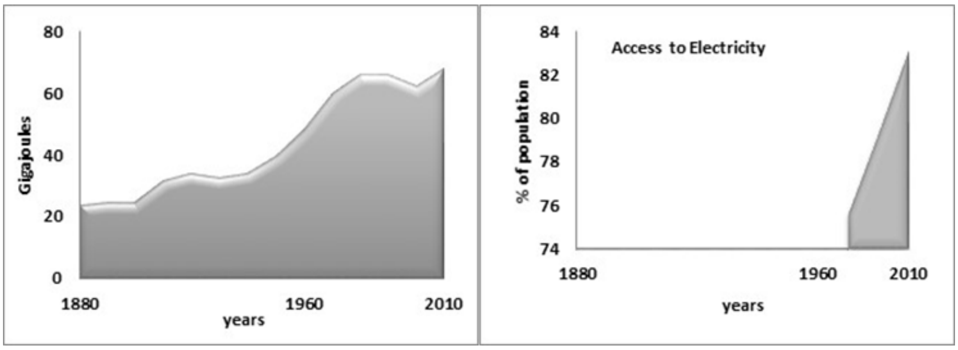
Strong Institutions



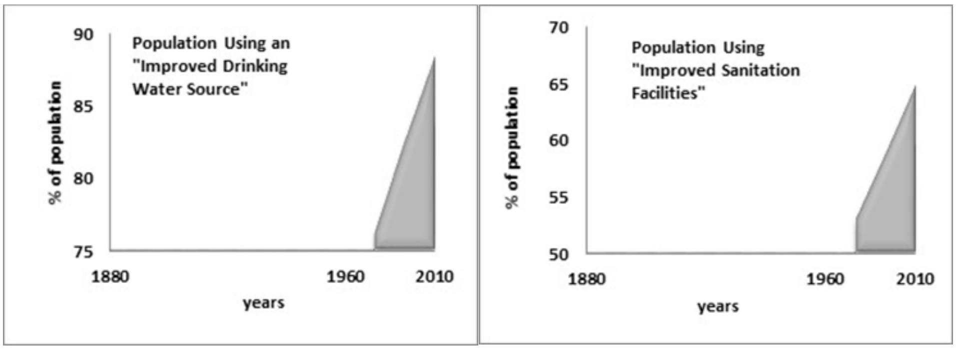
Gender Equality



Affordable Energy



Access to Water and Sanitation



Source: see Chapter 1.6

Overall, the core messages of the planetary boundaries concept largely correspond to the core messages of social boundaries concepts. Beyond a scientific basis, planetary boundaries also imply limits to our current economic activity, and include an assessment of economic and social drivers of global environmental degradation. Although there is no specification as to which growth model to follow, the continuation of the present model is implicitly rejected. The research group developing the concept also emphasize that the boundaries have a social character. The planetary boundaries are not so much scientific boundaries as social boundaries, which aim to safeguard human development and the functioning of our societies in the long term.

Socially characterized or reinterpreted planetary boundaries entail both opportunities and risks for environmental policymaking. The reinterpretation could on the one hand weaken the legitimacy of the concept, since the normative side of the concept is emphasized in comparison to the scientific side. On the other hand, the reinterpretation could help bring the worlds of environmental and development policymaking closer together.

Burden Sharing and Planetary Boundaries

The paper 'Burden Sharing and Planetary Boundaries' analyzes the different notions of justice the planetary boundaries concept induces, and highlights further potential for burden sharing and planetary boundaries. To do so it defines major distinctions of ecological justice and burden sharing. There are three distinctions that are in principle useful for the discussion of the planetary boundaries concept:

- *Distributive* justice refers to a state in which each referent object of justice (e.g., an individual or nation-state) has what is due to them (a specific benefit or burden, or a specific right or duty) on grounds of distributive principles (e.g., equality or want)
- *Corrective* justice implies a change to an unjust state which has been brought about by an action of an agent (e.g., individual or nation-state) and has harmed the referent object of the action
- *Procedural* justice requires that the formulation and implementation of the process of distributing benefits or burdens is fair

The paper subsequently looks at the discourse in the scientific community that defines and develops the concept to understand how proponents of the concept connect it to justice. Within the science discourse, *distributive justice* is a main theme discussed in terms of fair shares of the safe operating space, *corrective justice* is not currently discussed in connection with the planetary boundaries concept, while *procedural justice* is discussed with regards to the procedure of allocating fair shares.

In addition, German governmental discourse was analyzed as Germany's Federal Ministry for the Environment, Nature Conversation and Nuclear Safety is a principal advocate of mainstreaming the planetary boundaries concept and discourse, and thus represents a good case for analyzing how the concept is related to burden sharing in practice. The analysis shows that there were a range of different interpretations regarding the connection between the planetary boundaries concept and global ecological justice:

- In a first perspective visible in the discourse, planetary boundaries are seen as a *precursor for justice*. They are interpreted as the foundation for achieving other social goals, such as reducing violent conflicts and poverty, and promoting dignity for all
- In a second perspective, planetary boundaries are *interlinked with distributional justice*, especially the distribution of fair per capita access rights to resources and the fair distribution of detrimental effects on the environment
- A third perspective connects the concept of ecological boundaries to *procedural justice*, in particular participation in the normative aspects of the concept, such as defining the types and level of risks societies are willing to take, and setting sub-global targets

As a last step, further potential for distributive justice and planetary boundaries was analyzed to contribute to the question of what burden sharing could mean for each planetary boundary. Currently, the planetary boundaries best suited for application to the distributive justice principle are climate change, biosphere integrity, land system change, freshwater use and biogeochemical flows. The distributive justice principles best suited for the framework are, based on the preliminary analysis, the equality of per capita allocations and responsibility principle (for the climate change boundary) as well as the vertical and the right to development principle (for all planetary boundaries). Further research should analyze the implications of distributive justice principles for the respective boundaries in more detail (e.g., by studying specific examples of application).

Political focus topics: supporting political processes (see chapter 2).

In accordance with the division of the project into crosscutting issues and political focus topics, concrete input papers were formulated in the focus topic area for specific questions of the environmental ministry, which were to provide added value in the political process. These were not originally intended for publication (with the exception of the focus paper on a national nitrogen strategy). In the following, the results of individual papers are presented in order to provide an insight into the concrete operationalization within the framework of the project. These include a position paper that was formulated for an expert dialogue, the summary of an international expert dialogue on the topic of resource efficiency and planetary boundaries, and input papers that aimed to support the formulation of the BMUB's Integrated Environmental Programme 2030 and a national integrated nitrogen strategy. Due to the brevity of the paper and the workshop summary, only the focus paper on nitrogen is summarized below.

The Planetary Nitrogen Guard Rail as Reference Point for a National Nitrogen Strategy (see chapter 2.2)

The planetary boundaries describe a safe operating space within which the functioning of the Earth system is likely maintained in a constellation favorable to humanity. In this way, they can support the vertical integration of a national nitrogen strategy with global sustainability criteria and environmental goals – and thus also facilitate international cooperation. For the operationalization and application of planetary boundaries, the global planetary boundary values must be scaled down, represented spatially explicitly (downscaled) and translated for the respective context. Only then can they serve as benchmarks against which to compare the current national state of the environment and enable national strategies to be adapted where necessary (mainstreaming).

The planetary boundary for nitrogen is defined by Steffen et al. (2015a) as 63 million tons per year. This boundary, which is globally exceeded by a factor of two at present, refers only to the intended production and release of reactive nitrogen via biological fixation and fertilizer application. It does not include unintentional releases via combustion processes. This study derives a nitrogen boundary of 0.5 million – 0.7 million tons per year for Germany, depending on whether the global value is scaled down in relation to Germany's share of either global agricultural area or world population. From the point of view of planetary boundaries, this benchmark is compared with a current real value of approximately 2.3 million tons. If one accounts for nitrogen releases (external footprints) caused abroad due to German consumption and corresponding net imports of agricultural products, this value is even higher.

Such an application of the planetary boundary for nitrogen indicates that the German and European nitrogen targets – most of which have not been achieved – are not ambitious enough from the point of view of global sustainability criteria. For example, compliance with the EU Directive on National Emission Ceilings (European Environmental Agency 2016) would only reduce the current value by just under 0.5 million tons. Even if the recommendation by the German Advisory Council on the Environment (SRU) and the Environment Agency (UBA) to half the N-surplus on agricultural land were fully implemented, the planetary boundary for nitrogen, scaled down to Germany, would still be exceeded by around 200%. Additional emission reductions in agriculture and beyond (especially in the energy, transport and industry sectors) would be necessary to comply with this boundary.

Increasing nitrogen use efficiency at all levels and along the entire value chain is an important lever for achieving several environmental and sustainability goals. In addition to reducing nitrogen release into the environment, improvements (co-benefits) can be achieved (e.g., in relation to land, water, energy, food security and other development goals as defined in the SDGs). By increasing resource efficiency, the amount of nitrogen released into the environment can be reduced. Since the planetary boundary for nitrogen is defined by maximum allowable environmental concentrations, it can be set higher with increased resource efficiency.

A decisive factor for the vertical integration of German and international environmental goals and sustainability criteria is the "triad" of reducing nitrogen release within Germany, reducing Germany's (trade-related) nitrogen footprint abroad, and increased international cooperation to improve nitrogen use and resource efficiency (e.g., through investment, development cooperation, and knowledge and technology transfer). This triad corresponds to the guiding SDG implementation – SDGs are to be implemented within Germany and, at the same time, observed internationally (implementation in, by and with Germany). Starting points for improved vertical coherence between national, regional and global policy levels include the common European agricultural policy, international trade agreements and the various multilateral environmental agreements.

The operationalization and application of the planetary boundary for nitrogen to the integrated national nitrogen strategy provides indications for the further development of the planetary boundaries itself (e.g., with regard to its extension beyond the agricultural sector). The further development of planetary boundaries and their application must be iterative and reciprocal. To this end, the nitrogen strategy should be dynamically developed, with new knowledge (e.g., from accompanying research) continuously incorporated (adaptive management). In accordance with the systemic character of the concept and the complexity of the nitrogen cycle, this requires a comprehensive dialogue with partners from all relevant sectors, in accordance with the Future Earth principle of "co-design and co-production of relevant knowledge" (i.e., in mutual coordination between politicians, decision-makers and scientists).

Conclusion and next steps for the operationalization of the planetary boundaries concept (see chapter 3)

At an international conference in Berlin in April 2017, central questions concerning the further development and application of the planetary boundaries concept were discussed, including:

- How can the scientific basis of the concept – which is widely recognized internationally – be strengthened?
- How can the concept be applied to national environmental and sustainability policymaking?
- What opportunities does the concept present for technical, economic and social innovation, for operational risk and environmental management, and for environmental education and communication?

The aim of the conference was to bring together key stakeholders in sustainability transformation in order to develop an agenda for the further application of the planetary boundaries concept in science, politics, the private sector and civil society, with the conference representing an international milestone for the concept's dissemination, development and application. The conference focused on two topics:

- Conference topic 1: The scientific status of planetary boundaries, latest conceptual developments, critical aspects and deficits of the concept, and future research needs (e.g., the definition of the boundaries and interactions between them)
- Conference topic 2: The current application and implementation of boundaries at different geographical scales, in different political contexts and by different actors (e.g., political, private sector, civil society); and examples of the application of the concept within the EU, Germany, Switzerland, Sweden, South Africa and China

Starting points, goals, new networks, and next steps for implementation and research on planetary boundaries were developed, presented and documented. These next steps (roadmaps) are listed below.

Next steps for policy (see chapter 3.1)

The further implementation, application and transfer of the planetary boundaries will take place against the background of the concept's increasing inclusion in sustainability strategies (e.g., Germany's Integrated Environmental Programme 2030). The concept has potential for strengthening public and private sector sustainability and risk governance, for strengthening policy and strategy coherence, for improving communication with experts, stakeholders and the wider public, for supporting the negotiation of global environmental targets, and for mapping externalized environmental impacts.

With regard to the further communicative linkage of the concept, it is central to link the planetary boundaries with existing social and economic discourses, and to build a coherent narrative that highlights the integrity of the Earth system as a necessary condition for dignity, prosperity and peace. The link between the planetary boundaries and Anthropocene concepts should be highlighted. The planetary boundaries concept should be presented as complementary to and supportive of the 2030 Agenda for Sustainable Development. The planetary boundaries should be interpreted flexibly, with parameters of greatest relevance to individual regions or governance challenges prioritized, for example, by linking the concept with footprints along global value chains or the DPSIR framework.

Overall, the dialogue process on the planetary boundaries concept should be continued, building on previous events. This includes exchange within the European Union on the eighth EU Environmental Action Programme, the 2020 State of the Environment Report and the implementation of the 2030 Agenda for Sustainable Development, and within the frameworks of the European Sustainable Development Network (ESDN) and the European Environment Agency. Thematically, further dialogue should focus on risks for insurers, companies and the financial sector associated with transgressing boundaries, or on innovation within the safe operating space.

Politically, the concept should be applied to the national and European implementation of the 2030 Agenda for Sustainable Development. The concept should be incorporated into various global reports, including the UN Global Sustainable Development Report, UN environmental reports and the World Economic Forum's Global Risk Report. Particular emphasis should be placed on measures that reduce the "hockey stick" tendencies of increasing resource consumption and environmental pressures, particularly the transformation toward a social-ecological market economy and the further spread of alternative welfare models.

Policy-relevant research should focus on the governance challenge that arises from the concept. Strategies and policy approaches should be developed that ensure societies remain in or re-enter the safe operating space. Further research should address the implementation and shortcomings of existing strategies and policy instruments.

Next steps for science (see chapter 3.2)

The planetary boundaries concept has received widespread approval within the scientific community. However, the research community explicitly dedicated to the concept is still relatively small. At present, science funding is not directed toward the integrated development and operationalization of the concept. In future, modelling and data analysis should focus more on the applicability of the concept. Research on planetary boundaries is located between climate-oriented earth system sciences and implementation-oriented research (e.g., on SDGs and sustainability issues), which enables research on planetary boundaries to fulfill a mediating role between the two levels.

Research areas central to the further development of the concept include the realization of models that simulate planetary boundaries and interactions between planetary boundaries within the framework of earth system dynamics. Open areas of research include the creation of a systemic approach that takes into account the integrity of the biosphere (beyond the climate), the inclusion of human societies as dynamic biogeochemical components (anthropo-biogeochemistry), interactions between planetary boundaries and teleconnections, and nexus research (e.g., on land-ocean and land-water-energy agriculture).

A second area of research concerns the quantification of SDG pathways within planetary boundaries, such as the socioeconomic feasibility of normative paths, the quantification of shared socioeconomic pathways, the benchmarking of existing developments against planetary boundaries, the identification of synergies and trade-offs between SDG objectives, and the maintenance of the safe and just operating space.

Further research should address social-ecological complexity (e.g., the preconditions for the safe and just operating space), and the implementation of the concept by environmental and sustainability policymakers, and companies (across sectors and regions). This includes embedding the concept in decision-making, relating the concept to questions of environmental justice, cooperation and institutional design, and linking the concept with the circular and green economy.

Further research should also focus on the (political and social) orders and ontologies associated with the concept. This includes examining the socio-cultural implications of the concept, such as questions of image design and visual language, philosophical and moral questions of the formulation of planetary boundaries, and the role of transition narratives.

In addition, procedural steps should be considered. For example, regular assessments of planetary boundaries should be designed (in conjunction with the evaluation of SDG implementation), a dialogue platform including the business and financial sectors should be established, and reports on research gaps and costs of inaction should be prepared. An international circle of experts should be formed to advance the concept.

Next steps for the economy (see chapter 3.3)

A number of companies and sectors have begun to reference the concept in, and translate the concept into their operational and strategic plans. While the implementation and application of the concept is still at a formative stage in general, the concept can benefit business. On the one hand, the concept can be used for corporate communication, placing corporate action in a wider narrative context. Companies can use the concept internally to raise awareness of risks and externally to emphasize their commitment to sustainability to build consumer confidence (e.g., in the areas of corporate social responsibility and shared value), if credible steps are taken to reduce pressure on the planetary boundaries. In terms of content, the concept can be used as a “dashboard” that simultaneously formulates important dimensions of sustainability (conditions of sustainable development) and highlights links between the dimensions. For some of the planetary boundaries, the concept provides a global budget or large-scale, long-term performance indicators.

Initial steps for companies include contributing to the formulation of science-based targets and methodologies for downscaling, applying the concept at the company and industry level, analyzing corporate sustainability standards and linking standards to planetary boundaries, and promoting good practices and early-adopter companies. Secondary next steps for companies include supporting companies in implementing the concept, for example, by developing narratives and arguments (business model for companies), and creating a planetary boundary compass (e.g., with individual pioneers and good practice examples). A third step would involve the further dissemination of the concept in the corporate world, for example, by linking it to company-related dialogue processes.

1 Cross cutting issues

1.1 Das Konzept der Planetaren Grenzen – Chance für nachhaltige Entwicklung, Perspektiven für eine integrative Umwelt- und Nachhaltigkeitspolitik

1.1.1 Einleitung

Im Anthropozän mit seiner sogenannten „great acceleration“ (Steffen et al. 2015b) geraten das Erdsystem und seine Sub-Systeme immer stärker unter Druck. Es ist unklar, ob und wie lange deren für die Menschheit essentiellen Funktionen und Ökosystemdienstleistungen erhalten bleiben oder Überschreitungen kritischer Grenzwerte mit ungeahnten und gravierenden Folgen drohen sogenannte „regime shifts“.

Aufbauend auf Vorläufer- und verwandten Konzepten wie “limits to growth”, “carrying capacity”, “critical loads”, “tolerable windows” fasst das Konzept der Planetaren Grenzen den Stand der Wissenschaft zu großmaßstäbigen Umweltgrenzen bzw. Leitplanken zusammen und versucht einen globalen nachhaltigen Entwicklungsraum („safe operating space“) zu definieren. Die rasche Aufnahme in Politik und gesellschaftliche Diskurse verdankt das Konzept auch der guten Kommunizierbarkeit der einfachen Kennzahlen für die verschiedenen Umweltkompartimente, analog dem Zwei-Grad-Ziel aus Klimawissenschaft und -politik.

Umwelt- und Nachhaltigkeitspolitik nehmen seit der ersten Publikation des Konzepts (Rockström et al. 2009) auf allen Ebenen vermehrt Bezug auf Planetare Grenzen als globale Rahmenbedingung, so z.B. das High Level Panel on Global Sustainability (UN 2012) oder das 7. Umweltaktionsprogramm der EU (Europäische Kommission 2014), welches die „Erreichung wirtschaftlichen und sozialen Fortschritts im Rahmen der Belastbarkeit der Erde „Grenzen des Planeten“ fordert.

Auf nationaler Ebene wird das „top-down“ Konzept der Planetaren Grenzen über die vertikale Integration mit „bottom-up“ Umweltzielen anschlussfähig. Dieses Input Paper stellt das erste in einer Serie von Beiträgen zur Anwendung des Konzepts im Rahmen der deutschen Nachhaltigkeitsagenda dar. Diese Inputpapers stellen Ergebnisse des UFOPLAN-Vorhabens 3714 19 100 0 „Planetare Grenzen – Anforderungen an die Wissenschaft, Zivilgesellschaft und Politik“ dar. Weitere Inputpapers werden auf einzelne Anwendungsmöglichkeiten des Konzepts der Planetaren Grenzen, z.B. für das Integrierte Umweltprogramm 2030 (IUP) oder die nationale integrierte Stickstoffstrategie sowie die Kommunikation des Konzepts, das downscaling der globalen Werte und andere Aspekte der Operationalisierung eingehen.

1.1.2 Übersicht über die Planetaren Grenzen

Für die Planetaren Grenzen ist der historische Klima- und Erdsystemzustand (das Holozän) die Referenz. Dieser relativ stabile erdgeschichtliche Zustand ist der einzige, den die Menschheit in ihrer bisherigen Zivilisationsgeschichte erlebt hat. Die Planetaren Grenzen beschreiben maximal mögliche Abweichungen vom Holozänzustand, unterhalb derer die Stabilität des Erdsystems höchstwahrscheinlich gewährleistet ist. Im Anthropozän drohen diese Grenzen durch menschliches Handeln überschritten zu werden (siehe diverse exponentielle sozio-ökonomische und bio-physikalische Trends im letzten Jahrhundert; Steffen et al. 2015b), mit unzureichend bekannten Konsequenzen für das Erdsystem und die Menschheit.

Das wissenschaftliche Konzept der Planetaren Grenzen weist auf die Risiken hin, die mit einem Verlassen des bisherigen Holozänzustands verbunden sind. Es stellt den Stand der Wissenschaft zu globalen biophysikalischen Umweltgrenzen (in Bezug auf Ressourcennutzung bzw. -degradation oder Emission von Schadstoffen) dar, bei deren Überschreitung das Risiko negativer Folgen für die

Funktionsfähigkeit des Erdsystems und damit für die weitere gesellschaftliche Entwicklung inakzeptabel wird. Die Planetaren Grenzen verweisen gleichzeitig auf die Chancen für eine nachhaltige Entwicklung innerhalb der durch sie umrissenen stabilen Umweltbedingungen.

Die neun Planetaren Grenzen betreffen physikalische, chemische und biologische Prozesse des Erdsystems. Dies sind im Einzelnen: Klimawandel, Verlust der Integrität der Biosphäre, Landnutzung, Wassernutzung, biogeochemische Flüsse, Ozeanversauerung, atmosphärische Aerosolbelastung, stratosphärischer Ozonverlust, Einführung neuer Umweltsubstanzen. Es handelt sich dabei entweder um kritische Treiber, Druck auf die oder Zustände der betreffenden Umweltmedien. Der wissenschaftliche Konsens über die jeweiligen Grenzwerte, deren Erreichen bzw. Überschreiten und die entsprechenden (mit zu kommunizierenden) Unsicherheiten variieren zwischen den einzelnen Planetaren Grenzen (siehe Tabelle 2).

Die Planetaren Grenzen erweitern die Global Change-Debatte über das Klimathema hinaus. Aufbauend auf dem ursprünglich für das Klimathema entwickelten Leitplankenkonzept (WBGU 1995) sowie weiteren zumeist sektorspezifischen Vorläuferkonzepten regionaler und globaler Umweltgrenzwerte, wie z.B. dem critical loads-Konzept (UNECE 1979), bilden die Planetaren Grenzen einen globalen, alle Umweltkompartimente umfassenden Rahmen (und ein entsprechendes Narrativ), an dem sich gesellschaftliche Debatten wie Energie- oder Agrarwende, Welthandel, Umweltgerechtigkeit, Armutsbekämpfung und nachhaltige Entwicklung orientieren können. Entsprechend erweitern die Planetaren Grenzen auch die Transformationsagenda, wie sie der WBGU 2011 für das Klimathema erarbeitet hat („a dashboard for global sustainability“, Steffen et al. 2015b). Sie können dabei auf den langjährigen Erfahrungen mit den Klimaverhandlungen (UNFCCC) und dem Klimaziel (IPCC) aufbauen bzw. von diesen Prozessen lernen. Analog zum 2-Grad-Klimaziel (siehe 4° Reports: „Turn down the heat“, (World Bank Group 2014, 2012; Potsdam-Institut für Klimafolgenforschung 2013) sind die negativen Folgen von Grenzüberschreitungen aufzuzeigen. Ein wichtiger Aspekt dabei wird mit dem Slogan „reconnecting to the biosphere“ (Folke et al. 2011, S. 719) beschrieben, nämlich die Abhängigkeit nachhaltiger Entwicklung von intakten Ökosystemen und deren Dienstleistungen.

Die Planetaren Grenzen beschreiben den Zustandsraum des Erdsystems, in welchem nachhaltige Entwicklung möglich ist. Angelehnt an die Rio Deklaration von 1992 (UN 1992, S. 2)(“environmental protection shall constitute an integral part of the development process”)beschreiben die Planetaren Grenzen die globalen biophysikalischen Umweltbedingungen, welche Voraussetzung für eine nachhaltige Entwicklung und gesellschaftliche Ziele wie Armutsbekämpfung, Gerechtigkeit, Stabilität und Frieden sind, wie zum Beispiel das 2-Grad-Klimaziel. Überschreitungen von Umweltgrenzen stellen destabilisierende Faktoren dar, welche Chancen für eine global nachhaltige Entwicklung aller Wahrscheinlichkeit nach eher vermindern als sie zu vergrößern.

Planetare Grenzen basieren auf dem Vorsorgeprinzip. Die Planetaren Grenzen definieren einen sicheren Abstand von kritischen Grenzwerten oder Leitplanken (WBGU 2014) oder einen „safe operating space“, innerhalb dessen das Risiko bekannter oder unbekannter Veränderungen auf ein akzeptables Maß begrenzt bleibt (vergleiche mit anderen normativ festgelegten, als gesellschaftlich akzeptabel geltenden Risiken, z.B. bei der Reaktorsicherheit oder der Sicherheit anderer technischer Anlagen). Dieser Sicherheitsabstand von den kritischen Grenzwerten ist u.a. deshalb erforderlich, weil die genaue Lage der kritischen Grenzwerte noch nicht oder zumindest nicht genügend genau bekannt ist (wissenschaftliche Unsicherheiten), weil das Erdsystem und seine Teilsysteme mit Verzögerung auf anthropogene Störungen reagieren (z.B. Erwärmung der Ozeans, Schmelzen des Grönlandeises), weil positive Rückkopplungen möglich sind (z.B. Auftauen von Permafrost und die damit einhergehende Beschleunigung des Klimawandels) und weil gesellschaftliche Reaktionen (Nachhaltigkeitstransformationen) Zeit benötigen und ebenfalls mit Unsicherheiten behaftet sind.

Planetare Grenzen stellen (erd-)systemische Grenzen dar. Die den Planetaren Grenzen zu Grunde liegenden Prozesse (siehe Tabelle 2) interagieren – oft nicht-linear und mit Rückkopplungen - miteinander (siehe Abbildung), sie beschreiben also nicht neun unabhängige, parallele Dimensionen, sondern einen Gesamtzustand des komplexen Systems Erde und dessen Leitplanken. Damit schaffen die Planetaren Grenzen eine neue wissenschaftliche Grundlage und ein Kommunikationswerkzeug für eine integrierte Umwelt- und Nachhaltigkeitspolitik und die Ko-Transformation verschiedener Sektoren. Ein solcher systemischer Ansatz schafft einen Mehrwert, indem er sektorale Debatten und Handlungsfelder miteinander verbindet und mögliche Synergien, aber auch Zielkonflikte aufzeigt. Der systemische Charakter der Planetaren Grenzen verweist auch darauf, dass diese Grenzen dynamisch sind, sich also unter dem Einfluss der miteinander wechselwirkenden Triebkräfte verändern (z.B.: die Planetare Grenze für Wasser ändert sich durch Klimawandel).

Einige der Planetaren Grenzen sind bereits überschritten.
Vier der neun identifizierten Planetaren Grenzen befinden sich derzeit außerhalb des safe operating space (Klima, Land, Biosphäre, biogeochemische Flüsse) – siehe Abbildung. Dabei ist das Aussterben von Arten (Biosphärengrenze) als irreversibel zu betrachten, der Klimawandel nach menschlichen Zeitmaßstäben ebenso. Die Überschreitungen der Land- und biogeochemischen Flussgrenzen sind hingegen weitgehend reversibel. Das Vorsorgeprinzip kommt bei irreversiblen Reaktionen verstärkt zur Anwendung kommen, d.h. die gegenwärtigen Grenzwertüberschreitungen sollten möglichst schnell beendet werden, um die Risiken für Erdsystem und Menschheit möglichst gering zu halten.

Die Folgen von Überschreitungen der einzelnen Planetaren Grenzen sind noch nicht vollständig bekannt. Für einige Planetare Grenzen (z.B. Klima) sind die zu erwartenden Folgen von Grenzwertüberschreitungen trotz vieler offener Fragen bereits ausgiebig untersucht. Bei anderen (z.B. Land, Wasser) sind die Folgen im Prinzip bekannt, aber noch nicht hinreichend quantifizierbar. Wiederum bei anderen sind die Systemantworten weitgehend unbekannt (z.B. Biodiversität). Hier stellt sich die Frage, welche Risiken die Gesellschaft angesichts der bestehenden Unsicherheiten bereit ist einzugehen. Wichtig ist dabei auch die Abwägung, ob die Schwierigkeiten und Kosten einer Einhaltung der Grenzen kleiner und überschaubarer sind, als jene, die sich aus der Überschreitung von Grenzen ergeben.

Die Planetaren Grenzen werden zunehmend räumlich explizit und auf der Ebene der handelnden Akteurinnen und Akteure, v.a. Staaten, dargestellt. Die globalen Grenzwerte und die jeweilige räumliche Heterogenität werden bei der Weiterentwicklung des Planetare Grenzen-Konzepts und für dessen Operationalisierung räumlich differenziert dargestellt („downscaling"). Auf der Anwenderseite, wo die Planetaren Grenzen oft (insbesondere als Kommunikationswerkzeug) stärkeren Anklang finden als auf der wissenschaftlichen Ebene, erlauben sie eine Formalisierung des Prinzips „act local – think global". Sie beschreiben die globalen Rahmenbedingungen für lokales bzw. nationales Handeln und schaffen damit eine Basis für skalenübergreifendes Umweltmanagement. Damit bilden die Planetaren Grenzen auch einen globalen quantitativen, räumlich expliziten Bezugsrahmen für lifecyle- oder footprint-Analysen. Nationale Beiträge zu Planetaren Grenzen ergeben sich aus den jeweiligen Anteilen entweder an einem globalen Budget (z.B. nationale Kohlenstoffdioxid/CO_2-Emissionen) oder an dem erforderlichen Gesamtumweltzustand, welcher globale Systemeigenschaften sicherstellen soll (z.B. Anteile an erhaltenswerten aquatischen Ökosystemen oder Wäldern). Dabei sind auch räumliche Muster (z.B. besonders vulnerable hotspots) und Interaktionen zwischen den Regionen („teleconnections") von Bedeutung. Nationale Umweltassessments können einen Beitrag zum Monitoring der Planetaren Grenzen darstellen. Die konsistente Integration von (top-down) Planetaren Grenzen mit (bottom-up) Umweltgrenzen kleinerer räumlicher Einheiten und die entsprechenden institutionellen Antworten (institutional fit & policy coherence) stecken allerdings noch in den Anfängen.

Innerhalb der Planetaren Grenzen gibt es erhebliche Chancen für Transformationen („planetary opportunities" – DeFries et al. 2012). Das Konzept der Planetaren Grenzen überschneidet sich mit Fragen der Globalisierung, der internationalen Kooperation und Wirtschafts- und Finanzsteuerung sowie der geopolitischen Sicherheit. Chancen für Nachhaltigkeitstransformationen und neue Wohlstandsmodelle ergeben sich aus Technikinnovationen und verbesserter Ressourcennutzungseffizienz und Nutzung von Ökosystemdienstleistungen; außerdem aus verbessertem Zugang zu Ressourcen und den daraus erwachsenden Versorgungssicherheiten, räumlichen und sozialen Umverteilungen sowie skalenübergreifender Politikkohärenz einschließlich neuer Formen globaler Governance. Damit können wirtschaftliche Entwicklung und verbesserte Lebensbedingungen bei gleichzeitig vermindertem Druck auf die Umwelt erreicht werden, im Sinne einer Entkopplung und einer Green Economy[4]. Dies verlagert die Debatte von „Limits to Growth" (Meadows 1972) hin zu „Growth within Limits"(Crépin und Folke 2015).

Das Konzept der Planetaren Grenzen hat Implikationen für die Gerechtigkeits- und Nachhaltigkeitsdebatte. Die Verknüpfung des Prinzips „common but differentiated responsibilities" (siehe Rio-Deklaration, UN 1992) mit den globalen Budget- und Grenzwertansätzen der Planetaren Grenzen bildet eine Grundlage, auf der die politisch wichtigen Fragen der internationalen Verteilungs-, Finanzierungs- und Umsetzungsgerechtigkeit (Lastenverteilung) verhandelt werden können. Ausgehend von den aggregierten globalen Grenzen bzw. Zielen sind nationale Beiträge zu definieren. Für den jeweiligen nationalen Ist- und Soll-Zustand sind ggf. auch die externen Beiträge zur Grenzwertüberschreitung (insbesondere über Handel, wie in sog. „externen Fußabdrücken" dargestellt), zu berücksichtigen. Damit stellen die Planetaren Grenzen wissenschaftlich basierte Informationen für neue globale Governance-Prozesse von Umweltgütern bereit. Die SDGs (UNGA 2015) betonen die Universalität und Komplementarität von Umwelt- und Entwicklungszielen und betonen Umweltziele wie Klima- und Gewässerschutz sowie die Erhaltung der Biodiversität. Dabei werden die Planetaren Grenzen bzw. die Erhaltung des Erdsystems in seinem stabilen Holozänzustand als Grundvoraussetzung nachhaltiger Entwicklung jedoch nicht explizit benannt (WBGU 2014). DerSynthesebericht von 2014 (The road to dignity) erwähnt hingegen die Planetaren Grenzen.

Die wissenschaftliche Weiterentwicklung der Planetaren Grenzen konzentriert sich auf die globale Quantifizierung und regionale Anwendung der Planetaren Grenzen. Die Ziele dieser Arbeiten sind weiter oben im Text bereits benannt: Verringerung der Unsicherheiten bezüglich der jeweilige Lage und Dynamik der kritischen Grenzwerte (z.B. Skalierungseffekte und kumulative Effekte lokaler Grenzwertüberschreitungen), Reaktionen (und Trägheiten) des Erdsystems und dessen Teilsystemen bei Grenzüberschreitungen, einzuhaltender Sicherheitsabstände von den Grenzwerten („Leitplanken"), Interaktionen zwischen den einzelnen Planetaren Grenzen zugrunde liegenden Prozessen, downscaling auf politik- und entscheidungsrelevante Skalen und Operationalisierung der Planetaren Grenzen. Zu den wissenschaftlichen Herausforderungen gehört auch die konsistente Integration der bio-physikalischen Umweltgrenzen mit sozio-ökonomisch Erfordernissen (siehe z.B. Raworth 2012; Cole et al. 2014; Dearing et al. 2014) auf verschiedenen räumlichen Skalen sowie das hinter den Planetaren Grenzen stehende Kultur- und Naturverständnis (normative Aspekte) und neue multi-level Governance-Ansätze (siehe z.B. Biermann 2016), welche die oben genannten Nachhaltigkeits- und Gerechtigkeitsaspekte umfassen. Erforderlich sind transdisziplinäre Ansätze, integrative und skalenübergreifende Modellwerkzeuge und Datenharmonisierung.

[4] Improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP).

Im Folgenden nehmen wir Bezug auf die beiden grundlegenden Planetare Grenzen-Publikationen (Rockström et al. 2009; Steffen et al. 2015b) sowie auf die bisherigen nationalen und regionalen Anwendungen des Konzepts (Cole et al. 2014; Frischknecht et al. 2014; Hoff et al. 2014; Nykvist et al. 2013), die inzwischen recht zahlreichen Publikationen zu einzelnen Planetaren Grenzen sowie Kapitel 2 aus SRU (2015), das sich mit dem Konzept des „sicheren Handlungsraumes“ als Grundlage für Stickstoffminderungsziele beschäftigt. Außerdem wird Bezug genommen auf das WBGU-Politikpapier 8 (2014): „Zivilisatorischer Fortschritt innerhalb planetarischer Leitplanken – Ein Beitrag zur SDG-Debatte“ und die DIE Publikation: „The challenge for 2015: ensuring global development within planetary guard rails“ (Brandi und Messner 2015).

1.1.3 Weiterentwicklung der Planetaren Grenzen seit 2009

Dieser Abschnitt bezieht sich vor allem auf die beiden zentralen Planetare Grenzen Publikationen von Rockström et al. (2009) und Steffen et al. (2015b). Letztere nimmt Bezug auf die zahlreichen Publikationen, die seit 2009 zu einzelnen Planetaren Grenzen erschienen sind, auf die umfangreichen Diskussionen innerhalb und außerhalb der Wissenschaft und auf Fragen nach der Validität und Anwendbarkeit des Konzepts. Rockström und Steffen sind Leitautoren beider Publikationen. Darüber hinaus hat es einige Veränderungen bei den übrigen Autoren gegeben, welche die neueren Beiträge zu den einzelnen Planetaren Grenzen widerspiegeln.

Die Autoren haben wiederholt klargestellt, dass der Ausgangspunkt der Planetaren Grenzen die Funktionsfähigkeit und Stabilität bzw. Resilienz des Erdsystems und dessen biophysikalische Grenzen bzw. die Vermeidung von deren Überschreitung ist. Das Konzept umfasst weder Annahmen zur Treibern noch zu Maßnahmen zur Vermeidung von Grenzwertüberschreitungen oder zu Ressourcenproduktivität. Diese bleiben der Anwendung in Umwelt- und Nachhaltigkeitspolitik auf allen relevanten Skalen vorbehalten, für welche die Planetaren Grenzen einen quantitativen wissenschaftlichen Rahmen bieten (Galaz 2012).

Die Konzeptionalisierung, Definition und Quantifizierung der Planetaren Grenzen ist seit ihrer Veröffentlichung 2009 (Rockström et al.) kontinuierlich und durch die verschiedensten wissenschaftlichen Disziplinen weitergeführt worden und wird auch gegenwärtig intensiv weitergeführt. Zu den einzelnen Planetaren Grenzen und deren Wechselwirkungen sind jeweils spezielle Arbeiten publiziert worden welche diese kritisch untersucht haben (s.u.). Dabei sind einige Grenzen revidiert oder auch neu definiert worden, und es haben sich z.T. erhebliche Veränderungen der Grenzwerte und der bereits erreichten Grenzwertüberschreitung ergeben. Steffen et al. (2015b) fassen mit ihrer Planetary Boundaries 2.0 Publikation (die wahrscheinlich besser als „Planetary Boundaries 1.5“ zu bezeichnen wäre, da es sich nicht um eine Neu- sondern eine Weiterentwicklung handelt) den derzeitigen Stand der Wissenschaft – einschließlich der jeweiligen Unsicherheiten - zusammen und geben erste Hinweise für die Operationalisierung und Anschlussfähigkeit des Konzepts. Aus Sicht der Autoren ist darauf hinzuweisen, dass die Weiterentwicklung des Planetare Grenzen-Konzepts zum Teil durch unzureichende Forschungsförderung behindert wird.

Der **Risikoansatz** (Vermeidung eines inakzeptablen Risikos noch nicht vollständig überschaubarer, aber potentiell gravierender, Folgen für das Erdsystem und die Menschheit) für die Herleitung der Grenzwerte wird jetzt stärker betont. Während zwischen den beiden Planetare Grenzen-Publikationen (2009 und 2015) die wissenschaftliche Basis zu möglichen Grenzwerten und Kipppunkten für die verschiedenen Umweltkompartimente und -prozesse weiter gestärkt wurde, bleibt die Leitplankensetzung, d.h. die Bestimmung „inakzeptabler“ Risiken, mit normativen Elementen verbunden.

Im Einzelnen sind die Planetaren Grenzen wie folgt modifiziert oder übernommen worden (siehe Tabelle 2):

- **„climate change“** liegt unverändert bei 350 ppm CO_2 concentration und einem radiative forcing von 1 W m^{-2} radiative forcing; inzwischen gibt es zahlreiche neue Publikationen zu den Folgen stärkerer

Erwärmung z.B. den jüngsten IPCC Bericht (IPCC 2014) und die Berichte der Weltbank („Turn down the heat“);

- **„rate of biodiversity loss“** (2009) wurde **zu „change in biosphere integrity”** (2015), wobei ein zusätzlicher Indikator „biodiversity intactness index“ eingeführt wurde; Dabei sind die Arbeiten von Barnosky et al. (2011; 2012) in Hinblick auf die Aussterberate von Spezies eingeflossen. Der neu aufgenommene „biodiversity intactness index“ geht auf Arbeiten von Scholes und Biggs (2005) zurück. Mace et al. (2014) haben weitere biosphärische Grenzen und Running (2012) eine zusätzliche Planetare Grenze für Biomasseproduktion („net primary production“) vorgeschlagen. Diese Vorschläge sind jedoch nicht in die Planetary Boundaries 2.0 eingegangen;
- **„nitrogen & phosphorus cycle“** (2009) wurde zu **„biogeochemical flows“** (2015), worunter auch (bislang noch nicht quantifizierte) Grenzen für andere Elemente wie Silizium fallen. Für Stickstoff (N) und Phosphor (P) wurden zusätzlich zu den globalen auch regionale Grenzwerte eingeführt; die Quantifizierung beruht auf Arbeiten von Carpenter und Bennett (2011) für P und DeVries et al. (2013) für N;
- für „**land system change**“ wurde der Indikator von maximal möglichem Anteil Ackerland an der Gesamtlandfläche zu mindestens zu erhaltendem Waldanteil geändert und letzterer räumlich bzw. nach Biomen differenziert (tropische, temperate, boreale Wälder);
- die Planetare Grenze für **„freshwater use“** wird jetzt für jedes Flusseinzugsgebiet einzeln bestimmt, basierend auf dem Wasserbedarf aquatischer Ökosysteme („environmental flow requirements“) und daraus der global aggregierte Wert berechnet („bottom-up construction of the planetary boundary“); die Berechnung beruht auf Gerten et al. (2013) und Pastor et al. (2014);
- die Planetare Grenze für **„stratospheric ozone depletion“** ist unverändert;
- die Planetare Grenze für **„ocean acidification“** ist ebenfalls unverändert;
- für **„atmospheric aerosols“** wurde erstmals ein Grenzwert (atmospheric optical depth 0.25) festgelegt, allerdings nur für eine Region (South Asia Monsoon);
- **„chemical pollution“** (2009) wurde zu **„introduction of novel entities“**, wobei diese Planetare Grenze jetzt weiter gefasst wird und auch „modified life-forms“ umfasst. Hier wurden drei Kriterien für kritische Substanzen (Persistenz, Mobilität über Skalen hinweg mit entsprechend weiter Verbreitung, potentielle Auswirkungen auf wichtige Prozesse des Erdsystems oder seiner Sub-Systeme) definiert, allerdings noch keine Indikatoren oder Grenzwerte bestimmt. Grundlegend für diese Erweiterung sind die Publikationen von Persson et al. (2013), MacLeod et al. (2014) und Diamond et al. (2015).

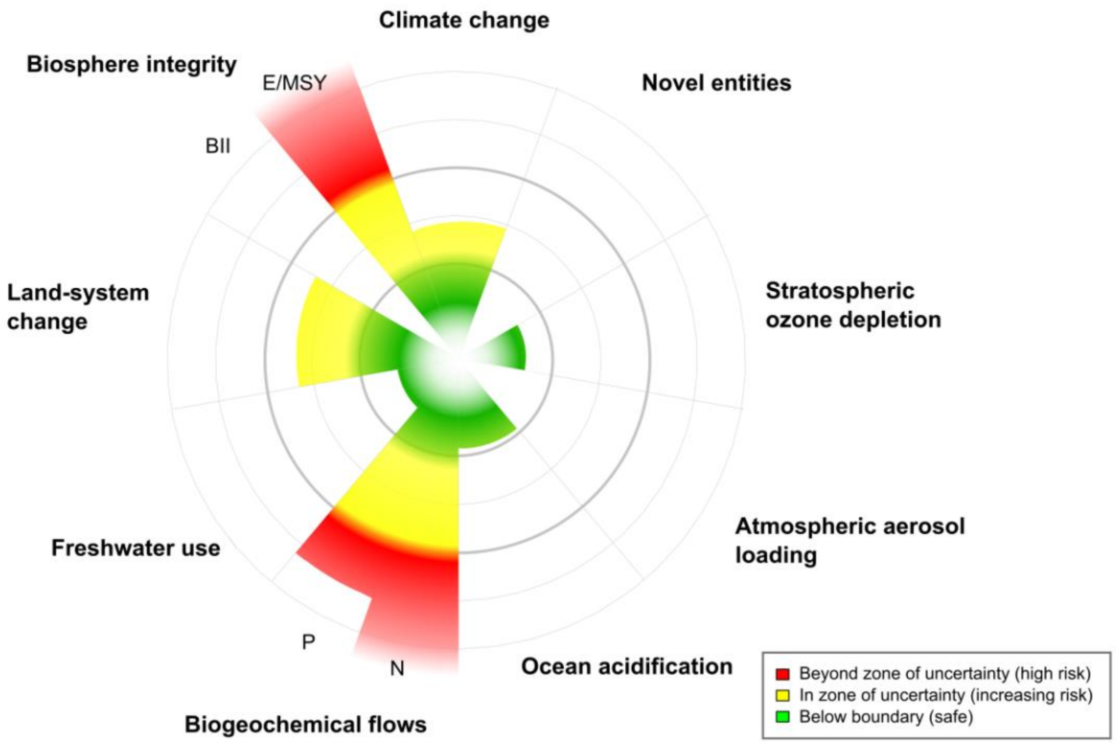
In der zentralen Grafik, dem Planetare Grenzen-Kreis (Fig. 3 in Steffen et al. 2015a; Abbildung) wurde gegenüber der Abbildung aus Rockström et al. (2009) ein zusätzlicher gelber Bereich erhöhten Risikos eingeführt, so dass der derzeitige Status einiger Planetarer Grenzen sich verändert hat. Dies bedeutet jedoch nicht, dass sich die Einschätzung zur Kritikalität der Gernzen, insbesondere der Klimagrenze, verändert hätte. Der sichere Bereich (grün markiert) und damit die Planetare Grenze ist und bleibt überschritten.

Zwei Planetare Grenzen, die für Klimawandel und die für Änderungen der Biosphärenintegrität, werden jetzt als „core boundaries“ mit besonderer Bedeutung für die Funktionsfähigkeit des Erdsystems herausgehoben. Sie stellen die am stärksten systemischen und Planetaren Grenzen dar und interagieren mit allen anderen Planetaren Grenzen (Friedrich 2013). Gleichzeitig sind die Folgen der Überschreitung dieser beiden Planetaren Grenzen als in menschlichen Zeiträumen irreversibel zu betrachten. Die bisherigen Übergänge von Erdzeitaltern waren stark von Klima- und Biosphärenveränderungen geprägt.

Durch eine beginnende räumliche Differenzierung und räumlich explizite Darstellung der globalen Planetaren Grenzen („downscaling“) wird der räumlichen Heterogenität von Umweltzuständen und Sensitivität gegenüber den zugrunde liegenden Prozessen (siehe Tabelle 2) Rechnung getragen. Damit wird auch die Operationalisierbarkeit und Anschlussfähigkeit der Planetaren Grenzen an nationale Umweltziele verbessert. Dieses downscaling ist für einzelne Grenzen (wie Wasser und Land) schon ansatzweise erfolgt (siehe z.B. Gerten et al. 2013), für andere noch nicht. Weitere Arbeiten dazu sind im Gange (z.B. Häyhä et al. 2016), um die Planetaren Grenzen in lokalen Kontexten wie auch bei der nationalen Implementierung der SDGs anwenden zu können.

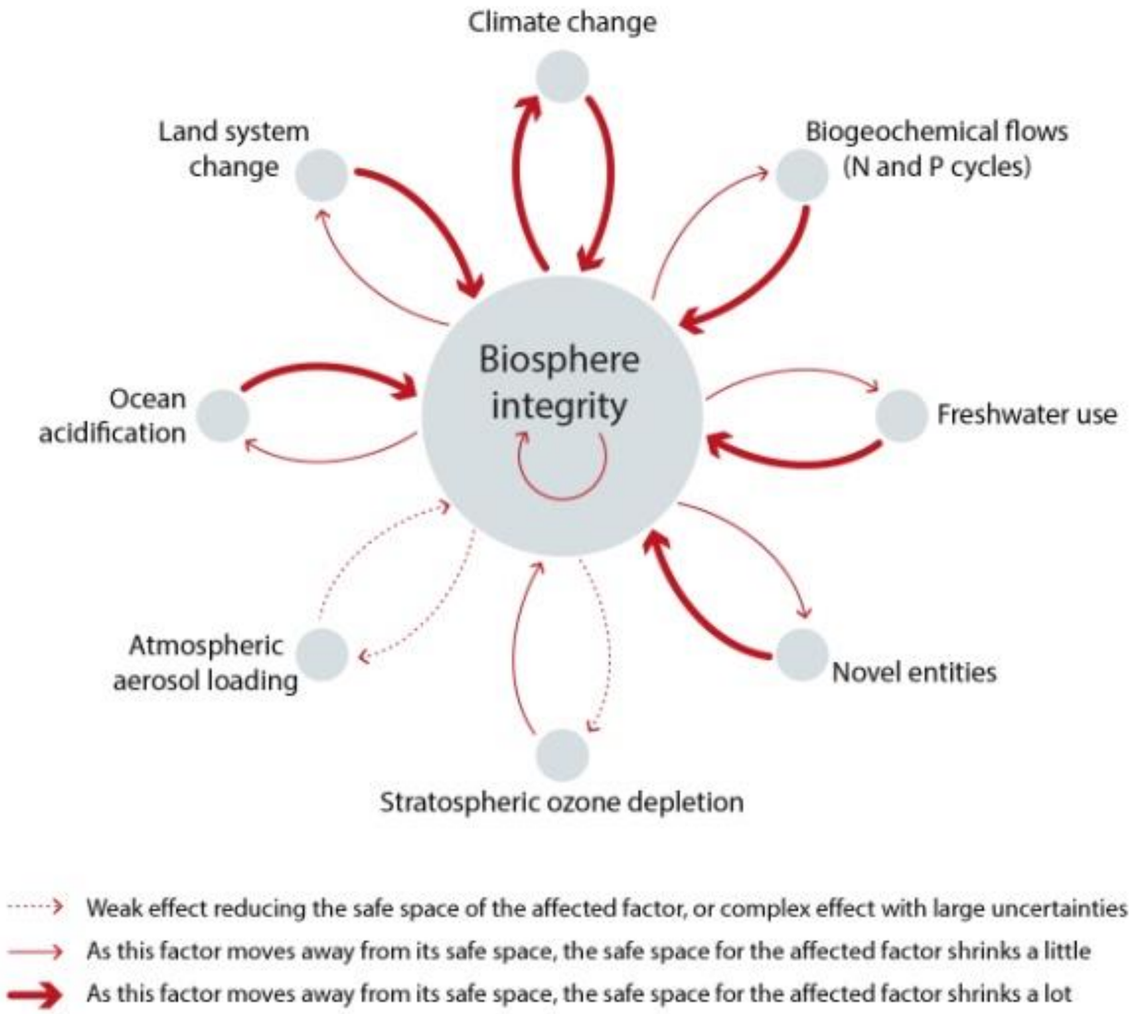
Die Folgen der Überschreitung von Grenzwerten werden jetzt differenzierter dargestellt, es werden nicht mehr für alle Planetare Grenzen abrupte Reaktionen („regime shifts“) an „Kipppunkten“ angenommen, sondern es werden auch moderate bzw. kontinuierliche Reaktionen in Betracht gezogen – siehe Abbildung in Steffen et al. (2015a). Auch haben nicht alle Kipppunkte globale Dimensionen, sondern z.B. die für Wasser und Land sind eher lokal bis regional, die kumulativen Folgen vielfacher lokaler Grenzwertüberschreitungen stellen allerdings wiederum ein Risiko für die Funktionsfähigkeit des Erdsystems dar (Galaz 2012).

Abbildung 17: Gegenwärtiger Status der Kontrollvariablen



Quelle: Steffen et al. 2015a; Grün markiert ist der sichere Bereich („safe operating space“) dessen äußerer Rand die Planetaren Grenzen darstellt, gelb eine Zone der Unsicherheit und rot ein inakzeptabel hohes Risiko, das mit der Grenzwertüberschreitung einhergeht.

Abbildung 18: Wechselwirkungen zwischen Planetaren Grenzen



Quelle: Steffen et al. 2015a

Tabelle 2: Die neun Planetaren Grenzen, ihre Unsicherheitsbereiche und ihr derzeitiger Status

Erdsystemprozess	Indikator	Planetare Grenze [mit Unsicherheitsbereich]	Derzeitiger Status
Klimawandel	a) Atmosphärische CO_2-Konzentration	350 [350-450] ppm	399 ppm !
	b) Energiebilanz am Rand der Atmosphäre	Änderung des Strahlungsantriebs i. Vgl. zu vorindustriellem Wert <1,0 [1,0-1,5] W/m^2	2,3 [1,1-3,3] W/m^2
Änderung der Biosphären-Integrität	a) Genetische Diversität	<10 [10-100], idealerweise ~1 Extinktionen pro Mio. Speziesjahre (E/MSY)	100-1000 E/MSY !!
	b) Funktionale Diversität	Biodiversity Intactness Index 90 [90-30]%, für Großregionen (Biome) od. funktionelle Großgruppen	? (84 % in S-Afrika)

Stratosphärischer Ozonabbau	Stratosphärische Ozon-Konzentration	<5 [5-10]% Rückgang gegenüber vorindustriellem Niveau (290 Dobson Units), pro Breitengrad	Über Antarktis im Frühjahr überschritten (~200 Dobson Units)
Ozeanversauerung	Konzentration von Karbonat-Ionen	≥80 [≥80-≥70]% der vorindustriellen mittleren globalen Aragonit-Sättigung der obersten Meeresschicht	~84 %
Biogeochemische Flüsse (Phosphor-, Stickstoffkreisläufe)	a) P-Kreislauf: Global: P-Eintrag von Flüssen in den Ozean; regional: P-Eintrag in erodierbare Böden	Global: 11 [11-100] Tg/Jahr; regional: 6,2 [6,2-11,2] Tg/Jahr auf erodierbare Böden aufgebracht	~22 Tg P / Jahr !!
	b) N-Kreislauf global: industrielle und biologische N-Fixierung	62 [62-82] Tg N / Jahr	~150 Tg N / Jahr !!
Landnutzungswandel	Global und regional: Waldfläche in % der ursprünglichen Fläche	75 [75-54]% als Mittel dreier Biom-spezifischer Grenzen: Regenwald 85 [85-60]%, Wälder gemäßigter Breiten 50 [50-30]%, boreale Wälder 85 [85-60]%	62 % !
Süßwassernutzung	Global: jährlicher Süßwasserverbrauch; regional: monatliche Wasserentnahme	Global: 4.000 [4.000-6.000] km^3/Jahr. Regional: Entnahme des mittleren monatlichen Wasserdargebots bei Niedrigwasser 25 [25-55]%, bei Hochwasser 55 [55-85]%, sonst 30 [30-60]%	~2.600 km^3/Jahr
Atmosphärischer Aerosolgehalt	Saisonales Mittel der Aerosol-optischen Dicke (AOD) über einer Region (da global sehr heterogen)	Regional (Bsp. südasiatischer Monsun): anthropogene AOD über Indien 0,25 [0,25-0,50], absorbierende (wärmende) AOD <10 % dieses Werts	? (0,30 über S-Asien)
Einführung neuer Substanzen und Lebensformen	Noch undefiniert	Noch undefiniert	?

Quelle: adaptiert von Steffen et al. (2015a); fett gedruckt und mit Ausrufezeichen versehen sind zugehörige Indikatorwerte, die sich bereits innerhalb des Unsicherheitsbereichs befinden (! in Abb. 1 gelb markiert) bzw. diesen überschritten haben (bezeichnet mit „!!“ in Abb. 1 rot markiert).

1.1.4 Nationale (und regionale) Anwendungen des Planetare Grenzen-Konzepts

Die Planetaren Grenzen sind als globale biophysikalische Umweltgrenzen in Hinblick auf die Erhaltung der Funktionsfähigkeit des Erdsystems entwickelt worden (s.o.). Sie bieten jedoch Anknüpfungspunkte für eine Operationalisierung, v.a. auf nationaler Ebene. Erste Interpretationen der Planetaren Grenzen gibt es für Schweden, die Schweiz, Europa und Südafrika.

1.1.4.1 Schweden

Nykvist et al. (2013) haben die Planetaren Grenzen für Schweden interpretiert in Hinblick auf das sogenannte "generational goal": «to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders» (Nykvist et al. 2013, S. 23) . Es zeigt sich, dass bei einer einheitlichen Pro-Kopf-Verteilung des zulässigen Ressourcenverbrauchs bzw. der zulässigen Emissionen auf die Gesamtbevölkerung der Erde, die schwedischen Pro-Kopf-Werte zumeist weit über dem erlaubten Wert (und über dem globalen Mittel) liegen und daher die meisten Planetaren Grenzen weit überschritten würden, wenn jeder Bewohner der Erde schwedische Werte erreichte (siehe dazu auch WWF 2014).

1.1.4.2 Schweiz

Frischknecht et al. (2014) haben eine rasch wachsende Externalisierung von Umweltauswirkungen (und damit des Drucks auf die Planetaren Grenzen) aufgrund von schweizerischen Konsummustern und entsprechenden Importen festgestellt. Die externen (d.h. sich außerhalb der Schweiz manifestierenden) Umweltauswirkungen sind von 56 % (1996) auf 73 % (2011) der gesamten Umweltauswirkungen gestiegen.

1.1.4.3 Europa

Hoff et al. (2014) haben für Europa ebenfalls gezeigt, dass die Pro-Kopf-Werte der Umweltauswirkungen weit über dem globalen Mittel und über den aus den Planetaren Grenzen errechneten zulässigen Pro-Kopf-Grenzwerten (bei gleichmäßiger Verteilung auf die Gesamtbevölkerung der Erde) liegen und dass sich die Umweltauswirkungen europäischer Konsummuster zunehmend in andere Weltregionen verlagern. Letzteres hat zu einer Verbesserung der Umweltsituation in Europa geführt, nicht jedoch zu einer Verminderung der entsprechenden europäischen Fußabdrücke („footprints") oder zu einer Verminderung des von Europa verursachten Druck auf die Planetaren Grenzen und ebenso wenig zu einer Entkopplung von der wirtschaftlichen Entwicklung. Europas neues Umweltaktionsprogramm "Living well, within the limits of our planet" (EC 2014) nimmt auf diese Externalisierung bzw. Europas Umweltauswirkungen in anderen Weltregionen kaum Bezug.

1.1.4.4 Südafrika

Cole et al. (2014) haben ein nationales "Barometer" entwickelt, welches die Nachhaltigkeit der Entwicklung in Südafrika in Hinblick auf einen „safe and just space" misst, also bereits versucht, biophysikalische Umweltziele mit sozio-ökonomischen Entwicklungszielen zu integrieren. Die Indikatoren sind dabei sehr spezifisch auf Südafrika zugeschnitten und haben z.T. nur entfernt mit den eigentlichen Planetaren Grenzen zu tun.

1.1.4.5 China

Dearing et al. (2014) haben das Planetare Grenzen-Konzept ebenfalls um sozio-ökonomische Grenzen erweitert und auf ländliche Gemeinden in der Yunnan und der Anhui Provinz in China angewendet. Sie zeigen dabei Interaktionen und Zielkonflikte zwischen den einzelnen Grenzen und Skalen sowie Verbindungen zwischen den Regionen auf.

Diese ersten Anwendungen der Planetaren Grenzen für spezielle (sub-)nationale oder regionale Kontexte zeigen, dass es der Interpretation, Übersetzung und Anpassung der Planetaren Grenzen bedarf, um diese für konkrete Umwelt- und Nachhaltigkeitszielsetzungen zu nutzen. Das downscaling kann nach verschiedenen Kriterien erfolgen (z.B. pro Landesfläche oder pro Kopf, mit oder ohne Berücksichtigung externer Umwelteffekte) und daher zu unterschiedlichen Zielwerten für das betreffende Land oder die Region führen. Insbesondere für die nicht vollständig globalen Planetaren Grenzen – wie z.B. Wasser, Land, Stickstoff, Phosphor – entscheidet der lokale Kontext mit über die Kritikalität von Grenzwertüberschreitungen. Gleichzeitig sind Konzepte wie fair shares, burden sharing oder common but differentiated responsibility zu berücksichtigen, um allen Ländern gleichermaßen eine Nachhaltigkeitstransformation zu ermöglichen. Dabei werden für einige der Planetaren Grenzen auch historische kumulative Ressourcennutzungen bzw. Emissionen relevant.

1.1.5 WBGU-Politikpapier (2014) und DIE Current Column (2015)

Abschließend wird in diesem Kapitel kurz Bezug genommen auf die beiden von WBGU bzw. DIE veröffentlichten Politikpapiere "Zivilisatorischer Fortschritt innerhalb planetarischer Leitplanken. Ein Beitrag zur SDG-Debatte" (WBGU 2014) und "The challenge for 2015: Ensuring global development within planetary guard rails" (Brandi und Messner 2015).

Der WBGU fordert darin eine Einbeziehung von planetaren Umweltgrenzen in die SDGs. Er greift die Forderung der Integration von Umwelt und Entwicklung von Rio (UN 1992) auf und stellt fest, dass Umweltziele den Entwicklungszielen nicht nur nicht entgegenstehen, sondern eine Einhaltung planetarer Leitplanken die Grundvoraussetzung für Versorgungssicherheit, Armutsbekämpfung und Entwicklung darstellt.

Der WBGU hat bereits 1995 das Leitplankenkonzept (für das Klimathema) entwickelt und argumentiert nun, dass die Antwort auf andere globale Umweltveränderungen zusätzlich zum Klimawandel ebenfalls in einer globalen Grenzwertsetzung (und deren politischer Kommunikation wie am Beispiel des Zwei- Grad-Ziels demonstriert) bestehen muss. Daher fordert der WBGU ein entsprechendes zusätzliches nachhaltiges Entwicklungsziel im Kanon der SDGs (siehe UNGA 2014), das durch entsprechende detaillierte und langfristige globale Umweltziele („targets") spezifiziert wird. Der WBGU schlägt dafür die Planetare Grenze für Klima, Ozeanversauerung, Biodiversität und Ökosystemdienstleistungen, Land- und Bodendegradation, persistente und schädliche anthropogene Substanzen und Verlust von Phosphor vor (die übrigen drei Planetaren Grenzen tauchen in der WBGU Liste nicht auf).

Weiterhin macht der WBGU erste Vorschläge, wie sich diese globalen Umweltziele einhalten lassen, wie z.B. über die Verbesserung der Ressourcennutzungseffizienz, nationale Transformationspläne mit korrespondierenden nationalen Umweltzielen, internationale Kooperation, begleitende Forschung und weitere Wissenschaft-Politik Schnittstellen für die übrigen Planetaren Grenzen analog zum IPCC (Intergovernmental Panel on Climate Change) für Klima und IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services) für Biodiversität. Ferner fordert der WBGU einen vollständigen Stopp der nationalen Beiträge zu den jeweils zugrunde liegenden Triebkräften des globalen Wandels (WBGU 2014, S. 4, S. 15).

Die DIE Current Column: "The challenge for 2015: ensuring global development within planetary guard rails" (Brandi und Messner 2015) fasst das WBGU-Politikpapier (2014) kurz zusammen und betont dabei die Notwendigkeit, die Planetaren Grenzen zu respektieren, um nachhaltig Armut zu bekämpfen und menschliche Entwicklung sicherzustellen. Die Kolumne argumentiert, dass in den letzten Jahren und Jahrzehnten der sozio-ökonomischen Entwicklung mehr Aufmerksamkeit zuteil wurde als der Nachhaltigkeit im Umweltbereich und dass nur drei der vorgeschlagenen SDGs direkt auf Planetare Grenzen- (bzw. Leitplanken-) relevante Umweltbereiche Bezug nehmen.

Wenngleich es die Planetaren Grenzen nicht in die Agenda 2030 für nachhaltige Entwicklung (UNGA 2015) geschafft haben, sind sie mittlerweile wissenschaftlich hinreichend begründet und anerkannt, um im Prozess der nationalen SDG-Implementierung den globalen Umweltrahmen zu bilden, innerhalb dessen Nachhaltigkeitstransformationen möglich sind. Die weitere Spezifikation der Planetaren Grenzen und ihre kontext-spezifische Übersetzung und Interpretation wird daher einen wichtigen Bestandteil der 2030 Agenda bilden.

1.2 Planetary Boundaries: current status, trends, risks, criticality – what do we know, and what do we need to know?

Executive summary

The planetary boundaries concept originates from Earth system science. It identifies precautionary limits to environmental modification, degradation and resource use. The planetary boundaries are large-scale, long-term, and systemic. They delineate an environmental safe operating space in which sustainable development can take place. Their operationalization can support evidence-based policy and decision making. Besides pointing out major uncertainties, this paper primarily addresses two main questions which have not been answered thoroughly before:

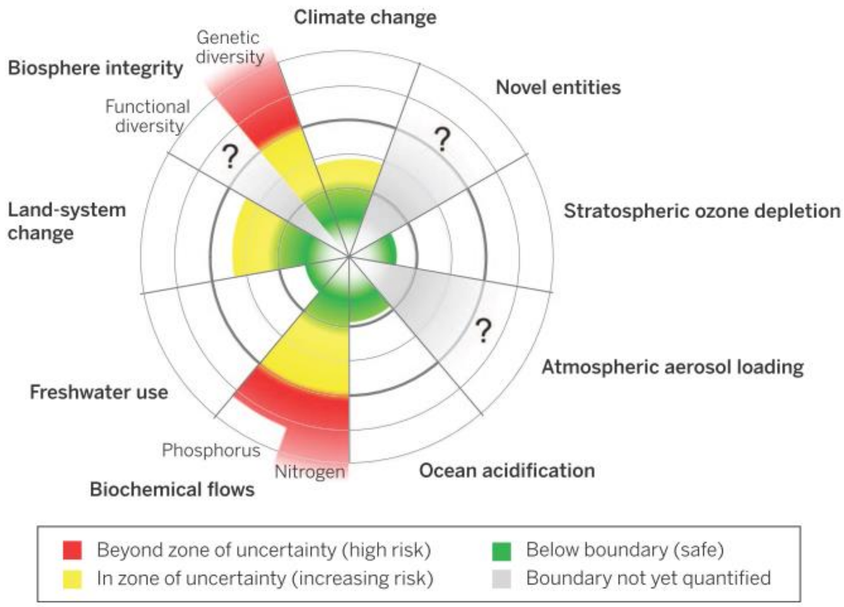
- What are main trends globally and in Germany with regards to planetary boundaries control variables? When have individual boundaries been transgressed for the first time or when will they be transgressed under different future scenarios? We derived widely diverging future pathways associated with different SSPs, some of which indicate the possibility to stay within / return to the safe operating space and hence indicate opportunities for sustainability transitions.
- What are associated risks and how critical are boundary transgression? To the extent possible, the paper differentiates per boundary the risks for different exposure units associated with increasing pressure on the respective boundary, as illustrated for the climate planetary boundary by the well-known burning embers diagram.

Another (minor) focus of this paper is on the operationalization of the planetary boundaries: how can we put them into practice in Germany, taking the above findings into account, further co-developing and mainstreaming the concept into existing institutions and policy frameworks.

1.2.1 Introduction

The planetary boundaries concept was initially formulated by Rockström et al. (2009) and updated by Steffen et al. (2015), building on previous concepts such as the WBGU guardrail approach, and formulating (environmental) conditions for sustainable development, namely not to transgress the nine identified boundaries of the planet, in order to achieve well-being within a safe operating space. The concept covers physical, chemical and biological processes of the Earth system, for which boundaries are defined (with the exception of the novel entities, the aerosol boundary and partially the biosphere integrity boundary for which either no control variable could be specified yet or for which data for monitoring the control variable globally are lacking). The updated illustration captures the nine boundaries and the current status with regards to the boundaries (Figure 19).

Figure 19 The planetary boundaries



Source: Steffen et al. 2015a

The key characteristics of the planetary boundaries concept should be taken into account when putting the concept in practice. The concept is concerned with the *stability* of the *Earth system*; local / regional environmental changes are included when their aggregate effect is hypothesized to have the potential to disrupt critical Earth system processes. The reference point for the definition of the boundaries is the *pre-industrial climate and Earth system state* (the *Holocene,* which has been relatively stable and hence beneficial for human development). The planetary boundaries describe how far humanity can use or degrade resources and pollute, up until the risk of potentially abrupt and irreversible undesirable Earth system changes becomes too large. They thus form a safe operating space for humanity.

The concept rests firmly on the *precautionary principle*. Boundaries are formulated because the precise risks of *Earth system* change are not known. For the climate system there is evidence for past state shifts (see e.g. Lenton et al. 2008) and that these shifts may not be beneficial for humans. Precautionary boundaries are also formulated because the precise position of thresholds are not known, e.g. due to delays in the Earth system reaction to anthropogenic pressures, or potential positive feedbacks which could amplify current trends (e.g. biome shifts in tundra and melting of permafrost with associated methane release which could amplify global warming), but also because policy reaction is usually slow. This has immediate consequences for interpreting the risk-based concept and its illustration, as well as putting it into practice. Planetary boundaries are not synonymous with tipping points; they are set within an (normatively) agreed upon safe distance from potential thresholds. Transgressing a boundary hence does not imply (but increases the risk) to hit a tipping point.

The planetary boundaries concept has been applied to the German Integrated Environmental Programme and the German Sustainable Development Strategy. It can add value to and guide environmental / sustainability policies for the next decade by providing a global, long-term and systemic environmental perspective. It is also part of policy-making on the EU-level (see 7th Environmental Action Programme: Living Well Within the Limits of our Planet), and in other European states (e.g. Switzerland, Sweden, Finland, the Netherlands), businesses (see WBCSD strategy 2020; Unilever, Mars, EN-ECO, etc.), foundations (DBU) and civil society (e.g. WWF). This paper intends to support these ongoing and potential future processes by describing the current status of each planetary boundary (position vis-à-vis boundary, data availability, consensus), trends and dynamics associated with each boundary (observed current trends, scenarios, teleconnections), risks (biophysical, social, economic risks; reversibility of and adaptabilities to these risks) as well as criticality (political priority, relevance of risks, in light of trends and vulnerabilities) and operationalization (potential for downscaling and policy implications). In a concluding chapter, this paper also highlights interlinkages between boundaries and describes ways forward in science and operationalization of the planetary boundaries concept. It is conceptualized as background paper for the German Environmental ministry and integrates i) research literature, ii) our own analyses and iii) expert knowledge from interviews.

The main objective of this paper is to clearly describe the state of relevant knowledge for policy- and decision-making regarding the planetary boundaries as well existing knowledge gaps which should be considered when issuing political statements on the concept and its implications. To the extent possible (within the limits of the resources for this paper) and subject to the availability of researchers, scientists were contacted (but no systematic, peer-review process has been undertaken, which would take place in much larger processes such as the IPCC-synthesis reports or within academic peer review).

For the analysis of trends and dynamics, this paper goes beyond the original objective and explores trend projections for individual control variables of specific boundaries, taking into account available time series data and SSP-scenarios and exploring opportunities for pushing the knowledge frontier. These trend projections can be regarded as complimentary to the original objective; they did not (yet) receive a scientific peer-review process and thus should not be regarded as finite result or new assessment or replacement of results of Steffen et al. (2015). Starting point and rationale for this analysis was that there were no scientific results yet available; the results thus represent merely a 'first attempt'.

The paper is part of a larger project on the operationalization of planetary boundaries, funded by the German Ministry of the Environment and the German Environment Agency (FKZ 3714 19 100 0). Previous papers published in this project assess the potential contribution of the planetary boundaries for the German Integrated Environmental Programme and a German Integrated Nitrogen Strategy, as well as its conceptual foundations, its potential for environmental communication, its relation to social boundaries and the different ways to downscale the planetary boundaries and use them for environmental benchmarking (e.g. illustrating the externalization of environmental impacts).

Excursus: Production- vs. consumption-based benchmarking

Important is the distinction between production-based (territorial) and consumption-based benchmarking of environmental performance against the downscaled planetary boundaries. Production-based approaches only account for environmental pressures within a country, e.g. Germany's domestic emissions of CO_2 or reactive nitrogen or domestic water use. Consumption-based approaches account for the total environmental pressures domestically and abroad, as associated with a country's consumption patterns and imports. As downscaling of the planetary boundaries is just beginning, the standard approach used so far in most cases is an equal per-capita allocation of the global allowance (e.g. total global allowable emissions of CO_2 or reactive nitrogen or water use) over all 7.5 billion people. There are certainly many other ways to allocate the planetary boundaries and to derive fair shares of the global planetary boundaries value, but in view of the vastly different endowment of countries and regions with natural resources, consumption-based benchmarking seems to be preferable to production-based (territorial) benchmarking. With that the planetary boundaries provide a quantitative measure and entry point for the operationalization of environmental fairness and protection of natural resources.

1.2.2 Boundaries

1.2.2.1 Climate change

Table 3: Climate change factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary transgressed in late 1980s	Observed trend	Atmospheric CO_2 concentration increasing; annual emissions currently not increasing	Large scale risks	e.g. extreme events, changes in water availability, changes in (agro-)ecosystems (more details in IPCC 2014a)
Data availability	Very good	Scenarios of future trends	Only a few of the RCPs reach net zero emissions by mid of the century	Reversibility, adaptability	CO_2 can remain in atmosphere for centuries, carbon capture potential is limited
Consensus	Broadly accepted	Teleconnections	Drivers (trade) and impacts (e.g. of deforestation)	Criticality	High

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The planetary boundary of CO2 level < 350 ppm for safely keeping global warming < 2° (as defined by Rockström et al. 2009) is significantly exceeded globally (currently ca. 400 ppm). For operationalization of the climate boundary, allowable emissions are used (CO_2 / CO_2equiv in ppm) instead of atmospheric concentrations. Most recent updates on the climate boundary (e.g. by Rockström et al. 2017) show that net CO_2 emissions have to decline to zero by about mid-century.

Germany's (production-based) per-capita CO_2 emissions (about 10 tons per capita and year) are about a factor of 2 higher than the global average (e.g. Le Quéré et al. 2015). Consumption-based emission, which also include external CO_2 footprints are even higher. According to Tukker et al. (2014), Germany has net annual per-capita imports of 2.1 tons CO_2equiv. Cumulative historic emissions of Germany or Europe are also much higher than its population share. Europe (with currently about 7% of the global population) is responsible for 23% of global historic emissions (Peters et al. 2015).

The data availability (time series of atmospheric CO_2 concentrations) is very good, given the globally more or less uniform distribution, also national GHG inventories are routinely available. The level of consensus[5] regarding the boundary is generally high. After initial UNFCCC agreement (1992) to "avoid dangerous anthropogenic interference with the climate system", the Paris Agreement, signed by almost all nations recognizes the need to keep global warming well below 2°C. The control variable – atmospheric CO_2 concentration (and derived from that: CO_2 emissions as a more operational control variable) is broadly accepted, so is the need to reduce net emissions to zero by mid of the century.

[5] We understand consensus as "commonly agreed position" (Hulme 2010) regarding the boundary (e.g. the criticality of the underlying process and need to set a boundary not to be transgressed, the scientific definition of a control variable and its position). We highlight disagreement within the scientific community on the specific boundary, as well as agreement.

Dynamic and trends

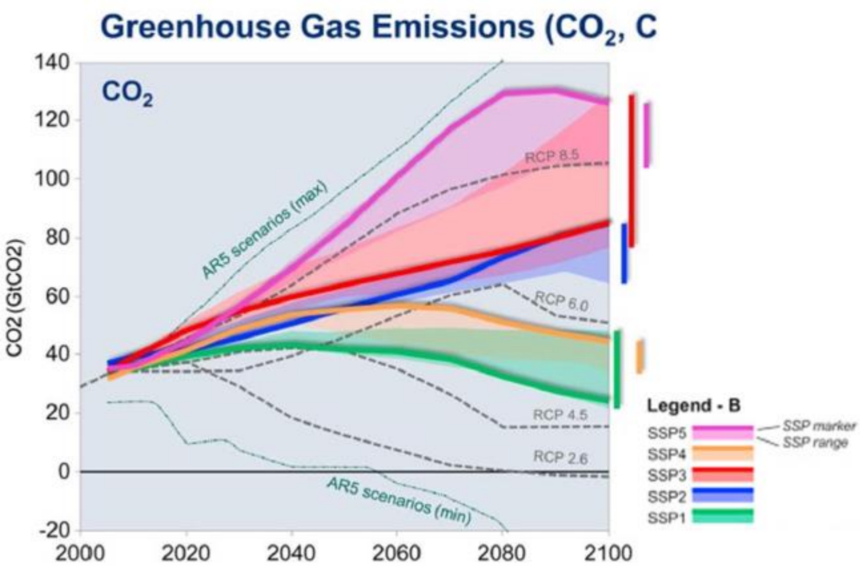
The 350 ppm boundary has already been transgressed in the late 1980s and atmospheric carbon dioxide concentration is still increasing. The increase in annual CO_2 emissions (a more operational control variable than atmospheric concentration) has come to a halt over the past ca. 5 years (Le Quéré et al. 2016) but has begun to increase again in 2017 by about 2% (Global Carbon Project - www.globalcarbonproject.org/carbonbudget). In order to meet the Paris Climate Agreement (global temperature increase well below 2 °C), net carbon emissions (including "negative emissions" via bioenergy and carbon capture and storage) have to decrease to zero by about mid of the century (Rockström et al. 2017). None of the SSPs (Shared Socioeconomic Pathways) and only a few of the RCPs (Representative Concentration Pathways) 8.5, 6.0, 4.5 and 2.6 reach net zero emissions by mid of the century (see Figure 20).

In Germany, production-based (territorial) CO_2 emissions have decreased over the past couple of decades. However externalized emissions in other countries as caused by Germany's consumption and imports have increased. Increases in Germany's consumption based CO_2 emissions in other countries as related to its imports have over-compensated the decrease in domestic CO_2 emissions (Wiebe et al. 2012). Note that Lutter et al. (2016) come to a different conclusion, that Germany's consumption-based CO_2 footprint is 10% lower than the production-based footprint. The reason for these different conclusions may be different methodological approaches. There is a need for more conclusive evidence, through further studies.

There are various ways of downscaling the planetary boundary for climate (or the Paris climate goal) and determining Germany's fair share of the remaining total global emissions or emission reduction requirement. Equal per-capita downscaling allocates the same remaining emission right to every person. Other downscaling principles refer to historic emissions ("debt") to the need for development, the capacity and ability to reduce emissions or others. In the case of the climate boundary the sum of all net emissions needs to reach zero in the second half of the century (e.g. Rockström et al. 2017).

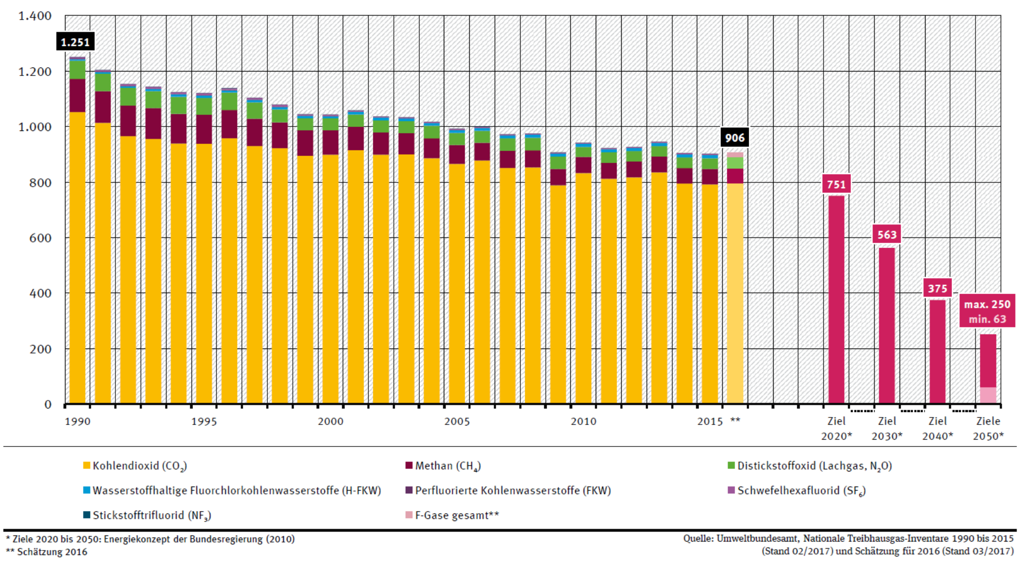
Figure 21 below suggests that Germany's emission reduction ambitions are well aligned with the global needs, but the current trajectory is not in line with the required global emission reduction pathway, given the stable rather than declining emission level over the past few years, and hence Germany risks to exceed its fair share of the climate planetary boundary.

Figure 20: Annual CO_2 emissions according to the different SSPs



Source: Riahi et al. 2017

Figure 21: GHG emissions in Germany in million tons CO_2equiv



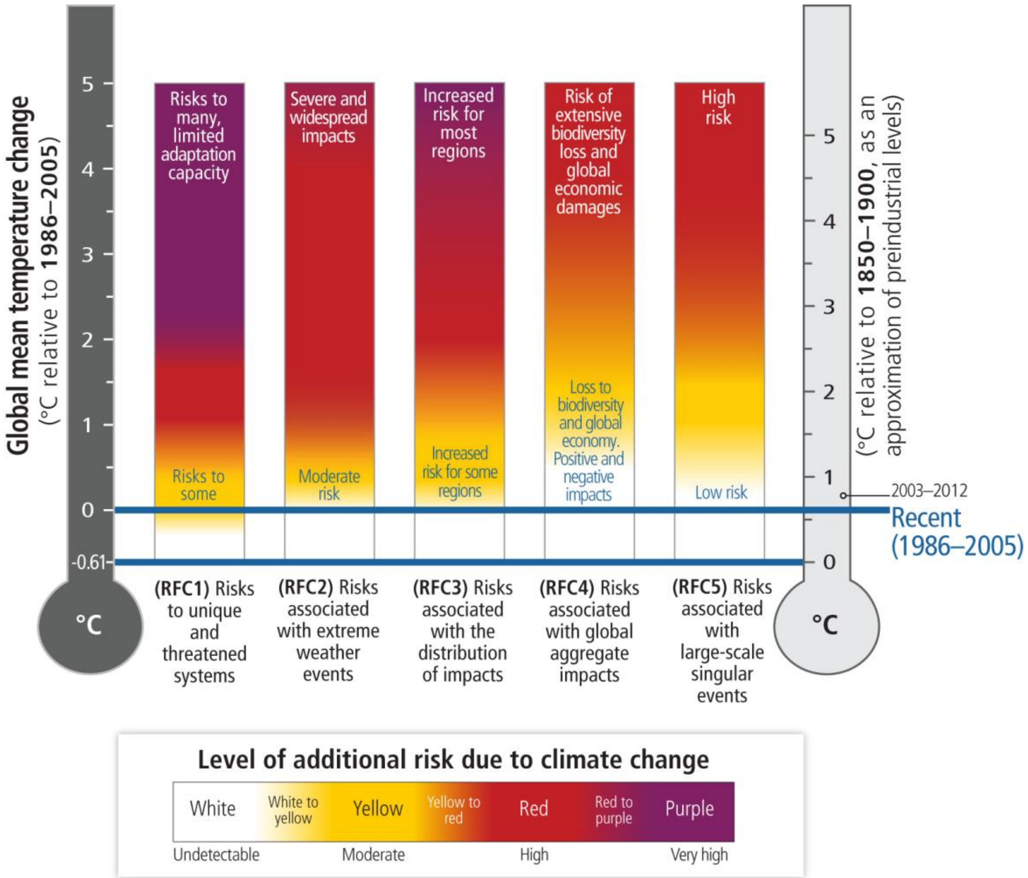
Source: UBA 2017b

CO_2 and climate have **teleconnections** in terms of drivers as well as impacts. On the driver's side, trade may cause external CO_2 footprints in distant regions. On the impact side, large scale climate effects and climate impacts related e.g. to deforestation may link distant regions. Teleconnections may also play out through climate impacts on supply chains and subsequently compromised supply securities (indirect climate change impacts). These teleconnections also link the climate planetary boundary with the water, land, N and other planetary boundaries.

Risks, reversibility and criticality of boundary transgression

There are increased risks from extreme events, changes in water availability, changes in (agro-)ecosystems and their productivity and services including terrestrial CO_2 sink function, rising sea level and impacts on marine ecosystems (also through ocean acidification) (more details in IPCC 2014a).

Figure 22: Burning embers diagram for climate change, indicating the different risk levels (colors) for the different exposure units for any given warming level



Source: IPCC 2014a

This burning embers diagram depicts the vulnerability of different exposure units to certain pressure levels (see O'Neill et al. 2017 on the reasons for concern framework which underlies this diagram). Once such burning embers diagrams are developed for all or at least several planetary boundaries, they can help to refine the emblematic original planetary boundaries circle diagram (Figure 22 above).

CO_2 can remain in the atmosphere and act as GHG for centuries after emission, mitigation and adaptation responses introduce further delays.

The **criticality** of this boundary is high in view of its significant transgression, the long persistence of CO_2 in the atmosphere, and the increasing certainty about climate change impact, some of which begin to be felt.

Downscaling and policy implication

The downscaling potential is good (given that this is a truly global boundary). In light of the criticality, the climate planetary boundary implies the urgent need for i) climate mitigation, e.g. along the lines of the recent proposal by Rockström et al. (2017) and ii) climate adaptation. Implementation should take place within Paris agreement framework.

1.2.2.2 Ocean acidification

Table 4: Ocean acidification factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Currently boundary not transgressed	Observed trend	Decreasing aragonite saturation	Large scale risks	Decreasing calcification; negative impacts on marine ecosystems, hatcheries and food security
Data availability	Limited	Scenarios of future trends	Boundary will be transgressed under all RCPs	Reversibility, adaptability	reversibility only over extremely long time scales
Consensus	Broadly accepted	Teleconnections	effects manifest far away from locations of CO_2 emissions	Criticality	High

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The planetary boundary is defined as > 80% of pre-industrial aragonite saturation (currently 84%)(Steffen et al. 2015: 1259855-4). The ocean acidification boundary is closely linked to the climate boundary (increasing atmospheric CO_2 concentration causes ocean acidification and associated lower aragonite saturation, a calcium carbonate formed by marine organisms): staying below 350 ppm atmospheric CO_2 concentration also ensures that ocean acidification remains within the safe operating space. A long term stabilization of the atmospheric CO_2 concentration at 450 or 550 ppm would bring the aragonite saturation to 74 or 64 % respectively of the pre-industrial value, i.e. significantly below the planetary boundary of > 80% (Caldeira and Wickett, 2005). So even the most ambitious emission reduction pathways (e.g. RCP 2.6) will lead to a transgression of the ocean acidification boundary in the long term (when a new equilibrium between increased atmospheric CO_2 concentration and ocean CO_2 concentration (including deep ocean) is reached).

Also, Germany's contribution to the transgression of the ocean acidification planetary boundary is closely related to Germany's contribution to the transgression of the climate planetary boundary or to Germany's (consumption-based) CO_2 footprint.

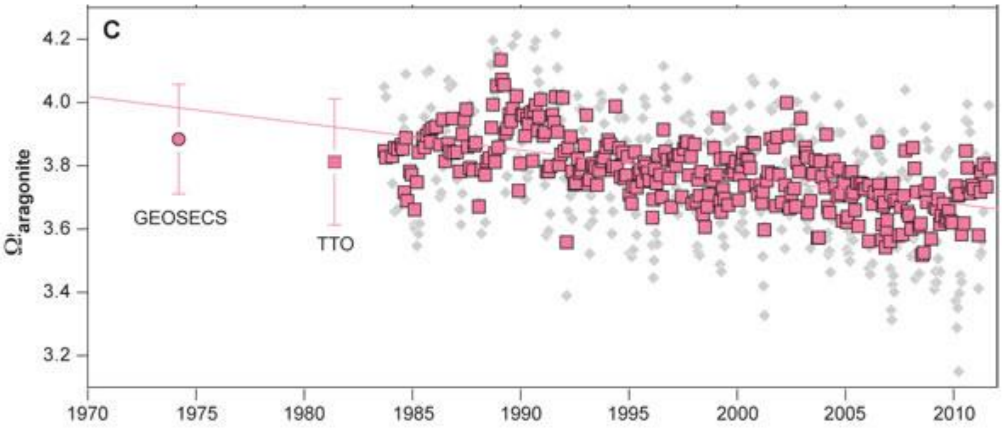
The global data availability is limited, due to lack of data on the status, progress, spatial and temporal distribution, drivers and impacts of ocean acidification. However, several initiatives are currently compiling global data on ocean acidification (Global Ocean Acidification Observing Network; Ocean acidification International Coordination Centre).

There is low uncertainty and general consensus that ocean acidification is closely linked (with some delay) to increasing atmospheric CO_2 concentrations and that it will have severe negative impacts on marine ecosystems. The planetary boundary and its control variable are broadly accepted within the planetary boundary community. Disagreement centers on the perceived static nature of the ocean acidification illustration, as the boundary is marked as green (in the safe zone), while impacts are already occurring and scenarios highlight that risks are likely to increase under different scenarios (see below).

Dynamic and trends

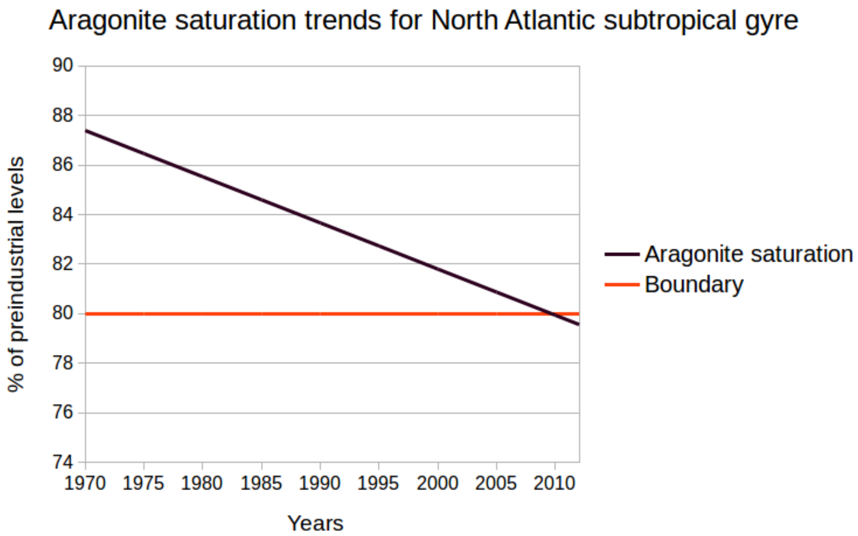
Aragonite saturation has been decreasing globally and continues to decrease with increasing atmospheric CO_2 concentration. Figure 23 shows time-series data of surface ocean aragonite saturation, displaying also data from GEOSECS and TTO expeditions in the North Atlantic Ocean. Steffen et al. (2015) suggest that aragonite saturation currently stands at 84%. So the planetary boundary will be crossed soon, unless drastic reductions in CO_2 emissions can be realized. Steffen et al. (2015) also point out the geographical heterogeneity is important. Figure 24 displays the aragonite saturation for one particular location, the Sargasso Sea in the North Atlantic Ocean close to Bermuda, where the planetary boundary value has been transgressed locally in 2010. The capacity of CO_2 uptake of surface waters in the North Atlantic has been found to be decreasing (Bates et al. 2012).

Figure 23: Time-series of surface ocean aragonite saturation globally



Source: OCB Ocean Acidification subcommittee 2012

Figure 24: Aragonite saturation for the Sargasso Sea in the North Atlantic Ocean and ocean acidification boundary



Source: Bates et al. 2012

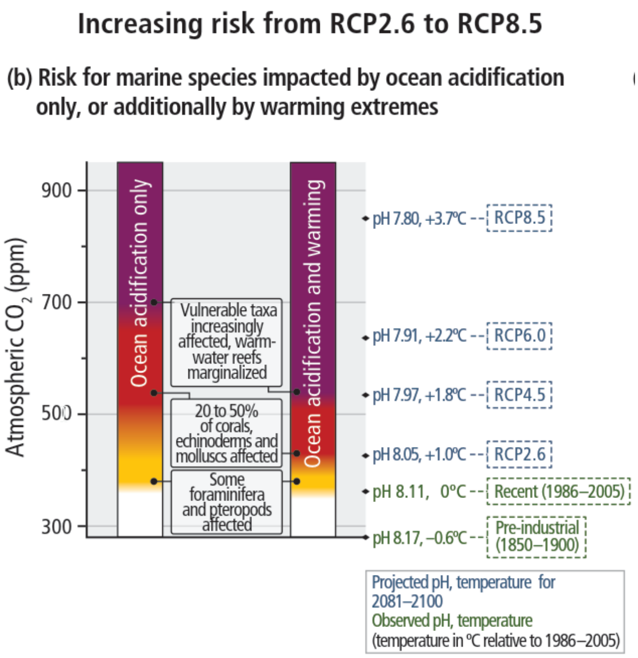
Risks, reversibility and criticality of boundary transgression

Ocean acidification is one of multiple stressors for marine ecosystems; other large scale stressors are sea-surface temperature rising, sea-level rise, changes in ocean salinity, stratification, ocean circulation, extreme weather events, UV light (UN 2017: 10-12); other local stressors are e.g. eutrophication and pollution (IPCC 2014a: 67). Ocean acidification is globally occurring; the underlying chemistry is well understood. Linking ocean acidification to impacts on organisms is difficult because science currently lacks comprehensive global monitoring coverage and the capacities to consistently link such data to impacts on organisms.

Currently observed impacts of ocean acidification comprise of i) decreasing rates of coral reef calcification (low confidence in IPCC 2014a: 51), ii) corrosion, dissolving of pteropod and foraminiferan shells (medium confidence in IPCC 2014a: 51), iii) economic impacts on oyster hatcheries in USA (Pacific Northwest), due to ocean upwelling. There might be other current impacts of which we are unaware of (due to limited monitoring and data).

Projected impacts for marine species are summarized below in Figure 25. The figure shows that ocean acidification alone as associated with RCP 4.5 will impact 20 to 50 % of all corals, echinoderms and molluscs. When taking into account the additional pressure from ocean warming, the same impact will already be reached under RCP 2.6. The scale of impacts could be global, with local/regional hotspots (e.g. polar region; regional impacts through upwelling / melting sea ice) (UN 2017: Chapter 5, 19).

Figure 25: Risks for marine species impacted by ocean acidification



Source: IPCC 2014a

The confidence for socio-economic impacts of ocean acidification is generally lower. Knock-on effects comprise of loss of ecosystem services (e.g. tourism – coral reefs), economic effects on capture fisheries and hatcheries (effects of ocean acidification through food web) (BIOACID 2018), and effects on food security, livelihoods and health, especially in regions with high dependence on protein from oceans (UN 2017: Chapter 2).

Adaptation could comprise of i) relying on "resilient species" and ii) diminishing other ocean stressors (e.g. N & P pollution; tourism; fishing industries) (IPCC 2014a: 97). Short term adaption is possible for hatcheries with technological / financial resources at their disposal (mainly in developed countries); subsistence fisheries / small-scale fisheries have low adaptive capacities (IPCC 2014a: 97).

Ocean acidification can only be reversed over extremely long time scales (irreversibility on human time scales). The criticality is potentially high in light of biophysical and socio-economic effects.

Downscaling and policy implication

The potential for downscaling and operationalization of the ocean acidification planetary boundary is closely linked to that of the climate change planetary boundary, given the close relationship of global warming, atmospheric CO_2 concentration and ocean acidification.

Policy implications comprise of i) climate change mitigation, ii) building up global data on ocean acidification, impacts on marine ecosystems / organisms, socio-economic impacts, iii) monitor ocean acidification globally, understand multiple stressors and their interlinkages, and iv) adaptation to ocean acidification to the extent possible.

The potential for implementation (primarily through reducing CO_2 emissions into the atmosphere) is good. Relevant mechanisms are the UNFCCC process and the UN SDGs (SDG 14; target 14.3); both agendas should be aligned.

1.2.2.3 Stratospheric ozone depletion

Table 5: Stratospheric ozone depletion factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Below boundary, except Antarctica	Observed trend	Ozone concentration has stabilized and/or slightly increased again	Large scale risks	Impacts on health (skin cancer), plants, biogeochemical cycling
Data availability	Good	Scenarios of future trends	Ozone concentration expected to increase further	Reversibility, adaptability	Fully reversible; adaptability depends on speed of change
Consensus	Agreement on criticality of the boundary and the need to reverse ozone depletion	Teleconnections	Locations of production of ozone depleting substances and of their impacts separated by large distance	Criticality	Decreasing

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

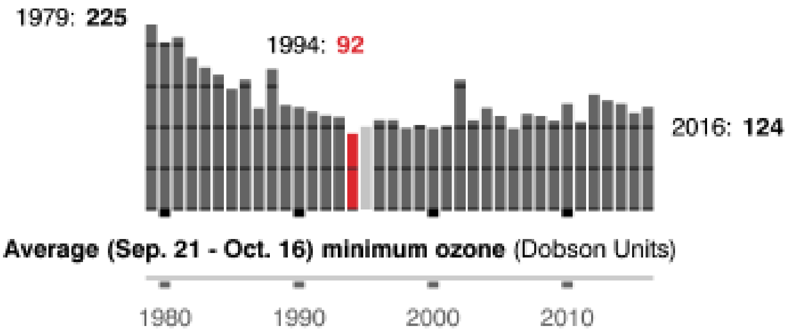
The ozone boundary is defined as < 5% loss of stratospheric ozone concentration relative to the pre-industrial level (O_3 concentration > 275 Dobson Units) – currently met everywhere except Antarctica. The data availability is good, thanks to a global multi-partner ozone observations network of ozone under WMO's Global Atmosphere Watch. There is strong agreement on the need to reverse stratospheric ozone depletion, see consensus reached in Montreal protocol.

Critique concerns i) the perceived unclear definition of a 5 % reduction (whether the reduction means 5 percent globally or 5 percent for each latitudinal zone respectively), ii) on not mentioning ozone depletion in the Arctic (e.g. in 2011; NASA 2013), iii) the political implication of the proposed boundary, as it appears to be difficult to act on limits to global concentrations (as opposed to limits on Ozone Depleting Substances).

Dynamic and trends

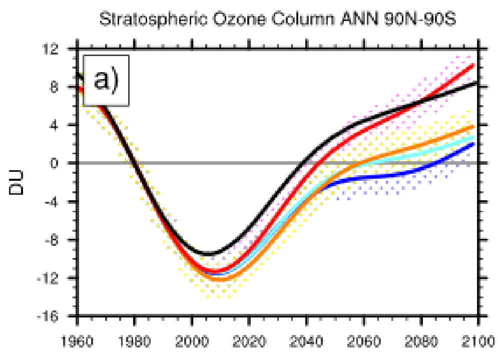
The ozone concentration has stabilized and begins to slightly increase again; there are "signs of recovery of the Antarctic zone" (UNEP 2016). The ozone concentration is expected to further increase in the future (moving back further into the safe operating space over the coming decades).

Figure 26: Trend in annual minimum ozone concentration, with slight recovery beginning after the year 2000



Source: NASA Ozone Watch 2017

Figure 27: Stratospheric ozone under different representative concentration pathways (blue: RCP 2.6, light blue: RCP 4.5, orange: RCP 6.0, red: RCP 8.5)



Source: Eyring et al. 2012

Recovery of the ozone layer from the effects of anthropogenic ozone-depleting substances is estimated to happen around 2050 in mid latitudes and around 2065 in the Antarctic (WMO, 2014). Recent literature, taking into account rising emissions of short-lived substances such as dichloromethane which can reach the stratosphere, suggests that the return of ozone concentrations to 1980s levels may be delayed until the end of the 21st century (Hossaini et al. 2017). Furthermore, in its 2016 progress report, UNEP's Environmental Effects Assessment Panel (expert panel informing the Parties to the Montreal Protocol) highlights the interaction between stratospheric ozone and climate change: "As concentrations of ozone depleting substances (ODS) decrease over the next decades, greenhouse gases

(GHGs) will become the dominant driver of changes in stratospheric ozone" (UNEP 2016: 6). According to the progress report, "the direction of change in the tropics depends on the emission scenario"; "if actual emissions of CO_2, CH_4 and N_2O could be aggressively reduced to the RCP2.6 scenario, UVI [radiation] would increase by up to 5% at all latitudes, except in the spring at high latitudes" (UNEP 2016: 6). Similarly, WMO 2014 finds that "changes in CO_2, N_2O, and CH_4 will have an increasing relative influence on the ozone layer as ODSs decline". This is in line with Figure 27 which also shows that higher greenhouse gas emissions delay the recovery of stratospheric ozone. Moreover N_2O itself has an ozone depletion potential of 0.017 (chlorofluorocarbons have potentials between about 0.05 and 1.0).

The locations of production of ozone destroying substances and locations of main impacts ("ozone holes") are separated by large distances, so there are significant **teleconnections**.

Risks, reversibility and criticality of boundary transgression

Increased exposure to UV rays can harm humans (e.g. skin cancer) and plants (plant diseases) including phytoplankton, with knock on effects on plant competitive balances or biogeochemical cycles, including greenhouse gases. Adaptability depends mainly on the speed of change.

The stratospheric ozone planetary boundary is fully reversible, if a ban of ozone destroying substances is enforced and if the rise of new ozone depleting compounds such as unsaturated chlorofluorohydrocarbons can be avoided. Criticality is decreasing in view of current trends.

Downscaling and policy implication

The potential for downscaling or allocation of fair shares, e.g. for countries is generally good (ozone being a global boundary).

Policy implications comprise broadly of continued i) monitoring of Ozone Depleting Substances as well asozone concentration, and ii) research on the interaction between climate change and stratospheric ozone. Potential for implementing these is good, see Montreal Protocol, through a ban of ozone destroying substances, these are well defined and substitutes are generally available, EU has set an environmental goal of a stratospheric Cl concentration < 1.3 ppbv.

1.2.2.4 Biosphere integrity

Table 6: Biosphere integrity factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary transgressed	Observed trend	Biodiversity loss could not be stopped	Large scale risks	Loss of ecosystem functions, services; impacts on health, economy and loss of resilience of social-ecological systems
Data availability	Fragmented	Scenarios of future trends	Biodiversity loss not stopped	Reversibility and adaptability	Extinct is extinct, species cannot be replaced; poor people depend more strongly on intact biosphere and hence adaptation is more critical

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Consensus	Boundary debated	Teleconnections	Externalization of impacts through supply chains but also through climate change	Criticality	High

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The biosphere boundary follows a two-component approach, i.e. i) genetic diversity (extinction rate < 10 extinctions per million species years, currently exceeded by a factor 10-100 globally) and ii) functional diversity / abundance of a diverse set of organisms (biodiversity intactness index > 90% – global status unknown). Newbold et al. (2016a) estimate that the diversity boundary has been exceeded on about 60% of the land surface.

Germany's ecological footprint (as a proxy for pressure on the biosphere) per capita is 4.6 ha (almost 3 times the global biocapacity), while the global average footprint is 1.8 ha. Germany is furthermore a leading country in terms of exporting biodiversity threats to other regions from which it imports goods and services (Lenzen et al. 2012). These externalized pressures need to be accounted for when benchmarking Germany's performance against its fair share in the global effort to stay within the safe operating space.

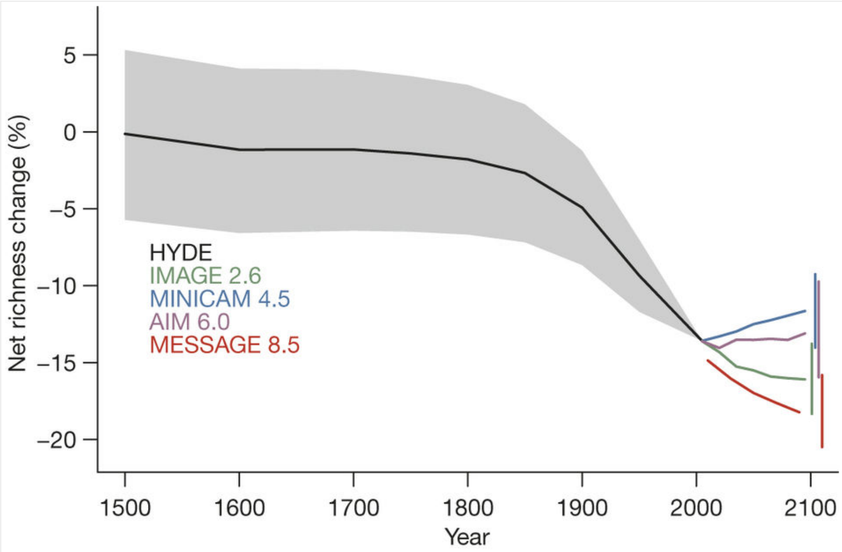
The data availability globally is fragmented; data exists only for selected groups, families of plants or animals or biomes; the biodiversity intactness index is only available for selected locations a global coverage is, however, available for species occurring in primary vegetation (Newbold et al. 2016b: 289).

There is an intense debate on a global boundary for biodiversity and the large-scale and systemic risks associated with biodiversity loss or loss of biosphere intactness; a fully quantified and agreed upon control variable is not available globally; extinction rate is a "weak indicator" (the effects of species extinction on ecosystems and the Earth system are not well understood) which doesn't scale well to global level (Mace et al. 2014), the biosphere intactness index and its precautionary boundary setting at 10% reduction from natural level come with high uncertainty. Critique has centered i) on treating the biosphere as a static entity, similar to physical entities, while the biosphere appears to be very dynamic and adaptive; ii) on the impression that the planetary boundaries intend to prescribe the current set of species / ecosystems, while other sets of species / ecosystem configurations might also provide relevant goods and services and might be equally resilient.

Dynamic and trends

Biodiversity loss could not be stopped yet (Secretariat of the CBD 2014; EEA 2015). Figure 28 below shows a slow decrease in species richness since the year 1500, with a drastic acceleration since the beginning of the 20th century. Again, different future scenarios show widely varying potential future trends, some bringing us back into the safe operating space, others not.

Figure 28: Projected net change in local richness from 1500 to 2095

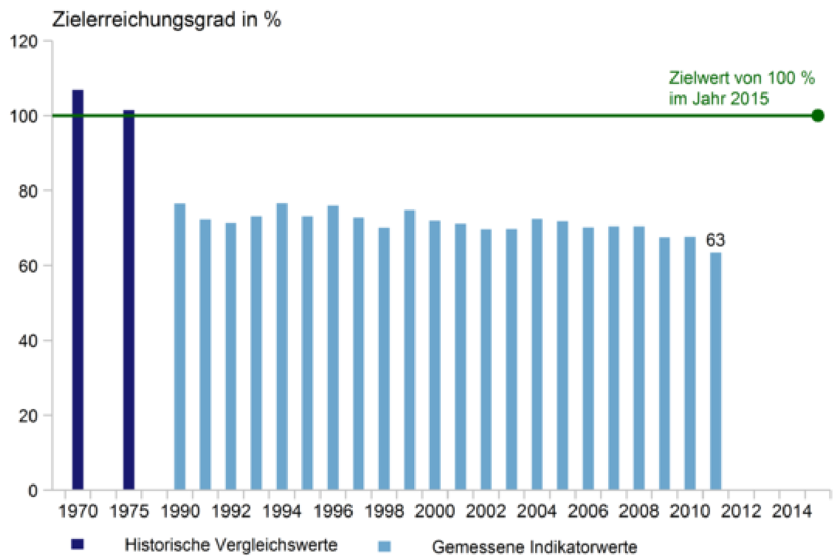


Future projections were based on the four RCP scenarios (Table 1). Historical (shading) and future (error bars) uncertainty is shown as 95% confidence intervals, rescaled to zero in 2005. The baseline for projections is a world entirely composed of uninhabited, unused primary vegetation; thus, the value at 1500 is not constrained to be zero because by then non-primary land uses were present (and in some regions widespread). The global average projection for MESSAGE 8.5 does not join the historical reconstruction because that scenario's human population projections start in 2010 and because human population and plantation forest extent have not been harmonized among scenarios.

Source: Newbold et al. 2015

There is no overall species extinction rate or (change in) biodiversity intactness index available for Germany. Trends in abundance as a proxy are indicated in the following figure (aggregated across different bird species in different landscapes and relative to a defined target). Figure 29 indicates that there has not been any improvement towards Germany's national target (100%).

Figure 29: Trends in aggregated abundance of different bird species in different landscapes and relative to the nationally defined target



Source: Bundesamt für Naturschutz 2014

Another possible proxy for species extinction rates is the loss of red list species. The fraction of extinct vertebrate species in Germany has increased from 3% of all red list species in 1998 to 8% in 2009

(Bundesamt für Naturschutz 2009). In comparison to Europe, Germany ranks among the countries with the highest percent of extinct and endangered species (Binot et al. 1998).

Our initial assessment, based on limited available data suggests that Germany's internal and external pressures on biodiversity are not in line with its fair share or contribution to the global efforts for staying within the safe operating space.

The biosphere boundary is subject to significant **teleconnections**, supply chains externalize pressure on biodiversity (and land and water) to other regions.

Risks, reversibility and criticality of boundary transgression

Impacts can be broadly systematized along the boundary's two-component approach (Steffen et al. 2015).

For the genetic diversity component: Species cannot be replaced (change is irreversible). For the functional diversity component, impacts include loss of ecosystem functions and services and resilience, both on a larger scale with high magnitude and low reversibility (e.g. dieback in the Amazon and effects on carbon cycle) and on smaller scales with low magnitude and higher reversibility (e.g. losing trophic structure, reducing ecological communities to just a couple of trophic levels, increasing vulnerability). Technology is likely not able to substitute / re-engineer the very basic supporting services (e.g. soil formation and water cycling) (Fitter 2013) nor maintain diversity and resilience. There are significant delays from species going extinct to new equilibrium states of ecosystems and subsequently to new states of social-ecological systems; also the recognition of a species becoming extinct may only occur much later than the actual process.

Risks include various knock-on effects in integrated socio-ecological systems, including additional economic costs, as economic growth might be held back (time / effort in recovering ecosystems) and immediate consequences for health and human well-being, especially for those that directly depend on ecosystem services. Adaptability is low for poorer population and those that most directly depend on ecosystem services.

The criticality is potentially very high, given the severe boundary transgression and continued further decrease in biodiversity – however the criticality of the extinction of individual species, vulnerabilities of specific biomes and consequences of boundary transgression are not well understood.

Downscaling and policy implication

Downscaling the biosphere integrity boundary requires contextualization. The criticality of species extinction or of individual red list species going extinct or the loss of natural or protected areas varies for different contexts. Also local or national extinctions or trends may not be in line with the global situation. Hence a simple linear downscaling of global control variables and boundaries is not sufficient for operationalizing and implementing the planetary boundaries including the biosphere boundary. Numbers provided above for Germany, according to Bundesamt für Naturschutz (2009; 2014) are merely an indication for biospheric trends not being in line with the global biosphere boundary.

The biosphere integrity boundary broadly implies to prevent major changes in large scale ecosystems which perform major functions such as the Tundra, the Amazon rain forest, the deep sea (biome protection), as well as local changes that could lead to such large scale impacts; also, global species extinction should not increase further.

Potential implementation mechanisms are the CBD, SDGs 14 and 15, and related SDGs (e.g. SDG 12 on sustainable consumption).

1.2.2.5 Land-system change

Table 7: Land system change factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary transgressed around 1990	Observed trend	Total global forest area keeps decreasing	Large scale risks	Loss of biodiversity and ecosystem services, change in large-scale climate and moisture recycling,
Data availability	Good	Scenarios of future trends	Widely diverging scenarios	Reversibility, adaptability	Deforestation difficult to reverse, in particular natural forest are hard to restore
Consensus	Broadly accepted	Teleconnections	trade related externalization of pressures on forests, hydrological and climatic impacts across large distances	Criticality	High

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The control variable chosen here for land system change is forest cover. The global boundary of > 75 % of original forest cover remaining globally, has been transgressed around the year 1990 - currently about 68% forest cover remain according to analysis undertaken with PIK's dynamic global vegetation model (LPJmL) or 62% according to Steffen et al. (2015).

The global boundary has been regionalized by Steffen et al. (2015) with the following values:

> 85% of original forest cover for tropical forests (currently about 75% are left and the boundary was transgressed for the first time around the year 1950),

> 85% of original boreal forests (currently about 85%, boundary has been slightly transgressed since about 1910), and

>50 % for temperate forests (currently 61%, no transgression so far)

Germany currently has about 34% of the original forest cover remaining, as calculated with LPJmL (30% of Germany's land area is currently covered with forest and other natural areas; Statistisches Bundesamt 2015). A consumption-based perspective for land use and forest cover change is important, because Germany is using about the same amount of agricultural land externally as domestically, for meeting its consumptive demands for goods and services (UBA 2017a). Domestic reductions in cropland use are compensated by growing imports of virtual land from other world regions. Between 1995 and 2010 these imports increased by 25% (UBA 2017a). Tukker et al. (2014) calculate for Germany about 2 ha of net total virtual land imports per capita, while UBA (2015) calculates net agricultural virtual land imports of 0.16 ha per capita.

A uniform downscaling of the planetary boundary (not accounting for differences in productivity) suggests that Germany's internal and external pressures on the land planetary boundary are not in line with its fair share. However this global boundary like some of the others (e.g. water or biodiversity) need to be contextualized or integrated with bottom-up sustainability criteria, in order to be made useful in policy and decision making. For example: most planted forests in Germany do not support biodiversity (biosphere intactness), which has been one of the reasons for defining a land boundary based on natural forest cover. Also different land production potentials in different climate zones need to be taken into account when contextualizing the land planetary boundary.

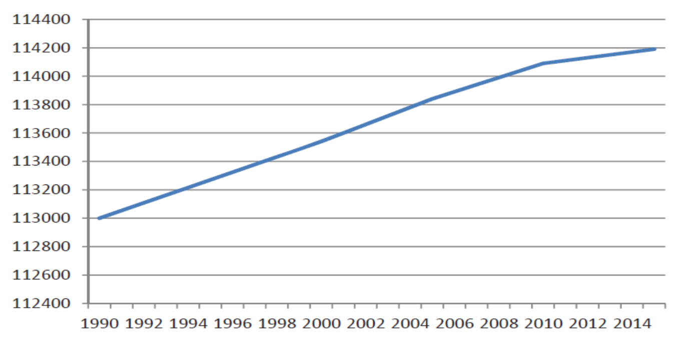
There is relatively good data, e.g. from the FAO Forest Resources Assessment. But there are differences between different data sources, see comment on Figure 30 below.

There is strong scientific evidence that land use change, in particular large scale deforestation, can have significant impact on the Earth system, e.g. in terms of climate change and moisture recycling, and hence further deforestation must be stopped. The exact level of forest cover that must remain is less well known.

Dynamic and trends

The total forest area keeps decreasing. While pressure on forests keeps increasing (UNEP 2012) and deforestation continues in particular in boreal and tropical regions, forest area in Germany is slightly growing. A consumption-based perspective that includes externalized deforestation is important, given that the EU is responsible for 10% of total trade-related deforestation globally (Cuypers et al. 2013).

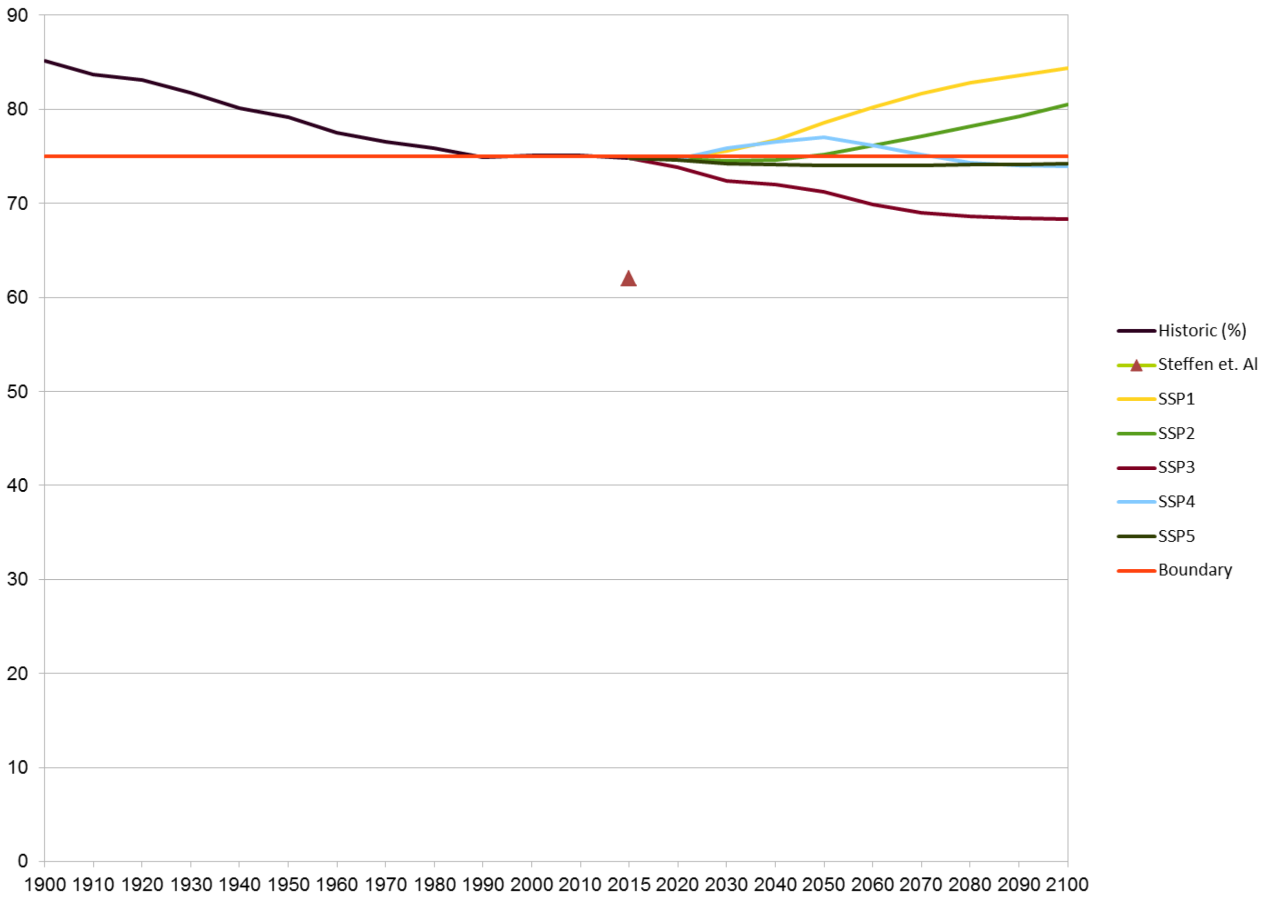
Figure 30: Forest area Germany in km^2



Source: World Bank 2017

Figure 31 below combines historic trends and future scenarios of global forest cover (% of potential natural forest cover) according to different socio-economic pathways (SSPs, note that we calculated for this and all following planetary boundaries the SSP scenarios with an RCP of 2.6, in order to be consistent with SDG 13).

Figure 31: Historic trends and future scenarios of % global forest cover, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015)



Source: historical data based on LPJmL calculations (forest cover as % of potential natural vegetation); land use data from Hyde 3.2, see Klein Goldewijk 2016; scenario data from IIASA SSP database and Riahi et al. (2017)

While Figure 30 is roughly in line with FAO's Global Forest Resource Assessment 2015 (which shows less than 3% loss in forest cover between 1990 and 2010), Hansen et al. (2013) find a significantly higher deforestation rate of almost 4% between 2000 and 2012. Our assessment yields slightly higher current forest cover than Steffen et al. (2015) who suggest a more significant transgression of the planetary boundary.

There are strong **teleconnections** in terms of drivers and responses, e.g. trade related externalization of deforestation (e.g. Henders et al. 2015), and hydrological and climatic impacts in response to deforestation (e.g. Keys et al. 2012).

Risks, reversibility and criticality of boundary transgression

Risks comprise of loss of biodiversity and large-scale consequences of land use change / deforestation, e.g. change in moisture recycling and downwind precipitation with tropical deforestation and change in albedo and radiative balances with boreal deforestation, but also effects on biodiversity and biogeochemical cycles including terrestrial carbon storage. Knock-on socio-economic effects comprise e.g. of i) impacts on food production (e.g. through loss of habitats for bees), ii) freshwater supply, iii) depletion of forest resources, iv) climate impacts (e.g. "urban heat islands"), and v) transmission of diseases (Foley 2005).

Deforestation itself is difficult to reverse. Return to the original forest takes very long time, impacts such as biodiversity loss or terrestrial carbon losses are irreversible (on a human time scale).

The criticality of the land boundary is high, given the (slight) transgression of the boundary, the continued negative trend and the potential severity of impacts.

Downscaling and policy implication

Downscaling and operationalization needs to take into account the local context. For example, in a densely populated country like Germany it is unrealistic to bring forest cover back to 50%.

Policy implications are broadly i) less land consumption per capita, ii) less land intensive production / consumption, and iii) more integrated land use planning which accounts for ecosystems and their services.

The potential for implementation is high, see e.g. European goal of "no net land take by 2050", or the German goal to allow natural development on 5% of the national forest area, but contextualization is required.

1.2.2.6 Biogeochemical flows, N and P

As all new work presented in this paper, also this section has not yet gone through a peer review process. We expanded the original task of the paper, when we found that there has been no previous attempt to quantify and depict trends of planetary boundary transgression. For consistency we have applied the Socioeconomic Shared Pathways (SSPs), which originate from the climate community, to all planetary boundaries addressed in this paper. The results are merely a first attempt to provide a dynamic view on past and future nitrogen and phosphorous trends relative to their Planetary Boundaries. The results are not meant to replace those by Steffen et al. (2015) or Rockström et al. (2009) and will need to be discussed in a thorough peer review process. Such a process would have to discuss for example the fact that the current definition of the nitrogen boundary only accounts for intentional nitrogen fixation, which does not include the release of reactive nitrogen from combustion processes. Also we only included in the analysis those nitrogen compounds which are part of the SSPs, namely NO_2 (for NO_x), NH_3 and N_2O (we corrected those compounds for their respective N-content (NO_2: 14/(14+32), NH_3: 14/(14+3), N_2O: 28/(28+16)). Nitrate, which plays a major role in nitrogen-related environmental pressures and in the N-boundary definition needs to be added to this first attempt, which will likely change the results significantly.

Table 8: Biogeochemical flows factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary transgressed according to Steffen et al. (2015)	Observed trend	Increase according to Steffen et al. (2015)	Large scale risks	Eutrophication of freshwater bodies coastal eutrophication and subsequent anoxic/dead marine zones, acidification of soils, changes in ecosystems

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Data availability	Good	Scenarios of future trends	Decrease in anthropogenic N-fixation* and global P-delivery under all SSP scenarios	Reversibility, adaptability	Reversibility moderate if strong measures are taken; adaptability low for poorer communities
Consensus	Medium to low	Teleconnections	Some of the N compounds are subject to long distant transports	Criticality	High

Source: from authors, PIK/adelphi; * note that an inclusion of all anthropogenic production pathways of reactive nitrogen (the nitrogen PB currently only covers a certain fraction of that) would possibly result in an increase in future trends

Control variable, quantification, uncertainty

According to Steffen et al. (2015) the N-boundary < 62 million tons (or Teragrams, Tg) of intended N-fixation (fertilizer production and use and additional anthropogenic biological N-fixation) globally per year, is currently transgressed by more than a factor of 2. According to historical data from Beusen et al. (2016) it has been transgressed around the year 1980 and has been continuously growing since then. However according to their model based results the boundary is currently transgressed by less than a factor of 2.

According to Steffen et al. (2015) the P-boundary < 11 Tg P of global inflow into the oceans per year is currently transgressed by a factor of 2, with an actual value of about 22 Tg. Beusen et al. (2016) find that the global P-boundary has not been transgressed yet (see Figure 32). Steffen et al. (2015) added a regional boundary of 6.2 Tg P flow from erodible soils, with a current value of about 14 Tg. Carpenter et al. (2011) converted the P-boundary into a water quality criterion of < 160 mg m^{-3} for rivers, and < 24 mg m^{-3} for freshwater lakes and reservoirs..

Our assessment indicates that Germany exceeds its "fair share", i.e. the downscaled N-boundary (equal per-capita or equal per-agricultural-land-area downscaling) by far. A downscaling of the global values by agricultural area (Germany's fraction of the global agricultural area) yields a fair share of 0.5 Mt per year, which compares to an actual value of 2.3 Mt. An equal-per-capita downscaling yields a fair share of 8.8 kg per capita per year, which compares to an actual value of almost 30 kg (Hoff et al. 2017). These are production-based (or territorial) values. The additional external N-footprint of Germany's consumption seems to be of similar magnitude as the domestic (internal) N-footprint (Eggers 2016), increasing Germany's overshoot of its fair share further. As discussed before, there are other possible approaches for arriving at fair shares of the global safe operating space, per country or per capita. These have not been tested in literature yet.

Regarding Germany's "fair share" of P, data by UBA (2017, Daten der Bundesländer und der Flussgbietsgemeinschaften - Berichterstattung an die OSPAR-Kommission; Datenstand 2016) indicate that total inflows of P into the North Sea amount to about 7000 tons per year with about 50 km^3 of annual river discharge, which is below the downscaled global P boundary (the global P boundary is 11 Million tons with global annual river discharge into the oceans of about 40.000 km^3).

The global data availability is good, but numbers e.g. extrapolations from measurements and modelling results do not agree well.

There is general consensus that impacts of nitrogen release into the environment go beyond local to national level, e.g. occurring also at regional to continental level (e.g. dead zones in the oceans), gaseous nitrogen compounds also have global scale impacts. Consensus for the N-boundary is medium to low. Disagreement centers on i) whether "fixation" (i.e. production) of reactive nitrogen is the right control variable, or if excess / release into the environment would be more appropriate, ii) if the current calculation of the boundary value may be too strict, in that it doesn't allow for increases in regions with low pollution levels (given the need for increasing food production which requires nitrogen fertilization) and iii) the missing contribution of combustion ("non intentional N fixation") in the current definition of the N-boundary. Regarding P it is important to note that it contributes to eutrophication and formation of dead zones in the seas globally, but at the same time it is also a limited non-renewable resource which is at risk of depletion globally. So there are good reasons for P use and release as a planetary boundary.

Dynamic and trends

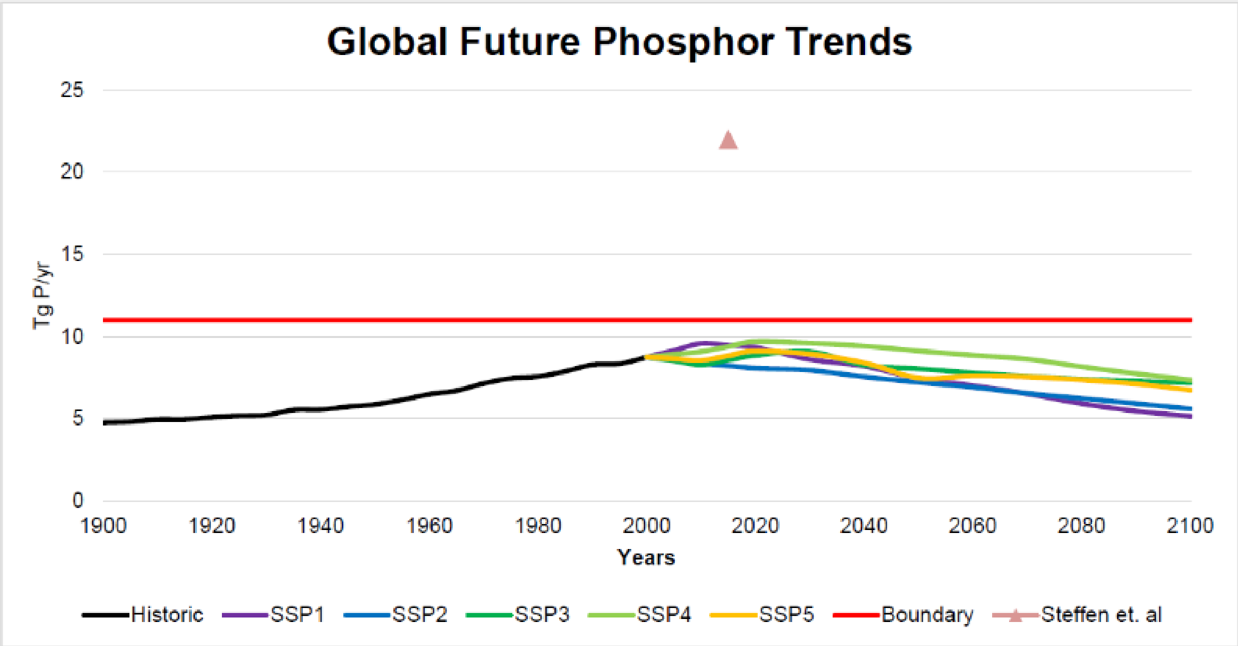
According to Steffen et al (2015), the global N-boundary has been significantly exceeded and intended N-fixation is further increasing. Our initial application of SSP scenarios show a decrease in future N-fixation. Note that these scenarios do not include all anthropogenic production pathways of reactive nitrogen (the nitrogen PB currently only covers a certain fraction of that), so they may underestimate the future trends. According to Steffen et al. (2015) the P-boundary has also been exceeded, however the latest results by Beusen et al. (2016) see the boundary not yet exceeded. SSP scenarios project a decrease in future P-release – see Figure 32 below (see Annex 4.3 for further description of trend projections and procedure).

Some of the N compounds are mobile in their respective environmental compartments (air, water) and may be subject to long distant transports so that their impacts may occur far away from their original release into the environment (**teleconnections**).

Figure 32: German production- based agricultural N-balance (excess N in kg per ha), 70 kg is the goal specified in the German Sustainable Development Strategy

Source: BMEL 2017, Statistischer Monatsbericht Kap. A

Figure 33: Historic trends and future scenarios of global P-delivery to surface waters, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015)



Source of historic data: Beusen et al. (2016), source of scenario data: IIASA SSP database and Riahi et al. (2017)

Risks, reversibility and criticality of boundary transgression

For the N-boundary impacts comprise of eutrophication of freshwater bodies with knock on effects on the freshwater planetary boundary, coastal eutrophication and subsequent anoxic/dead zones (currently growing in number and extent, Diaz et al. 2008), plus other impacts at all spatial scales, including greenhouse gas potential of gaseous N-compounds, eutrophication and acidification of soils, and ozone depletion (2.3). Related social and economic effects are the disruption of food webs and fisheries through loss of ecosystem services and biodiversity loss, health impacts (water pollution, air pollution, ozone, particulate matter).

For the P-boundary, impacts of phosphorus inflow include the eutrophication of freshwaters (lakes, rivers) and connected effects on ecosystems and the biosphere, soil eutrophication, eutrophication of coastal waters, and marine anoxia. There is robust evidence for these impacts, especially regionally, confidence is lower for large scale dead zones. The scale of these impacts is mostly local to regional; global scale impacts can arise i) when regional impacts are simultaneously occurring at many places on Earth, ii) through feedbacks in the system (eutrophication accelerating plant growth and CO_2 uptake), iii) through teleconnections such as global trade, and supply chains.

Connected social and economic risks are i) impacts for human livelihoods through non potable drinking water, cyanobacteria bloom (toxic for humans / livestock), oxygen depletion and fish kill, ii) economic impacts on cities and municipalities through decreasing water quality / water availability and associated mitigation / adaptation costs (e.g. buying bottled water), iii) impacts on recreational and commercial fisheries through oxygen depletion and fish kill / ocean dead zones / eutrophication of freshwater lakes and rivers, iv) impacts on tourism and on property value through cultural eco-system services loss, v) potential political risks through "peak phosphorus" (phosphorus exploitation getting more costly) and political dependencies on – not necessarily reliable - P producing countries (Morocco, Russia, China). Communities are generally adaptable to impacts of eutrophication; most exposed are poor communities around lakes, rivers, marine estuaries.

Return of soils and waters to previous conditions after eutrophication takes a very long time / reversibility is very low (due to feedback cycles / release of accumulated P from soils uphill or from sediments), knock-on effects on ecosystems and biodiversity may be irreversible on a human time scale, especially as it is difficult to decrease N- and P emissions (tied in with agricultural production; mobility, etc.).

The criticality for N and P are high in view of the severe boundary transgression and still increasing trends and impacts on other boundaries (climate change, land-system change, biosphere intactness, freshwater use); criticality especially high for lakes, rivers, estuaries due to importance for people's well-being and low reversibility of eutrophication.

Downscaling and policy implication

Carpenter et al. (2011) suggest a downscaled planetary boundary of P-concentration < 160 mg m^{-3} for rivers and 24 mg m^{-3} for lakes. For application, additional contextualization is required, e.g. in terms of soil conditions and vulnerability, groundwater vulnerability and resilience of terrestrial and aquatic ecosystems and co-risks. Downscaling and application of the N boundary also requires contextualization, e.g. in terms of previous nitrogen loads, denitrification potentials, vulnerability of receiving water bodies etc.

Policy implications of the N- and P-boundaries are broadly to i) raise awareness for N-and P-problem ii) monitor N and P emissions (distribution, magnitude, etc.) and impacts, iii) initiate / continue a science-policy dialogue on co-development of long-term goals to establish a circular economy and to reduce nitrogen and phosphorus emissions (global, regional, national), iv) take into account other relevant policy fields (especially related to food security).

1.2.2.7 Freshwater use

Table 9: Freshwater use factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary not yet transgressed	Observed trend	Consumptive freshwater use is increasing globally	Large scale risks	Impacts on aquatic ecosystems, changes in dilution of pollution, changing green water and atmospheric moisture flows
Data availability	No globally harmonized data on consumptive use available	Scenarios of future trends	Freshwater use increasing under all SSPs	Reversibility, adaptability	Direct effects reversible

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Consensus	Low: local to regional scale boundaries seem to be more critical than global boundary	Teleconnec-tions	Drivers and im-pacts of changes often separated, e.g. via trade and atmospheric moisture transport	Criticality	Multiple changes in the hydrological cycle and wa-ter resources are critical throughout the Earth system

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The freshwater planetary boundary: < 4000 km^3 of consumptive blue water use is not yet transgressed (actual value: 2600 km^3). Jaramillo et al. (2015) suggest that the boundary may almost be reached, when also taking into account all reservoir evaporations (which might be as high as 1250 km^3). Other sources find lower values for the current status, e.g. Hanasaki et al. (2013), see Figure 34 below.

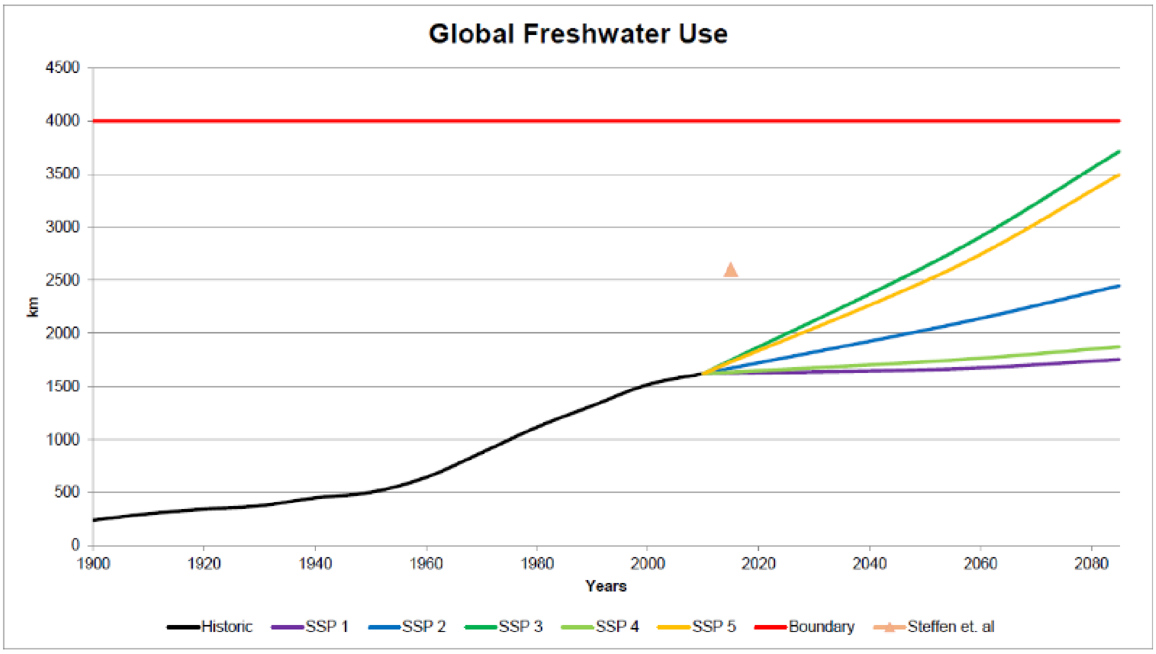
Globally harmonized data on consumptive water use across all sectors is not available; data synthesis needs a patchwork approach drawing upon various, potentially inconsistent sources.

Consensus on the need for and the definition of a global water boundary is low, given that most water problems are local to regional in scale. However water is very cross-cutting, linking to several other planetary boundaries, so it fits well with the systemic approach of the planetary boundaries.

Dynamic and trends

Consumptive freshwater use keeps increasing. Figure 34 shows the past trend and scenarios of future use relative to the boundary, for different socio-economic pathways (SSPs). This figure is based on agricultural water use simulations from the LPJmL model, while industrial, household and livestock water use is derived from Flörke et al. (2013) and reservoir evaporation from Shiklomanov et al. (2003). Scenarios were constructed after Hanasaki et al. (2013).

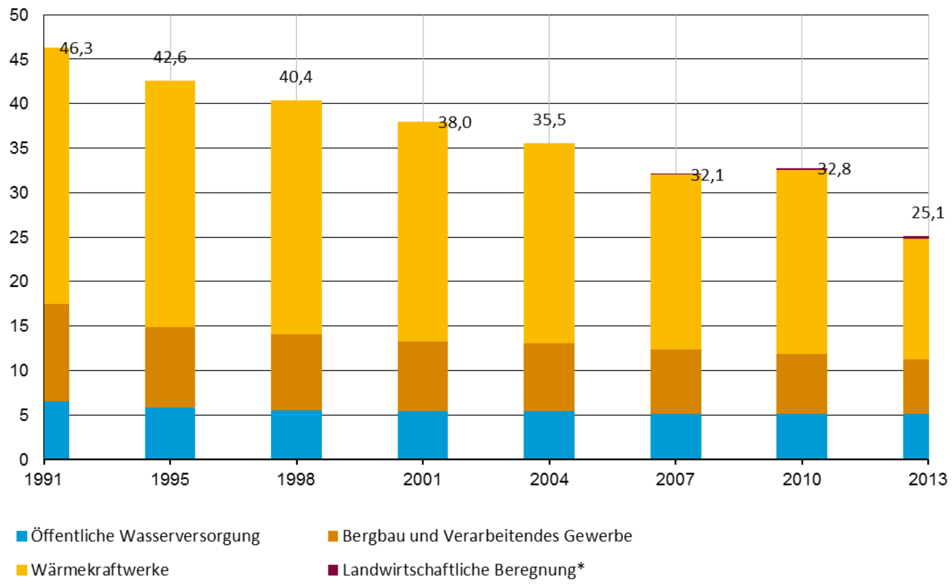
Figure 34: Historic trends and future scenarios of global consumptive freshwater (blue water) use, relative to the boundary, for different socio-economic pathways, triangle indicates the current value given by Steffen et al. (2015)



Source: Hanasaki et al. (2013) and IIASA SSP database and Riahi et al. (2017)

Water withdrawals in Germany have decreased by more than 40% since 1991 to 25 km³ in 2013 (Statistisches Bundesamt 2013a, 2013b)

Figure 35: Water withdrawals in billion m^3 in Germany, for public water supply, mining and manufacturing industry, production of electricity and agriculture (1991-2013)



Source: Statistisches Bundesamt 2013a, 2013b

Downscaling of the planetary boundary for freshwater by population (Germany hosting about 1% of the global population) yields a fair share of about 40 km^3 consumptive blue water use (note that consumptive use only makes up a small fraction of water withdrawals and that these theoretical values are not connected with potential environmental effects.) The actual consumptive blue water use for Germany according to Mekonnen 2011 is is 6.99 km^3. Most of that water use (68.8%) happens outside of Germany for products that are imported by Germany. That level of externalization of the country's blue water footprint is higher than the global average of 21.7% (Mekonnen 2011). Tukker et al. (2014) calculate much higher net virtual water imports amount of 294 m^3 per capita and year. Moreover Germany is a leading country in terms of net virtual water imports from water scarce countries (Lenzen et al. 2013).

Our assessment indicates that Germany does not exceed its "fair share", i.e. the downscaled water-boundary, not even when accounting for its large external water footprint. However Germany does contribute to local water scarcity in some of the source regions from which it imports goods and services.

Water has **teleconnections** in its liquid form (long distant transport with rivers), its vapor form (long distant atmospheric transports) and its virtual form (long distance transports with traded goods and services), hence drivers and impacts of changes are often separated over long distances.

Risks, reversibility and criticality of boundary transgression

Impacts on i) aquatic ecosystems if environmental flow requirements are no longer met, with subsequent effects on their services and on social-ecological resilience, ii) changes in dilution of pollution, water quality and biogeochemical cycles (e.g. P and N) if river flows decrease, and iii) changing green water flows or atmospheric moisture recycling with regenerate precipitation (Keys et al. 2012) (note that the control variable only refers to blue water consumption as measure for human interference with water systems, not yet to green water use).

Direct effects in the hydrological cycle are reversible, knock on effects on ecosystems and biodiversity less so.

While the criticality of local water problems is increasing in magnitude, intensity and frequency, the criticality of global-scale changes in the hydrological cycle and water resources (such as severe depletion of groundwater resources and river flows and changes in evaporation in many regions, with knock-on effects on atmospheric moisture flows and even sea level rise) are not well understood.

Downscaling and policy implication

Relatively easy to downscale (at least at local to regional scale, there are concerns about the interpretation of the downscaled planetary boundary for freshwater); operationalization requires contextualization such as (green and blue) water scarcity, ecosystem properties and vulnerabilities, and co-risks that potentially aggravate the effects of consumptive water use.

Policy implications comprise e.g. of i) awareness raising for local / regional water quantity and quality problems, ii) reduction of consumption based externalization (e.g. virtual water) to water scarce regions, iii) interconnectedness of water to many other environmental challenges at all scales.

1.2.2.8 Atmospheric aerosol loading

Table 10: Atmospheric aerosol loading factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	Boundary exceeded in south Asia	Observed trend	Spatially and temporally highly variable aerosol loading; growing in some world regions	Large scale risks	Global warming, hydrological cycle, air quality (health, ecosystems)
Data availability	Global dataset available	Scenarios of future trends	For particulates decreasing under different SSP scenarios	Reversibility, adaptability	Atmospheric aerosol loading is reversible, some of the impacts on human health or ecosystems not
Consensus	Medium to low	Teleconnections	Long distant transport in higher altitude	Criticality	Potentially high (health effects and climate effects)

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The aerosol optical thickness < 0,25, is already exceeded in south Asia (about 0.3) (Steffen et al. 2015).

Dynamic and trends

Atmospheric aerosol loading (or optical depth or optical thickness) is spatially and temporally highly variable. A large number of different datasets are available for different regions, periods and atmospheric pollutants. A global dataset by NASA is available with daily global data on an aerosol index, which was shown to be linearly related to optical thickness (NASA 2017, Hsu 1999).

Atmospheric aerosol loading is growing in many world regions, except Europe (Mao 2014). Lynch et al (2016) produced a global aerosol optical thickness (AOT) reanalysis product for the years 2003 – 2013 by fusing satellite and modeling data. Over that period they find an increase in AOT (or aerosol loading) for the Indian Bay of Bengal, Arabian Peninsula and Arabian Sea, Bohai Sea in East Asia and southern Africa. Many other regions including Europe show a decrease in AOT during that period.

Rao et al (2017) developed air pollution scenarios for sulfur and nitrogen oxides and particulates (black carbon) based on the SSPs. Particulates are closely correlated with AOD. All of their pathways show a strong global decrease in these pollutants after about 2020-2040, decreasing by up to 50% and more.

Aerosols may be subject to long distant transport in higher altitude, so their (e.g. climatic, hydrological and health) impacts may occur distant from their origin (**teleconnections**).

Risks, reversibility and criticality of boundary transgression

Aerosol effects in the climate system are complex and subject to intensive research. They have large-scale impacts on global warming by changing the radiative balance (with an overall reducing effect on global warming) and on the hydrological cycle, also shifting monsoon patterns, as well as acceleration of glacier melting, but also more local impacts on air quality (human health and ecosystems). Self-cleansing capacity of the atmosphere is (potentially) strongly non-linear. A global decrease in aerosols is expected to lead to an acceleration of global warming. The criticality is potentially high, given the health and climate effects.

Downscaling and policy implication

Downscaling requires contextualization. Policy implications comprise broadly of reducing air pollution. The human health effect is probably best represented by the WHO air quality guidelines for particulate matter ($PM_{2.5}$ and PM_{10}). PM concentrations exceed these WHO air quality guidelines in most urban regions in Germany.

1.2.2.9 Novel entities

Table 11: Novel entities factsheet

Control variable, quantification, uncertainty		Dynamic and trends		Risks, reversibility and criticality	
Current global situation	n.a.	Observed trend	n.a.	Large scale risks	n.a. (see e.g. ozone boundary for illustration)
Data availability	n.a.	Scenarios of future trends	n.a.	Reversibility, adaptability	Some pollutants and also plastics are very persistent, GMOs once released cannot be retrieved
Consensus	Necessity to include novel entities accepted	Teleconnections	Plastics distributed globally with ocean currents	Criticality	Potentially very critical

Source: from authors, PIK/adelphi

Control variable, quantification, uncertainty

The novel entities boundary does not have a control variable. It serves as a “placeholder” (Persson et al. 2013) for unknown planetary boundaries, related to chemical pollutants and other novel entities, including also modified life-forms. These become a global concern when they “exhibit (i) persistence, (ii) mobility across scales with consequent widespread distributions, and (iii) potential impacts on vital Earth-system processes or subsystems” (Steffen et al. 2015: 7). These conditions for novel entities that could become planetary boundaries were further specified by Persson et al. (2013: 12620), namely that they have i) “a disruptive effect on a vital Earth system process” of which we are “currently ignorant", ii) "the disruptive effect is not discovered until it is, or inevitably will become, a problem at a planetary scale" and iii) that "the effects of the pollutant in the environment cannot be readily reversed".

Current scientific deliberation focuses on i) identifying conditions for chemical pollutants or other novel entities to amount to planetary threats (Persson et al. 2013), ii) formulating scenarios that fulfil these conditions and generating chemical profiles for these scenarios (MacLeod et al. 2014), iii) formulating classification schemes, and iv) applying these conditions, scenarios, schemes to specific chemicals (Cousins et al. 2016; Jahnke et al. 2017; Reppas-Chrysovitsinos et al. 2017).

Applications of these conditions have focused on weathering plastic in the marine environment (Jahnke et al. 2017), Arctic contaminants (Reppas-Chrysovitsinos et al. 2017) and perfluoroalkyl acids in groundwater (Cousins et al. 2016).

The data availability category is not applicable for this boundary, as it is a placeholder for not yet identified planetary boundaries. In general, data on chemicals comes e.g. from REACH, etc. Consensus is in general high for this boundary, several researchers have picked up on the novel entities boundary.

Dynamic and trends

It is not possible to illustrate or calculate the dynamics or trends or relative position for unknown planetary boundaries. Similarly, future trends cannot yet be calculated and teleconnections not be described.

Risks, reversibility and criticality of boundary transgression

impacts can only be illustrated when disruptions of Earth system processes are already observed and these are attributed to chemical pollutants (examples are the climate change and ozone boundary).

We know with high confidence that the impact of some chemicals can be very high (high magnitude). As the novel entities boundary is a "placeholder" for currently not detected or identified planetary boundaries, it is however not possible to list impacts for these unknown chemicals posing an unknown threat.

Health impacts on humans / organisms are very much studied (very robust evidence), but not the primary focus of the planetary boundaries concept. Furthermore, we know from existing chemical planetary boundary problems that they could have severe social and economic impacts (see e.g. climate change).

Reversibility depends largely on the type of chemical used. Irreversibility could arise when a) the chemical is persistent in the environment, i.e. it shows no chemical decay or chemical/biological degradation (already dealt with in current regulation), b) the chemical is so tied to economic processes that it is not possible to sufficiently reduce emissions (e.g. CO_2) c) the effects of chemicals are non-reversible (e.g. through system shifts). Similarly, the introduction of (genetically) modified organisms is largely irreversible.

The adaptability category does not apply to the novel entities boundary in the sense used in the other parts of this paper (adaptability to impacts). In the context of this boundary, adaptability refers to whether societies are capable to address unknown planetary boundary threats.

The novel entities boundary is potentially very critical (depending on the scenario), but criticality yet unknown (can only be illustrated for past processes, "lessons learned").

Downscaling and policy implication

It is by definition not possible to downscale/ translate this boundary, as it is a placeholder for unknown boundaries.

The novel entities boundary has several policy implications. In general, the boundary implies that the likelihood of planetary boundary threats to arise should be minimized. Hence the Earth system needs to be monitored for early signs of disruption of vital Earth system processes. It is also crucial to avoid using chemicals that could lead to these disruptions. Therefore, chemical pollutants should be screened for potential disruptive effects, using the conditions, scenarios, chemical profiles formulated above. Furthermore, the boundary motivates policy-makers to implement a new of way of thinking, focusing on the precautionary principle, productively confronting societal ignorance.

The potential for putting this boundary into practice is medium. On the one hand, there are already mechanisms in place to screen for environmental effects of chemical pollutants; however, the novel entities boundary requires a mind shift, to embrace the precautionary principle.

1.2.3 Systems view, synthesis and conclusions, bringing the boundaries together

We compare in this input paper for several boundaries (for those with clearly defined control variables and available data Germany's transgression of its fair share of the respective planetary boundary with the global boundary transgression). Where possible we also compare Germany's production-based vs. consumption-based pressure on the planetary boundaries.

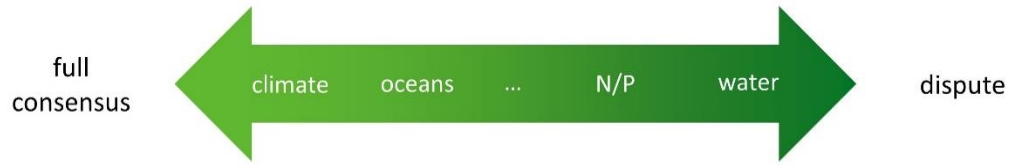
Not all boundaries are equal. They vary in their definition, in the level of scientific uncertainty / the assessment challenge (see Chapter 1.2.2), in their trends and (trends of) transgression and also in the criticality of (potential) transgression as well as in their policy implications and operationalizability (downscaling and contextualization).

We attempt here an initial comparison and ranking of the planetary boundaries for some of these properties, for the benefit of potential users of the planetary boundaries (e.g. in policy making or environmental decision making), but also pointing out knowledge gaps for a new science agenda and eventually for co-production of relevant knowledge in support of vertical (cross-scale, cross-level and cross-regional) coherence of sustainability limits, approaches and transitions.

1.2.3.1 Comparison of the different boundaries

Figure 36, Figure 37 and Figure 38 compare the boundaries in terms of consensus, uncertainty, reversibility, and timescale of impacts. Figure 39 impressively demonstrates the long-term perspective which the planetary boundaries provide, complementing their large-scale and systemic perspective.

Figure 36: Comparison of boundaries in terms of consensus about the need for a planetary boundary

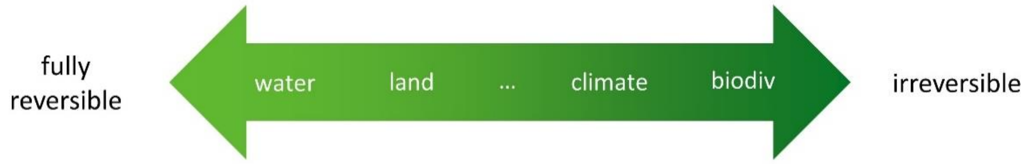


Source: from authors; PIK

Figure 37: Comparison of boundaries in terms of uncertainty around the boundary value[6]

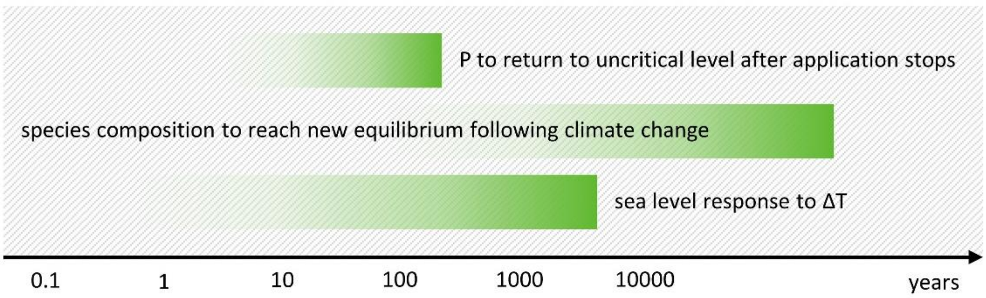
Source: from authors; PIK

Figure 38: Comparison of boundaries in terms of the reversibility of boundary transgression and resulting impacts



Source: from authors; PIK

Figure 39: Comparison of boundaries in terms of timescale of impacts from boundary transgression



Source: from authors; PIK

1.2.3.2 Systemic interactions and feedbacks between different boundaries and their role in Earth system dynamics

Planetary boundaries and their trends (or trends of boundary transgression) may interact positively or negatively, eventually affecting Earth system dynamics. Examples include the cooling effect of aerosols (and consequently the additional warming caused by reducing aerosol loads), the climate change mitigation effect of additional nitrogen loads via fertilization and increased biomass production / carbon sequestration, or the faster recovery of stratospheric ozone at higher global warming levels. There are many other examples of such interactions and feedbacks, requiring integrated approaches to staying within the safe operating space as delineated by several planetary boundaries simultaneously.

1.2.3.3 Key concerns

Key concerns which emerged during the analysis of each boundary were i) the perceived static nature of the boundary / its illustration as well as potential miscommunication of urgency (e.g. water and

[6] Note that also the availability of suitable data, harmonized across all countries and up to global scale varies significantly among the different boundaries. Available data often do not exactly match the control variable.

ocean acidification boundaries marked as green while local or long term threats are obvious), ii)a concern with some of the boundary definitions (e.g. N-boundary; biosphere boundary; ozone boundary), the choice of control variable and position relative to boundary (see diverging values in Steffen et al. and some of the literature; Annex 5.3 for explanation), iii) the treatment of the biosphere as static, iv) the pre-dominantly local nature of some boundary-related environmental problems (e.g. water), and v) the perceived over-simplification of some problems (e.g. aerosol loading) reducing them to one control variable.

1.2.3.4 Ways forward, making the planetary boundaries work and co-generating the required knowledge for sustainability transitions

The Planetary Boundaries provide specific environmental information from a large-scale, long-term, and systemic perspective. With that they add value to policy and decision making. They don't stand in isolation. Operationalization should happen through "mainstreaming", i.e. integration into existing frameworks, initiatives and activities.

Policy makers (and other actors) and scientists together can identify opportunities for mainstreaming the planetary boundaries into ongoing activities and for deriving relevant information in support of environmental protection / sustainable development / sustainability transitions. While doing so, they also need to be aware about the limitations of the concept, given that it reduces complex environmental processes to single control variables and boundary values. This reduced complexity and (resulting) communicative power makes it challenging to apply the planetary boundaries to specific contexts. These limitations are in part result of its benefits, that is, it is not possible to modify the concept for these without losing other functions (e.g. the concept's simplicity).

The concept appears to be helpful for very specific challenges related to i) awareness raising for large scale, long term and systemic current and potential future environmental problems, their causes, interlinkages and global consequences ii) justification and evidence base for global responsibility and global engagement (e.g. of consumers, companies or countries), iii) the need to protect global commons, iv) strongly including the precautionary approach in policy-making, and v) justifying a budget approach and absolute resource targets (vis-à-vis efficiency targets).

However, the concept needs to be translated, downscaled and contextualized (operationalized) in order to add value to ongoing environmental and sustainability activities. For that it needs to be integrated with bottom-up local to regional sustainability criteria in order to contribute to managing real world environmental problems (not originally intended). Furthermore the static presentation of the concept so far, needs to be complemented by trends / scenarios / decision points, e.g. when comparing the current illustration with IPCC illustrations (while this and other papers contribute to this point, and decision points could be included). These points highlight that opportunities for applying the concept in policy-making need to be carefully and jointly identified by scientists and policy makers, the concept should not be understood as a catch-all paradigm. This input paper is beginning to address some of the most relevant current limitations and invites the scientific community and policy and decision makers to join this effort.

1.2.4 Annex

1.2.4.1 Glossary

Explanations are direct quotes; explanations without reference were generated by the project team.

Aerosol	A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 µm and residing in the atmosphere for at least several hours (IPCC 2001).
Aerosol optical thick-ness	The density of aerosols defined by the depth of dispersal through a certain airmass (Stotts 2017).
Allowable emissions	Targets for emissions of greenhouse gases, agreed upon by most UN mem-ber states in the Paris Agreement (European Commission 2017).
Anoxic / dead zones	Hypoxic zones are areas in the ocean of such low oxygen concentration that animal life suffocates and dies, and as a result are sometimes called "dead zones" (NOAA 2017).
Anthropocene	The epoch of current time, where humans are classified as the main driver of changes in the Earth System (Zalasiewicz et al. 2008).
Anthropogenic	Resulting from or produced by human beings (IPCC 2001).
Aragonite	A colourless mineral, the stable form of calcium carbonate. It is different from calcite, the more common form of calcium carbonate, by its greater hardness. Aragonite is the mineral normally found in pearls and mollusc shells are formed of aragonite crystals (Marine Spatial Ecology Lab 2017).
Biome	A community of plants and animals living together in a particular climate (NASA Earth Observatory 2017).
Blue water	A category, like green and grey water, which specifies the form of water, in this case referirng to ground and durface water (Hoekstra et al. 2011).
Burning embers	Diagram used in the IPCC process to depict climate related risks.
Consumption based emissions	Consumption-based accounting methodologies take as their starting point the goods and services consumed within a territory, and then reallocate the emissions from production, wherever in the world that production may have occurred, to those final goods and services (Croft and Trimmer 2017).
Consumptive water use	Water use which depletes the respective system of water, in particular through evaporation (while non-consumptive use returns water to the system after use).
Control variable	"the most comprehensive, aggregated, and measurable parameter for indi-vidual boundaries" (Rockström et al. 2009).
Coral reef calcification	Mechanism of corals, where CO2 is produced for photosynthetic activity. It is assumed to decrease with higher acidity in the water (Birkeland 1997).
Criticality	Our assessment of the level of concern associated with a particular bound-ary and its transgression.
Disruptive effect	An effect which has the potential to rapidly change the state and stability of the system.
Downscaling	Translating the planetary boundaries into national-level fair shares of Earth's safe operating space (Häyhä et al. 2016).

Earth system / processes	The term "Earth system" refers to Earth´s interacting physical, chemical, and biological processes. The system consists of the land, oceans, atmosphere and poles. It includes the planet's natural cycles — the carbon, water, nitrogen, phosphorus, sulphur and other cycles — and deep Earth processes. Life too is an integral part of the Earth system. Life affects the carbon, nitrogen, water, oxygen and many other cycles and processes. The Earth system now includes human society, Our social and economic systems are now embedded within the Earth system. In many cases, the human systems are now the main drivers of change in the Earth system (IGBP 2017).
Echinoderms	Echinoderms (scientific name Echinodermata) are a major group of only marine animals. The name comes from the Greek word for "spiny skin". There are about 7,000 species found usually on the sea floor in every marine habitat from the intertidal zone to the ocean depths (MESA 2017a).
Ecological footprint	A measure of how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices (Global Footprint Network 2017).
Eutrophication	Eutrophication is a process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. It may occur naturally but can also be the result of human activity (fertiliser run-off, sewage discharge). These nutrients typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish (Eurostat 2014).
Evaporation	The physical process by which a liquid or solid is transformed to the gaseous state; the opposite of condensation (AMS 2012).
Functional diversity	The variation in the degree of expression of functions between the different individuals of a population, between populations of the same species, between species, or between ecosystems (Garnier et al. 2016).
Genetic diversity / phylogenetic diversity	The diversity of living organisms established on the basis of the degree of evolutionary relatedness between them (Garnier et al. 2016).
Guardrail	Thresholds whose transgression would cause inacceptable risks of dangerous interference with the system either today or in the future.
Holocene	The Holocene is the geological epoch which started approximately 11,700 years ago (Walker et al. 2009).
Molluscs	The Mollusca, or molluscs, is a large phylum (group) of invertebrate animals (animals without backbones). The name Mollusca means 'soft-bodied' and, although some have developed a tough shell, they are all soft on the inside. They are one of the largest animal groups with about 200,000 species worldwide which make up about a quarter of all marine animals (MESA 2017b).
Negative emissions	A situation of net negative emissions is achieved when, as result of human activities, more greenhouse gases (GHGs) are sequestered or stored than are released into the atmosphere (IPCC 2014b).
Net CO2 emissions	Gross CO2 emissions minus sequestration.
Net imports of virtual agricultural land	Imports minus exports of virtual land (while virtual land is the amount of agricultural land required for producing the goods and services imported or exported).

Operationalization	Putting the planetary boundaries concept into practice (e.g. through translating and downscaling the global scale concept to sub-global scale).
ppm	Parts per million
Precautionary principle	The precautionary principle aims at preventing dangers (here: to the environment) from arising in the first place. The precautionary principle therefore leads us to act in good time and with foresight in order to avoid environmental dangers such as pollution or other degradation. The two dimensions of the precautionary principle are risk prevention and taking care of resources (adapted from UBA 2017c).
Production based emissions	Production-based emissions only account for emissions within a countries territory (different from consumption-based emissions which account for all domestic and external emissions related to the countries consumption of goods and services.
Pteropoda	Part of the mollusc phylum
Foraminifera	The Foraminifera, ("Hole Bearers") or forams for short, are single-celled protists with shells which can have either one or multiple chambers, some becoming quite elaborate in structure. Depending on the species, the shell may be made of organic compounds, sand grains and other particles cemented together, or crystalline calcite. They are usually less than 1 mm in size, but some are much larger, and the largest recorded specimen reached 19 cm (MESA 2017c).
RCP scenarios	Representative concentration pathways, which were developed for the climate modeling community as a basis for long-term modeling experiments and scenarios.
Regime shifts	Large, persistent changes in the structure and function (here: of social-ecological systems) with substantive impacts on the suite of services provided by these systems, e.g. habitability for humans in the case of the Earth system.
Safe Operating Space	Scientifically based sustainable development space for societies in which the risk of uncontrollable and undesirable Earth system changes remains low.
Scenarios	Sets of potential future development pathways (from performing arts: a collage of a series of actions and events).
Soil Acidification	The process of decrease in the soil's pH making the soil more acid. Oftentimes it is brought about by intensified agriculture (Robson 2012).
Species extinction rate	Number of species turning extinct during a specified period of time.
SSP	Shared Socio-Economic Pathways
Supply chain	The sequence of steps and associated resources and institutions, involved in producing and transporting goods or services to the final customer.
Teleconnections	Cross-regional interconnections, wherein actions in one region impact quite specifically e.g. on the use of resources, pressure on the environment or more generally the sustainability of other regions.
Terrestrial CO_2 sink function	The capacity of terrestrial ecosystems to take up CO_2 from the atmosphere.
Tipping points	The moment when a system, e.g. the Earth system or a sub-system of the Earth system rapidly and potentially irreversibly changes its properties, behavior and functions.

Virtual water content	The virtual-water content of a product is the freshwater 'embodied' in the product, not in real sense, but in virtual sense. It refers to the volume of water consumed or polluted for producing the product, measured over its full production chain. If a nation exports/imports such a product, it exports/imports water in virtual form (Hoekstra et al. 2011).
Water withdrawals	The volume of freshwater abstraction from surface or groundwater. Part of the freshwater withdrawal will evaporate (consumptive use), another part will return to the catchment where it was withdrawn and yet another part may return to another catchment or the sea (Hoekstra et al. 2011).

1.2.4.2 Expert interview procedure and interview questions

Nine international experts on the planetary boundaries concept and risks of transgressing these boundaries were qualitatively interviewed (semi-structured expert interviews). Interviews were conducted via telephone, recorded and documented. Interviews lasted approximately 30 to 45 minutes. Interviewees were asked to assess the evidence base as well as confidence in their judgment.

Interview questions were:

1. What is your opinion on the planetary boundaries concept, from a science and/or policy perspective?
2. What impacts on biophysical systems are in your opinion connected with further increasing [*respective planetary boundary control*] and with the transgression of the [*respective planetary boundary*]?
3. Which interlinked social and economic risks are in your opinion connected with these biophysical impacts?
4. How reversible are these biophysical, social and economic impacts?
5. How adaptable are human societies to these impacts?
6. How critical are these risks in your opinion, in light of the vulnerability of ecosystems, of populations and of social-ecological systems?

1.2.4.3 Trend projections, description of procedure

Trends for the different planetary boundaries depicted in the figures above are based on available time series of control variables or similar variables. In the case of N, P and water, available time series show significantly lower current values of the respective control variable, in the case of land a significantly higher current value compared to that given in Steffen et al. (2015). We do not claim that the values presented in our figures are closer to reality than the Steffen et al. values but we point out the need for further analysis of available data in order to better characterize boundary transgression dynamics.

For future scenarios we used trends (no absolute data) for water, land and nitrogen from the IIASA SSP database (see Riahi et al. 2017) and let them start from the last available historical value. For P we used SSP trends for N. We did not represent the full range of scenario data, but only used the 2.6 marker scenario for each SSP.

1.3 Environmental policy-making in the Anthropocene

1.3.1 Introduction

"The 'Anthropocene' is a term … used … to denote the present time interval, in which many geologically significant conditions and processes are profoundly altered by human activities." (Working Group on the Anthropocene 2016)

The Anthropocene concept increasingly emerges in sustainable development debates. The term has been first used in an article by researchers Paul Crutzen and Eugene Stoermer (Crutzen and Stoermer 2000). It builds on earlier notions of the "Anthrocene", the "noösphere" and the "psychozoic era" (Steffen et al. 2011c: 843-845), all emphasizing the increasingly central role of humans in the Earth system. In 2009, the International Commission on Stratigraphy[7] picked up on the notion and established the Working Group on the Anthropocene which in 2016 recommended to formalize the Anthropocene as a geological epoch, based on the assertion that it is "stratigraphically real" [8] (Zalasiewicz et al. 2017). As the concept raises far-reaching questions on humanity's role on Earth, it has also gained prominence outside of the natural sciences e.g. in civil society, the arts, literature, philosophy and social science (Autin 2016). Media outlets have also reported on the concept, especially with regards to the Working Group's formal recommendation (for example, The Guardian titled "The Anthropocene epoch: scientists declare dawn of human-influenced age"; Carrington 2016) and helped to push the concept outside a purely political-scientific debate.

The Anthropocene forms the background for which Rockström et al. (2009) and Steffen et al. (2015b) developed the planetary boundaries concept (see the input paper on planetary boundaries for details on the concept). As Rockström et al. formulated it: "The Anthropocene raises a new question: What are the non-negotiable planetary preconditions that humanity needs to respect in order to avoid the risk of deleterious or even catastrophic environmental change at continental to global scales?" (Rockström et al. 2009: 32). However as we will argue in this paper, the Anthropocene concept is not merely a geological (or natural scientific) notion. In fact there are many more interpretations visible in the discourse. We describe three such interpretations which set humans in three different contexts (humans as preservationists, as gardeners and as Earth-engineers). The overarching thesis is that policy-makers can benefit from being aware of the existence of a variety of interpretations of the concept (its 'openness') and the implications these interpretations have for environmental policy-making (risks and opportunities)[9].

The paper's objective[10] is thus a political- and social-scientific analysis of the Anthropocene concept. The paper details very briefly the ideational and material changes in the human-nature relationship

[7] «The International Commission on Stratigraphy is the largest and oldest constituent scientific body in the International Union of Geological Sciences (IUGS). Its primary objective is to precisely define global units (systems, series, and stages) of the International Chronostratigraphic Chart that, in turn, are the basis for the units (periods, epochs, and age) of the International Geologic Time Scale; thus setting global standards for the fundamental scale for expressing the history of the Earth.» (International Commission on Stratigraphy 2017).

[8] Stratigraphy is the «geology that deals with the origin, composition, distribution, and succession of strata» (Merriam Webster 2017a), a stratum is « a sheetlike mass of sedimentary rock or earth of one kind lying between beds of other kinds » (Merriam Webster 2017b).

[9] In this paper, we understand the term «environmental policy-making» as overarching, comprising of environmental politics, policy and polity. When referring to different subtopics of policy-making (such as policies or the process of drafting policies) we name them accordingly.

[10] The research project "Planetary Boundaries – Challenges for Science, Civil Society and Policy" analyses the operationalization and political implementation of the planetary boundaries in the German context. Previous papers assessed the potential contribution of the planetary boundaries for the German Integrated Environmental Programme and the German Integrated Nitrogen Strategy, as well as its conceptual foundations, its potential for environmental communication, relation to social Boundaries and ways to downscale the planetary boundaries and use them for environmental benchmarking (e.g. illustrating the externalization of environmental impacts).

from pre-industrial times to the Anthropocene (1.3.2). It describes the three central Anthropocene interpretations (1.3.3) and analyzes implications for the self-conception, political instruments, institutional set-up (polity) and international cooperation (1.3.4).[11]

1.3.2 Charting the human-nature relationship from pre-industrial times to the Anthropocene

"It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene — the warm period of the past 10–12 millennia." (Crutzen 2002: 23)

In one of the most cited definitions the Anthropocene is designated as an epoch in which humanity "rival[s] the great forces of Nature" (Steffen et al. 2007: 614) as seen for example in the altered nitrogen cycle, elevated CO_2 emissions which display "a level not seen for at least 800,000 years" (Lewis and Maslin 2015: 172) and the greatly increased acidity of oceans. Humans now influence ecosystems and the terrestrial biosphere to a very large degree (Ellis 2011). The character of the Anthropocene contrasts with humanity's pre-industrial global footprint leading to across-the-board challenges for both people and planet.

At the same time, how humans perceive nature has also radically changed from ancient Greek down to the present day. The most drastic change was arguably Darwin's theory of evolution and the end of earlier conceptions of nature's inherent order and progress within nature (teleology).[12] To grasp these far reaching changes in the human-nature relationship, in this chapter we briefly detail major material and ideational developments of the past. The focus is mainly on the European context from pre-modern Europe (i.e. Antiquity and Christianity before the Renaissance) to the Scientific Revolution.

1.3.2.1 Human-nature relationship over time: pre-modern Europe and the rise of the scientific revolution

Prior to industrialization, human impact on nature was comparably small (Steffen et al. 2007).[13] Humans did however modify their environment: they hunted, modified landscapes, e.g. through fire and land clearing (Bowmanet al. 2009); they domesticated animals and plants (agriculture) and grew rice (Lewis and Maslin 2015; Steffen et al. 2007). Humans also possibly caused the Pleistocene megafauna extinction[14] and contributed to the invasion of species (Ellis et al. 2013). Possibly 1000 B.C. did land-use changes become widespread (Ellis et al. 2013; Ellis 2011). But overall, humanity lacked the organized capacity and technology to change natural processes on the scale observable today.

This comparably small impact increased dramatically with the onset of industrialization, especially in the period after the Second World War (Steffen et al. 2007 set the period from 1800 to 1945): the use of fossil fuels (coal, oil, gas) grew significantly, the Haber-Bosch process raised crop yields and human population numbers ascended together with economic activity. Deforestation and land conversion increased; hydrological, biogeochemical and carbon cycles were increasingly transformed (Steffen et al. 2007). From 1945 on, the magnitude and rate of global changes accelerated – including changes in the

[11] The input paper does not focus on the history of the Anthropocene concept (compare e.g. Steffen et al. 2011c for this), on purely communicative aspects of the Anthropocene (such as its potential for environmental communication) or (natural) scientific questions (e.g. the stratigraphic question of the onset of the Anthropocene), while all three points are still reflected upon in the paper.

[12] Teleological understandings see an inherent goal within nature (latin: telos) such as e.g. to strive for perfection.

[13] See however Ellis et al. (2013) who argue that "land use has been extensive and sustained for millennia in some regions".

[14] Megafauna are animals heavier than 44 kg (Barnosky et al. 2004). According to Barnosky «fifty thousand years ago, continents were populated with more than 150 genera of megafauna […]. By 10,000 years ago, at least 97 of those genera were gone» (Barnosky et al. 2004). In biological taxonomy, genera is one level above species in the hierarchy of biological classifications.

population, economy, petroleum use and degree of urbanization – leading to major global environmental impacts, such as a changing climate and the global loss of biodiversity.

Over time, understandings of nature and the human-nature relationships also changed.[15] The birth of the concept of nature was the idea to condense diverse phenomena such as plants, animals, rock and water into one term, describing both the physical world around us, as well as its internal makeup, the hidden power or order behind it. In pre-modern Europe, within ancient Greece, Homer was among the first to use the concept physis[16] in the Odyssey, designating the external characteristics of plants (Arias-Maldonado 2015).[17] Hesiod conceived of nature and natural forces as personified gods, acting on Earth (mythological understanding). In the same vein, the Roman poet Ovid identified the changing nature (e.g. the seasons) with the changing influence of gods (in his work Metamorphoses). Pre-socratic philosophers moved beyond single phenomena and their character and understood nature as an all-encompassing order with a specific (moral) purpose (a telos = goal), a specific design suitable for human needs (logos).

Another notable perspective is the ancient conception of nature as organic and valuable, identifying Earth as the 'nurturing mother'. This image can be traced back to the ancient Greek goddess Gaia (or her Roman equivalent Tellus) and to similar conceptions of the Earth goddess in other cultures such as in Northern Europe, and South- and East Asia (Verhagen 2008). Viewing nature as a mother, as nurturing, largely benevolent entity and of personal value, shaped the human interaction with nature. As the philosopher and historian Merchant writes (Merchant 1992, 2010):

> "The image of the Earth as a living organism and nurturing mother had served as a cultural constraint restricting the actions of human beings. One does not readily slay a mother, dig into her entrails for gold, or mutilate her body" (2010: 296).
>
> "As long as the Earth was conceptualized as alive and sensitive it could be considered a breach of human ethical behaviour to carry out destructive acts against it" (1992: 60).

The rise of *Christianity* replaced the 'autonomy' of nature with a more passive role as part of God's creation. The Christian God is "transcendent … he has created nature, but He is not nature" as compared to the pagan personification of the Earth (Aria-Maldonado 2015: 22). Nature was thus desacralized(Arias-Maldonado 2015: 22). Apart from this desacralization there is however no definite interpretation of nature in the Christian faith. The Bible gives rise to different understandings (both instrumental and non-instrumental) (Arias-Maldonado 2015). Medieval Christians for example stressed that humanity should act as a steward for God's creation, for instance based on the statement that "The land shall not be sold in perpetuity; for the land is mine, and you are but aliens who have become my tenants." (Bible: Leviticus Chapter 25: 23; translation according to the New American Bible 2002) – there is then no true property of the land, humans only lease the land and should treat it accordingly. According to this view, God was seen as the source of all values that guide and control life on Earth. This notion implies a culture of acknowledging and appreciating nature's life-supporting yields and God's 'ownership' of all his creation (Tanner 2004). It also generates the purposefulness of nature – created by God for human utilization. Leading to similar ethical conclusions, religious persons (e.g. Francis of Asisi) saw an intricate relationship between humans and nature (mysticism) and acknowledged that nature has intrinsic value.

On the other hand, Christian faith also allows for a much more instrumental view of nature:

[15] The following description draws mainly on Maldonado (2015).

[16] The term physis has different translations, depending on the context and use by different ancient Greek authors, among them the «the origi » or «original power», «the form or constitution of a person or thing as the result of growth», «the regular order», «the substance» or as a more specific term «creature», e.g. species or plants Liddell and Scott 1940.

[17] There is however only one instance of the term physis in the Odyssey (compare Liddell and Scott 1940).

> "[…] God had created light and darkness, the heavenly bodies, the Earth and all its plants, animals, birds, and fishes. […] God had also created Adam, and, as an afterthought, Eve to keep man from being lonely. Man named all the animals, thus establishing his dominance over them. God planned all of this explicitly for man's benefit and rule: no item in the physical creation had any purpose save to serve man's purposes" (White 1967: 1205).

In this view, Christian belief is anthropocentric, legitimizing human dominance over nature. Humans are the masters of nature because it is God's command to do so (White 1967). Contrary to animism where plants and animals are thought to have spirits this perspective allowed for "indifference" towards nature (White 1967: 1205).

Yet another view saw nature as wild and uncontrollable, causing violence, storms, famine and destruction. It was an authoritative superpower which pushed humans to rebel against it for protection and survival (Crutzen and Schwägerl 2011), or, from a religious viewpoint, as a cataclysmic force inflicted by God's wrath (Furedi 2007).

With the beginning of the Scientific Revolution in the sixteenth century, a new perspective emerged. The Scientific Revolution led to a sharp increase in investigating the physical nature, its 'laws' and scientific discoveries – from the telescope to the discovery of cells – turned the prevailing relationship upside down. Human rationality, empiricism and experiments became the central element for a newly perceived role of science and with every discovery new forms of power and control over nature were created. For example, Francis Bacon claimed that humans are the interpreters of nature, and that with the right knowledge of nature and the right tools, humans can govern nature. At this point, nature started to be perceived as incomplete, animals were conceived of as of machines, lacking life and soul (compare Descartes notion of a "bête machine" – literally "animal machine") (Allen 2016); humans were ranked above nature and nature separated from humans (dualism). At the advent of the Enlightenment this view became reinforced. Nature's laws were to be discovered through careful observation and study. As Hegel (belonging to the German idealism) foresaw, „the intellect will cognize what is intuited as a mere thing, reducing the sacred grove to mere timber" (Hegel 1977: 57).

In part a counter-reaction to the scientific rationalization of nature and to industrialization and the alienation experienced in the new cities and proletarian slums, Romanticism sought to emphasize the importance and aesthetic value of nature and that a close connection with it was mentally and morally healthy. Romanticism demanded that nature should not be rationalized and instrumentalized and that it was a creative force with aesthetic value (Casey 2008). The notion of the sublime influenced powerful images such as wilderness, becoming an almost sacred place to be preserved from human influence and civilization (Cronon 1996).

Around the same time, Darwin's theory of evolution exposed a nature characterized by an innovative, reproductive force and embedded humans within it, hence restoring some of its autonomy (holism). His theory demystified human-nature relationships (Janich 2010): nature was not mechanic or hierarchic with humans as 'rulers'; there was no internal purpose or telos within nature; there was no progress within nature, simply natural selection and mutation. Humans ceased to have a specific origin story, separating them from other species (Lewis and Maslin 2015).

With the Industrial Revolution forging ahead, nature became increasingly presented as raw materials ready for exploitation. The human-nature relationship was characterized by new confidence, from taming nature to dominating it. This gradually sparked a sense of superiority over nature. The new perception was now one of an inert and passive nature, not only open to discovery, but exploitation and dominion by "man". This also rendered nature separate from "man" and hence as increasingly instrumental for human purposes. This patriarchal view has dominated capitalist society since.

The brief overview illustrates that there were different and partially opposing understandings of nature. These understandings can be grouped in dichotomies:

- Instrumental vs. intrinsic value of nature: nature as resource for other purposes (an instrument; e.g. forest clear-cut) vs. inherent value of nature implying respect towards nature (nature e.g. as having aesthetic or spiritual value);
- Dualism vs. holism: nature and humans ontologically[18] separated (humans are structurally separate from nature, e.g. through rationality) vs. humans intricate part of nature (e.g. humans as animals and part of the process of evolution);
- Animism vs. materialism: non-human living entities have spirits (or lakes, rivers etc. represent gods) vs. nature consists solely of matter.

Some of these dichotomies echo (at least in part) in the concept of the Anthropocene (and thus in the Planetary Boundaries concept), continuing long-held assumptions on nature. Among them are:

- the notion of stewardship of nature (present in the Christian tradition);
- the notion of rationality and empirical scientific research as foundation for progress (present in the Scientific Revolutions focus on natural laws);
- the idea of an organic nature and nature as holism (partially present in the concept of an all-encompassing, interconnected Earth-System and coupled socio-ecological systems);
- in part the ideas of nature as material or nature as instrument for human interests (Planetary Boundaries as boundaries for human progress within the safe operating space);
- the materialist tendency (Planetary Boundaries focus on material changes in the subsystems of the Earth System);
- the hierarchy of humans within nature: present in the conceptualization of the concept as *Anthropocene*, signifying human dominance.

Other conceptions such as the metaphysical interpretation (gods acting in nature), dualism, animism, intrinsic value of nature appear to be less present in the Anthropocene discourse.

1.3.2.2 Human-nature relationship in the Anthropocene

The particular understanding of nature that was formed during the Scientific Revolution still influences our current relationship with the natural world. However, many scientists and activists claim that we have entered a new phase in this relationship (e.g. Crutzen and Schwägerl 2011). Their analysis is supported by the global environmental change and the changing social metabolism: In the twentieth century, the "Great Acceleration" of socio-economic and Earth system trends such as population growth and carbon dioxide concentrations show the fast and far-reaching advancement of our powers. While humanity seeks constant progress and improvement of knowledge and abilities, we are simultaneously influencing nature (Crutzen and Schwägerl 2011). From this perspective, humanity has now become a global geophysical force; for some it is evident that we in fact might become the "dominant force for change on Earth" (Crutzen and Schwägerl 2011).

As Crutzen and Schwägerl put it: a "long-held religious and philosophical idea– humans as masters of the Earth – has turned into a stark reality" (Crutzen and Schwägerl 2011). We already moved from managing parts of nature to influencing the planet on a systemic level with the effects of human actions possibly detectable "in the geological stratigraphic record for millions of years" (Zalasiewicz et al. 2008). Moreover, humanity's consumption and degradation of the environment led to a situation in which over eighty percent of the world's population live in countries that are "biocapacity debtors", that is, the use of resources is higher than their country's resource stock; consequently, resources

[18] Put simply ontology is «the study of what there is» (Hofweber 2014).

must be imported and/or the global commons of atmosphere and ocean are utilized (Global Footprint Network 2011).

Following this line of thought, in the Anthropocene, god is removed and humanity claims godlike power. In this perception, nature is “disenchanted” in the Weberian sense, meaning that the scientific understanding is more respected than belief. With every new method of exerting influence over nature, nature becomes increasingly passive. Today, it is often even invisible and merely holds value for our benefits. Earth’s terrestrial landscapes are characterized by heavy human use. Voices proclaiming the end of nature are growing louder, not least because of the extent of human colonization of the natural world, rendering it dependent from humans (contradicting a widespread understanding of nature as independent force; compare e.g. Purdy England). Where wilderness persists, it is often because of unprofitable exploitation circumstances. Our current perspectives disconnect the biosphere from human progress and economic growth so that the life-supporting character of the environment becomes increasingly external to society. Common indicators of progress such as GDP neglect deteriorations of the environment which are in fact so closely linked to human wellbeing and rather, the environment is often perceived as a sector in policy-making (Chapin et al. 2011).

From this angle, the concept of the Anthropocene claims human interference with the planet is so extreme and intense that we are creating new natures, breaking down the age-old distinction between nature and humans (as dichotomies). It is sometimes argued that “we no longer disturb natural ecosystems, but that we instead live in ‘human systems with natural ecosystems embedded within them’” (Ellis and Ramankutty 2008: 445). Similarly, it is argued that we no longer speak of ‘asocial’ nature, but live in a thoroughly syncretic world, an ’Usworld’, an era where ‘nature is us’ and where the Cartesian dualism between nature and society evolves into deep intertwinement (Lorimer 2012; Leinfelder 2011; Crutzen and Schwägerl 2011; Zalasiewicz et al. 2010). While for millennia humanity has fought against nature, in the era of the Anthropocene nature appears to have almost no remaining autonomy or agency since it is we who decide what nature is and what it will be – it is dependent on our management and goodwill (Baskin 2015; Crutzen and Schwägerl, 2011).

Interestingly, a substantial part of the scientific and academic discourse – while stating that humanity and nature have become undistinguishable – still presents nature as an object external to humanity with natural boundaries that can be controlled (Lövbrand et al. 2015). Our current socio-natural relations are hence characterized by a dichotomy: “humanity is both inserted into nature and re-elevated above it” (Lövbrand et al. 2015: 213). While we are creating new natures and “nature is us”, we have never been more mentally disconnected from it.

The outlook that the Anthropocene is a volatile and potentially risky age therefore renders a fundamental shift in perspectives and worldviews inevitable. As we show in the following chapter, the implications of these shifts are open for discussion, influenced by the understandings of nature we follow (outlined in this chapter) and the role we ascribe to humans.

1.3.3 The Anthropocene: exploring different interpretations

The Anthropocene marks a new phase of socio-natural relationships. But the concept is not clear-cut and self-explanatory. The following chapter details three interpretations of the Anthropocene which have been distilled from current academic and societal debates (see (Autin 2016; Steffen et al. 2007). These interpretations are not exhaustive but represent central themes in the debate. For each of these interpretations, this paper analyses the specific understanding of ‘Anthropocene’ and ‘nature’ / human interaction with nature, the goals that are implied within the interpretation and the means by which these goals are to be achieved. The focus in this chapter lies on the individual as well as the societal level. A latter chapter analyses the implications for environmental policy-making. The chapter does not intend to critique the respective understandings of the Anthropocene but to reconstruct their central tenets and lines of argumentation.

1.3.3.1 The Anthropocene – Open for interpretation

The Anthropocene is an ambivalent and ambiguous concept. It is a concept in need of interpretation. First, while often understood as a geological epoch (see Crutzen and Stoermer 2000; Steffen et al. 2007; Chapter 1.3.1 and 1.3.2 in this paper) the concept is not merely a geological notion. It also has political, moral, cultural and metaphysical connotations.

This is visible in the process of defining the Anthropocene. The initial move for proposing a new geological epoch did not come from within Stratigraphy but from outside, in part as a political move. Social advocacy pushed for a confirmation of the existence of the Anthropocene by the International Commission on Stratigraphy (Nature 2011; Finney and Edwards 2016). The underlying hope was that a formal confirmation of the Anthropocene would lead to recognition of the global and accelerating human footprint (Finney and Edwards 2016). The potential argumentative power of this recognition is e.g. visible in relation to climate change: the Anthropocene undermines views of climate sceptics that humans have no impact on the climate – its core metaphor ('human-dominated, geological epoch') contradicts these claims. Furthermore, the term also implies a (metaphysical) statement on human power and importance (Hettinger 2014). The Anthropocene thereby becomes a moral concept – assigning human control over natural processes implies responsibility for these processes (Ellis and Trachtenberg 2014).

Second, and partially as a result, there is thus far no precise scientific definition of the Anthropocene. There are debates on the onset of the Anthropocene and the boundary between the Anthropocene and Holocene[19] (see e.g. Finney and Edwards 2016). Several authors identified evidence for the new epoch (see Zalasiewicz et al. 2016; Lewis and Maslin 2015), but there is no uniform definition. This leaves the concept open for debate by the different scientific disciplines, politics and even pop-culture (see Autin and Holbrook 2012) and makes it a contested concept, useful for legitimizing different political agendas. It also means that different morals can be inserted into the concept (Autin 2016).

Third, the concept itself does not entail suggestions for future action. In its initial conception in Crutzen et al. (2000: 41), the term is meant as an acknowledgment of the "central role of mankind in geology and ecology" (such as population growth, cattle growth, urbanization, use of fossil fuels, release of SO2, industrial nitrogen fixation, etc.). It is the description of a particular state of human-environment interaction (e.g. deposits in the sediments; humanity rivaling nature) and possible future changes (acceleration; feedbacks). This implies a moral responsibility to react to this new epoch, but it is not clear from the concept itself what this responsibility entails, e.g. who is responsible for mitigation, with what measures and goals. This is for example visible in the discussion on the onset of the Anthropocene – when it is set to a fairly recent event (e.g. the first test of nuclear weapons), a larger responsibility for environmental degradation and protection lies with industrialized countries of the West. In contrast, by choosing a less recent onset e.g. the establishment of agriculture as human practice, the Anthropocene loses some of its urgency and the responsibility for environmental impacts has to be recalculated (Lewis and Maslin 2015).

As a result of this conceptual openness, there are many different interpretations of the Anthropocene as summarized in the table below.

[19] The Holocene is the geological epoch which started approximately 11,700 years ago (Walker et al. 2009).

Table 12: Anthropocene Interpretations

Anthropocene Interpretations: the Anthropocene is…	
Science	… a new geological epoch? … an ecological catastrophe? … human imprint on the Earth System? … an assault on archaeologists? … the end of uniformitarianism? … the obsolescence of geology textbooks?
Philosophy	… an expression of Modernity? … evolutionary nostalgia? … an attack on the Earth System? … the dystopian end of humanity? … a revelation about humanity? … an environmental meme?
Politics	… an assault on human rights? … a call for Feminism? … an outgrowth of Capitalism? … a global political phenomenon? … decoupling of human welfare from environmental impacts? … a political project?
Arts	… between apocalypse and nostalgia? … volatile, apocalyptic beast? … belonging to the invertebrate world? … an ethical and biological imperative? … excess in consumerism? … intimately disconnected and unhappy?

Source: directly quoted from Autin 2016

For environmental policy-making, the existence of multiple interpretations has important implications. Environmental political actors need to be aware of this multitude and the ambiguity of the concept. Relying on a particular interpretation of the Anthropocene might induce unintended consequences (such as re-affirming a business as usual scenario with regards to global human impacts) and might exclude other Anthropocene interpretations (Lövbrand et al. 2015). Interpretations of the Anthropocene also impact the operationalization of planetary boundaries as they influence whether and how planetary boundaries are to be respected. Political actors can make use of the conceptual ambiguities and form a particular understanding of the Anthropocene, e.g. a notion closer to scientific debates (geological epoch) or to cultural debates, depending on whether this notion serves environmental policies. The base for this decision lies in understanding current overarching interpretations.

In this chapter we attempt such a condensation, building on Steffen et al. (2007: 619) who proposed and briefly described three different "philosophical approaches" with regards to how to react to the Anthropocene: a business-as-usual approach (the continuation of the status quo e.g. upholding the present economic system), a mitigation approach (e.g. "improved technology and management […], careful use and restoration of the environment") and a geo-engineering approach (considering "more drastic options").

We propose two changes to Steffen's threefold distinction: First, this analysis goes beyond Steffen's distinction in analyzing in more detail the conceptual foundations of the Anthropocene understanding, discerning how the Anthropocene is construed, what nature is in a particular interpretation and which goals this interpretation implies (Steffen focuses mainly on the policy side). Second, we reconstruct the three named interpretations. We propose to rename the second interpretation (mitigation) to 'gardener of the Earth' to create a more metaphorical image. We also suggest widening the geo-engineering approach to an Earth engineering interpretation to highlight the fact that it is not unconceivable to develop large-scale technological fixes for other processes than climate change. We refrain from including a business-as-usual scenario as from an environmental policy perspective it does not represent a viable pathway (in contrast to other measures grouped within the three distinctions). Instead, we suggest to include a 'preservationist' interpretation of the Anthropocene, to group discussions such as restoration, wilderness, reconnecting to the biosphere and eco-sufficiency.

1.3.3.2 Three Anthropocene interpretations

Humans as Preservationists

> *"Implicit in the call by Steffen et al. (2011) – that humanity's management of the planet should aim to return it to the Holocene – is a sense that the Anthropocene gives us cause to step back." (Baskin 2015: 6)*

What 'is' the Anthropocene?

In this interpretation, the Anthropocene is perceived as a predicament that must be corrected. In the Anthropocene humanity is causing global systemic problems, from climate change to biodiversity loss. Our actions are already forcing natural cycles out of their hitherto normal paths, triggering the planet out of the stable Holocene state. Leaving the beneficial conditions of the Holocene and transgressing the planetary boundaries will likely entail catastrophic consequences. Human influence has to be cut back to allow nature to flow freely.

Even more importantly, the new epoch signals how our actions and views have become so abnormal and radical that we have lost connection to the natural world and to its intrinsic value. This development appears troublesome for both humanity as well as the planet. The biosphere as such is self-sustaining but currently suffers from the often violent and inconsiderate human influence while humans likewise undermine their future well-being by destroying the natural capital.

What is nature and how do humans interact with it?

In this interpretation nature is understood holistically; humans are an intricate part of natural cycles. Nature has intrinsic value; it is not object but subject of human-nature interactions. Nature is more than just matter, it is indeed animated. As a subject, we need to treat nature with respect. We are not masters of nature; we leave traces in the environment, but these are but grains of sand in a long history of nature. As humans we have an emotional relationship with nature that is often masked by our current way of living. When we think of nature, we have images of wilderness in the back of our minds. Nature does not consist of gods as in ancient conceptions, it does not have an inherent purpose, but from observation we learn that large scale natural cycles are in balance when we cut back our human interference. As we break the obligation to respect nature on a daily basis, we have to radically put an end to our large scale pressure on the planet.

Goals for steering away from the Anthropocene

Resulting from these assumptions and beliefs, the central goal would be to reinstate the Holocene state of the Earth system. We should aim at fundamentally cutting back our societal and economic pressure so that we return to an epoch in which we were in harmony with nature. "Reconnecting to the biosphere" is a crucial task to restore a sense of belonging to our surroundings and how important they are. Eco-sufficiency should become the main principle for our interaction with nature. Destroying nature would entail immense risks for the future of humanity and would be unethical. Instead of uncontrollably destroying the foundation for our socio-economic activities, we must ensure our actions are not too excessive and need to respect our subsidiary role in nature. In short, the safest option would be to curtail the 'experiment' Anthropocene, and restore as much as possible what has been unduly changed by humans and reinstate wilderness.

Example: Rewilding

A new approach in conservation is rewilding. The term has different meanings, ranging from trophic re-wilding (species re-introduction), Pleistocene re-wilding (return to Pleistocene baseline) to ecological re-wilding (decrease management and human interference). Especially in the European context, passive re-wilding has been proposed. The strategy involves letting nature take its course, accepting its autonomy and ability to self-sustain. Passive re-wilding would focus on areas where human utilization of nature has declined over times or which are deemed as suitable for ending human interference, such as "mountainous regions and areas with poor soils and harsh climates" (Schnitzler 2014) or previously managed landscapes. An example is the Bavarian National Park. Founded in the 1970s, forestry and management stopped largely in the 1990s (with the exception of a buffer-zone). When large areas of the forest where infected by bark beetle, no countermeasures were taken (even though there was resistance by parts of the public). As a result, a significant amount of trees died. In the aftermath, new, more resistant trees emerged and the bark beetle population declined. This example highlights, how nature is "allowed" to be autonomous, even with (potentially or perceived) detrimental effects for humans (e.g. periods of tree infection).

Source: Schnitzler 2014; Jørgensen 2015; Nationalpark Bayerischer Wald 2017; Corlett 2016

Humans as Gardeners of the Earth

"We aim to counterbalance current dystopic visions of the future that may be inhibiting our ability to move towards a positive future for the Earth and humanity." (Seeds of Good Anthropocenes 2016)

*"It seems, then, that we have no choice but to live in **an** Anthropocene." (Ellis and Trachtenberg 2014: 124)*

What 'is' the Anthropocene?

In this perception, it is acknowledged that the Anthropocene entails human-induced shortcomings and adverse impacts on people and planet. But there are also opportunities within the Anthropocene, there is the possibility to make it a good Anthropocene. In the Anthropocene humanity has driven the planet out of the Holocene, but it is still possible and desirable to maintain the most important conditions of a Holocene-like state and to accept the Anthropocene. The planetary boundaries must hence be respected to materialize these opportunities. Crucially, however, the Anthropocene tells us that we cannot continue with business as usual, that the status quo of managing our 'world system' will eventually lead to risks (the Great Acceleration is just one example of this development).

This new age clearly emphasizes the power we wield. Our activities are so influential that we are changing the Earth system. This unprecedented powerful role and the awareness of it stressed by the concept of the Anthropocene now offer a chance to utilize our influence to transform the socio-economic status quo – to stay within the boundaries that the planet sets. The recognition of our dominance provides the opportunity to use this power wisely and positively, ultimately enabling us to master the Anthropocene.

What is nature and how do humans interact with it?

In this conception, nature is seen ambivalently: both as object and subject, an instrument of our interests and something we should preserve. As gardeners, we feel connected with nature, but we use nature purposefully for our benefit. Nature is partially seen in materialistic terms, much less animated as in the first interpretation. We are part of nature, but our rationality separates and elevates us from it. We can use our rationality (e.g. instrumental rationality) to channel how nature takes its course. One of the images that we might have of nature is a protected lake near an urban centre.

Goals for steering through the Anthropocene

Since the Holocene is already over, we should face reality – the presence of the new epoch is an undeniable fact – which means the Anthropocene cannot be stopped. Moreover, the mantra of 'getting back to nature' will not be sufficient and restraining our actions is ineffective in encouraging a much needed change of behavior. Maintaining the planetary boundaries is only possible by transforming our socio-ecological and socio-economic systems within the boundaries that the planet sets. As a result of this understanding, a major goal for humanity would be to seize the opportunity to create a 'good' Anthropocene. In a 'good' (and sustainable) Anthropocene, humans know how to take responsibility and responsibly channel their collective power. This implies changing the 'system', i.e. inventing new models for societies, economies and cultures while protecting the planet. By embracing our growing influence, we can mobilize the necessary resources for significant transformations that are beneficial for both humans and nonhumans. Humans preserve the safe operating space by behaving like gardeners of the Earth – responsibly transforming the anthroposphere. As gardener, we transform the Earth and accept this fact, but do not systematically pursue Earth engineering (see further below).

Example: Urban transformation 'Cities for People'

In Montreal, the initiative 'Cities for People' seeks to address changing societal aspirations, environmental imperatives, shifting demographics and rising social inequalities. Acknowledging the growing civic appetite for involvement in local change and global governance, 'Cities for People' recognizes a momentous opportunity to harness this collective energy to shape better cities.

Cities around the world become increasingly active in combating pressing global challenges by initiating a range of programs from organic working farms to repair services to education, for instance based on 'social ecology', a dual and simultaneous approach to addressing social and environmental problems, rooted in community development. 'Cities for People' therefore strives to catalyze and connect these urban innovative efforts effectively to bring about systemic change that would make cities more resilient and livable, including new forms of decision-making and behavior change.

This initiative provides an example for how small scale approaches for more inclusiveness, sustainability and resilience provide an opportunity to be up-scaled to eventually trigger system-change. Cities are part of the problem in the Anthropocene as a considerable source of pollution, energy consumption and land-system change. However, human activities – here within cities – can also be transformed into becoming part of the solution in creating a better Anthropocene.

Source: Seeds of Good Anthropocenes 2016

Humans as Earth engineers

> *"If the process of socionatural hybridization cannot be stopped, an alternative possibility is to accelerate it, thus having not less, but more Anthropocene." (Arias-Maldonado 2015: 88)*

What 'is' the Anthropocene?

In this interpretation, the Anthropocene does not entail perilous consequences as such. The Holocene is considered gone for good and there is no turning back to previous environmental conditions. This should also not be our goal, since the Anthropocene simply shows how human activities have helped sustain an ever expanding population.

The Anthropocene demonstrates how we are disconnected from nature, that we are 'creating new natures' (human influence generated new forms of nature, such as anthromes) and hence removed all autonomy nature ever held. We turn nature upside down, but we do so deliberately for reasons that maximize our benefit. Growing human influence on the Earth system merely leads to changes, not necessarily to problematic changes. This explains why our new age should not be feared or perceived in a negative light, as our influences and abilities are already so advanced that environmental problems can be solved by this exact influence and ability. Having entered the Anthropocene means that our time has come, a time in which our knowledge and power allow us to develop freely without external natural limitations. Following this line of thought, the planetary boundaries together with the safe operating space can be considered as flexible since advancements in technologies will increasingly facilitate the molding of environmental limits according to our preferences (the boundaries are human constructs).

What is nature and how do humans interact with it?

In this conception, nature is an instrument for human security and prosperity. Earth-engineering involves intentionally manipulating nature on a large scale to protect us from the negative feedbacks of human impacts on the environment and create benefits. Earth engineering entails a judgement on our ability to devise large scale solutions for environmental problems which can overcome the boundaries that are hypothesized by scientists.. In this picture, humans are above nature. Nature does not appear as a subject of its own, an autonomous form. Nature does not have a specific spirit.

Goals for steering through the Anthropocene

The fact that this new epoch establishes humanity's power and influence on the Earth system means that it is not possible to stop the Anthropocene. In order to control the Anthropocene, we need to gain more knowledge and power.

The recognition of the Anthropocene in the making is an invitation to produce even more Anthropocene. The Anthropocene should not be seen as an impediment but we should reflect how we can utilize it in order to profit from this new 'status' and concomitant freedom to strive without constraints. The Anthropocene opens up spaces to think more intensively about how to use our technology to change nature for the better.

Human history shows that technological inventions can solve some (clearly not all) problems and advance our societies. In the Anthropocene, we should embrace our power, be bold and concentrate on perfecting our control of socio-natural relations. Hence, shaping the environmental limits instead of limiting economic growth presents the most fruitful approach to 'utilizing' the Anthropocene.

Since a timely reorientation of social preferences and behavior towards sustainability is unlikely and an approach to environmental protection proclaiming restraint and humility presents an obstacle to modernization, humans should opt for the most efficient path and take responsibility by tailoring the planet according to what deems best for us.

Example: Solar Radiation Management to Combat Climate Change

Since current efforts to combat climate change have thus far not produced the necessary and desired results, new approaches are considered. Solar Radiation Management suggests interventions to reduce the excess heat resulting from greenhouse gases. Two possible methods are space reflectors (mirrors) and the injection of sulfur dioxides in the atmosphere. However, once these techniques are introduced, they will entail far-reaching and large-scale consequences which cannot be foreseen yet.

This example introduces an approach that greatly intervenes in the Earth system with the aim to tackle climate change. It thus constitutes a measure that, instead of trying to reduce anthropogenic influences channels them into improved pathways outside of the safe operating space; technology supports this process.

Source: Macnaghten and Szerszynski (2013) and Szerszynski et al. (2013)

The following table sums up each interpretation's core aspects:

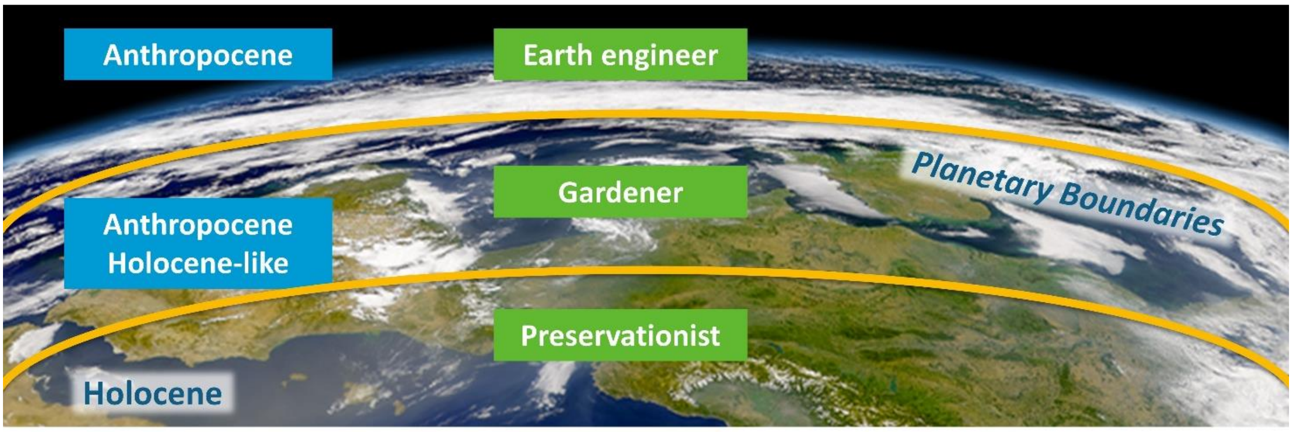
Table 13: Core aspects of three Anthropocene interpretations

	Humans as Preservationists	Humans as Gardeners of the Earth	Humans as Earth Engineers
Definition of the Anthropocene	Predicament to be corrected	Logical symptom of our increasing influence, providing both risks and opportunities	Opportunity and necessity
Goals	Correct the Anthropocene and going back to previous states of the environment (the Holocene) Focus on the biosphere Curb excessive economic activities and focus on sufficiency	Partially accept the Anthropocene, but transform the societal side of coupled human-social systems Utilize our power to create a better Anthropocene by means of changing the socio-ecological and socio-economic systems and respect the Safe Operating Space	Accept the Anthropocene Perfect our control of socio-natural relations Shape the planetary boundaries according to our preferences, using large-scale technologies

Source: from authors, adelphi

The following illustration relates the three interpretations to the planetary boundaries and the (material) state of the Earth system:

Figure 40: Anthropocene Interpretations, the Earth system and planetary boundaries



Source: from authors, adelphi; © Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

1.3.4 The Anthropocene: implications for environmental policy-making in a safe operating space according to each interpretation

As argued in Chapter 1.3.3, each Anthropocene interpretation implies a different vision of environmental policy-making, as each has specific political and moral connotations (Biermann 2014). These interpretations therefore will be a focal point for a new understanding of environmental politics, influencing how societal actors perceive the state's role towards nature and potentially creating entirely new political demands. This Chapter focuses on analyzing some of the implications for environmental policy-making, helping to understand possible political repercussions. This analysis is not meant to be policy-prescriptive (e.g. arguing for or encouraging a specific interpretation and policy-implication), but explorative (answering the question – what follows for policy-making if we adopt a specific interpretation). Which interpretation or policy-implication to follow is subject to political decisions.

The underlying message is that policy-making cannot evade the Anthropocene. It is crucial to form an understanding of the Anthropocene, to realize the different interpretations and to politically act, as the human pressure on the environment increases exponentially.

In this chapter we focus on (a) the self-conception, role and tasks of environmental policy-making, (b) instruments, institutional set-up and international cooperation and (c) degree of power, risks and opportunities for environmental policy-making of the three interpretations. The analysis builds on central dimensions of the 'environmental state' (Duit et al. 2015)[20]. For the sake of the argument, each Anthropocene interpretation is initially taken at face value; possible risks and opportunities for environmental policy-making are outlined at the end of each analysis. To facilitate the discussion, parts of the remarks focus on the German political system.

[20] The environmental state can be defined as «a state that possesses a significant set of institutions and practices dedicated to the management of the environment and societal-environmental interactions» (Duit 2015 : 71). Four dimensions of the environmental state are «system of regulation» (e.g. political instruments, laws, regulations, etc.), «administrative apparatus» (e.g. ministries and agencies), «ideational aspects of state environmental involvement» (e.g. new principles, strategies, concepts) and «arena for environmental conflict» (e.g. advocacy, defining problems and solutions etc.) (Duit et al. 2015 : 73-75).

Implications according to the first interpretation: Environmental Policy-making for Earth Preservation

> *Protected area critics[21] reliably demand fairness for human beings at the expense of nonhuman beings, who they treat as morally inconsequential. But justice is not only about just us. Conservation properly understood implies a fair division of Earth's resources between human and nonhuman beings. Justice demands setting aside at least half of Earth's lands and seas for nature, free from intensive economic activities.*
> *(Kopnina 2016)*

In this conception, environmental policy-making focuses on reinstating the lost past – the Holocene. Within this interpretation, there is a closer proximity to earlier understandings of preservation, focusing on the biosphere as one main object of concern, including the conditions necessary to preserve it, as well as tackling the societal forces identified as main drivers behind the Anthropocene. Environmental policy-making is important because of the necessity to turn around the current consumption and production patterns, the functional importance of the biosphere for the Earth system, and because of nature's intrinsic value. Plants and animals are protected not due to a specifically national agenda and preservation is also not about protecting out of aestheticism or romantic ideals of the 'pristine' but because they are thought to have value independent from humans. At the same time, returning to the Holocene implies the awareness that we have unduly changed nature, and so are confronted with forces that we cannot control anymore.

While contrasting older justifications of environmental policy-making (such as protection of areas deemed as important for the nation), the self-conception of environmental policy-making as preservationist shares some of the same policy motives as conservation in the beginning of the industrial era (and a somewhat similar narrative). Similarly, the Anthropocene and the planetary boundaries are a story of demise, establishing boundaries because of collective failure. Setting the starting point of the Anthropocene to the industrial era implies that environmental policy-making is fighting the forces that created these pressures in the first place, namely industrialization and untamed economic activity. The preservationist thus implies an opposition role to the status quo with potential ramifications for political dialogue with society and the economy and a notion of political radicalism, ensuring that human demise is indeed stopped, against the forces of business as usual.

Within this self-conception, there are several implications for the tasks of environmental policy-making. As the Anthropocene signifies how the human enterprise has led us afar from the Holocene, policies that address the drivers of human environmental pressures, such as societal and economic structures (the consumption and production patterns) as well as ideologies, values and lifestyles are of central importance. The goal is to significantly cut back resource consumption, going greatly beyond incremental change. As this task appears to be enormous and as time already has moved on, environmental policy-making becomes driven by a radical stance for eco-sufficiency.

It is furthermore central to protect (the biosphere), restore (previous damage) and re-wild (actively expand biodiversity), as the dangers of a new 'mass-extinction' are imminent and as it is crucial to let nature take its course. To slow down human interference with the biosphere, protected wilderness areas would need to expand dramatically. As the focus is on restoration prior to the onset of the Anthropocene, environmental policy-making would need to discern the baseline of preservation that is the precise environmental state to be re-created (which Holocene?). Environmental policy-making would also need to determine what exactly to preserve (which ecosystems and species) and how to deal with ecosystems already changed by humans.

[21] «Protected Area critics» refers to those that criticize calls to conserve lare areas of land for biodiversity protection e.g. on the basis of equity (Kopnina 2016).

Institutions, instruments and international cooperation

The Earth preservationist calls for direct action. As current efforts appear to be unsuccessful in halting global biosphere 'extinction' and reversing the Anthropocene, critical self-reflection needs to take place. Compromises and soft solutions such as voluntary commitments and non-binding strategies move out of the central agenda as they appear to deliver only slow and ineffective outcomes.

In the Anthropocene, preservationist policy-making is faced with a 'difficult reality', especially in the managed and cultivated European landscapes. As "anthromes" (Ellis and Ramankutty 2008: 445) and "novel ecosystems" (Hobbs et al. 2009: 599) increase, the baseline of preservation becomes more and more fluid. There is thus a temptation to 'give in', accept the 'new normal' and move from preservation to 'gardening', justifying 'development by design', conservation cooperation with corporations, to focus only on beneficial parts of the biosphere, having ultimately human concerns at the center of its concern (Kareiva et al. 2012).

The preservationist refuses these policy implications. While existing efforts such as protected areas, red lists and threatened species protection (Bridgewater 2016; Miller et al. 2011) have not been successful in halting or reversing global biosphere loss (Newbold et al. 2016), they were nevertheless important in slowing down biodiversity loss (Doak et al. 2014). Preservationists thus take into account the characteristics of the "Anthropocene biosphere" (Williams et al. 2015: 197) and set out to dramatically increase existing regulations and enforcement as well as educational measures to protect, restore and rewild. Policy instruments for protection, restoration and rewilding, need to focus on the elements of the Anthropocene which undermine biosphere integrity (Ellis et al. 2012). As research on the planetary boundaries shows in the interlinked Earth system these are especially land system change, climate change, perturbed biogeochemical flows, reduced freshwater availability, novel entities and increased ocean acidification (see Fig. S10 in Steffen et al. 2015a).

At the same time, as the economic machinery continues to grow, the preservationist refuses to give into calls for green growth and technological solutions. In this interpretation, the Anthropocene signifies how we can no longer solely put our hopes on efficiency measures, as efficiency gains have been and will be offset by the rebound effect and by continued growth in material and energy consumption (Lorek and Spangenberg 2014). Calls to accept the growth paradigm or to align it with ecological sustainability appear to be contradictory or insufficient from this perspective. Therefore, environmental policy-making needs to centrally focus on "social behavior and interactions of humans", e.g. consumptive behavior (Williams et al. 2015: 211). Conservation implies creating societal and economic conditions that do not harm the biosphere. The whole society and economy needs to be radically restructured. This involves setting preservationism high on the curriculum in the school and university system as well as radically changing the current economic policy, focusing on de-growth.

Within the German political system, the preservationist would imply major changes. Institutionally, the preservationist would mean to strengthen conservation as well as a dominant role of environmental policy-making vis-à-vis the economics ministries. The renewed focus on preservationism would also mean going back to older understandings of environmentalism, leading to a re-evaluation of existing policies and strategies, in how far they concur with the priority of the biosphere, the necessity to act quickly and whether they concur with the eco-sufficiency principle.

Globally, the tasks imply to push back the 'new conservationism'[22] principles in global institutions and strengthen the preservationist view of development. The preservationist implies that 'catch-up' modernization and business-as-usual development models are not to be followed – instead focusing on a new preservationist model (preservation as central to development, coupled with de-growth). It

[22] The new conservationist movement seeks to « de-emphasiz[e] the goal of protecting nature for its own sake in favor of protecting the environment for its benefits to humans » (Doak et al. 2014 : 77).

would also mean to focus specifically on conservation within the environmentally oriented Sustainable Development Goals (SDGs) (e.g. SDG 14 for marine ecosystems and SDG 15) as well as putting less emphasis on the growth side of SDG 8. Taking the proposition of strong and robust action into account, preservationism would see the SDGs as an important starting point, but would highlight that implementation needs to focus on binding measures.

Degree of power, risks and opportunities for environmental policy-making

In the preservationist interpretation, environmental policy-making requires strong intervention, claiming more power vis-à-vis other political actors as well as in relation to societal and economic actors.

There are some opportunities within this interpretation. Focusing on lifestyles and drivers of environmental pressures could help support mitigation of unacceptable global environmental change. Furthermore, by highlighting urgency, the interpretation points to the problems of gradual or incremental change, which might not be sufficient to 'turn the planet around'. By setting nature in the center, it revives and strengthens respect for it, supporting the principle of reconnecting to the biosphere.

But the interpretation also comes with several (political) risks:

- The nostalgic connotations of this interpretation do not really fit to the Anthropocene realities and hence could become problematic when used in the public debate, e.g. in political communication – some of the environmental changes underway are potentially irreversible; global change is speeding up and it appears unlikely that a return to the Holocene is possible; in fact what needs to be protected (nature) increasingly dissolves;
- It is also not entirely clear whether this model can and should be replicated in all societies; pushing for it globally, could therefore imply the risk of political deadlock.
- The development model appears to have no global appeal for middle and low income countries. Promoting de-growth globally would likely not resonate well. It is thus unlikely that there will be international political consensus on it.

Implications according to the second interpretation: Environmental Policy-making for Earth Gardening

> *"Nature could be a garden – not a carefully manicured and rigid one, but a tangle of species and wildness amidst lands used for food production, mineral extraction, and urban life." (Kareiva et al. 2012)*

Self-conception, roles and tasks of environmental policy-making

In this conception, environmental policy-making steps partially away from a vision of crisis and catastrophe. There is some value to be found in the Anthropocene, a good Anthropocene is possible. The good Anthropocene is the garden in which humanity thrives.

As the Anthropocene is not perceived as inherently and solely problematic, the tasks of policy-making shift accordingly. There is now less emphasis on significantly cutting back economic activity and focusing on eco-sufficiency. Not only are these points futile from the point of the "gardening" environmental policy-making, but they are not central for fostering the vision of achieving human dignity within the limits of nature. As nature is clearly a gradual concept, it is not of decisive importance to protect large areas of land. What matters is achieving social goals, while accepting that nature sets pre-conditions on achieving human development. Environmental policy-making within the gardener perspective is hence in fact sustainable development in the planetary boundaries reframing.

The metaphor of the gardener exemplifies this view. Similarly to this metaphor environmental policy-making appears as a rational and prudent agency, which is able to oversee nature's course ("monitoring" the garden), realize problems that might occur (when failing to prudently manage nature) and counteract accordingly. The step away from apocalyptic visions is visible in the metaphor: there are not power plants, smoke, polluted rivers in this vision, rather an image of flowers, almost an Earthly 'Garden Eden'. The anthropocentrism of this perspective is as well exemplified in the metaphor: gardens are human constructs. A garden might have some more or less undisturbed areas, but they are within the fence, and the garden exists because of human welfare. Simultaneously however, the gardener accepts that he cannot control or change significant parts of nature.

But environmental policy-makers nevertheless realize that current affairs do not resemble the vision yet. 'Garden Eden' is potentially reachable, but environmental policy-making needs to ensure that society actually gets there. To reach the garden, the current consumption and production patterns have to change, while still allowing for green growth and the green economy. According to the gardener perspective, we have been always adapting to environmental change and found solutions that both respect the environment and achieve progress (DeFries et al. 2012).

The tasks are therefore, to become aware of the beneficial side of the Anthropocene, to respect the boundaries of nature and realize human well-being (conditions of human development), deliberately and rationally transform the socio-ecological system, to focus on green growth, and to build on gradual change and the notion of steering, rather than abrupt disruptions and radicalism as in the first Anthropocene interpretation.

Institutions, instruments and international cooperation

The gardener metaphor has a communicative and a policy-side. For the communicative side, according to this vision, the political language has to change. It is assumed (from the gardener perspective) that speaking only about the perils of the Anthropocene does not motivate society to move towards garden Eden; instead what should also be talked about are the promises of the good Anthropocene, simultaneously with risks. Behind that lies the assumption that humans are utility maximizers and are motivated to act if they see some material benefit in their action, and are not only motivated by pointing to a dangerous future. The gardener environmental policy-making therefore also speaks about opportunities, gains, benefits, synergies, innovation, win-win, solutions and so forth. But in contrast to the Earth engineering perspective, they nevertheless admit that boundaries exist and are a precondition of development. The gardener can thus be understood as a completing-narrative, turning the 'story of demise' into a story that also includes parks and flowers.

For the policy side, policies need to be integrated (achieving social and environmental goals). To reach the promises of the garden, environmental policy-making need to take on an enormous task – to reign in the societal and economic structure, without the radicalism of the preservationist, with precision, to move material and energy flows and the drivers behind them, on a sustainable path. Environmental ministries then become the central planning agencies behind transformation, in close vertical and horizontal coordination. Behind that lies the realization that transformation and change is already happening (the Anthropocene dynamics) but that these need to be steered to stay on a sustainable 'win-win' path.

Within the gardener vision of environmental policy-making, there is a much closer political relationship to economic actors and the idea of mutual cooperation between all sectors of society and between science and society. Proponents propose a "social contract" (DeFries et al. 2012: 603) between science and society, to deliver solutions (rather than critique of the status quo and implementing 'sweeping' countermeasures). Also, voluntary or soft-instruments are not necessarily disregarded, as the outlook is on long-term transformation. There is the inherent belief that while strong regulation is needed, bottom-up transformation, and voluntary behavioral change is possible. This is motivated by the utility argument and the idea that by changing the language of the Anthropocene, actors could be pulled towards sustainability.

The gardener metaphor appears to be the 'new consensus' in German environmental policy-making. This is visible in speeches (see e.g. BMUB 2014) and also in the new Integrated Environmental Programme (BMUB 2016a). The term is not explicitly used, but there are many elements that resemble it, such as focusing on the benefits of environmental policy-making simultaneously with respecting limits (challenges), moving away from 'classical environmentalism' to transformative politics. Deduced from this new consensus are new institutional demands such as the right for initiative in other policy areas and cost-benefit analysis of policies (BMUB 2016a). To further implement the gardener vision, stronger institutional changes might be necessary such as a veto right for specific policies, if they do not respect the fair share of planetary boundaries, and (prior to that) systemic / integrated impact analysis of policies building on planetary boundaries (and e.g. SDGs).

Globally and for international cooperation, the gardener metaphor is present e.g. in the notions of green growth (World Bank 2012a) and green economy (UNEP 2011). It is also present in the SDGs, especially through its now more comprehensive outlook (social and environmental goals) and the mixture between 'opportunity oriented' SDGs such as SDG 8 (Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all) and more environmental SDGs. However, especially the 'boundaries' side of the gardener vision would need to be globally strengthened (the SDGs do not include the planetary boundaries). The gardener vision would demand that SDG implementation strongly includes the concept.

Degree of power, risks and opportunities for environmental policy-making

The gardener metaphor assigns a much larger than current control capability to policy-makers. It entails the notion that environmental politics is able to control human systems as well as natural systems, to detect trade-offs and materialize benefits.

This particular Anthropocene interpretation also involves several political risks:

- The language of the good Anthropocene comes with its own pitfalls – by emphasizing opportunities, win-win situation and the possibility of the good Anthropocene, it becomes less obvious why the environment should be wholeheartedly and decisively protected; if there are so many opportunities in the Anthropocene, it might become unclear why the Anthropocene should not be fully embraced;
- It also not entirely clear whether it is only utility that motivates pro-environmental behavior; research shows that there are also other factors in place (such as external, contextual factors (Kollmuss and Agyeman 2002); this means that the strong urge to focus on opportunities might not be enough or might even set the wrong 'tone';
- Inherent in the sustainability transformation is a belief in progress and rational policy-making, but setting such a large scale target (changing society) is difficult to reach, potentially impacting environmental policy-making's credibility;
- The gardener metaphor is easy to grasp, but it is not entirely clear whether it is a good metaphor. The metaphor might hide inequalities (e.g. the different capacities of humans to be gardeners, or the different responsibilities). The metaphor also appears to diminish ethical approaches that set respect for nature at the center.
- By emphasizing central planning and control, the gardener metaphor is a more apolitical vision of environmental policy-making ('political' understood as participatory deliberation process)

Implications according to the third interpretation: Environmental Policy-making for a Human-engineered Planet

> *"By 2100, nearly all of us will be prosperous enough to live healthy, free, and creative lives. Despite the claims of Malthusian pessimists, that world is both economically and ecologically possible. But to realize it, and to save what remains of the Earth's ecological heritage, we must once and for all embrace human power, technology, and the larger process of modernization." (Nordhaus und Shellenberger 2011)*

Self-conception, roles and tasks of environmental policy-making

In this perspective, the Anthropocene is embraced. Boundaries are not biophysically prescribed but human constructs. The Earth system is much more resilient than planetary boundaries researchers often assume. As humanity evolves, so boundaries can be shifted. From the Earth engineer's perspective, humans have constantly emancipated themselves from nature. Respect for nature might be a romantic ideal, but it is not a necessary precondition for human development. To the contrary, it was technology and human ingenuity which ensured that we now have the potential to feed humanity, not respect for natural flows.

This also implies a much different understanding of environmental policy-making. Instead of focusing on the precautionary principle and respecting boundaries because we don't know what lies beyond them, we should trust in a positive future. Catastrophes of the past and the dark sides of the Anthropocene are but steps to a better outcome, once 'counter-forces' of technology and human creativity step in. This perspective implies breaking with traditional environmentalism and traditional instruments of environmental policy-making. It does not mean however, to entirely disregard the risks that human induced (and natural) environmental change can have for human development. Risks exist but they cannot be grasped by setting limits on the planet, as this view neglects human adaptability. Instead, potential future impacts on humans should be monitored and, if necessary, be avoided by using technology.

The role of environmental policy-making changes within this interpretation. Environmental protection is no longer a structural, societal force (implementer of the great transformation) or the main institution charged with inducing the return to the Holocene. Environmental policy-making now has the immense role to deliberately modify the Earth on a large scale for human development, to avoid and (potentially) correct negative, large-scale environmental impacts. Environmental policy-making becomes itself a major force for the Anthropocene, accepting the need to change the Earth. Vis-à-vis economic forces, the role is now much less oppositional. There is a tendency to accept the current social metabolism, current production and consumption patterns, and to allow the human enterprise to allow flowing, as ultimate faith rests in the human capability to overcome the challenges of our time. As environmental policy-making is confronted with a shrinking operating space – currently applied mitigation approaches do not appear to be sufficient to change the trend – Earth engineering options become increasingly relevant.

Institutions, instruments and international cooperation

With Earth engineering, technologies move into the center of environmental policy-making.[23] They to a large degree influence which political steps to pursue in order to avoid non-beneficial environmental change; they set the parameters of governance. Depending on the type of technology, different governance challenges arise. This is visible in the debate on geo-engineering (Humphreys 2011). There are

[23] So far, geoengineering research has mostly focused on experiments within laboratories as well as on modelling. In 2017 it was announced that researchers from Harvard University will test solar radiation management by aerosol injection on a small scale in the atmosphere (Neslen 2017). There are hence no concrete examples yet, for the application of geo-engineering.

technologies which will only be useful if collectively applied (so called territorial geo-engineering). Examples are (1) 'roof whitening' which involves painting roofs white to reflect sunlight, (2) setting up sun reflectors or (3) 'afforestation' that is increasing the global forest area (Humphreys 2011). For these technologies, a collective action problem arises: only if a sufficiently large number of countries collectively applies these technologies will there be a large enough effect.

There are other technologies however which do not necessarily require the collectivity of states, so called commons based geo-engineering (such as 'ocean fertilization' or 'stratospheric sulfate injection' Humphreys 2011). Ocean fertilization implies releasing nitrogen or other nutrients in the ocean to increase algae; stratospheric sulfate injection means to set sulfate in the stratosphere in order to increase the amount of sunlight being reflected (Galaz 2012a). For these technologies, unilateral action is possible. Not all states have the capability to devise and deploy the technologies. A precondition is likely the degree of development and relative power (vis-à-vis other countries) to act without multilateral consensus. Unilateralism also means that there is a higher degree of uncertainty among other states and the potential for conflict, when single states move forward to applying a technology, potentially with harmful unintended consequences.

Similarly to geo-engineering, it is likely that there will be both technologies that create a collective action problem and technologies that lead to the problem of unilateralism within Earth engineering. Within both scenarios, German environmental policy-making as well as its instruments would be reshaped.

First, environmental policy-making would become even more internationalized and essentially a function of international action. For both territorial and commons based Earth engineering, German unilateral action would not be feasible or unlikely. Local action would likely only be engaged with the effects of geo-engineering (e.g. impacts on local eco-systems) (Galaz 2012a). Second, German environmental politics would become further dependent on the scientific community. In both scenarios, scientists would devise, monitor and help implement Earth engineering solutions. To test the technologies and to detect and potentially avoid non-beneficial environmental change and to identify unintended consequences, scientific models would be needed and policy-makers would be dependent upon the validity of these models and scientific prediction.

Both for territorial and commons based Earth engineering, similarly to the mitigation of climate change, German environmental policy-making would need to rely on multilateral action in conjunction with like-minded states and the European Union. Under the uncertainty inherent in the international system, it would be likely that some sort of international institution would be devised, either stopping short from an actual treaty and operating within already existing conventions or establishing a new treaty or framework convention (institution is here used in the sociological sense, see footnote, and does not equate with international organizations).[24] For the unilateralism scenario, it would even be more important to devise an international institution to decrease uncertainty and minimize conflict risks.

The institutional design for both scenarios would depend on the specific situation at hand (which environmental change is intended to be avoided or countered; what are the goals to be achieved; what technologies are available etc.). To date, there is no adequate international governance system for such a technical management of Earth system processes with international institutions that hold a sufficiently broad mandate to cover the wide range of tasks, from assessing risks and problems to regulat-

[24] "International institution" is understood broader as "relatively stable sets of related constitutive, regulative, and procedural norms and rules that pertain to the international system, the actors in the system (including states as well as nonstate entities), and their activities" (Duffield 2007). Hence, international institutions would comprise of more than formalized entities such as international organizations (also of other social practices such as rules and procedures).

ing and supervising these activities. Potentially and for the period prior to the establishment of a governance architecture, international action could rely on a set of rules, such as the Oxford principles (House of Commons Science and Technology Committee 2010). These principles have been originally established by researchers at the Oxford Geoengineering Programme and were subsequently endorsed by the UK House of Commons Science and Technology Select Committee working on "The Regulation of Geoengineering". They also informed the Asilomar Conference on Climate Intervention Technologies outcomes and are also more widely discussed within the literature (Humphreys 2011; Szerszynski et al. 2013).

In analogy to these principles, it would be necessary to regulate Earth engineering as a public good (by states and the international level), ensure public participation (to secure legitimacy), disclose Earth engineering research and research results, independently asses impacts and establish a governance architecture before deployment. Similar to the climate mitigation regime, any governance architecture would also need to address the question of funding, especially how to support least developed countries who would need to contribute to implementation when collective action is required.

It is likely that there will be negative side effects of Earth engineering (see e.g. Heck et al. 2016 for a modelling study for terrestrial carbon dioxide removal), as future impacts of action are hard to predict and alter the Earth system (Victor 2008). This has two implications for environmental policy-making. The first would be the necessity to devise compensations for those countries hit by unintended side effects (loss & damages), potentially entailing obligations for developed countries. The second would be the necessity to provide countries that are likely to be hit by unintended environmental change the capacity to adapt to it (resources, etc.). Both points are especially difficult to achieve as the attribution of effects of Earth engineering are very complex due to the complexity of the Earth system, making it more unlikely to establish liability (Blackstock and Long 2010).

Degree of power, risks and opportunities for environmental policy-making

This Anthropocene interpretation entails increasing tasks for environmental policy-making. While the international character of deploying technical solutions to address Earth systemic challenges shifts the focus of environmental policy-making on the global stage and minimizes local solutions, the objectives become enormous (monitoring, controlling, and manipulating the Earth system for human development).

The aim of shifting planetary boundaries according to our needs (e.g. creating a climate favorable for human development) and solving environmental issues by means of technologies with often far-reaching implications entails significant risks environmental policy-makers need to consider and account for:

- So far, the knowledge base for assessing Geo-engineering is low (IPCC 2013: 635);
- Limited current analysis of geo-engineering proposals (Solar Radiation Management and Carbon Dioxide Removal) suggests that they "carry side effects and long-term consequences on a global scale" (IPCC 2017: 29), such as modification of the global water cycle (Solar radiation management; IPCC 2017: 29); Biological carbon sequestration (another currently discussed option) "would produce a biogeochemical shift in the terrestrial biosphere which is, in absolute terms, even larger than that already produced by historical land use change" (Heck et al. 2016: 213);
- unknown hazards resulting from approaches such as geoengineering might be revealed at a later time;
- the approach, fully implemented, would likely result in delay in mitigation (as discussed above continued human development without behavioral or economic changes would be the goal of the Earth engineer);

- the approach would require large investments in technology;
- ecosystem-services are difficult to impossible to replace by technology, especially supporting services (compare Fitter 2013);
- path dependencies can occur; as more time and money is invested in a potential solution, it becomes more and more difficult to prevent it from being implemented even if it is regarded as problematic approach at a later stage;
- society's commitment rates to a technology might fall quickly, potentially leaving policy-makers with an inflexible long-term policy approach that cannot be halted;
- Such interventions are unlikely to become universally acceptable by different countries. Risks of "a restricted set of knowledge networks, highly dependent on top-down expertise and with little space for dissident science" (Macnaghten and Szerszynski 2013: 2812) present further examples of potentially problematic environmental policy-making carried out in this Anthropocene scenario;
- Environmental policy-making becomes itself a force for the Anthropocene and would increasingly distance itself from conservation, sufficiency and the current move towards socio-ecological transformation; such a transformation of the self-conception would inherently create intra-organizational resistance and would in itself require deeper organizational change (as currently socio-ecological transformation is in the political centre; compare the Integrated Environmental Programme 2030);

1.3.5 Conclusion

In the Anthropocene, environmental policy-making is confronted with a new reality. This is a time where humans change the environment on an unprecedented scale (see the discussion in Chapter 1.3.2) and policy-making should adapt to these changes. However, entering the Anthropocene means entering a world of ambivalence (see Chapter 1.3.3). Being political, scientific and even 'pop-cultural', the concept evades easy definitions. For environmental policy-making, it is essential to critically examine the connotations of the term 'Anthropocene' and realize their potentially far reaching implications. This also implies to critically separate ideational changes from material developments (the conceptual from the material side). The Anthropocene concept mixes both aspects, making it much more than a geological notion. Environmental policy-making should be aware of the ideational nature of the concept and what it could entail (see Chapter 1.3.4). This would also mean to take part in the public discourse on the Anthropocene, potentially shaping these interpretations.

As described in the introduction, the Anthropocene forms the planetary boundary concept's 'backbone', the context for which boundaries are formulated. The three outlined interpretations differ with regard to their coherence with the planetary boundaries concept. The preservationist interpretation shares the connotation that the Anthropocene is problematic, that the planet has boundaries with regards to resource consumption and pollution and that we should reconnect to the biosphere. Differences lie in its insistence to move back to the Holocene, to cut back economic activities and to reinstate wilderness – the planetary boundaries concept focuses on open development pathways within boundaries, sets out to achieve Holocene-*like* conditions and focuses on Earth system stability.

The gardener interpretation comes very close to the planetary boundaries concept. Both share the conviction that the Anthropocene comes with risks and that it is only possible to achieve Holocene-like conditions. The planetary boundaries also resemble the gardener metaphor in its belief in the power that humans yield. Both differ with regards to the transformation focus, the planetary boundaries leave this question open. With regards to Earth-Engineering, commonalities are that environmental change causes risks for humans and that humans are one cause of these risks. Differences lie in accepting the Anthropocene (Earth engineering), understanding environmental limits as flexible and with regards to the strong belief in technological fixes.

Which of the three main interpretations (humans as preservationists, humans as gardeners, humans as Earth-engineers; see Chapter 3.3.3.2) environmental policy-makers should follow is essentially itself a matter of politics. It is a decision, which clearly not only involves environmental concerns. The gardener metaphor appears to be a good starting point – being a middle ground between passivity and over-activity. But the gardener metaphor comes with its own flaws, for example diminishing ideas of respect for nature and the risk of overestimating human control over natural processes. The metaphor is also not fully articulated. There are more questions to be tackled. What about global inequality? How can we equitably divide the burden from mitigation (burden sharing)? These are questions that need societal input and discussion.

1.4 Operationalization of the planetary boundaries: ways forward and first results for Germany and the EU

Executive Summary

The planetary boundaries have generated significant interest beyond the scientific community from where they originate. They delimit a global safe operating space for sustainable development, by providing a single number per boundary or environmental process. Regionalization and operationalization of the planetary boundaries can integrate this global environmental perspective into local, national and regional policy and decision making, and can thus improve vertical policy coherence across scales. Given the systemic character of the planetary boundaries (with reference to the Earth system), their operationalization can also support horizontal coherence across sectors.

However, before applying the planetary boundaries framework to any specific context, it will be important to clarify how they can add value, and which planetary boundaries may be relevant. The objective, required data and information, and the process of planetary boundary operationalization need to be specified for the respective context. Through cooperation of scientists and policy makers, the planetary boundaries can be downscaled and translated into relevant information that is compatible with the national or regional context for benchmarking of environmental performance. This involves normative decisions about "fair" allocations of the global safe operating space (equal-per-capita allocation may serve as a default). This "co-operationalization" of the planetary boundaries by scientists and policy makers provides legitimacy, while ensuring scientific underpinning.

Demand driven operationalization and eventually mainstreaming[25] of the planetary boundaries can use entry points such as new national strategies or policies, directives, e.g. the:

- Integrated Environment Programme 2030
- German Sustainable Development Strategy
- Integrated Nitrogen Strategy

Such new initiatives can be tested for their consistency with global boundaries, by benchmarking their expected outcome against downscaled planetary boundaries. The systemic planetary boundaries framework (a dashboard for sustainability) also helps to identify tradeoffs between the different strategies, policies and environmental objectives.

While the different planetary boundaries have different characteristics and there is no blueprint for their application, a number of common elements of a universal method for planetary boundary operationalization are beginning to emerge. These include:

[25] Mainstreaming means integrating a new concept into existing contexts and that way adding a new perspective and value.

- downscaling (disaggregation and allocation) of the PB to the relevant scale
- including temporal dynamics in the downscaling
- benchmarking production-based environmental performance against the downscaled planetary boundary
- benchmarking consumption-based environmental performance against the downscaled planetary boundary
- mapping the results of the previous steps onto relevant policy contexts and integration with context-specific environmental sustainability criteria and data

Initial exploration and application of the planetary boundaries to the national and European level has demonstrated the importance of going beyond territorial or domestic environmental performance and include also external environmental pressures, mostly transmitted via trade. Benchmarking consumption-based performance against the planetary boundaries captures a nation's full environmental impact and resource use (responsibility for planetary boundary transgression) related to its consumption patterns. It also specifies where on Earth the impact / resource use occurs and what that means for the Earth system.

Applying the planetary boundary framework to the German and EU context through the above methodological elements that are developed, applied and presented in this paper, can improve vertical and horizontal policy coherence. It also provides a few initial conclusions: per-capita contribution to planetary boundary transgression is significantly higher than global average. For the boundaries explored so far (climate change, land use change and nitrogen) it doesn't matter whether the respective global boundary is already transgressed or not, the downscaled planetary boundary[26] is transgressed at the German and EU level, in particular when taking a consumption-based perspective. Positive trends of decreasing pressure on planetary boundaries are generally limited to the territorial performance of Germany or the EU. Increasing externalization of environmental pressures through trade (over-)compensates these territorial improvements. Total consumption-based environmental performance doesn't seem to improve for these planetary boundaries.

More specifically, initial downcaling and benchmarking of the planetary boundaries for Germany / EU yields the following insights for the climate and land use change boundaries (for nitrogen see Hoff et al. 2017):

For climate change:
German and EU per-capita CO_2 emissions are above the global average, by about 100% (Germany) and by about 50% (EU) from a production-based (territorial) perspective, and even more so from a consumption-based perspective that includes resource use beyond Germany's / the EU's territory but for German/EU consumption.

While production-based (territorial) CO_2 emissions have decreased over the past 2-3 decades, externalized emissions in other countries as caused by Germany's / the EU's consumption and imports, have increased and (over-) compensated the domestic progress.

The EU's consumption-based carbon footprints currently are about 10-20% higher than production-based (territorial) footprints.

Depending on the selected climate target and criteria for allocating the global emission budget, German and EU emissions need to be reduced by about 50-90% by 2030 compared to 1990 (while the current EU target stands at -40% reduction). This would have required an emission reduction rate of about 2-5% per year since 1990, while the actual annual rate was only in the order of 1%. Accordingly

26 The initial downscaling was done based on equal per capita and/or per area allocation of the global value, for a more detailed description of the downscaling see main text below.

much higher annual reduction rates of up to 10% are required from now on, in order not to transgress the respective share of the global climate change boundary.

For land use change:
The boundary for land-system change (≥75% of forest cover should remain) has not only been transgressed globally, with about 62% of original forest cover remaining, but also at the German level (34% of natural forest cover remaining) and at the European level (43% of original forest cover remaining), despite the rather low boundary for temperate forests (50% original forest cover remaining) which applies in Germany and most of the EU.

Many EU countries have high per-capita land use, with consumption-based land footprints much higher than production-based footprints and largely above global average.

Given the large net imports of agricultural commodities and biomass of Germany and the EU, they strongly externalize land use. Currently about the same amount of agricultural land is used outside of Germany and the EU as within their territories for producing goods and services finally consumed there. Reductions in cropland use (and pressure on the planetary boundary for land-system change) within Europe are compensated by growing imports of virtual land from other world regions.

Forest cover is slightly increasing in Germany and in the EU. All of the EU's consumption-based deforestation occurs outside of the EU, with the EU being responsible for 10% of total trade-related deforestation.

Different from the climate change boundary, drivers of land use change are very context-specific and criteria for sustainable land use at local and national level may be quite different from those represented by the planetary boundary for land-system change. Further development of the land use change boundary and its operationalization need to go hand in hand, enabling more context-specific downscaling.

The Context

Human imprint on the environment is increasing. In the Anthropocene modify the Earth system significantly, with largely unknown consequences for its functioning. The great acceleration of human activities and associated environmental impacts (Steffen et al. 2015b) raises questions about potential critical thresholds in the Earth system, beyond which unexpected, possibly abrupt "regime shifts" would occur, that could threaten the living conditions for humans and their well-being. These issues and the need for precautionary management of these risks have been addressed by Rockström et al. (2009) and more recently Steffen et al. (2015b) in their planetary boundaries framework. The planetary boundaries have received continued attention across all sectors of society, and are now also referenced in German and European policy making, and in the context of the 2030 Agenda:

- "…. The planetary boundaries of our Earth together with the objective of a dignified life for everyone constitute the ultimate parameters for political decisions (Federal Government 2018, p. 48)
- "… the way in which we consume and make use of the world's resources cannot be continued permanently and not even over the coming decades, because this leads to exceeding our planet's ecological limits (or "planetary boundaries") (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety 2016, p. 1)
- "Living well, within the limits of our planet." (EU 7th Environment Action Program)
- "We are determined to protect the planet …through sustainable consumption and produc-tion, sustainably managing its natural resources….", "each government setting its own national targets guided by the global level of ambition but taking into account national cir-cumstances." (Agenda 2030)

While each of the planetary boundaries still needs to be further explored and specified, and the interactions between boundaries and their dynamic in the Earth system are yet to be assessed, the operationalization of the planetary boundaries can begin in parallel. By exploring options for planetary boundary downscaling and using the downscaled planetary boundaries as benchmarks for specific contexts, their added value in policy and decision making can be tested. That "ground-truthing" in turn enables feedback to the planetary boundary development itself, so that the information requirements of policy makers and other stakeholders, in terms of a large-scale and global environmental perspective, can be better addressed.

While there is great interest in applying the planetary boundaries for specific contexts, stakeholders also need to be informed about the scientific evidence underlying each of the planetary boundaries, including the associated uncertainties, critical issues and disputed aspects, so that these can be taken into account when applying the planetary boundaries, e.g. for policy making, environmental management and sustainable consumption and production. It is this co-design and co-development (Mauser et al. 2013) between scientists and other stakeholders, of the planetary boundary framework and its operationalization, which generates most added value when addressing environmental and sustainability challenges across scales and sectors.

This paper presents – after a short introduction to the planetary boundary framework itself (chapter 1.4.1) – a suggested methodology for planetary boundary operationalization (chapter 1.4.2). This methodology starts from the previous disparate and rather uncoordinated attempts for planetary boundary downscaling, which have been applied in different countries and regions. In order to move beyond those initial planetary boundary applications, this paper develops some common elements for a systematic and transferrable method for planetary boundary operationalization. It discusses the feasibility, remaining gaps and per-spectives of a universal method for applying the planetary boundaries in policy making. These elements are (as much as possible) quantitatively explored and illustrated in chapter 1.4.3 for Germany and the EU, with focus on the climate, land and nitrogen boundaries.

1.4.1 The planetary boundaries framework

Operationalization of the planetary boundaries has to start from the current state of the planetary boundaries framework, its conceptualization, development, level of quantification and also limitations. This chapter briefly summarizes the state-of-the-art, including the inherent uncertainties, controversies and knowledge gaps.

The planetary boundaries delineate a safe operating space with respect to the Earth system and its desirable stable state for sustaining human livelihoods and well-being. Boundary values (and ranges of uncertainty) are specified for each relevant environmental process, such as climate and land use change, production of reactive nitrogen, biodiversity loss, water use etc. The planetary boundaries refer to the Holocene as "a scientific reference point for a desirable planetary state" (Rockström et al. 2009). Large- up to global-scale environmental guardrails and targets are formulated as acceptable deviations from the natural state. At the same time, the planetary boundaries framework acknowledges the fact that we have entered a new era, the Anthropocene, in which humanity is rapidly increasing its imprint on the environment, not only locally but at the level of the total Earth system - with largely unknown consequences.

The planetary boundaries framework is precautionary. In view of the increasing risks that the deviation of the Earth systems and its components from the natural state poses to humanity and the inherent uncertainties about critical thresholds, and systemic responses to threshold transgression, the PBs have been set as guardrails ahead of likely thresholds. The transgression of such thresholds may lead to regime shifts or other changes, which can compromise the functioning of the Earth system and its components in its Holocene state, and with that the living conditions for humans. The guardrails delineate a safe operating space in which sustainable development is possible, and outside of which the risk of unwanted changes becomes unacceptably high. Defining acceptable risks and setting guard-rails accordingly is inevitably a normative process, which has to involve all relevant stakeholders. The risk-based approach of the planetary boundaries is depicted by the green-to-red color coding in the emblematic planetary boundary figure (see below). It makes the planetary boundaries compatible with policy making.

The planetary boundaries are systemic boundaries, given the interactions between all of them and their reference to the Earth system. These interactions and feedbacks occur at various levels and spatial and temporal scales. For example, land system changes such as deforestation affect evapotranspiration, atmospheric moisture transport and eventually water availability across regions and scales. With that, land system changes can modify the freshwater boundary. Similarly, climate change affects the freshwater planetary boundary, the biodiversity boundary and other planetary boundaries. So the planetary boundary framework becomes an integrative "dashboard for sustainability", which can inform sustainability strategies and transitions about large-scale global environmental limits, but also opportunities. The systemic and often non-linear interactions between the different planetary boundaries and the resulting system dynamics at various scales up to global scale are currently intensively studied and modeled in Earth system science. Scientific tools include Earth system and integrated assessment models and associated scenario analyses. The systemic character of the planetary boundaries and their dashboard function makes them a useful concept in support of integrated approaches and vertical and horizontal policy coherence across scales and sectors, as required e.g. in SDG implementation. With that the planetary boundaries can also help to integrate different environmental footprints as requested by Galli et al. (2012).

Not all planetary boundaries are equal. While the planetary boundaries have been developed based on the original climate change boundary (global warming below 2 degrees), they are in fact of quite different nature: some planetary boundaries such as the climate change boundary address global common goods: the atmosphere presents a globally well mixed pool, to which all greenhouse gas (GHG) emissions contribute equally, no matter where they originate. The disaggregation or downscaling of such a boundary is rather straightforward and can be achieved in a top-down manner, allocating the safe operating space (remaining greenhouse gas emissions) irrespective of biophysical context.

Other planetary boundaries prescribe large-scale spatial patterns upon which Earth system functioning de-pends, such as the land boundary: changes in vegetation, in particular deforestation may differently drive Earth system changes, e.g. impacts on climate or on the biosphere, depending on their locations and spatial patterns. Similarly, for the aerosol boundary, resulting Earth system changes, e.g. impacts on the atmosphere and the climate (monsoon changes for example) also depend on the locations and patterns of emissions. So the downscaling of such a boundary needs to be spatially explicit (rather than globally uniform), accounting for these patterns and local context when allocating the safe operating space.

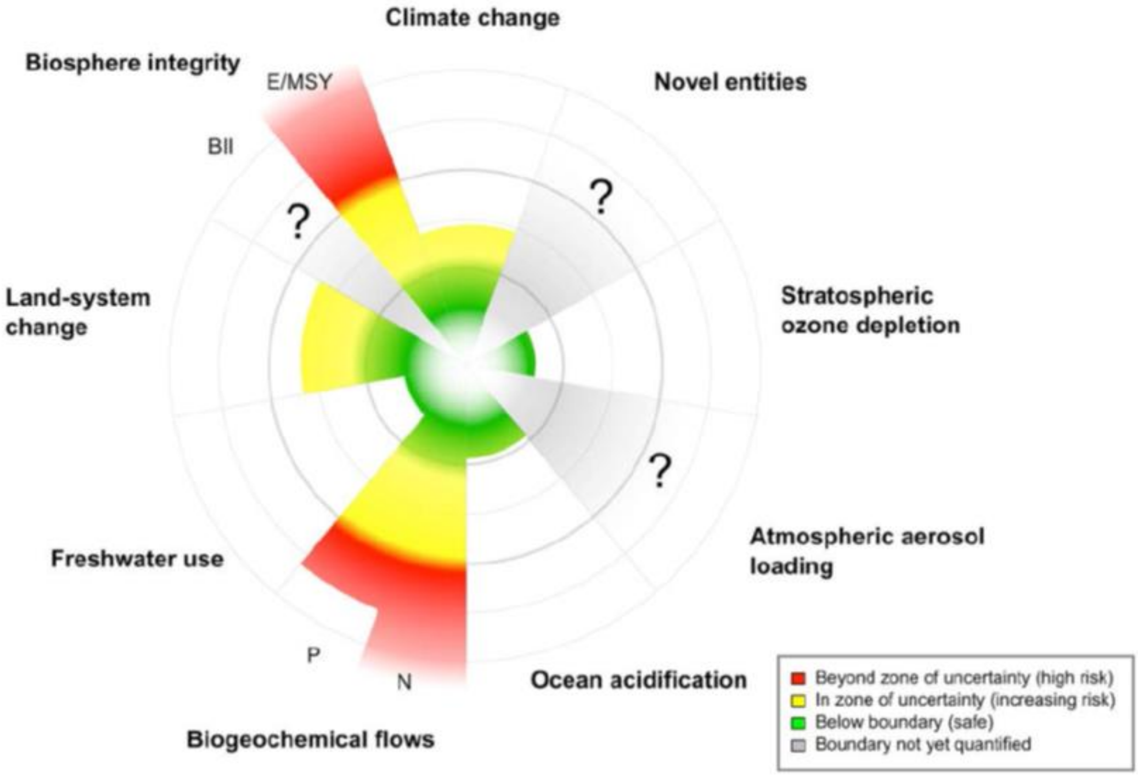
Yet other planetary boundaries may refer to large-scale environmental impacts and their consequences for the Earth system functioning, such as large-scale anoxic zones in the oceans or repercussions for different global biogeochemical cycles, as a result of multiple and extensive trans-gressions of local nitrogen or phosphorous boundaries.

Some planetary boundaries refer to stocks, others to flows of resources or emissions. The climate change boundary implies a limited stock or budget of remaining total global GHG emissions (which will be used up in the near future). The water boundary is an example of a flow boundary, for which the control variable is the annual consumptive freshwater use (since water is a renew-able resource, this flow will be available year after year). Accordingly, the temporal dynamics of the control variable, and with that also the temporal dynamics of the operationalization of the boundary, vary between stocks vs. flow boundaries.

Planetary boundaries also delimit the space in which social-ecological systems can develop sustainably. While this was not part of the original biophysical definition of the planetary boundaries (the referred to "Earth system functioning"), the need for reconciling global environmental goals with devel-opment-related goals was initially explored e.g. by Raworth (2012). She expanded the safe operating space to a "safe and just operating space". Within such a safe and just operating space, fair and equitable access to resources and ecosystem services and eventually human (water-, energy- and food) security can be achieved and integrated with environmental sustainability. Based on the planetary boundaries framework, the safe and just operating space is currently further developed. Dearing et al. (2014) and Cole et al. (2014) provide regional examples of integrating socio-economic and environmental targets in their initial operationalizations of the planetary boundaries for China and South Africa respectively. The 7th Environment Action Program of the European Union refers to the integration of environmen-tal and socio-economic targets in its title: "Living well within the limits of the planet") – however as EEA also shows, countries currently either offer their citizens to live well OR remain with their share of the planetary limits, but no country achieves both, the development and the environment goals simultaneously. The urgent need for integrating environmental and global development or social justice goals, has also been emphasized by the German Minster for the Environment, and is central to the national implementation of the Sustainable Development Goals (SDGs). The planetary boundaries and their operationalization can provide a scientific basis and framework for the required Sustainability Transition.

Some planetary boundaries have already been transgressed. Their status, or more precisely: the current knowledge about their status is depicted in Figure 41 below. This figure illustrates that at least for 4 planetary boundaries the state of the control variable has moved outside of the safe operating space. The color coding from green to red indicates that the risk of detrimental changes increases with distance from the original / natural state (with reference to the Holocene). Accordingly there is no unanimous single value, beyond which regime shifts inevitably occur, but rather a zone of increasing risk, ahead of which precautionary guardrails have been set. For those boundaries depicted in in yellow and red color that guardrail has been transgressed.
We can expect this picture to further develop as new scientific results emerge. As will be described below, initial analysis indicates that irrespective of the global status of these planetary boundaries, Germany has transgressed its share of the climate and land (and also other) planetary boundaries by far.

Figure 41: The Planetary Boundaries and their transgression status (Steffen et al. 2015a)



Source: Steffen et al. 2015a

The attractiveness and communicative power of the planetary boundaries which this figure illustrates (one global number per critical environmental trend) comes at a cost: the reduction of complex multi-dimensional and multi-scale environmental processes to single numbers ("boundaries") results in in-completeness, missing detail, nuances and also dynamics. This has led to criticism by the scientific community, about the insufficient level of detail and depth of analysis which disciplinary science typi-cally requires.

The PB framework contains a number of uncertainties, which are being addressed by ongoing re-search. These uncertainties include for example the exact location (and even the existence) of each of the boundaries and underlying thresholds, as well as the current posi-tion of the Earth system and its components relative to these thresholds and their potential responses to threshold transgression. Also the interactions and feedbacks between the different boundaries and the resulting dynamics (or iner-tia) of each boundary and the Earth system are largely unknown. Accordingly, very little knowledge is available on potential re-sponses of the Earth system and its components to threshold transgressions or on possible societal responses.

So the operationalization of the planetary boundaries has to take place against this backdrop of the current status of the planetary boundary framework, with all its uncertainties, limitations and ongoing further development. This operationalization requires transdisciplinary science and bridging and inte-gration of science and policy making, in order to "co-operationalize" the planetary boundaries and co-produce relevant knowledge (Mauser et al. 2013). That mutual promotion of planetary boundary development and operationalization should not be delayed any further, but should be initiated now for various context and from there should be iteratively improved[27]

1.4.2 Operationalization of the planetary boundaries – a methodology[28]

Since 2009 when the initial planetary boundary paper was published by Rockström et al. there has been continued interest in the practical implications of the planetary boundaries framework and its operationalization, by policy makers, civil society and the private sector. The planetary boundaries framework provides an Earth system perspective, describing and quantifying large-scale environmental processes and limits. Operationalizing, accounting for and mainstreaming the planetary boundaries can add value to policy and decision making. The fact that complex and often non-linear processes are reduced to single numbers (boundaries) makes the planetary boundaries framework particularly attractive, but also comes at a cost (potential over-simplification).

Policy making, environmental management or collective agency mostly occurs at the local to national or regional level. Accordingly disaggregation, allocation and eventually also spatially explicit translation of the planetary boundaries are required for the respective context. The downscaled planetary boundaries then can be accounted for, i.e. they can serve as benchmarks for environmental performance, complementing local sustainability criteria and regulations from an Earth system perspective. The global number of the respective planetary boundary (e.g. 4000 km3 of consumptive freshwater use per year in the case of the water boundary) or the global pathway to stay within the safe operating space (e.g. reduction of global net CO_2 emissions to zero in the second half of the century for the climate change boundary) need to be disaggregated and allocated among all nations and individuals.

Allocation of limited global common goods or resources or burden sharing among nations, invariably raises normative or ethical issues and discussions about criteria to be applied. This normative and political discussion is well underway for the climate change boundary (in the context of the UNFCCC), but has yet to take place for other planetary boundaries. For example: should all 7.4 billion people on Earth have the same rights to resources and responsibilities and obligations to reduce environmental impacts? Or are there minimum safe standards of human well-being and human securities that have to be achieved first (in particular for the poorest), before any equal-per-capita (or other) allocation schemes for planetary boundaries can be implemented? What exactly does the right to development for the poor entail and how does it constrain or determine international resources and burden sharing schemes? What about the historic responsibility of industrialized countries, which often over many years have used much more than their fair share, in order to sustain their rapid development and high consumption levels: do they still have the same future per-capita rights as the less developed countries with their much lower per-capita historic and current use? Should national (e.g. land and water) resource endowments, which vary widely among countries, play a role in allocating the safe operating space for the respective boundary? These and other normative questions on the roles, rights and responsibilities of different countries, in terms pressures on planetary boundaries and potential planetary boundary transgressions, have to be addressed jointly by scientists and other stakeholders when downscaling, allocation and eventually operationalizing the planetary boundaries.

While it is unlikely that these issues will be resolved quickly, initial downscaling and allocation schemes of the planetary boundaries can already be tested now – ideally based on existing accounting schemes developed for other purposes –, so that indicative benchmarks become available, against

[27] The constant mainstreaming of new scientific evidence into policy and decision making is also called adaptive governance and management (Pahl Wostl 2007: Transitions towards adaptive management of water facing climate and global change, Water Resources Management, 21, 49–62)

[28] Methodology: a systematic analysis for understanding which method(s), or best practices can be applied (here for PB operationalization).

which actual (e.g. national) environmental performance can be compared. Such initial, tentative operationalizations also provide feedback to the planetary boundary development itself, in terms of information requirements of the user community. For such initial planetary boundary operationalization, elements of a method begin to emerge, which need to be discussed broadly and then further developed, so they can eventually be used routinely and universally internationally. Important in this method development for planetary boundary operationalization are the associated system boundaries: a country's environmental performance doesn't end at the borders of its national territory, but it encompasses also the external environmental pressures ("external footprints[29]") caused by its consumption patterns elsewhere in the world, as transmitted through trade. This externalization of environmental impacts and resource use (and pressure on planetary boundaries) proceeds rapidly with globalization (e.g. UNEP IRP 2015)[30]. Growing external environmental footprints often compensate or even over-compensate domestic environmental improvements, threatening the whole narrative of environmental Kuznets curves and of decoupling economic development from environmental pressures and resource use (as in the Green Economy). Environmental pressures in many cases do not decrease, but are instead externalized or "discounted over distance" (Daily et al. 1992). The sum of external and internal footprints, and hence a countries full responsibility for planetary boundary transgression, can be captured in the form of consumption-based footprints.

This chapter presents a methodology how to address these issues, identifying initial ele-ments of a universal method for planetary boundary operationalization. In the following chapter (chapter 1.4.3) the use of these elements is explored for Germany and Europe and illustrated for the climate and land planetary boundaries.

Initial attempts of planetary boundary downscaling and allocation for specific contexts, e.g. by Nykvist et al. (2013) for Sweden, Cole et al. (2014) for South Africa, Dearing et al. (2014) for China, Hoff et al. (2014) for Europe and Dao et al. (2015) for Switzerland were largely inconsistent and used different approaches and methods, which could not be generalized. Moreover by adapting the planetary boundaries to the respective local context, universality in some cases was lost, so that the methods and results could no longer be transferred and aggregated back to global level. Here we propose a more systematic method for planetary boundary operationalization, building on the Steffen et al. (2015) and Häyhä et al. (2016), which consists of the following elements:

- downscaling of the planetary boundary to the relevant scale
- adding temporal dynamics to the downscaling
- benchmarking of production-based environmental performance against the downscaled PB
- benchmarking of consumption-based environmental performance against the downscaled PB.
- mapping the results of PB downscaling and benchmarking onto relevant policy and environmental management areas and integration with context-specific bottom-up sustainabil-ity criteria

Below, these elements of a method for planetary boundary operationalization are described in more detail, including their feasibility, limitations, uncertainties, data requirements, related ethical and normative issues etc.

[29] Note that the term „footprints" is used in literature in many different ways. For the purpose of this paper, foot-prints stand for internal or external pressures on PBs or contributions to their transgression.

[30] International trade in resources.

Note that these elements are not meant to be applied in a strict consecutive order. Eventually a method for planetary boundary operationalization may rather apply these elements iteratively and in variable order.

Element 1: downscaling of the planetary boundary, to the relevant scale

The single global planetary boundary values cannot be directly used in policy and decision making. They need to be disaggregated, allocated and possibly also made spatially explicit, e.g. at national level. The different planetary boundaries require somewhat different downscaling approaches and methods. While all PBs have in common that they are systemic with reference to the Earth system, there are some planetary boundaries which refer to a global common good or pool (e.g. the climate change boundary), others which prescribe large-scale spatial patterns (e.g. the land-system change boundary), and yet others which are defined by large-scale yet spatially explicit environmental impacts (e.g. the nitrogen boundary).

Eventually, such normative, ethical or fairness criteria for top-down allocations of boundaries may be applied individually or in different combinations. This will need a thorough assessment of the feasibility (e.g. in terms of available data or in terms of reaching international consensus) and implications of each of these criteria. Initial explorations of such different allocation rules and schemes for Germany are presented in chapter 1.4.3.

For those planetary boundaries that prescribe large-scale spatial patterns of resource use and/or which are context-specific in their drivers and impacts, top-down allocation schemes need to be integrated with bottom-up local sustainability criteria. An example for that is the land boundary, which requires certain minimum fractions of remaining tropical, temperate and boreal forests, in order to stay within the safe operating space. Such a pattern approach to planetary boundaries downscaling may initially only be qualitative, until sufficient data become available. Similarly, the biosphere integrity boundary accounts for spatial patterns or hotspots of biodiversity and critical species, with particular relevance for the resilience of the Earth system (not yet known). Also the aerosol boundary requires spatially explicit downscaling and allocation patterns, as related e.g. to context-specific impacts of boundary transgression on the stability of monsoon system.

For those planetary boundaries, which account for large-scale environmental impacts that reach beyond national level, as for example extended marine dead zones in the case of the nitrogen boundary, integration of top-down allocations with context-specific bottom-up sustainability criteria may be required, e.g. specific environmental vulnerabilities or scarcities or co-risks. Examples for bottom-up criteria may be the vulnerabilities of ecosystems, soils or groundwater to excessive nitrogen inputs, or also the importance of key or endemic species in the case of the biosphere boundary. There is however no experience yet with context-specific downscaling and integration with bottom-up criteria for any of the planetary boundaries. The planetary boundary operationalization for South Africa (Cole et al. 2014) and for China (Dearing et al. 2014) was context-specific, but deviated significantly from the original planetary boundary definitions, so that their methods and control variables are not generalizable or transferrable to other countries. With that the universal applicability gets lost, which is essential for ensuring that national contributions cumulatively remain within the global safe operating space.

The climate change boundary, based on which the other boundaries and the planetary boundaries framework have been developed, may provide some lessons also for other planetary boundaries and for developing a general and universally applicable method for planetary boundary downscaling and operationalization: while earlier climate agreements (in particular the Kyoto Protocol) were only based on a top-down prescription of emission reductions for a certain group of countries, more recently a complementary bottom-up approach has been agreed upon. The Paris Agreement is built around Nationally Determined Contributions (NDCs) for all countries, which cumulatively must achieve the global emission reduction target (net zero emissions in the second half of the century) – see e.g. Rogelj et al. (2016) or Schleussner et al. (2016). These NDCs are subject to periodic review in order to establish a "ratchet up" mechanism which should en-sure that the global boundary (keeping global warming well below 2°) is met. This experience with the climate change boundary may also inform the downscaling and allocation of the other planetary boundaries and the required negotiations and agreements among countries (and related ethi-cal aspects). Eventually, Nationally Determined Contributions (NDCs) need to be defined for other planetary boundaries as well, which cumulatively have to comply with the respective safe operating space.

Beyond the climate experience, the SDG process and other multilateral environmental agreements may also provide helpful insights into normative, ethical or fairness aspect of the country-specific operationalization of universal goals and targets, possibly also in terms of follow up, monitoring and review.

Element 1 of the proposed method, the disaggregation and spatially explicit allocation of planetary boundaries to the scale of decision- and policy making (and also the following elements) requires joint learning and co-development of the relevant knowledge. That process, which also includes normative choices about allocating the safe operating space to individual countries, has to involve a broad range of stakeholders, and requires underpinning with the latest available Earth system and sustainability science. In chapter 1.4.3 we explore and present some initial downscaling results for Germany and Europe.

In summary, planetary boundary downscaling has been limited so far to uniform top-down approaches of equal allocation (either per capita or per area), with the exception of some initial explorations of additional allocation rules for the climate change boundary. Other than that, neither normative nor ethical allocation criteria which would differentiate among countries (common but differentiated responsibility), nor spatial pattern approaches, nor context-specific bottom-up criteria have been applied to planetary boundary operationalization yet. Also, disaggregation below national level, to the scale where environmental impacts (footprints) mostly play out, through integration of downscaled planetary boundaries with context-specific local data has yet to happen.

Element 2: adding temporal dynamics to the downscaling

For some boundaries, in particular stock boundaries, their temporal dynamics can be important. For flow boundaries on the other hand, temporal dynamics may be less relevant: the water or phosphorus boundaries for example present constant rates year after year (4000 km3 of consumptive blue water use per year, or 11 Teragram P flows into the oceans per year) which can be disaggregated and allocated. Planetary boundaries that refer to a limited stock on the other hand, such as the climate change boundary, may need to be downscaled temporally explicit. For example, the remaining total global budget of CO_2 emissions, does not lend itself to even disaggregation and constant allocation over all years to come. Instead, disaggregation and allocation, e.g. to national level, needs to be aligned with the required global reduction pathway. Global emissions have to be reduced quickly, from the current level to net zero emissions in the second half of the century. Accordingly, the sum of all national reduction pathways must remain within the dynamic global safe operating space.

Here again, different normative or equity or fairness criteria need to be tested, negotiated, and applied, for allocating the global reduction obligations. The principle of equal per-capita allocations may provide a good starting point in this case too, but other normative, ethical and fairness criteria, as listed above, will be required for operationalizing the planetary boundaries. Given the very different current per capita emissions of the different countries, allocation criteria and schemes will have to result in convergence pathways (see e.g. Meinshausen et al. 2015), with high emitting countries having to reduce their emissions much faster than the global average reduction rate, while least emitting countries may still have some room for increas-ing their emissions.

Another reason for including temporal dynamics in downscaling, are the planetary boundaries themselves as part of Earth system. Their dynamics and those of the whole Earth system depend on the interactions among planetary boundaries (e.g. a change in total water availability due to land use change or climate change). Also changes in population require dynamic planetary boundary downscaling: currently the planetary boundaries have to be allocated across 7.4 billion people, in future across 9 or 10 billion people. Another set of temporal dynamics comes into play when benchmarking environmental per-formance against the planetary boundaries (see below), such as changes over time in life styles, consumption patterns, technologies and resource intensities, all of which (together with population dynamics) can change environmental performance. Lastly, also scientific knowledge and understanding of the planetary boundaries and the Earth system context is evolving. Those dynamics also need to be reflected when operationalizing the planetary boundaries by way of downscaling and benchmarking.

While Earth system science is improving the knowledge base in terms of planetary boundary dynamics, none of these dynamics have been accounted for yet in any planetary boundary downscaling exercise. So far, only initial static snapshots in time have been produced. An exception is the study by Cole et al. (2014) which begins to analyze the dynamics of planetary boundary control variables for South Africa, showing an increase in almost all (locally adapted) control variables over the past 20 years, indicating that South Africa is approaching and transgressing most downscaled planetary boundaries over the past decade. In chapter 1.4.3 we explore for Germany and Europe the downscaling of temporally dynamic boundaries.

Eventually, for benchmarking environmental performance against downscaled planetary boundaries, these temporal aspects have to be consistently addressed and included as relevant for the respective boundary. However, until Earth system science has further assessed planetary boundary dynamics, benchmarking remains mostly limited to static downscaling of the planetary boundaries.

Element 3: benchmarking of production-based environmental performance against the downscaled planetary boundaries

Downscaled planetary boundaries can serve as benchmarks for actual environmental performance, somewhat similar to the earlier “biocapacity” against which environmental footprints were benchmarked (see WWF 2014). Benchmarking of environmental performance against the downscaled planetary boundaries can inform countries or companies or consumers how well their actual or planned policies, regulations or activities and the resulting current and future environmental footprints comply with large (up to global) scale environmental goals, or to what extent they contribute to boundary transgressions. The initial operationalization by Nykvist et al. (2013) compared the Swedish environmental performance with the downscaled planetary boundaries, Dao et al. (2015) did so for Switzerland and Cole et al. (2014) for South Africa. Production-based (or territorial) benchmarking only looks at resource use and environmental impacts within the national territory. It uses available national environmental data or projections, primarily from statistical offices (e.g. DESTATIS and UBA in the case of Germany) that describe the internal environmental pressures (or internal footprints) within the national boundaries and com-pares those to the downscaled planetary boundaries. For that, environmental data need to be (made) con-sistent with the respective planetary boundary.

For some of the planetary boudaries the required national statistical data for measuring and monitoring environmental performance are already available, as for example CO_2 emissions in the case of the climate change boundary or anthropogenic nitrogen fixation (nitrogen boundary) or freshwater use (water boundary). For other planetary boundaries the required data are lacking, e.g. biodiversity intactness or species extinction rates (biosphere boundary) or not in the right format. In that case iterative harmonization of national environmental data and planetary boundary control variables may be required (but the universality and global comparability of the control variable used must be ensured). For yet other planetary boundaries, the metrics or control variables haven’t been fully developed, as for the novel entities planetary boundary. As explained above, most planetary boundaries in principle require the integration of top-down disaggregation and allocation of global values with bottom-up context-specific local data and sustainability criteria, accounting e.g. for specific drivers, environmental vulnerabilities or resource scarcities. Once those integrated top-down bottom-up approaches for context-specific planetary boundary downscaling become available, benchmarking should be done against those. For the moment however, environmental performance can only be benchmarked against uniformly downscaled and mostly static planetary boundaries.

Similarly, once the different normative or ethical criteria for planetary boundary downscaling (see above) are further elaborated, benchmarking can take place against a broader range of downscaling results representative of the different criteria, rather than single downscaling results that are limited to equal-per-capita (or per-area) downscaling. An initial example has been given by Dao et al. (2015) for Switzerland, which currently exceeds its allowable share of CO_2 emissions by a factor of 8. This factor increases to 23, when accounting for (some of) Switzer-land's cumulative past emissions. This is due to the fact that Swiss (and generally European) past contributions to global emissions have been much higher than nowadays.

Temporal dynamics are not only important in terms of the planetary boundaries themselves, as explained above, but also in terms of environmental performance. In order to account for these temporal dynamics, future projections of environmental performance can be derived e.g. from extrapolating current trends or from model simulations, but also from assessing the likely effectiveness of new environmental (or other) strategies, policies and legislation.

In chapter 1.4.3 we explore for Germany and the EU options for benchmarking actual environ-mental performance against the downscaled planetary boundaries.

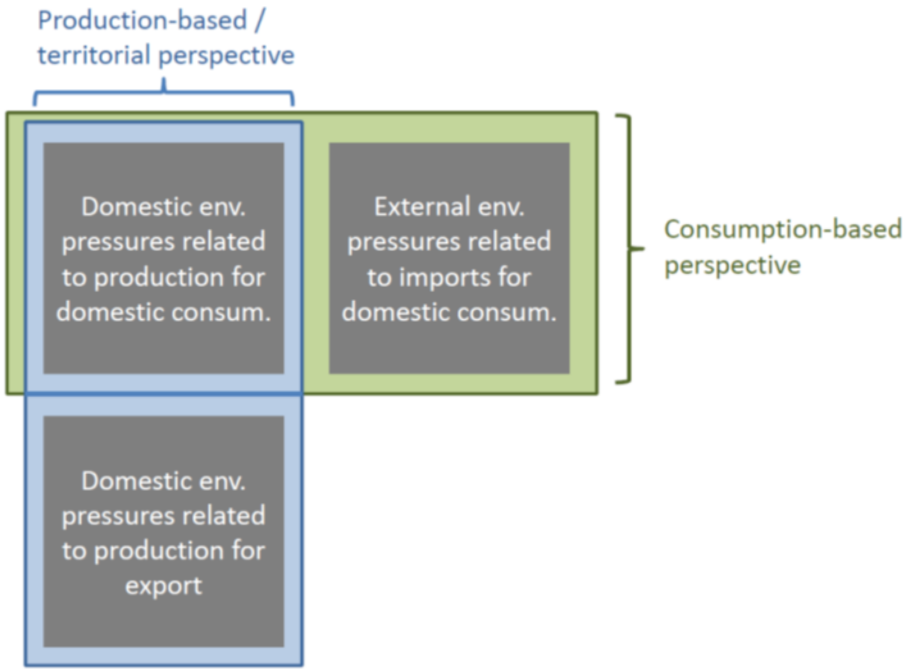
In conclusion, benchmarking of national environmental performance (or targets and indica-tors such as those defined in the German Sustainable Development Strategy or in the European Environment Action Program) against planetary boundaries requires further improvements in planetary boundary downscaling and in the national environmental performance measures. The latter depend on further harmoni-zation of environmental data with the respective planetary boundaries, including time series and projections into the future. Eventually local context information that is relevant for the resulting environ-mental impacts (such as vulnerability or degradation status of land, water or ecosystems, scarcity of resources or hotspots of biodiversity and endemism) also needs to become part of the benchmarking. However, these challenges should not prevent initial benchmarking exercises based on the currently available data and information. Any such initial benchmarking exercise can help to anchor large scale and global environmental sustainability criteria, as represented by the planetary boundaries in national policy- and decision-making and at the same time can help to build a community of practice on planetary boundary downscaling and benchmarking.

Benchmarking of consumption-based environmental performance (against downscaled planetary boundaries) goes further than production-based benchmarking, by also taking into account external environmental pressures or resource use in other countries and regions, as caused by national consumption and externalized via international production chains and trade. While production-based (territorial) benchmarking only compares environmental pressures that occur within the respective country to the downscaled planetary boundaries, a consumption-based approach includes the full internal and external environmental pressures related to the country's total consumption of goods and services.

By including the external impacts, a country's contribution to and responsibility for planetary boundary transgression can be more comprehensively assessed, compared to production-based benchmarking. That also enables a more meaningful comparison among countries of per-capita contributions to planetary boundary transgression, irrespective of where (domestically or externally) the pressure on the planetary boundary is exerted. Furthermore, tracing resource use and environmental impacts back to those external locations from which Germany imports its commodities, will eventually allow to better specify the consequences for Earth system functioning, which for some planetary boundaries depend on the location where the pressure is exerted (e.g. land use change in Brazil has a different effect on the global climate and Earth system than if the same size area is subject to land use change in Germany). Lastly, making external pressures on planetary boundaries and the related external footprints spatially explicit also facilitates the integration of local-to-national-to-regional-to-global environmental sustainability criteria and with that the integration of bottom-up and top-down approaches to sustainability transitions.

The difference between a production-based and a consumption-based perspective is visualized in the following figure:

Figure 42: Production-based vs. consumption-based perspective (after Wilting et al. 2015[31])



Source: after Wilting et al. 2015

Note that the consumption-based approach excludes domestic (territorial) environmental pressures related to the production of export commodities – see lower box in Figure 42. These pressures are allocated to the country to which these products are exported and in which they are eventually consumed.

While environmental policies and environmental management are still mostly limited to do-mestic (territorial) environmental pressures, globalization is causing a rapid externalization of these pressures to other countries and regions. Germany and Europe in particular are large importers of agricultural products and have in fact become net importers of agricultural products over the past decades (Lugschitz et al. 2011, von Witzke and Noleppa 2010). Germany alone is the third largest importer globally, e.g. importing large amounts of feedstock from Latin America. Accordingly, external environmental footprints are growing rapidly, in absolute terms and relative to internal footprints.

The calculation of consumption-based environmental performance or footprints requires a thorough understanding and quantification of increasingly more complex and longer supply chains and the attribution of trade-related external environmental pressures all along those chains. This is a major conceptual, methodological and data challenge, as vividly illustrated by the current 7th Environment Action Program of the European Union. Despite its title "Living well within the limits of our planet", the program almost exclusively addresses environ-mental and sustainability issues within the EU and its member countries, except for a couple of paragraphs at the very end of the document. This is largely due to a (perceived) lack of a consistent applicable framework with associated reliable and consistent data for a global consumption-based approach. The next (8th) Environment Action Program of the EU will certainly pay much more attention to the "limits of our planet".

The standard tools for analyzing supply chains and for calculating consumption-based pressures are environmentally extended Multi-Regional Input-Output (MRIO) models and Physical Flow Accounting (MFA), see e.g. Tukker et al. (2009) , Wiedmann and Barrett (2013) or Schaffartzik et al. (2014) . MRIO analysis is based on financial interactions between coun-tries and economic and industrial sectors in combination with physical data and environmen-tal extensions, capturing the full global supply chains including all international flows and processing steps of raw and processed commodities. With that, MRIOs go beyond previous analyses of bilateral trade data, which cannot account for indirect or embedded flows of "virtual" commodities (commodities and underlying resource inputs which are used along the supply chain without physically entering the importing country) nor for re-exports of imported commodities. Environmental extensions (also called "satellite accounts") of MRIO models associate these commodity flows e.g. with land or water or nitrogen use or CO_2 emissions.

While MRIO analysis starts from the consumer end of the supply chain tracing back all consumed goods and services through all processing steps to the countries of origin of the primary inputs, physical flow accounting starts from the production end. It physically follows the flows of commodities along the trade chain. Consumption-based resource use and environmental impacts can be calculated by combining physical flow accounting with input and conversion factors of resources, throughout the different processing steps to all the way to the consumable products. While MRIO approaches are limited in resolving industrial sectors and countries and often also in temporal coverage and resolution, physical flow accounting methods suffer from truncation of the supply chain or limited system boundaries.

These tools are increasingly applied for tracing flows of commodities with international trade and their associated external environmental footprints and total (internal + external) environmental performance. Consumption-based environmental performances of countries have been calculated e.g. for climate by Peters et al. (2011), for water by Lenzen et al. (2013), for land by Bruckner et al. (2012)[32] , for biodiversity by Moran et al. (2016) and for nitrogen by Oita et al. (2016). Some of the MRIO models now also begin to address socio-economic external footprints, enabling an integration of environmental and socio-economic sustainability criteria.

The initial assessment of consumption-based footprints for Sweden (Nykvist et al. 2013), Switzerland (Frischknecht et al. 2014 and Dao et al. 2015) and Europe (Hoff et al. 2014) point towards significant (and growing) externalization of environmental pressures, while domestic (territorial) pressures tend to slightly decline. That means also that domestic improvements ("decoupling of environmental pressure and resource use from economic devel-opment") are compensated or even over-compensated by increasing external footprints.

Frischknecht et al. (2014) calculated for Switzerland, where more than half of the environmental footprints occur outside of the country, that the external carbon and nitrogen foot-prints (caused by Swiss

[32] Data made available on request to researchers by SERI, Vienna.

consumption) have grown by 56% and 57% respectively over the past 20 years, while the internal footprints have decreased by 17% and 6% respectively in the same period.

Consumption-based benchmarking for planetary boundary operationalization is not only relevant for policy making (accounting for externalized environmental pressures in national - e.g. trade and agricultural - policies), but also for environmental management by the private sector, e.g. for transnational companies and their international supply chains, or for consumers and their consumption patterns. At the same time, the more complete assessment of a country's environmental performance relative to the planetary boundaries also enlarges the opportunities for staying within the safe operating space.

Consumption-based footprints, e.g. for carbon, land, water or nitrogen are increasingly becoming available in scientific literature. However, they have not yet been used for bench-marking environmental performance against the planetary boundaries, due to methodological and data limitations. They also raise questions about attribution along the production-to-consumption chain, e.g.: is only the consuming country with its consumption level and externalization of production responsible for boundary transgression, or also the producing country with its choice of production method and the associated resource intensity and environmental impacts?

In any case, available studies already provide a wealth of consumption-based data and information, which can be used for initial benchmarking and planetary boundary operationalization exercises. By undertaking and coordinating such exercises in different countries, a community of prac-tice can be developed, eventually developing a harmonized universal method (and data-base) for planetary boundary operationalization.

Element 5: mapping the results of planetary boundary downscaling and benchmarking onto relevant policy and environmental management areas and integra-tion with context-specific bottom-up sustainability criteria

There is a wide range of policy and environmental management areas, for which the planetary boundaries as large-scale environmental benchmarks may be relevant. While the planetary boundaries do not provide path-ways or even tools for sustainability transitions (transitions e.g. in the energy or agricultural sector or economy-wide), they can motivate, inform and concretize the integration of large-scale and global (and often also long-term) sustainability criteria into strategies, policies, indicators and activities.

The relevance of the planetary boundary framework and the potential of each of the planetary boundaries to add value to existing or new regulations, policies and strategies need to be assessed, before any attempt is made to downscale them. That assessment, and eventually also the operationalization of the planetary boundaries have to be jointly undertaken by scientists and other stakeholders. Only then can the planetary boundaries gain the required legitimacy and relevance, while at the same time maintaining their scientific basis and accuracy.

Moreover, the planetary boundary framework is risk-based, with guardrails set at safe distance from critical thresholds. The definition of acceptable risks (but also the definition of fair criteria for planetary boundary downscaling) is a normative process, which also requires cooperation between scientists policy makers and other stakeholders, or co-design and co-development of relevant knowledge (Mauser et al. 2013).

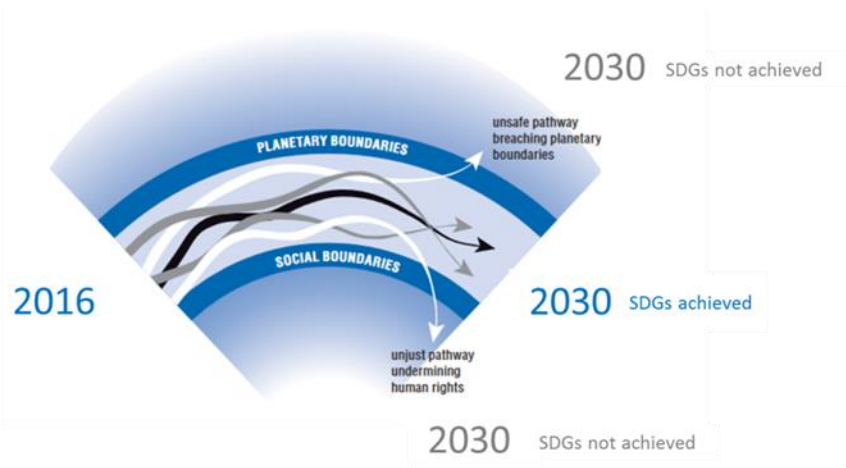
The integration of large-scale with local to national-scale sustainability criteria can support vertical policy coherence (across scales). At the same time the systemic nature of the planetary boundaries (emphasizing cross-planetary boundary interlinkages throughout the Earth system) can support horizontal policy coherence across sectors. With that, the planetary boundaries may eventually also enhance coherence (and reduce tradeoffs) between different environmental, sustainability and other policies such as in climate, energy, agriculture, economy, trade or development cooperation.

Planetary boundaries can also help to pro-actively assess new and planned strategies, policies, legislation and targets, by specifying the global context and providing benchmarks, against which to compare the expected environmental effects of the new initiatives. That type of "planetary boundary proofing" can increase the compatibility of national and regional initiatives with international regimes and targets. An initial example has been provided by Hoff et al. (2017), who compared existing and newly proposed nitrogen targets for Germany and Europe to the downscaled N-boundary, and found none of them to be sufficiently ambitious to meet the (downscaled) global nitrogen target.

Another entry point for planetary boundary operationalization is the Agenda 2030. The SDGs contained in Agenda 2030 are by definition universal and hence their implementation in one country must not compromise sustainability in other countries, nor global sustainability. The draft of Germany's new Sustainable Development Strategy (from May 2016) reflects that by stating that "our consumption patterns do not sufficiently account for planetary boundaries", and that "sustainable consumption and production would have to meet the needs of current and future generations, considering planetary boundaries…." with "countries like Germany having a strong responsibility for the economic, environmental and social effects of international trade" (own translation). The planetary boundary framework and its operationalization can concretize and scientifically underpin and quantify this international and global responsibility and the implications for national level SDG implementation.

For achieving sustainability transitions, planetary boundary operationalization must also be integrated with socio-economic targets (see Raworth 2012, Cole et al. 2014 for South Africa and Dearing et al. 2014 for China) and with concrete approaches and interventions for sustainable development, such as improvements in resource efficiency, innovative production systems, demand management and sufficiency, new economic models, environmental justice etc.

Figure 43: Co-development within a safe and just space as delimited by environmental and socio-economic sustainability criteria, from Leach et al. (2013)

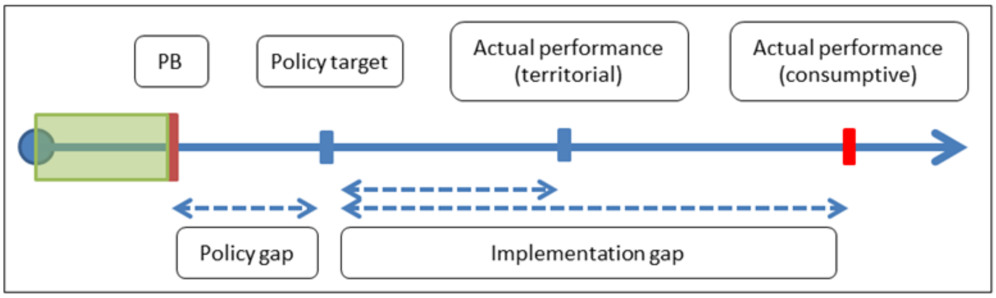


Source: Leach et al. (2013)

Given the temporal dynamics of the planetary boundaries and environmental performance, as discussed before, and the constantly evolving scientific knowledge, there is a need for adaptive management and governance when operationalizing the planetary boundaries. Accordingly, Galaz (2012) calls the PBs "a bid to reform environmental governance at multiple scales".

While Earth system science can reduce the uncertainties inherent in the planetary boundary framework, and with that better inform policy targets so they better meet the planetary boundaries, an additional and persistent limiting factor for sustainable development is the typical policy implementation gap. Implementation gaps frequently increase the distance between actual environmental performance and the required sustainability targets. Figure 44 depicts national and international implementation gaps and the resulting distance from the planetary boundary and the safe operating space (depicted in green). Note that the "implementation gap" also includes policy failure.

Figure 44: Actual environmental performance vs. PB and safe operating space, from Hoff et al. 2014



Source: Hoff et al. 2014

1.4.3 Initial exploration and illustration of this methodology for Germany and the EU

This chapter begins to explore, what the proposed elements of a universal methodology for planetary boundary operationalization would mean, if applied to Germany and the EU for the climate and land system change (and nitrogen) boundaries. This initial exploration can only address a few of those criteria for downscaling and benchmarking mentioned above. Focus will be on equal-per-capita downscaling for 80 / 500 million citizens of Germany / the EU which resemble about 1% / 7% respectively of the global population of 7.4 billion.

The three boundaries i) climate change, ii) land system change and iii) nitrogen (biogeo-chemical flows), represent three main types of planetary boundaries, i.e. i) a boundary that refers to a global common such as the atmosphere or climate, ii) a boundary which specifies large-scale spa-tial patterns relevant for the Earth system functioning, and iii) a boundary which is defined by its large (> national level) impacts as well as interactions with other global processes, in particular other biogeochemical cycles. The climate and land system change boundaries at the same time represent the two "core boundaries" according to Steffen et al. (2015), which are most strongly interlinked with all other planetary boundaries.

Previous attempts to assess Germany's performance relative to global boundaries, found significant transgression, as for example Germany's ecological footprint of 5.3 global hec-tares per capita, which exceeds the available global biocapacity of 2.3 ha per capita by more than 130% (WWF 2014) . Our initial exploration of Germany's and the EU's environmental performance relative to the downscaled planetary boundaries finds similar transgressions, even in cases where the global boundary itself is only slightly exceeded (such as in the case of the land boundary). According to these initial explorations, any positive trends, i.e. decreasing pressure on planetary boundaries, are limited to the territorial performance of Germany or Europe. Increasing externalization of pressure on planetary boundaries through trade (over-) compensates these improvements. Total consumption-based environmental performance is not improving.

Below the climate and land boundaries are explored in more detail, using the elements of a general method for planetary boundary operationalization described in section 2 of this paper.

Planetary boundary climate

CO_2, once emitted, stays in the atmosphere for a long time, effectively forever, when seen from a policy-making perspective. Accordingly, global cumulative emissions budgets can be determined for any selected global warming limit (Allen et al. 2009). That also means, that stabilizing atmospheric CO_2 concentrations (at any level) eventually requires net emissions close to zero. The climate planetary boundary has been set by Rockström et al. (2009, confirmed by Steffen et al. 2015a) to an atmospheric CO_2 concentration of 350 – 450 ppm, with 350 ppm setting a very strict precautionary limit for safely staying below 2° warming. That boundary value and also the second control variable of the climate planetary boundary (a radiative forcing of 1 W/m2, which may be consistent with the 1.5oC warming target) are already transgressed.

More recent publications have specified remaining global CO_2 emission budgets, which would likely keep warming below 2° (1000 Gt CO_2 emissions) or even below 1.5° warming with a 66%/50%/33% chance (400 / 550 / 850 Gt CO_2 emissions, IPCC 2014a)[33]. Given the persistently high and even further increasing global CO_2 emissions, these remaining budgets will also be used up very quickly, i.e. within a few years, unless emission rates drop rapidly. Accordingly, emission reduction pathways need to be specified, which start from the current high emission levels and bring net emissions down to zero at latest in the second half of this century. Negative emissions are integral part of these pathways, in order to compensate for the quasi unavoidable overshoot in the near term future.

Our initial explorations and applications of the elements presented above for a universal method for PB operationalization for Germany and the EU indicate that[34]:

German and EU per-capita CO_2 emissions are above the global average, by about 100% (Germany) and by about 50% (EU) from a production-based (territorial) perspective, and even more so from a consumption-based perspective.

While production-based (territorial) CO_2 emissions have decreased over the past 2-3 dec-ades, externalized emissions in other countries as caused by Germany's / the EU's con-sumption and imports, have increased and (over-) compensated the domestic progress.

The EU's consumption-based carbon footprints currently are about 10-20% higher than production-based (territorial) footprints.

Depending on the selected climate target and criteria for allocating the global emission budget, German and EU emissions need to be reduced by about 50-90% by 2030 compared to 1990 (while the current EU target stands at -40% reduction). This would have required an emission reduction rate of about 2-5% per year since 1990, while the actual annual rate was only in the order of 1%. Accordingly much higher annual reduction rates of up to 10% are required from now on, in order not to transgress the global climate change boundary.

Planetary boundary climate, element 1 - downscaling of the PB to the relevant scale

Element 1 of the methodology – disaggregation and spatially explicit allocation of the remaining global emissions budget if done statically without referring to the required global emission reduction pathway – is a rather impractical approach for the climate change planetary boundary. However, it does reveal some information about countries' contributions to and responsibilities for planetary boundary transgression.

[33] note that other GHG are not taken into account here, because of their generally shorter lifetime ("short lived climate forcers), which makes it difficult to consistently integrate them in a joint budget with CO_2. However, emissions of these other GHG need to be reduced simultaneously, which may in fact generate a number of co-benefits.

[34] more detailed description follows below

The static downscaling by Nykvist et al. (2013) started from a remaining total global budget of about 1450 Gt CO_2 for likely staying below 2° warming, which they spread out equally across the 21st century and across a constant world population of 7 billion people. From that they calculated an allowance of 2 tons per capita and year for the rest of the century.

The more recently calculated global budgets of about 500 – 1000 Gt CO_2 (for staying below 2° or even 1.5 ° warming, IPCC 2014a), if equally allocated over all 7.4 billion people, would results in remaining per capita emissions of about 70-130 tons CO_2 (own calculations, Peters et al. 2015). At the current average emission levels of the EU (about 7 tons per capita and year) the remaining budget will be used up in about 10-20 years. At the current emission level of Germany (about 10 tons per capita and year) this remaining budget will be used up in 7-13 year. As will be shown below, Germany's consumption-based per-capita emissions are currently in the order of 12 tons per year, which further shrinks the remaining time until the national allocation of the global budget is used up to about 6-11 years. Similarly, Dao et al. (2015) calculated that the Swiss budget would be used up in about 5 years.

The above calculations are based on equal per-capita allocations of the global budget. There are also other allocation criteria. These will be explored in element 2 of the method (below).

PB climate, element 2 - adding temporal dynamics to the downscaling

Element 2 of the methodology, adding temporal dynamics to planetary boundary downscaling, can be related in the case of the climate change boundary to the goal of reducing global net GHG emissions to zero, sometime in the 2nd half of the century, in order to stay well below 2° warming (Paris Agreement). Possible global emission reduction pathways for achieving this goal have been explored e.g. by Rogelj et al. (2016). Meinshausen et al. (2015) and other authors (e.g. Steininger et al. 2015) discussed different principles for "fair" downscaling and allocating this (dynamic) global goal to individual countries:

1) equal per capita allocation across currently 7.4 billion people, also accounting for the future increase in population

2) a so-called "grandfathering" (or inertia) approach, according to which current per-capita emission levels determine a country's allowed fraction of the remaining global budget

3) a combination of 1 and 2 which would result in a convergence of all countries' per-capita emissions

4) a "corrective justice" approach according to which countries with historically high per-capita emissions would have higher emission reduction obligations than countries with lower historical "debt" (as proposed for example by Brazil)

5) least cost approaches, which concentrate emission reductions to those locations where they can be achieved at least cost (e.g. Tavoni et al. 2014 , van Vuuren et al. 2016)

These and other allocation option or "common but differentiated responsibility" (including for example the right to development of the capacity to reduce emissions, see e.g. Pauw et al. 2014) will increasingly rely on renewable energy and also carbon sequestration and stor-age.

In terms of Europe's historically very high emissions, the GCP (2015) shows that the EU 28, while hosting about 7% of the global population is currently responsible for more than 10% of CO_2 emissions, and has contributed 23% of global historic emissions (Peters et al. 2015).

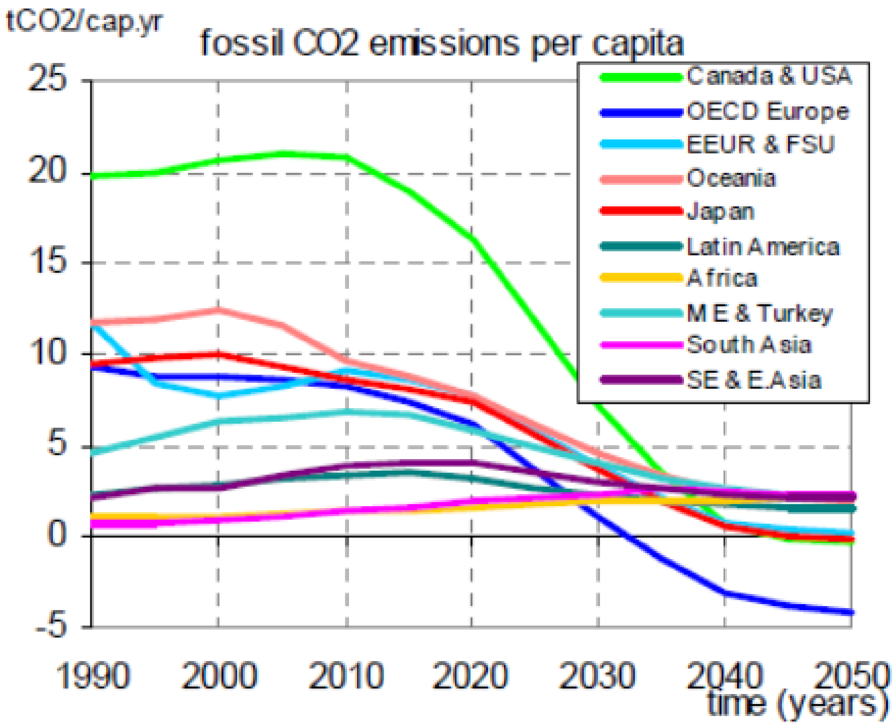
Accordingly, Meinshausen et al. (2015) suggest that industrialized countries like Germany could take a leadership role. For Germany they suggest emission reduction by 2030 of about -50% to -90%, depending on the "fair" allocation chosen.

Raupach et al. (2014) calculated Europe's required emission reduction rates to -6% to -2% per year (for a remaining total CO_2 emissions budget of 1400 Gt to stay below 2° warming with a 50% chance).

For a stricter climate target, e.g. meeting the 1.5° target (and remaining global CO_2 emissions of 550 Gt) the annual emission reduction rates would accordingly have to be much higher, up to -10% emission reductions per year. Comparing this to current and past rates of about -1% shows the challenge to remain within the Earth's safe operating space. The probable overshoot of the remaining emissions budgets in the near term future will need to be compensated by negative net emissions later in the 21st century.

Figure 45 shows stylized possible emission reduction pathways for different world regions (based on remaining total global CO_2 emissions of almost 2000 GtC for the 21st century as calculated at that time). The required reduction rates depend on the current per-capita emission levels. OECD (western) and eastern Europe are the regions that have the highest per-capita emissions (after North America) and hence require most drastic emission reductions. Possible negative net emissions in the 2nd half of the century would compensate for the probable overshoot in the near term future and also for the high historic emission rates, due to early industrialization and long-standing high living standards.

Figure 45: Stylized emission reduction pathways for different world regions, from Den Elzen et al. (2003)



Source: Den Elzen et al. (2003)

Plentary boundary climate, element 3 - benchmarking of production-based environmental performance against the downscaled PB

Static territorial benchmarking shows that current per-capita emission rates for Germany are 10 tons and for the EU about 7 tons of CO_2 per year (compared to a global average of 5 tons), according to Le Quéré et al. (2015).

A dynamic approach to territorial (production-based) benchmarking of environmental performance against the downscaled global climate change boundary, can use national or Euro-pean CO_2 emission statistics: for Germany reduction emissions of 27.7% (CO_2 eq[35]) have been reported for the period 1990 – 2014, which equals an average rate of slightly more than 1% per year. Most of that reduction has been achieved in the 1990s (after reunification), the annual rate in the 2000s has been even less than 1% (UBA 2016b). Achieving Germany's emission reductions targets of -40% until 2020, -55% until 2030, -70% until 2040 and -80% to -95% until 2050 (relative to 1990), would from now on (2016) require emission reduction rates of -4% to -8% per year.

EU-wide annual emission reductions have had almost exactly an average annual rate of -1%, with a total reduction of -20% between 1990 and 2013 (CO_2 equivalents), EEA (2016). In order to reach the EU's target of -40% by 2030, from now on an annual reduction rate of almost -2% per year would be required. In order to reach the emission reductions of -50% to -90% (by 2030) as calculated from downscaled global emission reduction pathways (see above), much higher reduction rates of up to -10% per year would be required from now on.

Planetary boundary climate, element 4 - benchmarking of consumption-based environmental performance against the downscaled planetary boundary

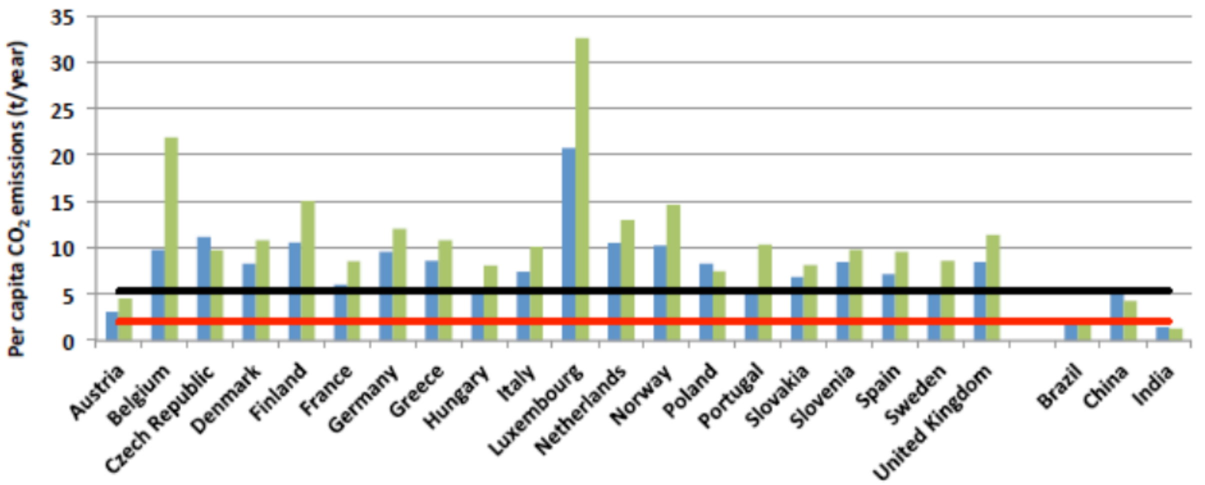
The production-based benchmarking, as discussed in the previous section, does not reflect the full German or European responsibility to the transgression of the global climate change boundary. It misses the growing externalization of CO_2 emissions via trade. Wiebe et al. (2012) showed that Germany's net carbon emissions have increased by about 50% between 1995 and 2005, with Germany having become the third largest net carbon importer globally.

Tukker et al. (2014), using the Exiobase MRIO model show that Europe's consumption-based carbon footprints amount to about 7.7 Gt per year (CO_2 equivalents), of which 1.6 Gt are associated with net imports, i.e. these 1.6 tons are not accounted for in production-based (territorial) footprints. In other words: more than 20% of Europe's pressure on the global climate change boundary has been externalized and occurs outside of Europe. For Germany they calculate, that about 12% of the total carbon footprint (in terms of CO_2 equivalents) are net imports.

Hoff et al. (2014) compare production-based (blue bars in Figure 46) and consumption-based (green bars) per capita CO_2 footprints. They find that Germany's consumption-based CO_2 footprint exceeds the production-based footprint by more than 20%.

[35] Note that CO_2 equivalents are not fully comparable with CO_2 itself. Currently about 75% of total GHG emissions (expressed in CO_2 eq) are CO_2, the remainder are other often short lived climate forcers

Figure 46: Annual per capita CO_2 emissions (blue: production-based, green: consumption-based), from Hoff et al. (2014). Black line: global average per capita CO_2 emissions, red line: allowable per-capita emissions according to Nykvist et al. (2013), CDIAC (2012)

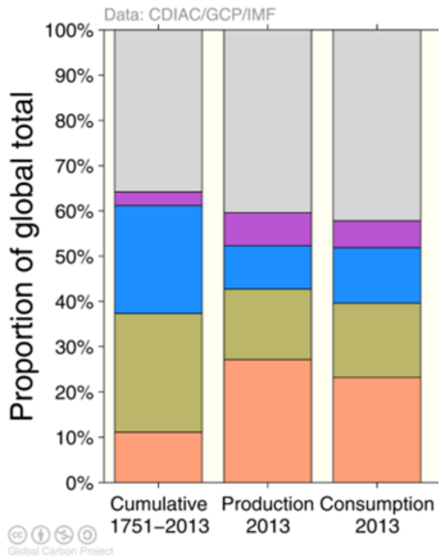


Source: Hoff et al. (2014)

UBA (2016b) come to a different conclusion, that Germany's consumption-based CO_2 foot-print is 10% lower than the production-based footprint.

The trend of increasing external CO_2 footprints (over-) compensating domestic improvements has been demonstrated for Switzerland by Dao et al. (2015). They show that Swiss domestic CO_2 emission reductions of about -17% over the last 15 years, have been counter-acted by much larger increases in Swiss external CO_2 emissions, so that the total Swiss consumption-based CO_2 footprint has increased over that period by +7%.

Figure 47: Comparison of Europe's consumption-based, production-based and historical contribution to total CO_2 emissions – Europe is shown in blue (orange: China, green: US, purple: India, grey: all others), GCP (2015)



Source: GCP (2015)

When accounting for the growing externalization of CO_2 emissions related to Germany's and the EU's consumption and trade and with that for the full responsibility for transgressing the global climate change boundary, the emission reductions discussed in the previous section need to be even higher. However, both consumption-based and production-based bench-marking yields important (complementary) information for environmental and other policy making.

Planetary boundary climate, element 5: mapping the results of planetary boundary downscaling and benchmarking onto relevant policy and environmental management areas

The initial exploration of the above methodology for downscaling the climate planetary boundary (or more generally: the global boundary for climate change as further elaborated in recent scientific literature) and benchmarking actual environmental performance (CO_2 emissions and emis-sion reduction rates) against the downscaled planetary boundary, would, if adopted, have severe implications for policy making at all levels and across all sectors: rapid decarbonization of all sectors will be necessary to meet the downscaled global emission reduction trajectories. This concerns not only the environment, energy and transport sectors, but also a broad range of others such as agriculture, land use, households, sustainable production and consumption and also those sectors responsible for external CO_2 emissions, such as industry, trade and development cooperation.

Accounting for externalized CO_2 emission on top of the already the very high internal (territorial) emissions, and possibly also for the high cumulative historic emissions and for the right to development of the poor, Germany's emissions have to shrink quickly by about a factor of 10 and net emissions have to be zero in the second half of the century.

Planetary boundary land

The land boundary has been set in view of the fact that land use is globally affecting ecosystem functions, threatening biodiversity, and undermining the Earth system's regulatory capacity through changing climate and the hydrological and other biogeochemical cycles (Rockström et al. 2009, Steffen et al. 2015a). The land planetary boundary was originally defined by the fraction of land that could be converted to cropland, setting the boundary to ≤ 15% of global ice-free land surface. An estimated 12% of the global land surface is under crop cultivation (Foley et al. 2005). Steffen et al. (2015) shifted the focus of the land boundary from biodiversity and ecosystems (link to biosphere integrity boundary) more towards the biophysical processes that regulate climate as well as terrestrial carbon storage and other biogeochemical cycles. As new control variable they chose the fraction of original forest cover remaining. With that the land planetary boundary begins to account for spatial patterns and context by differentiating the three main forest biomes: tropical, temperate, and boreal forests. Tropical forests affect the global climate system primarily via evapotranspiration and related fluxes of moisture and latent heat between land and atmosphere, whereas boreal forests are particularly important in terms albedo and radiation. Thereby forest cover changes (mostly deforestation) affect regional energy exchanges as well as terrestrial carbon storage. Both of these forest biomes have strong teleconnections. The biome-level boundary for tropical and boreal forests was set to a remaining fraction of ≥85% of natural forest cover, and to ≥ 50% for temperate forests - assuming these temperate forests would play a smaller role in the energy system.

Initial exploration of the elements for planetary boundary operationalization, which have been described above, indicate that:

The new land boundary (≥75% of total remaining forest cover) has not only been trans-gressed globally, with about 62% of original forest cover remaining, but also at the German level (34% of natural forest cover remaining) and at the European level (43% of original for-est cover remaining), despite the rather low boundary for temperate forests.

Many EU countries have high per-capita land use, with a consumption-based land footprints much higher than production-based footprints and largely above global average. Given the large net imports of agricultural commodities and biomass of Germany and the EU, they strongly externalize land use. Currently about the same amount of agricultural land is used outside of Germany and the EU as within, for producing goods and services for final consumption in Germany / the EU. Reductions in cropland use within Europe (and pressures on the planetary boundary land) are compensated by growing imports of virtual land from other world regions.

Forest cover is slightly increasing in Germany and in the EU. All of the EU's consumption-based deforestation occurs outside of the EU, with the EU being responsible for 10% of total trade-related deforestation.

Different from the climate change boundary where all CO_2 emissions contribute to the same global pool (the atmosphere), drivers of land use change are very context-specific and criteria for sustainable land use at local and national level may be quite different from those represented by the planetary boundary land.

Given that no downscaling and benchmarking has been reported yet in literature for the new-ly defined land planetary boundary (minimum fraction of natural forest cover remaining), the following section still largely refers to the old / original land boundary definition of maximum cropland fraction of total land area.

Planetary boundary land, element 1 - downscaling of the planetary boundary to the relevant scale

Element 1 of the planetary boundary operationalization, downscaling of the global value, according to the old land boundary requires cropland not to exceed 15% of total ice free land, and according to the new boundary requires a remaining fraction of more than 50% of the original forest cover.

As for the climate change boundary, different "fair" allocations of the global boundary can be defined. Bringezu et al. (2012) argue that despite differences e.g. in development status, technical capability, land endowment, land use efficiency and climate, equal per capita targets (consumption-based) seem to be the most feasible option for operationalizing the planetary boundary land, also to prevent problem shifting e.g. between food, biofuel and other biomass production

Planetary boundary land, element 2 - adding temporal dynamics to the downscaling

Different from the climate change boundary, the land boundary does not represent a budget which will be depleted at some stage, but instead a flow boundary. If land is managed well, the land area available for agriculture and other uses remains constant and available year after year.

Planetary boundary land, element 3 - benchmarking of production-based environmental performance against the downscaled planetary boundary

The old / original land boundary of less than 15% cropland of total land area has been significantly transgressed for Germany (33% cropland according to DESTATIS) and the EU (24.7% cropland according to Eurostat, ranging from 4.3% in Sweden to 48.5% in Denmark). v

Planetary boundary land, element 4 - benchmarking of consumption-based environmental performance against the downscaled planetary boundary

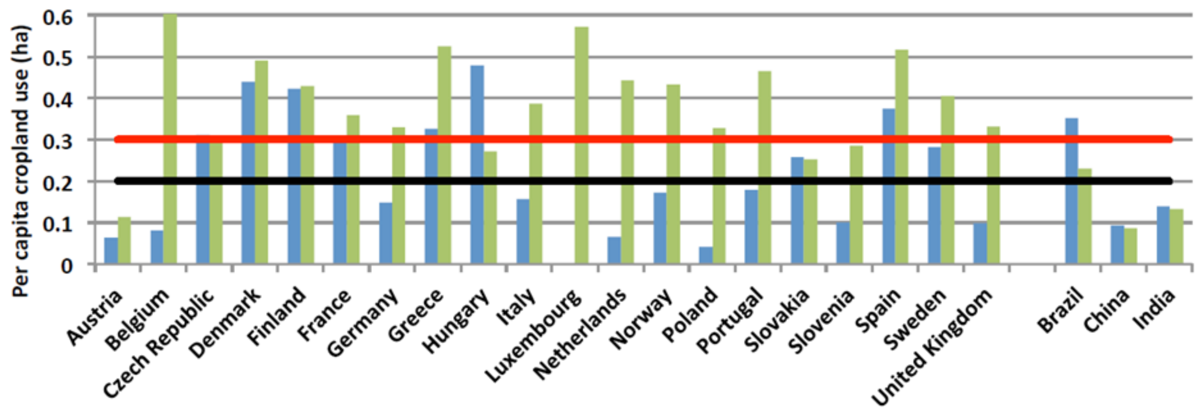
The increasing externalization of consumption-related pressures (through trade) is a key issue for the land boundary, even more so than for the climate change boundary. Germany and the EU are large net importers of agricultural commodities and biomass and hence strongly depend on agricultural production in other regions (e.g. soy from South America, palm oil from South East Asia or coffee and cocoa from Sub-Saharan Africa). Globalization causes trade with biomass-based products to grow much faster (at 4% annually between 1960 and 2010 - FAOSTAT) than their production (growing at 2% per year - FAOSTAT). Europe's net virtual land imports[36] with agricultural commodities follow this trend and have increased between 2000 and 2008 by about 10 million ha, from 25 to 35 million ha (excluding grassland), an area equivalent to the size of Germany (von Witzke and Noleppa 2010). Kastner et al. (2014) found that in the EU-15 the cropland area decreased (from around 70 Mha to 60 Mha), whereas consumption has stayed quite stable, so that imports of virtual land accordingly had to increase (from around 35 Mha to around 45 Mha).

Initial consumption-based benchmarking of land use against the downscaled planetary boundary land has been enabled by multi-regional input-output models and physical flow analysis methods. Yu et al. (2013) found that more than 50% of land use for the EU's consumption occurs out-side of the EU, by appropriating for example 23% of Argentinian cropland or 20% or Brazilian cropland.

Similarly, Tukker et al. (2014) found for the EU total (not only cropland) consumption-based land footprint of more than 2 ha per capita - more than twice the production-based land footprint, meaning that more than 50% of Europe's pressure on the planetary boundary land occurs externally, outside of Europe. For Germany they calculate net imports of virtual land of about 2 ha per capita. UBA calculate more than 13 million ha of net imports of virtual agricultural land (or 0.16 ha per capita). This agricultural land area in other countries for producing export goods for final consumption in Germany is almost the same as Germany's domestic agricultural area (14.7 million ha). UBA (2016a) finds that 2/3rd of all land use for meeting Germany's consumptive demands takes place outside of Germany, most of it in other EU countries, followed by South America, Sub-Saharan Africa and South-East Asia.

Hoff et al. (2014) compare for different European countries production- and consumption-base per capita cropland use:

Figure 48: Europe's per-capita cropland use, from Hoff et al. 2014



Source: Hoff et al. (2014)

Blue bars indicate production based per-capita cropland use, green bars consumption-based per capita cropland use. The black line indicates the actual global average per capita land use and the red line the allowable per capita land use for equal per capita downscaling of the old land boundary: while only very few European countries exceed the downscaled planetary boundary land on a production-basis, almost all countries do so on a consumption-basis, after Nykvist et al. (2013), Bruckner et al. (2012), and FAOSTAT.

[36] „Virtual land" imports stands for land used along the supply chains to produce the goods and services that are eventually imported

Soy production alone (soy is almost not produced in Germany) requires 2.4 million ha of land abroad for meeting Germany's total consumptive needs (Dawkins et al. 2016), which equals about 15% of Germany's total domestic agricultural land or about 25% of Germany's total cropland. Most of that soy (primarily used in Germany as livestock feed) is produced in South America, where it directly or indirectly replaces forests, hence contributing to defor-estation and to transgression of the land boundary. That confirms the finding by DeFries et al. (2010) that loss of tropical forests is positively correlated with exports of agricultural products. The EU is responsible for 10% of the total trade related deforestation. In terms of deforestation related to the trade with crop and livestock the EU is even responsible for 36% (Cuypers et al. 2013).

In order to assess the local impacts ("footprints") of export production, e.g. for German consumption, high resolution (higher than country level) data about the exact production location is required. Recent work by the Stockholm Environment Institute (SEI) has achieved that high resolution, tracing for example Germany's soy imports back to individual municipalities in Brazil (Dawkins et al. 2016). Such an accounting for local context in the export production country, e.g. in terms of resource scarcity or vulnerability of land and ecosystems, enables true footprints in the sense of local impacts and eventually the contextualization of downscaled planetary boundaries. Godar et al. (2015) could show with this method for example, that Brazilian land use for export production to Europe has shifted from long-settled agricultural regions in the south of the country more recently towards the Cerrado and Eastern Amazon.

Planetary boundary land, element 5: mapping the results of planetary boundary downscaling and benchmarking onto relevant policy and environmental management areas and integration with context-specific bottom-up sustainability criteria

The results of the initial downscaling of the global land boundary and benchmarking Germany's and Europe's actual environmental performance against the downscaled boundary are relevant for a range of different policy areas, related to environment, sustainability but also other sectors

Possible entry points for mainstreaming the above results on the global land boundary include (but are not limited to):

- the German land target of converting less than 30 ha per day into settlements or traffic areas per (by 2020)
- the no-net-land-take target of the EU (by 2050)
- the Forest Strategy (Waldstrategie 2020 of Germany)
- the Integrated Environment Program (Germany)
- the Environment Action Program (EU)
- the Common Agricultural Policy (EU)
- Bioeconomy Strategies of Germany and the EU[37]
- the raw materials strategy (Rohstoffstrategie of Germany)
- the flagship initiative "resource efficient Europe"
- Circular Economy Strategy (EU)
- Trade agreements

[37] Non-food biomass production on external land has the highest growth rates (UBA 2016)

However, the downscaled global land boundary is only one element in informing sustainable land use. Besides global environment and sustainability criteria, also local, national and regional criteria need to be taken into account, eventually requiring an integration of top-down and bottom-up criteria in policy and decision making. Accounting for local context and criteria also has to include land quality related metrics (beyond quantity related metrics such as hectares of land use), such as land use intensity, type of agricultural land use or forest, land degradation status etc.

1.4.4 Conclusion

In conclusion, the planetary boundaries will continue to be developed and refined further by the scientific community. Given the large interest by potential "user groups", i.e. policy and decision makers, this development should be aligned with the initial efforts towards planetary boundary operationalization. The exploration of elements of a potential method for downscaling planetary boundaries and of using these as benchmarks for environmental performance in the German and EU context as presented here, shows that relevant new information and added value can be generated this way, while this exploration at the same time can feed back insights to the scientific community about the relevance of the planetary boundaries as they are currently defined.

Scientists and policy makers need to collaborate on further developing the proposed elements of a method for planetary boundary operationalization, for example by further defining the normative and ethical aspects involved and by further contextualizing the downscaled planetary boundaries. Initial science-policy dialogues show that there are numerous opportunities for demand driven planetary boundary operationalization, starting from ongoing policy processes, to which downscaled planetary boundaries can add value, in particular by strengthening vertical and horizontal policy coherence (across scales and sectors). With that the planetary boundaries can take a role as dashboard for sustainability (Cornell and Downing 2014).

The initial exploration and application of the planetary boundaries to Germany and the EU has demonstrated the importance of going beyond territorial or domestic environmental performance and include also external environmental pressures and resource use, mostly transmitted via trade. Only such benchmarking of consumption-based performance against the planetary boundariess can capture a nation's full responsibility for planetary boundary transgression, as related to its consumption patterns. It can also specify where on Earth the impact occurs and what that means for the Earth system.

Additional conclusions from this initial exploration of planetary boundary operationalization for Germany and the EU are: per-capita contribution to planetary boundary transgression is significantly higher than global average. For the boundaries explored so far (climate change, land use change and nitrogen) it doesn't matter, whether the respective global boundary is already transgressed or not, the downscaled planetary boundary is transgressed at the German and EU level in any case, in particular when taking a consumption-based perspective. Positive territorial or domestic trends of decreasing pressure on planetary boundaries are often (over-) compensated by increasing external pressures. Total consumption-based environmental performance doesn't seem to improve in Germany and Europe for these planetary boundaries.

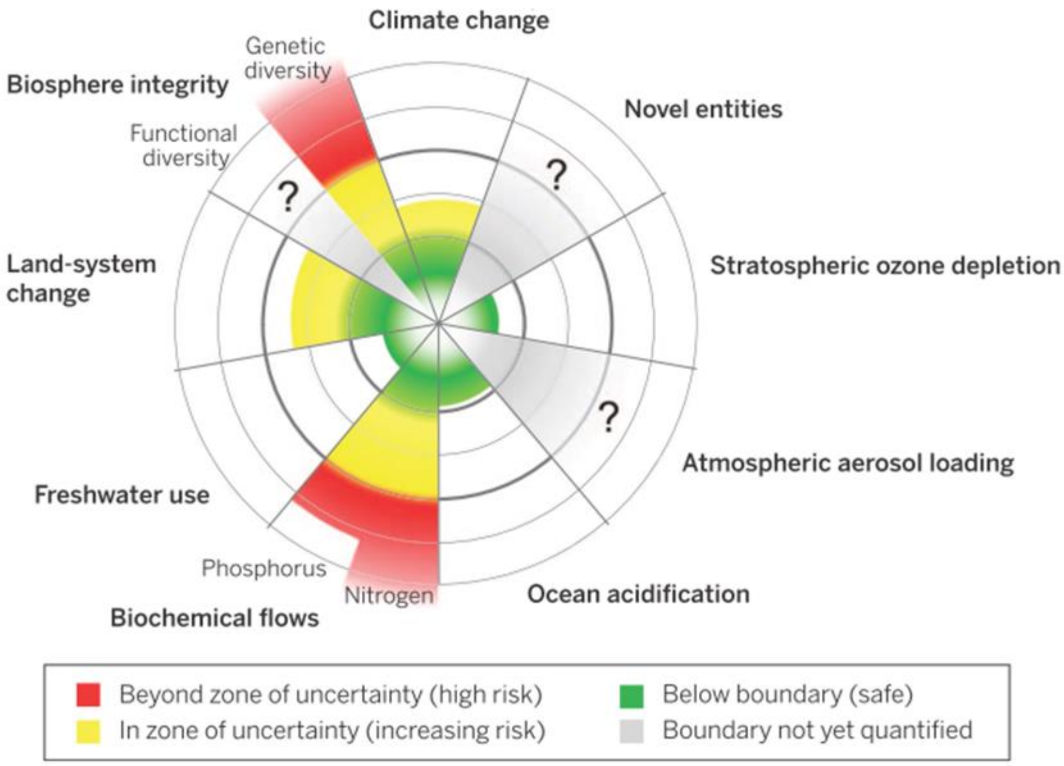
1.5 The communicative potential of the planetary boundaries concept

1.5.1 Introduction: communicating planetary boundaries

As environmental degradation continues apace, the scientific community has increasingly warned of the repercussions for humanity. One such warning takes the form of the planetary boundaries framework (Rockström et al. 2009; Steffen et al. 2015a). Originally published in a 2009 article by a group of 29 scientists led by Johan Rockström, the planetary boundaries framework outlines global environmental problems facing the Earth. The report identifies nine processes that are vital for ensuring the functional stability of the Earth's system, namely: climate change, novel entities, stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biochemical flows, freshwater use, land-system change and biosphere integrity (Steffen et al. 2015a). The authors argue that global thresholds exist for these processes and establish boundaries for ensuring a "safe operating space for humanity" (Rockström et al. 2009).

Of key importance in terms of communicating the planetary boundaries framework is a central illustration contained in the report. This illustration – Figure 49 – presents the nine processes and their current status.

Figure 49: The planetary boundaries



Source: Steffen et al. 2015a

The planetary boundaries framework has a number of goals, including environmental monitoring and the provision of an overarching research framework. One major goal is communication: at its heart it aims to inform readers about the risk of certain environmental developments and illustrates the need to focus on a safe operating space for humanity. The implicit hope is that the planetary boundaries framework can provide a focal point for governments, enabling them to target sustainability.

The planetary boundaries framework is still a relatively new concept. It has received great attention in the scientific community and to some degree among policymakers and civil society. It offers opportunities for environmental politics by highlighting the importance of environmental policy measures, raising awareness of the international dimension of environmental efforts, and enabling a connection to be made with socio-economic development issues – vital for reaching a broader audience. It is thus of great interest for national environmental politics.

In this paper we examine how the planetary boundaries framework can be used in environmental politics. In particular, we investigate here the communicative aspects of the planetary boundaries framework: its language, illustrations, messages, contents, communicative functions, and its use with target audiences.

Research into the communicative aspects of the planetary boundaries framework is rather sparse. Most publications to date have focused on the scientific arguments, such as how the boundaries are calculated (e.g. Bass 2009; Brook et al. 2013). The limited number of studies that have come from the social sciences mostly deal with questions of governance (e.g. Biermann 2012; Galaz et al. 2012b; Galaz et al. 2012c) and analyse the "governance challenge" arising from the planetary boundaries message. Others research the concept's relationship with social justice, establishing and applying social boundaries (e.g. Raworth 2012; Dearing et al. 2014). Some of these studies touch on communicative questions, for example when reviewing the evidence for the planetary boundaries framework (Nordhaus et al. 2012) or critiquing its incorporation of thresholds (Schlesinger 2009). However, the question of communication generally remains a side issue for the studies' authors.

In this paper, then, we aim to address this gap. We systematically assess the planetary boundaries framework potential for environmental communication.

It is important to differentiate between different understandings of the scope of the planetary boundaries framework, namely:

- The original article by Rockström et al. published in the journals Nature[38] and Ecology and Society[39], and its updated version from 2015 by Steffen et al. (Steffen et al. 2015a)
- Related research that further develops the planetary boundaries framework, such as contributions to the debate on the N-Boundary (e.g. de Vries et al. 2013)
- Attempts by Rockström and others to spread the message of the planetary boundaries framework in additional papers, articles, interviews, etc.

This study assesses the potential of the planetary boundaries framework primarily with regards to the two original articles by Rockström (2009) and Steffen et al. (2015). For this there are two reasons. First, the two articles form the backbone of the framework and the focus point of the subsequent debate. Second, including secondary sources such as additional contributions and interviews would make it difficult to differentiate between the framework and its application.

This paper is structured as follows. First we examine the communicative strengths of the planetary boundaries framework. Next we look at the German discourse on planetary boundaries, identifying specific risks and opportunities when using the planetary boundaries framework for communication and specifying the precise communication gap.

Following this we seek to understand the communication gap by outlining specific communicative weaknesses in the concept. In a fourth step we describe the messages of the planetary boundaries framework and their complexity. After this we describe particular functions of the planetary boundaries framework for communication and look at the target audiences. Finally we provide recommendations for the further conceptual development of the planetary boundaries framework from a communication perspective, with suggestions on how to improve the visual language and ideas for supporting narratives.

[38] Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: A safe operating space for humanity. In: Nature 461:7263, pp 472–475.

[39] Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: A safe operating space for humanity. In: Nature 461:7263, pp 472–475.

1.5.2 Planetary Boundaries: communicative strengths

The planetary boundaries framework is often regarded as a success story, offering great potential for environmental communication[40]. For example, Bob Howarth (Professor of Ecology and Environmental Biology at Cornell) argues that the planetary boundaries have a strong communicative value (Lalasz 2013):

> *"Targets are inherently artificial, and yeah, you're going to go over them, but they are an effective way to communicate to policymakers and the public […]. So I view planetary boundaries as a pretty powerful synthesis and communications tool."*

Sarah Cornell outlines how the planetary boundaries framework can be used at a national level or among other actors (Cornell 2015):

> *"One way in which it is already being used is as a powerful communication tool about global sustainability, informing discussions in local communities, businesses, and many kinds of organisation."*

In a survey of members of the European Sustainable Development Network, Pisano and Berger describe the situation in the Netherlands as follows (Pisano and Berger 2013):

> *"In the Netherlands, the concept is particularly seen as a strong communication tool, visualising the main challenges, especially in the early stages of policy formulation (agenda-setting)."*

At first sight, then, the planetary boundaries framework appears to be an attractive communication tool with a number of highly positive characteristics:

Easy-to-grasp message

Parts of its message are easy to grasp. For example, the notions of "boundaries" and "limits" are already present in the political discourse and are easy to understand. The same goes for the idea of human impacts on the environment and the risk of an inhospitable planet, which already exist in the debate on the impact of climate change. These ideas do not need much further explanation.

Universal appeal

The planetary boundaries framework has universal appeal. It is directed towards the whole of humanity and encompasses all possible actors – individuals, organisations, businesses, governments, supranational and international organisations, etc. It also touches on a broad variety of topics, from climate change to water and land use. As a consequence the planetary boundaries framework can be used in a wide range of environmental discussions and refers to many actors.

Metaphorical and visual nature

The planetary boundaries framework uses metaphors ("the great acceleration", "an inhospitable planet", "boundaries") and other images ("the Earth", "space"). These are important tools for communication, making it easier for the audience to grasp the underlying message.

[40] There are different definitions of environmental communication (compare Jurin et al. 2010). Cox for example defines it very broadly as "pragmatic and constitutive vehicle for our understanding of the environment as well as our relationships to the natural world; it is the symbolic medium that we use in constructing environmental problems and negotiating society's different responses to them" (Cox 2010: 20). In this paper we take a narrower perspective – the term refers to communication by governmental and non-gonvernmental actors to "inform and educate individuals" on environmental problems and risks and the necessity of environmental protection, to "achieve some type and level of social engagement and action" or changing the more long term, structural factors of "social norms and cultural values" (Moser 2010).

A concept grounded in science, with trustworthy messengers

The planetary boundaries framework is grounded in science. It includes contributions from various academic fields and builds on debates taking place within the scientific community. This is beneficial in terms of its communication, as scientists are generally viewed as credible authorities by society.

The planetary boundaries framework thus appears to have significant potential for reaching different segments of society, including the broader public, businesses, civil society and political actors. In theory it can serve as a central tool for communication about the environment, encouraging target audiences to reflect on its message (e.g. targets, global sustainability, key-challenges), changing their awareness of the state of the environment, and redirecting the discourse where necessary.

But is the planetary boundaries framework really as effective as the above comments would appear to suggest? It is to this question that we turn our attention in the following chapters.

1.5.3 Tracing the German planetary boundaries discourse: realising the communication gap

There are two good reasons for charting the German discourse on planetary boundaries. First, doing so provides us with insights into the impact of the planetary boundaries framework on potential target audiences, showing whether actors from different segments of society have used the framework and if so, how. It thus serves as a reality check for the communicative potential of the planetary boundaries framework.

Second, it helps us understand the risks and opportunities relating to the framework. Environmental communication operates within a discursive environment. This overarching discourse can legitimise or de-legitimise specific arguments, environmental values, behaviours, policies and so on. Different discourses and the actors connected with them make use of different concepts and approaches, including scientific findings and messages. Vitally, we must be aware in our environmental communication of how a particular concept is used and by whom, what discourse it appears in, how it is interpreted, and what political measures it legitimises.

The planetary boundaries framework includes various concepts, and is thus connected with the discourses where these concepts arise. The concepts include:

- The "Anthropocene": humanity is altering geological conditions and processes so profoundly that it has become a geological force which has triggered the planet to enter a new geological age (Crutzen 2002; Steffen et al. 2011c)
- The "resilience of the Earth": the planet's ability to stay within a Holocene-like state is impacted on by human actions
- "Tipping points" on a planetary scale: crossing these points could result in a planetary "regime shift"
- "Sustainable development", which implies the importance of "guardrails" (see below) for human development

These concepts are explicitly mentioned in the original framework (Rockström et al. 2009; Steffen et al. 2015a). However, it is unclear to what extent they and other concepts appear in the discourse on planetary boundaries framework in practice.

In this paper we focus solely on the situation in Germany. While limited in terms of how far the findings can be generalised, this is an important first step in increasing our understanding. We focus on political discourse rather than the scientific debate, as it is often difficult to separate a specifically German contribution to the scientific debate from an international contribution (many German researchers participate in the global research community).

For the purposes of our analysis, 107 documents dating from the period 2010-2015 were collected from diverse sources (see annex for a full list). They included:

- Documents from German civil society (32 documents)[41]
- Documents from German federal ministries and the German government (10 documents)
- Debates in the Bundestag (the German parliament; 18 documents)
- Documents from political foundations and parties (39 documents)

The documents were collected by searching for the terms "Rockström", "Steffen", "planetary boundaries" and "safe operating space" (in German and English) using publicly accessible search engines from relevant organisations and institutions. References were then analysed on the basis of the following questions:

- Who is using the framework?
- How is the framework interpreted?
- For what purpose is it used and what discourses are connected with it?
- What means are legitimised?

We also looked at how the planetary boundaries framework has been used over time by the press (for the period 2009 - 2015). We did this by searching the WISO press database, which covers the archives of many of the larger German-language newspapers and entails ca. 146 million articles (e.g. SPIEGEL, Focus, Neue Zürcher Zeitung, taz, Die Welt and many smaller newspapers; for a complete list, see WISO 2016).

Use of the planetary boundaries framework over time

The level of use of the planetary boundaries framework has changed over time. Some actors have used it more as time has gone on, while others have maintained more consistent levels. For example, the majority of references by the Bundestag and the German government date from 2015, signifying an increase over time; political parties, political foundations and civil society organisations on the other hand are more constant, with no visible increase in frequency. Looking across all references, it took until 2011 before the planetary boundaries framework was referred to more widely. The growth in the frequency of references by some actors may imply that the PBF is increasingly seen as an important factor in political debate and environmental communication.

Actors

German government institutions occasionally refer to the planetary boundaries framework. This includes the Federal Chancellery and the following ministries: (1) the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB); (2) the Federal Ministry for Economic Cooperation and Development (BMZ); and (3) the Federal Ministry of Family Affairs, Senior Citizens, Women and Youth (BMFSFJ). Chancellor Angela Merkel referred to the planetary boundaries framework in speeches on refugees and the causes of migration, and when talking to the Council for Sustainable Development. Environmental Minister Barbara Hendricks referred to the planetary boundaries framework in two speeches: during a parliamentary debate on climate change and in a debate on the Post-2015 agenda. The BMUB and BMZ referred to the planetary boundaries framework in the context of the Post-2015 agenda. The BMFSFJ referenced it in a report on the implementation of

[41] Given the large number of civil society organisations in Germany, it was not possible to cover all instances of discourse on the PBF.

the Peking +20 action platform. There were also several debates in the Bundestag where speakers referred to the planetary boundaries framework, e.g. debates on ocean pollution, global education and conflict minerals.

Political foundations used the planetary boundaries framework on various occasions. Examples include references in documents on resource justice, food security, disaster reduction, and on the planetary boundaries framework itself. The German Advisory Council on Global Change (WBGU) draws on the concept, although it prefers the term "guardrails": for example, in a policy paper to the SDG debate, the WBGU argues for incorporating these guardrails into the SDG catalogue (WBGU 2014). Also, in a major study advocating a social contract for transition, the WBGU both refers to and uses the concept of the planetary boundaries framework (2011), and it promotes the concept in some of its outreach material, too.[42]

German civil society also occasionally makes references to the planetary boundaries framework, mainly though charitable and development organisations (e.g. Brot für die Welt) and climate and environmental lobby groups (e.g. Germanwatch; BUND). For example, Brot für die Welt used the planetary boundaries framework in a report on Agenda 2030, the BUND used it when criticising the government for a new law on electric appliances, and Greenpeace referred to it when directing its political demands to the government.

The German mass media rarely refers to the planetary boundaries framework. In the WISO press database the search term "planetare Grenzen" in German ("planetary boundaries") returns just 13 results for the period since 2009, the term "planetary boundaries" in English 10 results, and "Johan Rockström" 56 results, mainly in articles on the awarding of the German Environment Prize (Deutscher Umweltpreis) to Johan Rockström by the Deutsche Bundesstiftung Umwelt.

Interpretation of the planetary boundaries framework

The planetary boundaries framework is interpreted differently depending on the context. Very often, it is explicitly or implicitly referred to as an objective, absolute, scientific, authoritative account of the risks facing humanity. For example, in a parliamentary debate on the German environmental budget, the Green Member of Parliament Steffi Lemke asserted as follows (Drs.-Nr. 18/138; translation ours):

"We have evidence from a sufficient number of studies that four of the nine planetary boundaries have already been transgressed."

The planetary boundaries framework is seldom presented as a new finding, however. Instead it is argued that it repeats well-known facts which people should be more aware of, such as the degradation of the environment.

Interestingly the planetary boundaries framework appears to lend itself to a selective interpretation. Some features are rarely mentioned, such as the interaction between boundaries and the systemic character of the approach. Sometimes the focus is on specific boundaries, most often the climate change boundary. This indicates that the full message of the PBF is not reaching its audience.

Several misconceptions appear in how the planetary boundaries framework is interpreted:

(1) Frequently, uncertainties that are acknowledged in the original framework (e.g. about the existence or exact level of thresholds, or the interaction between different boundaries) are not addressed.

(2) In some cases thresholds/tipping points and boundaries are confused or the terms used interchangeably. Thus a report for the political foundation Konrad Adenauer Stiftung (Haas 2010; translation and emphasis ours) states that:

[42] See, for example: http://www.wbgu.de/en/videos/videos-wbgu/en-video-leitplanken.

"In their study on the safe operating space, Rockström and his colleagues have tried to determine ***thresholds*** for the nine ecological factors named, which should not be transgressed for reasons of safety. They found that humans are operating outside of ***these boundaries*** in three cases. With unknown consequences."

(3) In one case it is implied that the safe operating space and the transgression for the climate change boundary can be interpreted as showing the healthy state of the boundary and more room for CO_2 emissions (Drs.-Nr. 1843, translation ours):

"We all acknowledge that the planetary boundaries – that is, the limits of the ecological dimension of the globe – risk being reached and transgressed. This has already happened with nitrogen. With $CO_{2,}$ we still have a huge budget. At least, the number looks huge; but it is not that huge."

In fact, the climate change boundary is indicated as already having been transgressed in both Rockström et al. (2009) and the update by Steffen et al. In the logic of the planetary boundaries framework, an increased risk of crossing thresholds already exists. Thus it would appear that the yellow climate change boundary in Steffen's update (Steffen et al. 2015a) is open to misinterpretation.

Argumentative purposes and discursive connections

The planetary boundaries framework is used for different purposes. This connects it to the discourse on (1) global challenges, (2) sustainable development and transformation, (3) climate change, (4) environmental degradation, and (5) human safety and survival.

Some actors use the planetary boundaries framework simply as an example of the global crises or planetary challenges that the political process is facing. Planetary boundaries, their transgression and the need to respect them are merely examples in a long list of other priorities, such as unemployment, civil wars and refugees. The details of the framework (e.g. the number and precise nature of the boundaries and the consequences of transgressing them) are not relevant for this use; it is taken for granted that the audience intuitively knows that going beyond certain ecological limits is potentially risky and that preventing this therefore merits high priority.

The planetary boundaries framework is also used within the discourse on sustainable development to illustrate the apparently conflicting goals of development and sustainability. Here, the planetary boundaries framework is often employed as the latest version of ecological sustainability – without however referring to other elements of the framework, such as the notion of "tipping points" or "regime shifts" on a planetary scale, or the uncertainties contained in the framework.

Sometimes the planetary boundaries framework is used merely to depict the state of the environment, sub-processes of the environment (climate change, extinction of species) or even highly specific impacts (e.g. the impact of food waste on the environment). This ignores the developmental dimension of the planetary boundaries framework – that the planetary boundaries are a condition for sustainable development; no mention is made of the fact that the planetary boundaries framework focuses on the planetary dimension and does not, in its original conception, easily correspond to local environmental impacts such as that of nitrogen.[43] This use also neglects other environmental problems not covered by the framework, such as industrial and traffic noise or radiation.

On occasion the planetary boundaries framework is referred to in the context of climate refugees, peace, resource conflicts or even the survival of humanity. For example, in a parliamentary motion on trade politics, the Green Party argued (Drs.-Nr. 18/6197, translation ours):

"In light of future challenges, political room for manoeuvre for additional regulations should not be impeded to secure the survival of future generations within planetary boundaries."

[43] Note, however, recent attempts at downscaling (e.g. Nykvist et al. 2013; Cole et al. 2014; Dearing et al. 2014).

The connection with security and survival not only attracts people's attention, it also risks unintentionally legitimising more robust security measures (see Buzan et al. 1998). To depict a phenomenon as an existential threat for the survival of humanity legitimizes exceptional measures by governments such as the use of force. However, the effect might as well be the opposite: Doubts about apocalyptic scenarios connected to the planetary boundaries framework might delegitimize the whole concept.

The Anthropocene, "resilience" and "tipping points" are rarely referred to. It appears that, unlike "planetary boundaries", these concepts are less accessible to many in the political realm and would need further explanation for their target audiences (e.g. for discussions in the Bundestag). It also appears that the planetary boundaries framework is not primarily used as a clarification or further development of these concepts.

Policy measures

A multitude of different measures are proposed for respecting planetary boundaries, directed at different levels and covering different topics. For example, some measures are directed at individuals: changing personal lifestyles and consumption patterns, say. Others focus on a single country (in this case Germany), for example demanding the transformation of the socio-technical regime be it by means of the "Energiewende" ("energy revolution"), a change in resource consumption or the end of coal mining and coal-based energy production. Sometimes a larger frame is opened up and it is pointed out that improvements in development policies such as adequately financing development, formulating and implementing strong post-2015 SDGs or improving education for sustainable development (ESD) are necessary prerequisites to achieve sustainability.

The measures proposed also differ in terms of their contents. Sometimes they recommend general improvements in political processes, such as increasing political coherence, changing existing policies, achieving political unity or reviewing the national Sustainable Development Strategy. In other cases they relate the planetary boundaries framework to specific environmental policies and priorities, such as sustainable city policies, the reduction of environmentally harmful subsidies, the implementation of existing biodiversity targets and the two-degree climate change target or improved nitrogen regulation. In some instances, boundaries, innovations, new technologies and economic development are proposed to help boundaries be respects. Or it is argued that the solution for staying within planetary boundaries lies in taming the markets, ending the free trade dogma and radically altering the economy.

The wide range of suggestions indicates that the planetary boundaries framework does not lead directly to specific political measures but rather blends into the existing debate around policy actions. Nor does it appear to prompt new debates on policy initiatives.

Conclusion

In conclusion, the planetary boundaries framework is sometimes misunderstood and often used and interpreted selectively. It does not change the existing discourse, and those who draw on it may refer to discourses that are not included in the planetary boundaries framework while ignoring others that are included in it.

To some extent the planetary boundaries framework has thus moved from being a scientific debate (by and between specialists) to the wider political realm. Occasionally it is referred to by actors in civil society, but it has not reached the private sector (with the exception of few companies like MARS, H&M, ENECO) or the broader public. The extensive academic discussion around the PBF is only partially mirrored in the political community, the world of business, and society.

Although political actors refer to the planetary boundaries framework sometimes, they use it to underpin their existing political demands rather than start a discussion about the PBF as a whole and its significance for policymaking.

At present, then, the role of the planetary boundaries framework in environmental communication is rather limited. A significant gap exists between the communicative potential claimed for it and its actual impact so far.[44]

1.5.4 Understanding the communication gap: communicative weaknesses of the planetary boundaries framework

As we have seen in Chapters 1.5.2 and 1.5.3, a gap exists between the aspirations of the planetary boundaries framework in terms of communication and its actual impact to date. In this chapter we attempt to account for this gap by examining the communicative weaknesses of the framework. This should to some extent explain the limited communicative role of the planetary boundaries framework so far.

Complexity

The planetary boundaries framework is fairly complex, encompassing many different topics and issues (see Chapter 1.5.5). This complexity is due to two main factors: the openness of the concept for different interpretations (risk vs. opportunities), and the fact that it incorporates a number of different, multilayered issues such as boundaries, transgressions, risk zones and as yet unquantified areas. If social boundaries are also included (as discussed in a forthcoming input paper), communication becomes even more difficult.

The term "planetary boundaries"

The term "planetary boundaries" only partially captures the concept underlying the planetary boundaries framework. It fails to communicate the systemic character of the approach and its multi-scale nature (see Cornell 2012 on the different scales at which the control variables are observed). The term "planetary boundaries" also lends itself easily to scare-mongering: the discussion can easily focus on the negative aspects of the concept, such as transgressing boundaries, rather than the positive image of a safe operating space with possible links to other important areas such political and economic aspects and the vision of human stewardship preventing harmful global environmental change.

In the German context there is additional conceptual confusion regarding the term "planetary boundaries". The word "boundaries" is sometimes translated as Leitplanken ("guidelines", "guardrails"), sometimes as Belastungsgrenzen ("loads"), and sometimes as Grenzen ("limits"). While this is a specifically German problem, it implies that there may be problems in applying the planetary boundaries framework in specific countries: problems of translation or interpretation may blur the message of the planetary boundaries framework.

Weak positioning in time and place

The planetary boundaries frameworks message is not strongly rooted in a specific time and place. In terms of place, it refers to the Earth system, the planet as a whole, and the globe; with regard to time, it talks about the Anthropocene and the Holocene – two very long epochs which are hard to imagine. The updated version of the planetary boundaries framework (Steffen et al. 2015a) focuses more on the regional dynamics of some of the processes, but as a whole the PBF does not relate its message of complex, interdependent, long-lasting causes and effects to specific places and time spheres that people can easily relate to.

[44] Our comments refer primarily to Germany, but the situation is likely to be similar in other countries. In fact, with the WBGU, a semi-governmental institution, already advocating the concept, communicating it and disseminating it in the public discussion, Germany is something of a "best case"; there is little reason to believe the situation is substantially better in other countries.

Unclear implications

The consequences of transgressing planetary boundaries and tipping the Earth system into a new regime are unclear in the planetary boundaries framework. The framework alludes to an "inhospitable" planet, but what this precisely entails – who is impacted, to what extent, and can the effects be reversed – is not outlined. It is left to the individual imagination what exactly this inhospitable planet would look like. Moreover, several planetary boundaries (e.g. the biochemical boundary) have already been transgressed but the Earth system has not yet tipped into a new regime and the impacts are not widely felt by the populace. We are thus faced with the problem of not being able to paint a precise picture of the consequences of overstepping the safe operating zone in our environmental communication efforts.

Uncertain prioritisation

The planetary boundaries framework allows for the prioritisation of environmental problems, implicitly giving the various boundaries different weight. However, there are a number of different ways to derive priorities from the framework.

The first, most obvious way is to use the illustration contained in the planetary boundaries framework and derive priorities on the basis of the colours used (see Figure 49):

- High risk: biosphere integrity, biochemical flows
- Medium risk: land-system change, climate change
- Low risk: fresh water use, stratospheric ozone depletion, ocean acidification
- Unknown risk: novel entities, atmospheric aerosol loading

However, the planetary boundaries framework itself points out that the different boundaries interact with each other, albeit in a way that is not well understood. This means that neglecting one boundary could be detrimental to another boundary (see also Steffen et al. 2015a), calling into question the above prioritisation.

The updated version of the planetary boundaries framework points to the central role of climate change and biodiversity for the resilience of the planet. This implies another prioritisation. Yet climate change is only considered "medium risk".

For a proper prioritisation we would need to know the current trends and dynamics for the various boundaries and the degree of reversibility of transgressions. The planetary boundaries framework does not contain this information. Thus while the planetary boundaries framework sends out a strong signal about key environmental problems, it does not clearly state which problems are the most important.

No indication of next steps

The planetary boundaries framework does not recommend political or other measures for respecting planetary boundaries; the focus is on the "guardrails" for sustainable development rather than specific pathways. From a communicative standpoint, a message that simply points out dangers or risks without outlining practical steps leaves further action open to discussion and misses out on the opportunity to provide guidance to target audiences. Readers are left with the impression that the Earth system is at risk – four boundaries have been crossed – but the way out is unclear (see Chapter 1.5.8 for the role of political actors for formulating political measures to stay within the safe operating space).

Ambivalent normativity

The planetary boundaries framework sits somewhat ambivalently between normative and non-normative arguments. On the one hand, it sets out to determine science-based boundaries, condensing existing findings on the Earth system, thus implying a certain objectivity while not ignoring uncertainties. On the other, it is inherently normative, as the proposed boundaries include subjective risk considerations and are ultimately based on social considerations (see the forthcoming input paper on social boundaries). This normativity is not arbitrary; it is a reflection of the assumed risks for crossing thresholds. However, it represents a weakness of the planetary boundaries framework in terms of its communicative strength.

Low level of public involvement

The planetary boundaries framework lacks references to participation by citizens or public involvement. While not explicitly precluding such participation – e.g. by arguing for top-down policy measures only – it indicates implicit barriers in some areas: control variables and boundaries are set top down through scientific discourse; humanity is conceived of as an aggregate (this is sometimes dubbed the "problem of the invisible human"); secondary characters are elites such as scientists and political decision-makers. As a consequence, many important actors such as businesses, societal organisations and individuals may not be able to see their role in relation to the planetary boundaries framework.

Technical language

The planetary boundaries framework uses different levels of language. In places it is quite technical: Rockström et al. speak of "biogeochemical cycles", "thresholds" and "resilience", while Steffen et al. speak of "atmospheric aerosol loading", "stratospheric ozone depletion", "global and regional scales", "biomes" and so forth (Steffen et al. 2015a; Rockström et al. 2009). The planetary boundaries framework also includes more narrative language, for example when outlining the risks for humanity or telling the story of human perturbation. Overall, the often abstract, technical language requires further clarification for some potential target audiences. These include not just companies and individuals but also civil society organisations working in non-environmental areas.

Display of Dangers

The introductory paragraph and the summary in the original article argue that the human impact on the Earth system could be "deleterious or even catastrophic for human well-being" (Rockström et al. 2009). It speaks of "dangerous thresholds", a "dangerous level", a "danger zone", "dangerous climate change" and "planetary risks". This scenario is contrasted with the Holocene state, which provided for a "relatively stable environment" that "allowed agriculture and complex societies, including the present, to develop and flourish" (Rockström et al. 2009). The updated planetary boundaries framework softens the language somewhat, using the word "danger" only once. It replaces "deleterious" and "catastrophic" with the expression "much less hospitable" (Steffen et al. 2015a). For environmental communication, the use of loaded language represents a particular problem: risk communication research has shown that talking about dangers, threats and horror scenarios create initial attention with target audiences but has no long-lasting effects (Adomßent and Godemann 2011; O'Neill and Nicholson-Cole 2009).

Misleading illustrations

The grey fields and question marks in the main illustration represent the boundaries "novel entities", “functional diversity” (biosphere integrity boundary) and "atmospheric aerosol loading", which are not yet quantified. This is a problem. The underlying communicative challenge is that the risks associated with these processes are not yet fully known or visible. Another problem is the colours used in the updated illustration (Steffen et al. 2015a): climate change, for example, is coloured yellow and not red (see Figure 49) despite the fact that – as the latest assessment report of the IPCC and also the Paris accords at the COP21 show – climate change should be assigned high priority. This fact could be blurred by the illustration. A third problem is that the best known illustrations from the PBF do not show interactions between boundaries, neglecting an important aspect of the framework.[45]

The planetary boundaries frameworks updated illustration is static, whereas Rockström's initial illustration also included developments for some boundaries (see Rockström et al. 2009). The new illustration shows the status of control variables at a specific point in time and does not show developments. Thus while the framework itself speaks of a "great acceleration", this acceleration is not visible in the illustration. Also, it is not clear when specific control variables (e.g. for ozone depletion) have increased or decreased, if at all, and to what factors these changes are attributable.

Conclusion

As demonstrated above, there are a number of reasons for the rather limited communicative impact of the planetary boundaries framework to date. Some of these problems can be overcome by additional research, improved language, a sharper focus on target groups and the like. Others are inherent to the PBF, such as the high degree of complexity, and can be mitigated but not entirely eliminated.

Despite the communicative weaknesses of the PBF, there are many areas where it can be used effectively. In the following chapters we attempt to define these areas by examining the planetary boundaries frameworks messages, its function and its target groups in more detail.

1.5.5 Planetary boundaries: messages

The communicative potential of the planetary boundaries framework is closely connected to its contents and the messages it implies. Understanding the planetary boundaries framework better can help us close the communication gap by providing a more sophisticated understanding of the role of the planetary boundaries framework in environmental communication. Two approaches are possible here: examining individual messages which can be derived from the planetary boundaries framework, and looking at the overarching picture created by it. Both approaches have specific implications for environmental communication.

The concept of "planetary boundaries" implies a multitude of separate yet interlinked messages. The planetary boundaries framework contains several core messages and many additional messages directly or indirectly related to them. These core and additional messages can be derived from the planetary boundaries frameworks main illustration (see Figure 49), from the broader framework and from other discourses connected with the contents.

For the status of the global environment, core messages of the planetary boundaries framework include for example:

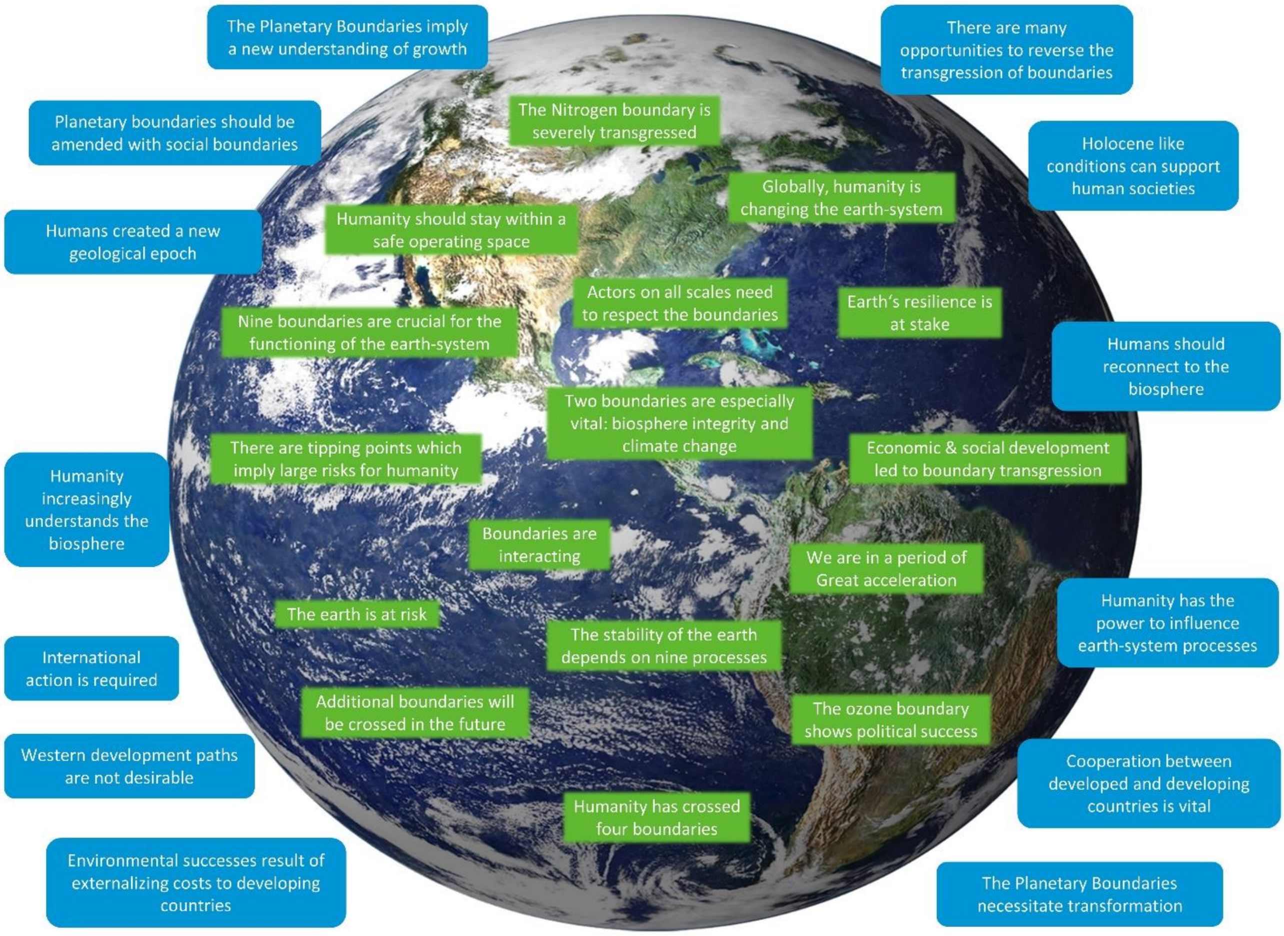
- The Earth system is at risk
- Four boundaries are transgressed
- Environmental degradation is rapidly increasing (the "great acceleration")
- Crossing boundaries risks global regime shifts
- For human-nature interaction, the additional messages include for example:
- Humanity should reconnect with the biosphere
- Humanity has the power to influence processes in the Earth system

[45] Note, however, Steffen et al.'s (2015) illustration in the supplementary material (see also Chapter 1.5.7).

- Humans have created a new geological age

Figure 50 (below) presents a selection of the messages contained in the planetary boundaries framework. Green clouds represent core messages, blue clouds additional messages.

Figure 50: Core and additional Messages of the Planetary Boundaries Framework



Source: from authors, adelphi

The messages shown in Figure 50 cover various areas of relevance for environmental politics and thus implicitly for environmental communication.

Important areas are for example:[46]

1) The environmental status: current aggregated global impacts, the dynamics of these impacts and possible future developments (the "great acceleration")

2) The role of societies and individuals in the environment, including their place on the planet and their behaviour towards the environment

3) The central principles of environmental politics, such as the precautionary principle, the principle of cooperation and the "polluter pays" principle

[46] These areas are exemplary and highlight the relevance of the PBFs message for environmental politics. They are not meant to be exhaustive, but focus on important elements of environmental politics such as the status of the environment (1), environmental principles (3) and the role and tasks of environmental politics towards society (2,4,5).

4) The strategic role of environmental politics in the political arena and society (transformative/integrative environmental politics)

5) The tasks of environmental politics and the areas it covers (German: "Schutzgüter")

With regard to the first area, some of the core messages – such as the current levels of control variables – contribute to an understanding of the environmental status. The planetary boundaries framework also often touches on the dynamics of environmental impacts, pointing out the startling and rapid increase in human perturbations to regulating sub-processes of the Earth system since the Second World War.

In the second area, the planetary boundaries framework also clearly implies to the need for individuals, businesses and society to reflect on their own role in causing environmental degradation and to find ways to operate within the boundaries, while not directly addressing them.

On point three, the planetary boundaries framework implies several specifications or re-specifications of core environmental principles. They include: emphasising the importance of the precautionary principle and interpreting the principle as respecting the planetary boundaries (keeping distance from thresholds); creating new (governance) options for cooperation at global level, and at the same time improving cooperation at regional and local level and for all sectors of society to respect planetary boundaries; and reflecting on the major polluters responsible for boundaries being transgressed, attribution gaps and time frames of mitigation.

In the fourth area, the planetary boundaries framework implies a new understanding of environmental politics. This involves considering global environmental change at all policy levels, focusing on the transformative role of environmental politics in all segments of society, and contributing to an economy that respects planetary boundaries.

As for the fifth area, the planetary boundaries framework has implications for the tasks of environmental politics and the areas it covers. It puts conditions for humanity in the centre of the analysis, with less of a focus on nature conservation. It also focuses on regulating ecosystem services rather than provisioning ecosystem services.

The multitude of different messages in the planetary boundaries framework and their connections with environmental politics result in communicative complexity, as we have seen in Chapter 1.5.4. The planetary boundaries framework does not have (or imply) a single overarching message or interpretation. It is a "communicative chameleon",[47] allowing for multiple perspectives on causes, consequences, the role of society and the role of individuals.

How the planetary boundaries framework is perceived depends on what "lens" the reader views it through. We identify two such lenses: a "risk-aware lens" and an "opportunity-orientated lens". Both lenses have implications for environmental politics and hence for environmental communication.

A risk-aware lens emphasises conservation. When viewed through this lens, the planetary boundaries frameworks messages become more negative. One might, for instance, stress the point that humanity can only live safely within a stable environment, or that if developing countries follow the unsustainable development paths seen in industrialised countries, more boundaries will be transgressed.

The opportunity-orientated lens, by contrast, emphasises humanity's creative and transformative power. Viewed through this lens, the planetary boundaries frameworks messages are more positive: one might stress that humanity is understanding the biosphere better and better and has considerable potential to control environmental impacts and problems.

[47] See Kahlenborn (2015): Das Konzept der Planetaren Grenzen. Kommunikative Bezüge zwischen dem Konzept der Planetaren Grenzen und dem IUP.

It is difficult to say which lens – risk-aware or opportunity-orientated – is to be preferred, or which is more effective in environmental communication. Each has its advantages and disadvantages. At first glance a risk-aware lens supports environmental politics in many ways, for example by outlining the importance of internationally agreed measures against detrimental global environmental change: highlighting the global risks of global problems (four boundaries crossed) legitimizes increased international cooperation and far-reaching policies. By contrast some of the messages associated with the opportunity-orientated lens appear to be less supportive of environmental politics, as they neither contribute to an understanding of the risks facing humanity nor immediately support political measures: illustrating human ingenuity could for example feed into a world view in which technological solutions or resource efficiency measures are perceived as sufficient.

On the other hand, the more negative messages associated with the risk-aware lens could feed into a discussion based on fear. This runs the risk of making target audiences apathetic. The more positive messages associated with the opportunities-orientated lens, by contrast, could inspire target audiences and have a positive impact on them.

The relative effectiveness of the two perspectives for reaching target audiences also depends on additional factors such as the accompanying messages, the predisposition of audiences to hear the messages, the overall communicative situation, and so on. It is thus not possible to say in advance which of the perspectives will be more effective.

In conclusion, the fact that the planetary boundaries framework contains a multitude of different statements is both strength and a weakness. It is important to realise that the planetary boundaries framework cannot be reduced to a single issue, such as the safe operating space. The range of different topics it covers means that it can be used in many different contexts, as is evident from our analysis of the discourse surrounding it (see Chapter 1.5.3). Thanks to its manifold messages it is also suitable for selective communication supporting environmental positions in specific debates (e.g. on climate change or nitrogen, or in integrative environmental politics).

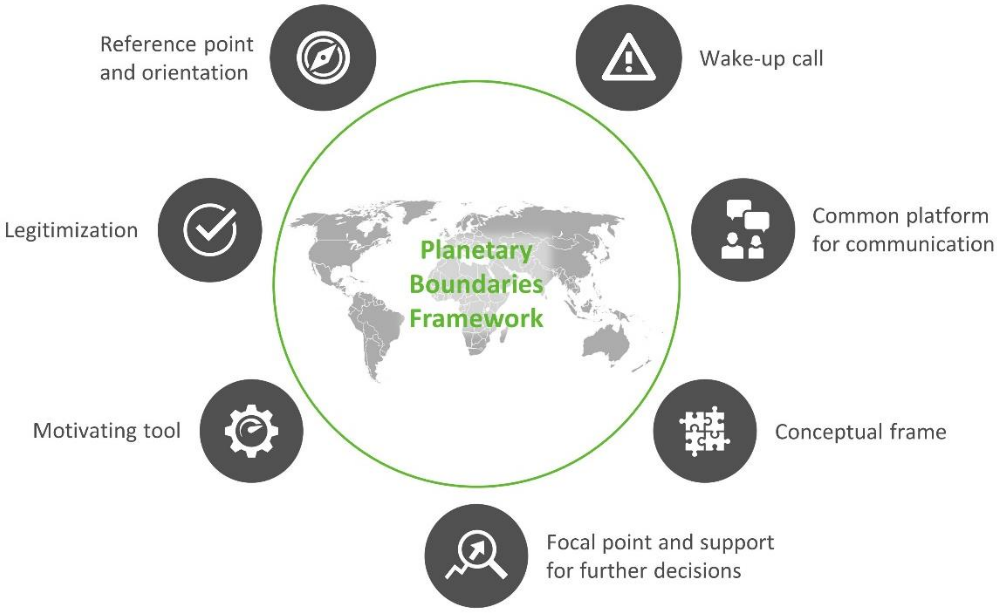
Furthermore, the openness of the planetary boundaries framework means it can be connected to broader strategic discussions, such as transformative environmental politics and policies. The planetary boundaries framework raises questions about the future role of environmental policy that are also subject to perception through a risk-aware or opportunity-orientated lens. In Chapter 1.5.6, we discuss some of the communicative functions that build on these different messages and different perspectives.

1.5.6 Understanding the planetary boundaries framework potential: communicative functions

From the perspective of environmental communication the most important aspect of the planetary boundaries framework is, of course, the messages that it contains. However, as seen in our discussion of discourses in Chapter 1.5.3, the role of the planetary boundaries framework in environmental communication cannot be reduced solely to these messages. It is important to consider its wider communicative functions, too.

No coherent theory on the functioning of environmental communication suitable for the research question at hand exists at present. For this reason our examination of the communicative functions of the planetary boundaries framework cannot draw substantially on existing theoretical concepts. It is worthwhile, however, looking at the various functions which the planetary boundaries framework may fulfil in environmental communication now and in the future, as illustrated in the figure below.

Figure 51: Communicative Functions



Source: from authors, adelphi

Wake-up call

The planetary boundaries framework refers to matters of urgency. Part of its communicative function is thus to serve as a wake-up call. The notion of "tipping points" implies that planetary changes could happen abruptly and that political actors and societies have limited time to react. The planetary boundaries framework also argues that several boundaries have already been transgressed and we are already at risk. The planetary boundaries framework can function as a communicative device for demanding increased political action and civil society and business sector engagement to combat environmental degradation, as well as further scientific research into early detection and warning.

In scientific areas the planetary boundaries framework has indeed led to increased activity, although it is difficult to say if this is due to general scientific interest in new ideas or as a result of the wake-up call. Overall, it appears that the planetary boundaries framework has only functioned weakly as a wake-up call so far, perhaps due to the lack of information it contains about the implications of transgressing the tipping points.

Motivating tool

The planetary boundaries framework paints a picture of humanity as a powerful force, able to drive the planet into a new epoch – the Anthropocene. As such, the planetary boundaries framework can function as a motivating tool for human action: if humans have the capacity to degrade the environment, they also have the capacity to save it by changing course. This is especially important as research into environmental communication has shown that it is necessary for messages to show that pro-environmental behaviour is possible (Moser 2010).

This line of argumentation has not featured much in planetary boundaries framework discussions as yet. It contains some obvious risks: for example, it might be used to support geo-engineering activities and hence a climate policy strategy not favoured by most actors concerned about strengthening climate mitigation. Nevertheless, it is an important aspect that should form part of the discussion.

Reference point and orientation

The planetary boundaries framework can function as a reference point for various actors. It includes quantifications for several boundaries in the form of the control variables and their values. Actors can relate to the framework, especially if these boundaries are "downscaled". For example, civil society actors working in the area of species conservation can refer to the biodiversity boundary and point out that it has already been transgressed. Environmental communication can make use of the planetary boundaries framework as a reference point in their political strategies, too, for example when criticising policies and practices that are harmful for the environment. Initial attempts in this direction are already underway.[48] Thus environmental policy at the national level is beginning to refer to the planetary boundaries specified in the planetary boundaries framework. Some boundaries have also been calculated for regional or local levels, informing local policies (Cole et al. 2014; Dearing et al. 2014).

Focal point and support for further discussion

The planetary boundaries framework can serve as a focal point for further discussion. It supports the approach of environmental politics as societal politics, and of transformative environmental politics and policies (see Chapter 1.5.5). It can be used to argue that all sectors of society need to do their share in respecting planetary boundaries and that social politics need to take the environment into account. To stay within the safe operating zone, cultural change is essential, including changing societal environmental awareness.

While the planetary boundaries framework itself does not argue for transformation, it can be used to promote it and translate it into concrete action. For example, it can be argued that the transformation of the socio-technical regime is necessary due to the planetary boundaries frameworks findings and must itself respect the boundaries. The planetary boundaries framework can also be used to highlight the fact that there are limits to how much resource use the planet can absorb, and that increases in resource consumption are not an end in themselves (see Rockström 2015).

Common platform for communication

The planetary boundaries framework potentially provides a common platform for communication, simplifying and facilitating interaction between different actors in various sectors and at various governance levels. It supplies actors with a unified language, building on concepts that are already widely used, such as the "risk approach", "resilience" and the "precautionary principle" (note however the mentioned translation issues; see Chapter 1.5.4). The planetary boundaries framework also includes a multitude of interacting environmental processes and represents a good starting point for discussion, grounded in scientific research.

Currently the planetary boundaries framework is still on its way to becoming a platform for such exchange. Within the scientific community the "pb-net" is a step in the right direction, but no more general platform exists for other actors. The potential of the planetary boundaries framework to serve as such a platform will depend not least on its future appeal to the various actors. In this respect, developments regarding downscaling[49] the planetary boundaries framework may provide important impetus.

[48] See for example the research project WiLoP (lead: EEA) which applies the concept to the EU context. Compare also the national applications for Sweden (Nykvist et al. 2013), Switzerland (Frischknecht et al. 2014) and Germany's integrated nitrogen strategy (Hoff, Holger; Keppner, Benno und Kahlenborn Walter (2017): Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie.)

[49] Downscaling refers to the spatially explicit interpretation of PBs for the respective (political) context (local to national), so that the PBs can serve as benchmark, against which actual environmental performance, resource use and emissions of harmful substances ("footprints") can be compared (see also Cross Cutting Paper on Downscaling and Externalization of Planetary Boundaries Pressures within this project).

Conceptual frame

The planetary boundaries framework is a useful tool for framing sustainable development, environmental politics and environmental policies. It can be used to describe the necessary conditions for sustainable development, such as "respect the planetary boundaries". It can also be used to highlight the tasks for environmental policies, the need for increased international cooperation and action on the problems identified, and common and individual responsibility. Moreover, it can help frame other important processes such as the transition to resource and energy use efficiency in a Green Economy, the SDG debate or urban transformation. It can also relate the social dimension to the environmental dimension (see the forthcoming input paper on social boundaries). Initial attempts in this direction have already been made, such as the report by WBGU entitled “Human Progress Within Planetary Guard Rails – A Contribution to the SDG Debate” (WBGU 2014). With further progress on the various planetary boundaries, the PBF may become more attractive as general framework for environmental debates.

Legitimisation

The planetary boundaries framework can help legitimise environmental policies by supporting the need for stronger measures, for example in situations of political deadlock, and by underlining the importance of existing policies. It can also be used to legitimise criticisms of environmentally harmful practices and point out the need for all segments of society to consider environmental impacts, as well as reducing resource consumption and pollution (see forthcoming short paper on planetary boundaries and resource efficiency).[50]

The value of the planetary boundaries framework as a legitimising tool has been recognised by many actors. As discussed in Chapter 1.5.3, the planetary boundaries framework is already often used as a supportive argument when calling for stronger climate protection policies (for example to outline the conditions that lead to climate refugees; see Brot für die Welt 2010). However, its real potential here lies in legitimising fundamental shifts in environmental policies (see for example Steffen et al. 2011a on the implications for economic growth). The wide-ranging implications of the planetary boundaries framework validate the longstanding claims by some leading environmental activists that more powerful action must be undertaken to ensure the Earth system's stability.

1.5.7 Understanding the planetary boundaries framework potential: target audiences

Having examined the weaknesses of the planetary boundaries framework (Chapter 1.5.4), its multitude of messages and interpretations (Chapter 1.5.5) and its communicative functions (Chapter 1.5.6) in detail, we now turn to the planetary boundaries framework potential for reaching specific target audiences, namely the scientific community, bodies involved in environmental policy, the business world and the general public. We examine the issues related to each of these audiences in turn.

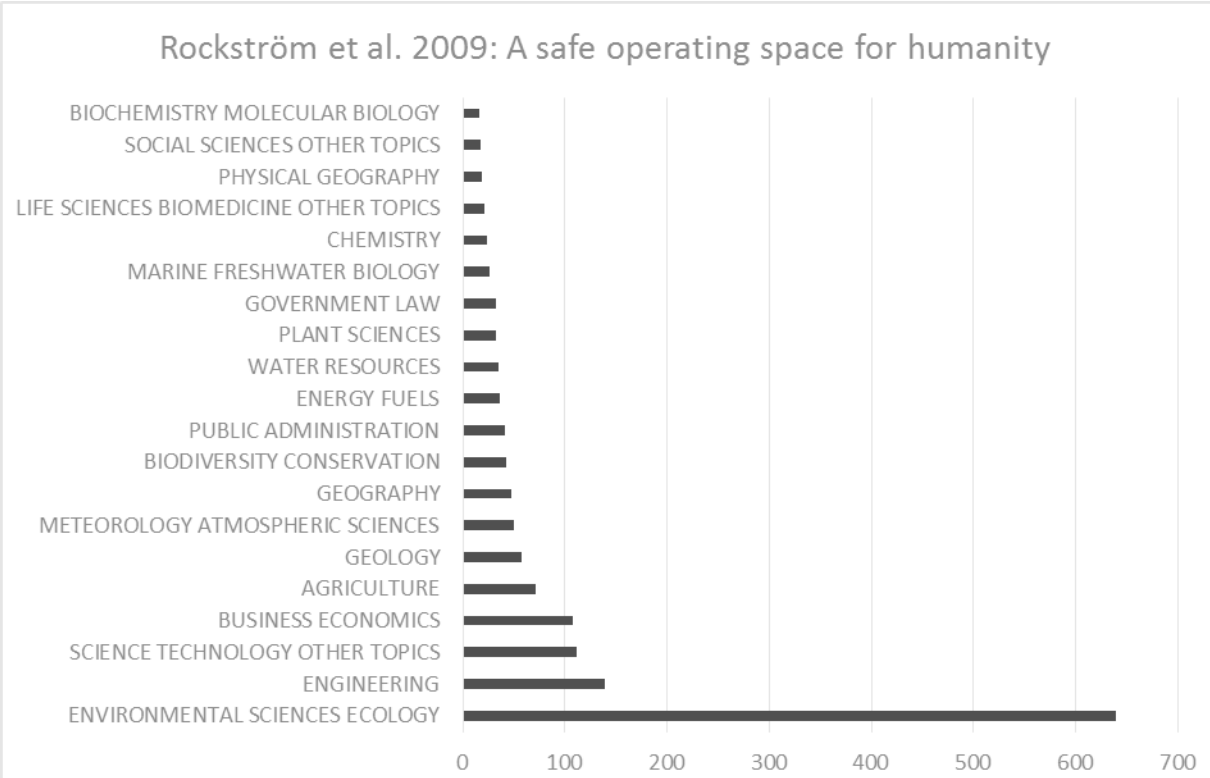
Scientific community

The planetary boundaries frameworks greatest potential for communication is with the scientific community. This is reflected by the number of times it has been cited in academic publications: Rockström

[50] The short paper is the result of an international workshop on planetary boundaries and resource efficiency which took place on February 29th in Potsdam, Germany (as part of this research project).

et al.'s 2009 article in the journal Ecology and Society[51] has been cited 292 times, while their 2009 feature in Nature[52] has been cited 1,345 times (figures from Web of Science; see Figure 52 for an overview of publications by research field). The high number of citations is partly because the planetary boundaries framework refers to major scientific debates and addresses many different issues. The planetary boundaries framework also serves, as we have seen, as a common platform for scientists and a reference point for research strategies, as well as to some extent as a conceptual framework for strategic research. Increasingly the planetary boundaries framework also provides a focal point for interdisciplinary research (i.e. research going beyond pure Earth systems science) and for communication between researchers.

Figure 52: Number of Citations of Rockström et al. 2009 in Nature grouped by Research Areas



Source: Web of Science

Certain points of contact already exist for communicating with the scientific community. These are of two types: (1) points of contact related to specific boundaries, such as climate change, nitrogen, water; (2) points of contact related to other topics, such as international cooperation, regime shifts, limits, resource consumption, regulating ecosystem services, risk analysis, etc. These points of contact can be

[51] Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: Planetary Boundaries: Exploring the Safe Operating Space for Humanity. In: Ecology & Society 14:2, p 32.

[52] Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: A safe operating space for humanity. In: Nature 461:7263, pp 472–475.

used to initiate a discussion on the implications of planetary boundaries for policymaking, or to formulate specific requirements for making the planetary boundaries framework even more relevant for policymaking. Examples of the latter would be the question of how to further relate resource efficiency targets to the planetary boundaries framework, or how the planetary boundaries framework can be used in relation to ongoing environmental political processes and goals such as the circular economy or transformation.

Another important step forward would be to bring planetary boundaries scientists and the policymakers involved in drafting overarching environmental research strategies together to exchange views on the further development of the planetary boundaries framework, and how this could be facilitated by research strategies; in other words, what sort of research is needed to further solidify the planetary boundaries framework. Another key point would be to highlight the need for increased research in the social sciences on the planetary boundaries framework and its implications, especially research into policy-related issues such as governance questions, for example the institutions and processes of decision-making and the implications for multilevel governance.

Political Actors

With regards to environmental policy, the planetary boundaries framework has the greatest potential to communicate with governmental units (in different political sectors and at different levels) and bodies that interact politically with the government, such as civil society organisations and political parties and other actors. This, again, is due to the nature of the planetary boundaries frameworks communicative functions, most of which lie in the realm of political processes. Thus the PBF's functions as a "common platform", "frame", "reference point" and "focal point" can contribute to policy integration, the coordination of political actors, the framing of political programmes and the conceptualisation of political strategies. Many of the planetary boundaries frameworks core and additional messages are also useful in the political realm, such as the need for stronger political measures to respect planetary boundaries. The existing communicative potential here could be broadened by downscaling or up-scaling the planetary boundaries[53] framework and using particular boundaries as a gateway.

Business world

Some parts of the business world are already interested in the planetary boundaries framework. For example, the Action 2020 plan of the World Business Council for Sustainable Development is based on the findings of the PBF, the company MARS[54] uses the planetary boundaries framework in its business approach (MARS 2015), ENECO refers to it (ENECO 2016), and H&M uses it in its 2013 Sustainability Report (H & M 2013). However, it is generally only referred to by large corporations – probably because smaller businesses focus on short-term goals and the planetary boundaries frameworks risk-centred approach appears too long-term for them.[55]

A more general problem is that the planetary boundaries framework does not provide explicit information on the role of companies in transgressing boundaries. As a result the consequences of the planetary boundaries frameworks messages for them remain somewhat unclear. Nor are businesses strongly affected by the planetary boundaries frameworks central messages – although to an extent this depends on the sector in question. One such central message is the transgression of the climate change boundary and the implications for reducing CO_2 emissions; however, this message is already

[53] See, for example, Hoff, Holger; Keppner, Benno und Walter Kahlenborn (2017): Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie.

[54] According to its website, MARS uses the Planetary Boundaries to guide their business operations. MARS focuses on three areas in which the company believes it can contribute most to respecting the planetary boundaries: greenhouse gas emissions, water use and land use. MARS states that it assesses its impact within these areas and formulates steps to reducing these impacts.

[55] Another explanation would be that smaller businesses are not sufficiently aware of the planetary boundaries framework.

present in the climate change debate. The water and land boundary messages (esp. in the narrower sense of the planetary boundaries framework) do not refer to major problems for most businesses[56], such as energy costs or costs of raw materials. Furthermore, references to other natural resources, such as minerals and ores, are not included in the planetary boundaries framework, while e.g. ocean acidification and biosphere integrity most often only relate to business activity indirectly.

Some of the functions and messages of the planetary boundaries framework are nevertheless useful for environmental communication. For example, political actors could point out that businesses can benefit from using the planetary boundaries framework as a "common platform" so they can more easily interact with governmental units and other societal actors. Companies can profit from the planetary boundaries frameworks function as a "reference point" by using it to frame their business approach, for example. Several messages from the planetary boundaries framework are relevant for businesses, too, for example that sustainable development is conditional on respecting boundaries or that the planetary boundaries imply the need for early warning and monitoring (an important issue for insurers, for instance). Furthermore, the framework is useful for pointing to global responsibility as it highlights the detrimental effects of externalising environmental costs to other countries via the relocation of production. It is also useful for discussing opportunities (the safe operating space) and risks (the planetary boundaries) – although for businesses the risks are easier to grasp in the current version of the planetary boundaries framework than the opportunities, which are still very abstract.

The planetary boundaries framework could be used to introduce discussions on topics only partially related to the framework, for example the efficient use of water. Equally, the planetary boundaries framework could be used to argue for making the environment and environmental politics a priority in business decisions. For example when communicating with corporations that are less open to questions of sustainability the risks for businesses when transgressing the safe operating space could be highlighted (such as making the world less hospitable and risking disturbances for smooth business operation).

One important step forward would be to include the planetary boundaries framework in the sustainability ratings of (eco-)rating agencies. Practically this could mean that companies are ranked according to their sustainability performance and in relation to downscaled, context-specific boundaries (e.g. their performance with regards to greenhouse gas emissions). This would raise the profile of the planetary boundaries frameworkand could trigger more interest in the business community; companies would be pushed to take the planetary boundaries framework into account. It also would help to frame the planetary boundaries frameworkfor the business community.

Similarly, when downscaled for companies, the planetary boundaries framework could be useful for their strategic planning and risk management, and for communication both with and between businesses, in the latter case serving as a common platform.

General public

As mentioned above, the planetary boundaries framework suffers from having a fragmented narrative, weak localisation and a language barrier. These factors make it less accessible to the general public. At present the planetary boundaries framework is not directly related to the personal experience of individuals. However, its functions and messages could still be useful for reaching the broader public.

To highlight the urgency and feasibility of changing course, the planetary boundaries frameworks functions as a "wake-up call" and "motivating tool" can be useful. To communicate more effectively, individual aspects or messages of the framework could be selected and used for communication – for

[56] Notice however Mars reference to the water and land boundary.

example the message that humanity is powerful and that humans can only thrive in a stable environment, or that individuals are all part of a globalised interdependent world that is subject to environmental risks.

To make the communication more effective, some of the language used should be softened and explained, and supporting narratives introduced (see Chapter 1.5.8). For example, less drastic expressions for some of the mentioned displays of dangers[57] should be developed (see Chapter 1.5.4).

As soon as the scientific basis of the planetary boundaries framework has been further solidified, it could also become part of general education and included in textbooks. This would start to make it part of the cultural foundation of society. For environmental politics, awareness of the planetary boundaries framework among the general public is important as it can help legitimise more far-reaching policy demands, such as the "great transformation".

It would be possible to focus on specific social environments within the general public, using selected messages from the planetary boundaries framework for each of these milieux. E.g. six key social groups are identified (from BMUB and UBA 2015: 16-17, translation ours):

- Traditional milieux: usually aged over 70; many retired people; differing levels of income; great appreciation of order, security, stability, preserving the status quo
- Upper-class milieux: aged 40-70; high level of education; achievement-orientated; guiding principles are feasibility and efficiency
- Critical and creative milieux: various ages; average to high level of education; enlightened; cosmopolitan; committed; interested in intellectual and cultural topics; guiding principles are critical reflection and a meaningful life
- Young milieux: aged under 30; often economically dependent on parents or still in education; affinity with digitalisation and globalisation; view the future as uncertain
- Middle-class milieux: aged 40-70; average education; middle income; view themselves as the core of society; sense of community; orientated towards comfort and convenience; afraid of downward social mobility
- Precarious milieux: all age groups; low level of education; low income; little participation in consumption and social life; guiding principle is "getting by"

Different messages might be directed at each of these milieux. Thus, for traditional milieux, emphasis could be placed on the fact that scientific research (i.e. the planetary boundaries framework) has shown that order, stability, security and preserving the status quo are only possible by taking decisive steps to reduce environmental impacts. For upper-class milieux, that it is indeed possible to reverse the trend of environmental degradation (using the "motivating tool" function of the planetary boundaries framework) and that the planetary boundaries framework is the outcome of intense scientific deliberation – addressing the high educational level of these milieu. For critical and creative milieux, it could be stated that the planetary boundaries framework is basically a fundamental critique of the status quo: humanity is not doing enough to preserve the planet. It could also be argued that one of the PBF's messages is to live respectfully and responsibly within the safe operating space. For young milieux, it could be stressed that the planetary boundaries framework provides guidance and direction: we must live responsibly, we must be aware of our own environmental footprint, and we must think globally. For middle-class milieux, the message would be that a trend already exists towards respecting the environment but that increased efforts are needed, as the planetary boundaries framework

[57] Such as that the human impact on the earth could be deleterious or even catastrophic for human well-being (see Chapter 1.5.4).

shows. Furthermore, our comfort and the achievements of society can only be maintained by respecting the boundaries. Finally, in the case of precarious milieux, social goals needed to be added to the PBF and an emphasis placed on the interdependency between the environmental and social realms.

1.5.8 Exploiting the planetary boundaries framework potential: closing the communication gap

In the previous chapters we have examined various aspects of the communicative potential of the planetary boundaries framework. Thus we have seen that there are high expectations of the planetary boundaries framework in terms of its communicative strength (Chapter 1.5.2) – expectations which are not entirely mirrored in the discourse associated with it (Chapter 1.5.3). This is in part due to several communicative weaknesses (Chapter 1.5.4). Nevertheless, the planetary boundaries framework provides a multitude of useful messages which can support environmental politics (Chapter 1.5.5) and which endow it with a number of communicative functions (Chapter 1.5.6). These messages and functions in turn help to reach target audiences, but the potential of the planetary boundaries framework varies from group to group (Chapter 1.5.7).

In Chapters 1.5.8, 1.5.9 and 1.5.10 we formulate ways forward – actions that can be taken to bridge the communication gap and overcome the weaknesses discussed in Chapter 1.5.4. These actions are as follows: refine the conceptualisation of the planetary boundaries framework; take into account the results of the analysis presented here in environmental communication by the government; develop supporting narratives; and further improve the visual language of the planetary boundaries framework.

Conceptualisation of the planetary boundaries framework

The scientific community can play an important role in refining the communicative potential of the planetary boundaries framework. Scientists should be aware of the communicative weaknesses of the framework when updating it – its loaded language, abstract terms, fragmented narrative, low level of public involvement and the problems with the central illustration. To address some of these weaknesses, "risk language" should be used consistently. Moreover, wherever possible the more abstract terms should be replaced with simpler wording, including a sort of lay-person's version of the central illustration (e.g. using symbols instead of technical labels).

To address the problem of the low level of public involvement and the "invisible human", researchers should look at how the public could be meaningfully involved[58]. This might involve investigating the use of different channels (e.g. digital channels, town halls), what audiences should be addressed (e.g. particular segments of society), who should have decision-making competences (e.g. who can make suggestions, who has the final say) and in what part of the process suggestions can be made (e.g. before or after expert input, or continuously).

Research could also focus on the share of responsibility of particular segments of society (e.g. companies, individuals) for each boundary. This would make the framework more meaningful for those specific audiences.

Researchers could boost the communicative potential of the planetary boundaries framework by clarifying the impacts of crossing planetary boundaries and hence the risks of doing so. The different degrees of uncertainty can be explained using the nomenclature of the IPCCC. It should be identified where possible what impacts are likely and who will be hit the most (e.g. what regions, what segments of society), as is currently done in climate change and vulnerability studies. The costs of impacts should also be estimated, and different scenarios for crossing planetary boundaries analysed, taking into account different policy instruments.

[58] This is certainly also a task for political actors.

Researchers should also try to explain the difference between thresholds and boundaries, and further clarify the question of prioritisation. The meaning of the various scientific concepts used should be illustrated with examples or brief summaries tailored for the different target audiences.

The scientific community can also contribute to the communicative development of the planetary boundaries framework by further specifying the grey fields in the illustration and revising the central illustration (see Chapter 1.5.9), and by contributing to the downscaling and up-scaling of the planetary boundaries framework. Downscaling initiatives could focus on improving and applying contextual criteria, testing them in different countries. Up-scaling might involve developing a process by which countries or sub-country actors formulate specific targets for their contribution to respecting specific boundaries. Such an endeavour could draw on the experiences of the climate-change INDCs.

Environmental communication and the planetary boundaries framework

To make use of the full potential of the planetary boundaries framework, three interrelated recommendations should be considered. First, the weaknesses apparent in the discourse on planetary boundaries should be overcome (see Chapter 1.5.3). Scientific uncertainties – about regime shifts, the consequences of transgressing boundaries, boundary interactions – should be spoken about openly; trying to conceal them would risk the planetary boundaries frameworks credibility being undermined, particularly when it receives more attention and scrutiny by the media. Furthermore, some central features of the planetary boundaries frameworks message that are currently often ignored in the discourse need to be reinstated, for example the planetary boundaries frameworks systemic character or its discussion of boundaries other than climate change. (This also applies to the selective communication described in Chapter 1.5.5; while focusing on a specific boundary, it is still important to communicate the planetary boundaries frameworks central tenets.) To avoid inducing apathy when communicating almost apocalyptic scenarios, it must be carefully weighed up whether the survivalism and security discourse should be employed, and if so, to what extent. Overly drastic scenarios should be avoided, especially if they are not supported by scientific data.

Second, the communicative weaknesses of the planetary boundaries framework should be overcome wherever possible (see Chapter 1.5.4). Recommendations for environmental action should be included, tailoring them to the specific communicative purpose and target audience in mind. When using the planetary boundaries framework for prioritisation, the centrality of the climate change and biodiversity boundary should be highlighted (see Steffen et al. 2015a). Furthermore, the more abstract technical terms need to be explained when communicating the framework to lay audiences. The term "planetary boundaries" should be translated in local language in a consistent manner. To aid public outreach, references to public involvement should be included, for example highlighting the normative aspect of the planetary boundaries framework, an expression of societies' willingness to take risks, and asking for public input. Including the planetary boundaries framework in a dialogue process could also be considered, focusing on specific aspects that should be debated by the public (e.g. risks). Furthermore, supporting narratives should be used to reach out to a broader public (see Chapter 1.5.10).

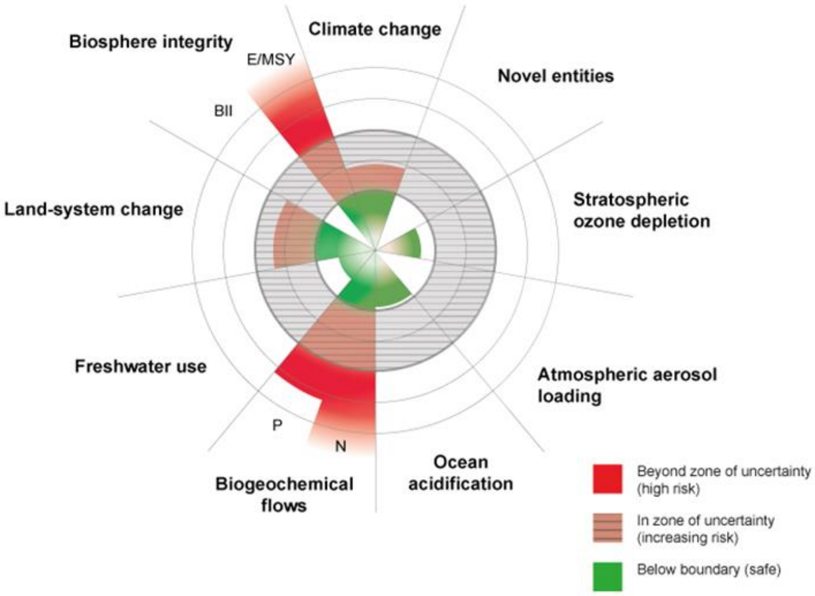
Third, the communicative functions of the planetary boundaries framework discussed further above should be exploited. Political actors can rely on the planetary boundaries framework when coordinating with other actors on multiple levels of governance, when attempting to frame environmental discussions and when trying to raise awareness about the risks for the planet and society. The planetary boundaries framework can also be used as a reference point in communication and when talking about transformation and environmental and social politics.

1.5.9 Visual language

The illustration of planetary boundaries in the original article by Rockström et al. (2009) and its updated version by Steffen et al. (2015) are appropriate for a scientific audience but can lead to misunderstandings in communication with the broader public. As we saw in Chapter 1.5.5, the illustration has several weaknesses, relating in particular to the grey fields and question marks, the interactions between fields (boundaries), the static nature of the illustration and the choice of colours. The first three problems – grey fields and question marks, interactions between fields, static nature – can only be completely solved by further scientific research (see Chapter 1.5.8). For the other issue – choice of colours -, however, potential solutions already exist and for the static nature and interactions ideas for ways forward can be formulated.

In terms of the colours used, red could be used both for "zones of uncertainty (increasing risk)" and for areas "beyond the zone of uncertainty (high risk)". The former areas could be coloured a lighter red to indicate the milder but still risky nature of the problem, as shown in Figure 53.

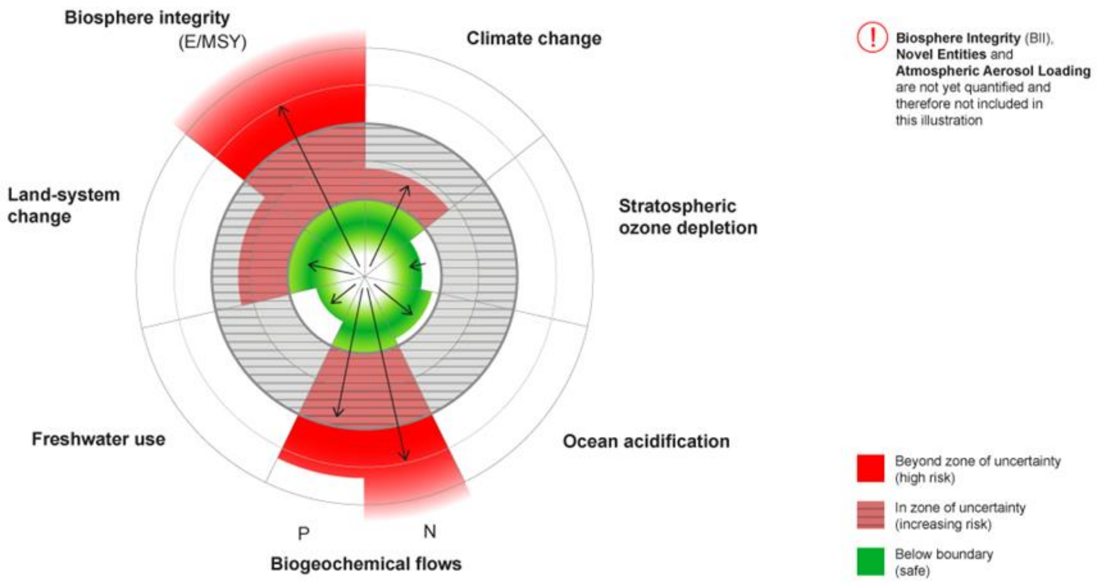
Figure 53: Revised illustration based on Steffen et al. 2015a



Source: from authors, adelphi, based on Steffen et al. 2015a

As regards the static nature of the illustration, arrows could be added showing the direction and speed of the perturbation, as in Figure 54. This example is illustrative rather than based on actual data, as more research would be required to determine exactly what the arrows should look like.

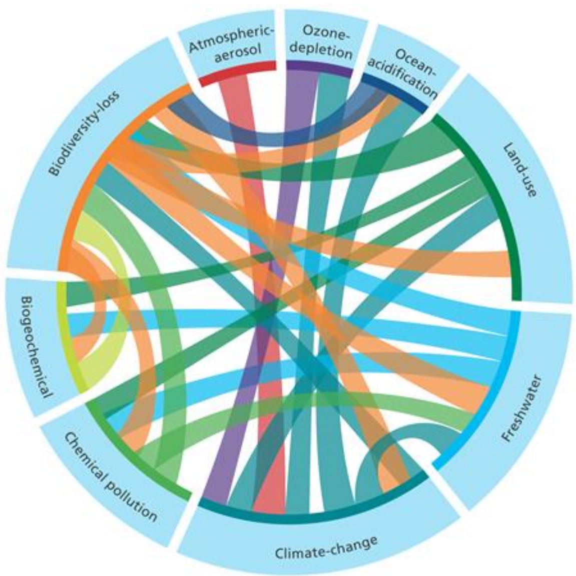
Figure 54: Revised Illustration with arrows building on Steffen et al. 2015a and Rockström et al. 2009



Source: from authors, adelphi, based on Steffen et al. (2015a) and Rockström et al. (2009)

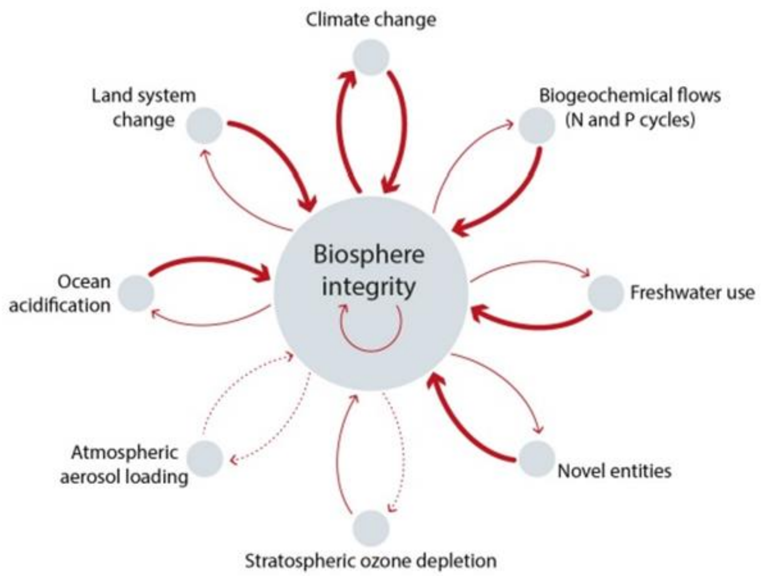
Figure 55 and Figure 56 show how the interactions between all planetary boundaries and between one specific planetary boundary and the rest can be illustrated.

Figure 55: Planetary Boundaries Interaction



Source: from authors, adelphi, building on Friedrich 2013

Figure 56: Biosphere integrity and interactions



Source: Steffen et al. 2015a

The reality is that the planetary boundaries framework is too complex for all its messages to be contained in just one illustration. For communication with civil society it will be important to focus on one or two illustrations which convey key messages. Depending on the key message chosen, the main illustration could also focus less on the boundaries themselves and more on the safe operating space and social aspects, as is the case with Raworth's "doughnut" graphic (Raworth 2012). This will be considered further in the forthcoming input paper on the planetary boundaries framework and social boundaries.

1.5.10 Narratives and the planetary boundaries framework

The planetary boundaries framework has an easy-to-grasp message and contains narrative language. This makes it generally suitable as a "storytelling" tool. However, it also presents some communicative challenges such as its low level of localisation and its remoteness from people's everyday experiences, which make it difficult to exploit its full potential (see Chapter 1.5.4). Developing supporting narratives is therefore an important task. These narratives could also include pictures showing environmental degradation in different regions (e.g. clear-cutting in the Rainforest; see Rockström and Klum 2012).

Narrative theory and the planetary boundaries framework

To formulate supporting narratives for the PBF, we rely on narrative theory (see, for example, Jones and McBeth 2010; Lejano et al. 2013). According to Jones and McBeth, a narrative should be understood as a "temporal sequence of events […] unfolding in a plot […] that is populated by […] dramatic moments, symbols, and archetypal characters [and] culminat[ing] in a moral to the story" (Jones and McBeth 2010). The success of a narrative depends on whether it meets certain "effectiveness criteria" or not (Lejano et al. 2013; Jones and McBeth 2010). Below we outline three important effectiveness criteria relevant for communicating the planetary boundaries framework.

First, narratives should present an "interesting sequence of events" (Lejano et al. 2013). In other words they should not simply list facts and make assertions, but should follow a specific structure – a storyline – and create a homogeneous whole. Second, narratives should involve interesting characters (Lejano et al. 2013) – messages should not only describe events but also how the main protagonists develop. Third, narratives should be sufficiently localised in time and place (see Chapter 1.5.4).

Applying these criteria to the planetary boundaries framework, we find that the PBF has an implicit storyline which can be divided into three sections: (1) the Holocene-like state of the Earth system, a state which "can support contemporary human societies"; (2) human activities which destabilise the Holocene-like Earth system; and (3) the Anthropocene, an era which is "much less hospitable" to humanity (Steffen et al. 2015a). However, the planetary boundaries frameworks storyline is not sufficiently localised (see Chapter 1.5.4): it focuses on geological periods and humanity as a whole rather than specific human actions, experiences and impacts.

Furthermore, the description of the planetary boundaries frameworks main protagonist – humanity – is fragmented. The only direct statement describing humanity is that humans are "the dominant driver of change to the Earth system" (Rockström et al. 2009). Other than this, humanity appears only through its actions: it has "transgressed three planetary boundaries", has "entered deep into a danger zone", but still has "[the] flexibility to choose a myriad of pathways for human well-being and development" and "freedom to manoeuvre in the pursuit of long-term social and economic development" (Rockström et al. 2009). The unclear character of the main protagonist of the narrative is due to the fact that humanity is seen as an aggregate: individual people, social movements, states and businesses are all conflated into one body.

Supporting narratives can be used to transform the planetary boundaries framework into a series of more concrete messages with storylines, featuring concrete protagonists. These narratives could focus on specific aspects of the planetary boundaries framework such as thresholds and regime shifts, the interaction between planetary boundaries, or the notion of the "great acceleration" and future impacts of the transgression of boundaries (Steffen et al. 2007), moving these to the realm of concrete personal experience.

(1) Narratives about thresholds and regime shifts

Narratives about the impact of crossing planetary boundaries can make use of the threshold database produced by the Resilience Alliance (Resilience Alliance 2016a). This database comprises 103 instances of regime shifts, detailing for example certainty, location, system type, ecosystem type, resource use, ecosystem service, spatial scale reversibility, disturbance, mechanism and references. Another useful database is the Regime Shifts DataBase, hosted by the Stockholm Resilience Centre, which gives examples of regime shifts (Stockholm Resilience Centre 2015). Narratives can also rely on the literature on regime shifts and tipping points (e.g. Rocha et al. 2015; Barnosky et al. 2012; Hughes et al. 2013a; Hughes et al. 2013b; Lade et al. 2013; Lade et al. 2015; Lenton et al. 2008).

Supporting narratives for thresholds should state that regime shifts are already visible on a smaller than planetary scale – e.g. on a regional level – and that regime shifts at this level have led to observable detrimental outcomes for humans through a loss of ecosystem services. The narratives should then turn to the planetary boundaries framework, pointing out that such detrimental outcomes could also occur for the planet as a whole.

Below we outline four possible supporting narratives for thresholds and regime shifts. They deal with the following cases: Newfoundland cod fisheries, soil erosion in Iceland, the vulnerability of atoll Islands to climate change, and the overexploitation of phosphate in the island of Nauru. Three of the narratives (numbers 2-4) also relate to specific planetary boundaries, although they do not rely on the precise control variables used in the planetary boundaries framework. These three narratives could also highlight the importance of the specific boundary for the functioning of the Earth system as a whole.

Supporting narrative 1: Newfoundland cod fisheries (thresholds)

For centuries, fishermen in Newfoundland relied on the income provided by cod fishing. But after 1990, overfishing combined with a colder water temperature led to a sudden decrease in cod stock to just 1% of its previous level. Levels have recovered very slowly since then, albeit with a major increase detected in 2015. As a result of this abrupt decline, cod ceased to exist as a food source for local communities and the loss of income had major repercussions for local fishermen, many of whom became unemployed and had to leave the region to look for work elsewhere.

The Newfoundland fishermen experienced a process known as "regime shift". A regime shift is a process in which a rather stable socio-ecological system (large fish stock, fishing with trawling) is replaced by a new socio-ecological system (fishing with drag nets, sudden decrease of cod levels, end of the cod fishing industry). When certain tipping points are passed – in this case the tipping points "overfishing" and "change in water temperature" – the regime shifts. The regional processes seen in Newfoundland illustrate a mechanism that is likely to exist for the planet as a whole, too. As Rockström et al. suggested in 2009, there is a risk that the Earth system might undergo a regime shift from a rather stable and beneficial state to a state which is less hospitable, comparable to the shift that affected the Newfoundland fishermen.

Source: Rose and Rowe (2015); Patel et al. (2015)

Supporting narrative 2: Soil erosion in Iceland (Planetary boundary: land-system change)

Southern Iceland's farmers have relied on pasture for their sheep for centuries. The local grazing land is of poor quality. Since the thirteenth century, communes have functioned as the basic administrative unit and regulations have been established regarding common pasture as a way to limit the overstocking of farmland and avoid overgrazing and land degradation. Despite changing climatic conditions, the system of land management was not altered. When the pressure from grazing became higher than the replacement rate of vegetation, the pasture became overgrazed and ultimately eroded. This deprived the farmers of an essential resource for their work and, as a result, of their livelihood.

The regional process of soil erosion in Iceland illustrates a mechanism that is likely to exist for the planet as a whole, too. As Rockström et al. suggested in 2009, there is a risk that the Earth system might undergo a regime shift from a rather stable and beneficial state to a state which is less hospitable, comparable to the shift that affected the Icelandic farmers. Rockström et al. identify nine processes that are vital for the planet; the Icelandic case demonstrates the significance of the land-system change process.

Source: Resilience Alliance (2016); Simpson et al. (2001)

Supporting narrative 3: The vulnerability of atoll islands (PB: climate change)

Kiribati, the Maldives, the Marshall Islands, Tokelau and Tuvalu are the only countries in the world made up solely of low-lying atolls, approximately two metres above sea-level. Their inhabitants have been living on the islands for millennia. Atoll islands are characterised by high population densities: around 416,000 people live on the five atolls in total. Three of the islands – Kiribati, the Maldives and Tuvalu – belong to the group of "least developed countries".

The conditions typical of these islands make them very vulnerable to "external" events. Climate change presents by far the biggest threat to the inhabitants' livelihoods and the future habitability of their homes. A rise in temperature of 2°C or more and increases in coral bleaching episodes would lead to an increase in sea levels that would make the islands inhabitable and force hundreds of thousands of islanders to migrate to other countries.

The underlying mechanism seen in the case of the atoll islands illustrates a process that is likely to exist for the planet as a whole, too. As Rockström et al. argue, there is a risk that the Earth system might undergo a regime shift from a rather stable and beneficial state to a state which is less hospitable. Rockström et al. identify nine processes that are vital for the planet; the case of the atoll islands demonstrates the importance of the climate change process.

Source: Barnett and Adger (2003); Resilience Alliance (2016)

Supporting narrative 4: Overexploitation of phosphate (Planetary boundary: biogeochemical flows)

Nauru, an island country in the Central Pacific, boasted the highest per capita income in the world between the 1960s and '70s, solely generated by the extraction of phosphate, of which the country had vast deposits. While the Nauruans enjoyed a luxurious life without having to work or pay taxes, they gradually destroyed their island's natural flora and fauna through intense phosphate mining. The vast majority of soil and vegetation was stripped away and many indigenous species disappeared. Due to this environmental degradation and biodiversity loss, agriculture is now almost impossible and it is difficult to establish a viable ecosystem.

The shift from a thriving society with diverse flora and fauna to a state of social and ecological degradation, as exemplified by the case of Nauru, illustrates a process that is also likely to exist for the whole planet. As Rockström et al. argued in 2009, human perturbations of important processes could trigger a regime shift for the planet. Rockström et al. identify nine boundaries that are vital for the functioning of the Earth system; the case of Nauru shows the importance of the biogeochemical flows process.

Source: Anderson (1992)

(2) Narratives about interactions between planetary boundaries

The planetary boundaries framework also draws attention to the fact that boundaries interact. Narratives could support the understanding of such interactions by showing their impact on humans. Developing narratives of this type is difficult, however, as it is not yet entirely clear what the interactions are. What the narratives can do is to make use of Steffen et al.'s overview on the interactions between the core boundaries of biodiversity and climate change and the other boundaries (see Supplementary Materials, Table S3). Supporting narratives for interactions should point out that interactions are already visible and that these interactions have led to observable detrimental outcomes for humans.

Supporting narrative 5: Oceanic dead zones in the Gulf of Mexico (interaction between biogeochemical flows and climate change)

The Gulf of Mexico provides a livelihood for many fishermen, supporting various fishing industries. However, the water quality of the ocean basin greatly deteriorated in the second half of the twentieth century. The main reason was "ocean eutrophication", a form of oxygen depletion that causes severe stress and mass mortality of ocean fauna in what are known as "oceanic dead zones". This was caused by the high levels of nutrient – mainly nitrates – flowing down the Mississippi River from farmland in the American Midwest. Higher temperatures resulting from climate change also raise the level of nutrient intakes to estuaries by heightening nutrient release from soils. Higher water temperatures cause greater bacterial activity, which depletes oxygen from the water and activates the release of the nutrients already present in the bottom sediments.

The result of this deterioration of water quality has been a large drop in the level of finfish, shrimp and crab. Local fishermen have felt the economic impact of an entire food chain being upset, mainly due to transgression of the biochemical cycle of nitrogen, exacerbated by the impacts of crossing the climate change boundary. Given human population growth and the corresponding increase in demand for food (which is likely to lead to an even greater use of nutrients), combined with a further rise in global temperatures, the prevalence of oceanic dead zones is likely to grow in future. This will entail an increase in the frequency of regime shifts, in turn forcing fisheries out of business.

The Gulf of Mexico case exemplifies a mechanism likely to exist for the planet as a whole. As Rockström et al. argued in 2009, there are nine important processes that interact with each other and are vital for the planet, including climate change and biogeochemical flows. Just as in this case, these interactions risk making the planet as a whole inhospitable.

Source: Diaz (2001); Moss et al. (2011); Resilience Alliance (2016a)

(3) Narratives about the "great acceleration"

The PBF states that a "great acceleration" took place after the Second World War (see Rockström et al. 2009; Steffen et al. 2007). As Steffen et al. point out, in this period of human history the global population increased dramatically, and with it the global economy, resource consumption and urbanisation. At the same time pressures on ecosystems grew rapidly.

Supporting narratives should outline current impacts, and then state that these exemplify the great acceleration. Narratives should also underline the need to take the planetary boundaries framework into account, as environmental degradation is likely to progress rapidly in the future, risking planetary tipping points being crossed. Narratives could also show how political measures can help alleviate some of these impacts.

Supporting narrative 6: Pollution in Beijing

Beijing, the Chinese capital, has approximately 21 million inhabitants. The city is located in the country's most heavily polluted region and is ranked the thirteenth most polluted city in China. This represents a threat to the health of residents.

Chinese cities are known for their particularly high levels of air pollution, causing 4,400 deaths each day. Some of the main pollutants found are nitrogen oxides (NOx). NOx pose considerable threats to human health, including raising the risk of heart disease, stroke, respiratory illnesses and cancer. The World Health Organization (WHO) recently found that poor air quality, to a large extent caused by the release of NOx, accounts for seven million deaths worldwide each year. This makes it the fourth-biggest risk factor for death, and the leading environmental risk for disease. Most cities worldwide fail to meet the WHO guidelines on safe air quality; half of the world's urban populations are exposed to air pollution 2.5 times higher than the recommended rate.

After the ranking of Chinese cities in terms of air pollution appeared at the beginning of 2015, Beijing introduced stronger measures for cleaner air. Part of the plan now in place focuses on reducing the use of coal and increasing reliance on non-fossil fuels. Experts regard these steps as the start of a long-term upward trend in air quality.

The case of NOx pollution illustrates the larger process known as the "great acceleration". This process has been described by several researchers (e.g. Steffen et al. 2007). According to these scientists, since the end of the Second World War the human population has doubled, the global economy grown dramatically, and resource consumption exploded. As Rockström et al. argued in 2009, this rapid acceleration in human pressures risks making the whole planet inhospitable. Future human pressures could have even greater impacts on human health. The case of Beijing shows, however, that human measures can help alleviate some of the impacts.

Source: WHO (2014); Watt (2015)

1.5.11 Annex

Political Level	**German Parliament (Bundestag)** *Motions:* Deutscher Bundestag 18. Wahlperiode. 12.11.2014. Drucksache 18/3156. Antrag der Fraktion BÜNDNIS 90/DIE GRÜNEN: Gipfeljahr 2015 – Durchbruch schaffen für Klimaschutz und globale Gerechtigkeit. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btd/18/031/1803156.pdf Deutscher Bundestag 18. Wahlperiode. 30.09.2015. Drucksache 18/6197. Antrag der Fraktion BÜNDNIS 90/DIE GRÜNEN: Starke Schutzstandards – Ziel statt Zielscheibe moderner Handelspolitik. Retrieved July 21, 2016, http://dipbt.bundestag.de/dip21/btd/18/061/1806197.pdf *Plenary Protocols:* Plenarprotokoll 17/43 Deutscher Bundestag. 20.05.2010. Stenografischer Bericht 43. Sitzung. Retrieved July 21, 2016, from http://dipbt.bundestag.de/doc/btp/17/17043.pdf Plenarprotokoll 17/46 Deutscher Bundestag. 10.06.2010. Stenografischer Bericht 46. Sitzung. Retrieved July 21, 2016, http://dipbt.bundestag.de/doc/btp/17/17046.pdf Plenarprotokoll 17/228 Deutscher Bundestag. 14.03.2013. Stenografischer Bericht 228. Sitzung. Retrieved July 21, 2016, http://dipbt.bundestag.de/doc/btp/17/17228.pdf Plenarprotokoll 17/243 Deutscher Bundestag. 6.06.2013. Stenografischer Bericht 243. Sitzung. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btp/17/17243.pdf Plenarprotokoll 17/246 Deutscher Bundestag. 13.06.2013. Stenografischer Bericht 246. Sitzung. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btp/17/17246.pdf Plenarprotokoll 18/33 Deutscher Bundestag. 08.05.2014. Stenografischer Bericht 33. Sitzung. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btp/18/18033.pdf Plenarprotokoll 18/88 Deutscher Bundestag. 26.02.2015. Stenografischer Bericht 88. Sitzung. Retrieved July 21, 2016, http://dipbt.bundestag.de/doc/btp/18/18088.pdf Plenarprotokoll 18/91 Deutscher Bundestag. 05.03.2015. Stenografischer Bericht 91. Sitzung. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btp/18/18091.pdf Plenarprotokoll 18/100 Deutscher Bundestag. 23.04.2015. Stenografischer Bericht 33. Sitzung. Retrieved July 21, 2016, http://dipbt.bundestag.de/doc/btp/18/18100.pdf Plenarprotokoll 18/115 Deutscher Bundestag. 02.07.2015. Stenografischer Bericht 115. Sitzung. Retrieved July 21, 2016, http://dip21.bundestag.de/dip21/btp/18/18115.pdf

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1.6 The Planetary boundaries as social boundaries: re-framing the doughnut

1.6.1 Introduction: planetary and social boundaries

The debate on the interlinkages between human development and the state of the environment has long roots dating back to the first truly global conference on the human environment in Stockholm, 1972. Since this starting point, the discourse gained further momentum, with the catchphrase of sustainable development as focal point and with an increasing number of actors deliberating on social well-being within the limits set by the environment. Now the Sustainable Development Goals (SDGs), adopted 2015 in New York by the UN General Assembly, are at the centre of attention guiding countries worldwide. The planetary boundaries are part of this global discourse – they further concretize the environmental pre-condition necessary for achieving sustainable development, previously often only vaguely described, providing a reference point for policy-makers and a global wake-up call as well as delineating a "safe operating space for humanity".[59] But the increasing use of the planetary boundaries by policy-makers and civil society actors raises an important question: How do the planetary boundaries relate back to the social side of development?

Kate Raworth (2012) provided a first and important answer to this question by drafting a "safe and just operating space" (the "doughnut") by adding social boundaries to the planetary boundaries. In Raworth`s conceptualization, the social boundaries are health, food, water, income, education, resilience, voice, jobs, energy, social equity and gender equality. The PBs then describe the environmental pre-condition (the outer boundary) and the social boundaries the social pre-condition (the inner boundary) for sustainable development (Raworth 2012). This new conceptualization opened the door for debates on how the planetary boundaries relate to poverty alleviation and to eradicating deprivation.

Furthering this discussion is important for several reasons: including social boundaries in the planetary boundary framework could help attract more actors to the framework, e.g. those that operate primarily on social issues within development cooperation and could thereby facilitate political support for observing the planetary boundaries by integrating development NGOs / INGOs under the planetary boundary umbrella framework. Furthermore, connecting the planetary boundaries with social development is vital for progress in environmental and social policy: including social boundaries helps to create a socially equitable and stable world which is a necessary precondition for respecting the planetary boundaries. On the other hand, social boundaries can only be respected in the long run, when planetary boundaries are not transgressed.

It is therefore necessary to further analyse how the planetary boundaries are related to social development and whether Raworth's doughnut captures this relationship aptly. It is also vital to reflect how to relate both boundaries in the debate and how to further conceptualize their interlinkages. Finally, it is beneficial to reflect on the strategic value of combining both boundaries and how to use them for environmental politics.

This paper intends to contribute to this analysis. It is structured in four parts. Chapter 1.6.2 provides conceptual background on social boundaries and the interlinkages between plane-tary and social boundaries. Next, Raworth's doughnut is analysed and evaluated (chapter 1.6.3) before reflecting on a re-framing of the discussion (chapter 1.6.4). In the last chapter (chapter 1.6.5) this paper looks at ways forward for further developing the debate.

[59] See Keppner, Benno; Kahlenborn, Walter and Teresa Sophie-Rath (2016): On the communicative potential of the planetary boundaries concept.

This paper does not focus on social justice aspects of the debate as a later paper will deal with justice and burden sharing. Its main focus is on the conceptualization of the interlinkag-es between the environmental and social realms, intending to contribute to the debate on the doughnut and planetary and social boundaries.

1.6.2 Combining planetary and social boundaries: understanding the debate

Combining planetary and social boundaries is part of a larger debate on the relationship between the environment and development. The discussion on social boundaries and the safe and just operating space (the doughnut) can benefit from looking at this debate by understanding the positions and premises of previous combination attempts, thereby gaining a contextualized understanding of Raworth's model. This chapter provides this background by conceptualizing the social pre-condition of sustainable development and by briefly analysing important combinations of environmental and social pre-conditions.

Conceptualizing the social minimum

The concept of social boundaries rests on the idea of a social minimum (see White 2015) which can be defined by "the bundle of resources that a person needs in order to lead a minimally decent life in their society" (White 2015) or through other elements such as political and social freedoms. The type and scope of resources or other social minimum elements a person needs for a decent life is however debated. The underlying reason is that the question of a social minimum is at the heart of what we value as a society and what we perceive to collectively owe to each other.

The perception of values and collective responsibility is however time-bound and context specific. For example the notion of "gender equality" in Raworths conceptualization has its roots in the feminist movement, while the concept of "voice" and political participation is rooted in the idea of democracy and social movements striving for the democratization of authoritarian rule. To structure and conceptualize the discussion on the social minimum, we focus on three interrelated strands: philosophical positions relevant for the current discussion, conceptualizations of the social minimum building on legal propositions and "soft law" (non-binding agreements). These strands are chosen because they provide valuable insight into the discussion of the social minimum and resonate in the political realm.

The philosophical debate on the social minimum is very extensive, comprising of more than 2000 years of deliberation. To organize the debate it is useful to differentiate separate strands or positions of thought rather than detailing the history of these ideas to focus on the positions that are relevant for the current discussion. The following structure builds on White's (2015) approach. There are three main positions on the content of the social minimum important for this paper: Welfarism (Jeremy Bentham), the Capability Approach (Amartya Sen; Martha Nussbaum) and Resourcism (John Rawls; Ronald Dworkin) (White 2015).[60] These positions attempt to equalize different phenomena for all humans.

According to Welfarism, the social minimum is defined as the minimum amount of happiness necessary for an individual (White 2015). Happiness is usually measured as the difference between pleasure and pain and more recently also by the amount of desires satisfied. This understanding of the social minimum is central for traditional welfare economics measuring the "utility" of an individual e.g. through the economic choices she can make, thereby satisfying her desires.

The Capability Approach on the other hand sees wellbeing as defined by the "functionings" a person needs to live in dignity (beings and doings), such as "being happy" or "participating in communal life". The social minimum is then conceptualized as the minimum capabilities to achieve these "beings and

[60] These distinctions draw on the "equality of what" debate in philosophy which asks what should be equalized for everyone (White 2015).

doings" (capability is the person's power to achieve these functionings). The Capability Approach for example influenced the human development index (HDI). The HDI integrates life expectancy at birth, education and standard of living. It is used by the United Nations Development Programme for its annual Human Development Report.

According to Resourcism, income or wealth provide the appropriate "currency" of a social minimum as they are universal means for living a good life and can be used to fulfil various desires and wishes. A social minimum is then the minimum income or minimum amount of wealth. This notion is very present in the current discussion, e.g. in the debate on minimum wage or the idea of social security measures such as unemployment benefits.

In contrast to these philosophical arguments, legal approaches base the content of the social minimum on legal propositions. Nevertheless, they are also clearly influenced by philosophical deliberations: the idea of individual human rights for example has its roots in the enlightenment discourse. What renders legal conceptualizations different from philosophical deliberation is the underlying legitimacy – when being democratically enacted – and their enforcement character, being backed up by the coercive power of the state (depending however on the legal order; see the lack of enforcement for public international law).

It is useful, to distinguish three legal orders, when looking at social minimum legal propositions, as these differ with regards to their legal character. As an illustration, for the German case (and also for other countries which are part of the supranational European Union) the three legal orders of international human rights law, European law and national law are relevant. These legal orders interlink in a complex and debated manner. They are also complex with regard to the precise social minimum envisioned or deducible. For example, a conceptualization based on the German case has to take into account the German constitution, rulings by the German constitutional court and other courts and other relevant statutes. Similarly, for a "European" conceptualization of the social minimum e.g. the European Convention on Human Rights, the European Social Charter or the Charter of Fundamental Rights of the European Union have to be looked at. Here, we focus on International Human Rights Law and highlight some important rights relevant for the debate, as these are beneficial for a discussion of a *global* social minimum.

On the international level, there are the legally binding International Covenant on Civil and Political Rights and the International Covenant on Economic, Social and Cultural Rights. There are also special conventions on e.g. torture, the rights of the child or the status of refugees. The international covenant on Economic, Social and Cultural Rights is especially important in this regard. It guarantees the equal right of men and women to the enjoyment of all economic, social and cultural rights as specified in the covenant (Art. 3) relating directly to the social minimum discussion. These rights[61] are for example the right to an adequate living standard (Art. 11), including food, clothing and housing. Other rights are e.g. the right to physical and mental health (Art. 12), work (Art. 6) and education (Art. 13). Furthermore, the International Covenant on Civil and Political Rights is also important because it adds e.g. individual freedom to an international conceptualization. It stipulates inter alia that every human being has the inherent right to life (Art. 6), to be free from torture and slavery (Art. 7 and 8) and to enjoy security of person (Art. 9). The International Labour Organization (ILO) has proposed a set of social minimum standards – the social protection floor – which demands that countries ensure a minimum level of health care and income security for children, older persons and persons who are not able to earn sufficient income. The ILO aims at achieving at least this "nationally defined minimum level" (ILO

[61] Note however that these economic / social / cultural rights do not imply real state duties as they are limited by Art. 2 of this convention which stipulates that a "state undertake steps […] to the maximum of its available resources".

2016) while gradually reaching more progressive goals in line with the Social Security (Minimum Standards) Convention such as more extensive standards for sickness benefits. The rights in both conventions as well as the ILO's social security convention form an international vision for a global social minimum.

Finally, soft law relevant for the discussion on the social minimum are the SDGs and the UN Global Compact. The UN Global Compact is a "voluntary initiative based on CEO commitments to implement universal sustainability principles" (UN Global Compact 2015). It comprises of ten principles, meant to inform business strategies and operations. Covered areas are human rights, labour rights, environmental protection, and anti-corruption.

The SDGs are central for the discussion, including the targets for eradicating poverty (SDG 1), ending hunger (SDG 2), ensuring good health and well-being (SDG 3), quality education (SDG 4), gender equality (SDG 5), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8) and reduced inequalities (SDG 10). The SDGs can both justify and define the content of a social minimum. The predecessor of the SDGs, the now terminated Millennium Development Goals (MDGs), also established eight goals conceptualizing a social minimum – for example the goals of poverty and hunger eradication (MDG 1) and universal primary education (MDG 2).

Conclusions: Bringing social and planetary boundaries together

The brief conceptualization of the social minimum shows that there are many (competing) ways to define it. The wealth of positions implies that it is no easy task to bring planetary boundaries and the social boundaries together, as doing so involves a difficult decision on what social dimensions to choose to form a social boundary. However, as we will show in chapter 1.6.5, there are several ways to facilitate the integration of social minima in the planetary boundaries framework including by relying on participatory approaches (e.g. surveys). Furthermore, the 2030 Agenda has considerably strengthened the legitimacy of internationally agreed upon social minima. As described in its preamble, the 2030 Agenda is universal (addressing all countries) and has also been universally agreed upon. It is recommended to rely on the 2030 Agenda and the SDGs and targets for combining planetary boundaries with social sustainability.

Combining social and environmental boundaries – predecessors

There are several predecessors to Raworth's doughnut both in the political and the scientific realm who have combined the concept of a social minimum with e.g. the concept of carrying capacity. Both are usually connected by referring to the resources or other services provided by an intact nature which are needed for a decent life. Looking at these predecessors helps understand the premises of Raworth's model.

Cocoyoc-Declaration

A first predecessor is the Cocoyoc-Declaration. It is the outcome of an expert symposium on patterns of resource use, environment and development which took place in Cocoyoc, Mexico (1974). The declaration argues for a new economic world order which is based on novel principles. These principles are: the redefinition of development – satisfying the basic needs of the poorest segments of society and guaranteeing political freedoms; the diversity of development – recognizing the different development pathways and alleviating both the problem of underdevelopment and overconsumption; and self-reliance – using national resources and people as well as reducing foreign dependence.

The declaration conceptualizes the interlinkages between the environment and development as a model with inner and outer limits (or ceilings and floors). The inner limits (floor) are the basic human needs such as housing, food or education (limits of man); the outer limits (ceilings) are defined by the finite carrying capacity, resource availability and physical integrity of the planet (limits of nature). The central problem in the interacting cluster of environment and development are, according to the Cocoyoc-Declaration, overconsumption by the wealthy threatening the outer limits and under-consumption by the poor threatening the inner limits.

Brundlandt Report

Another predecessor is the 1987 Brundlandt report. It famously defines sustainable development as "meet[ing] the needs and aspirations of the present without compromising the ability to meet those of the future" (WCED 1987: 43) and frames the questions of environment and development as one single issue – sustainable development. It thereby created a catchphrase that dominated the political agenda since then.

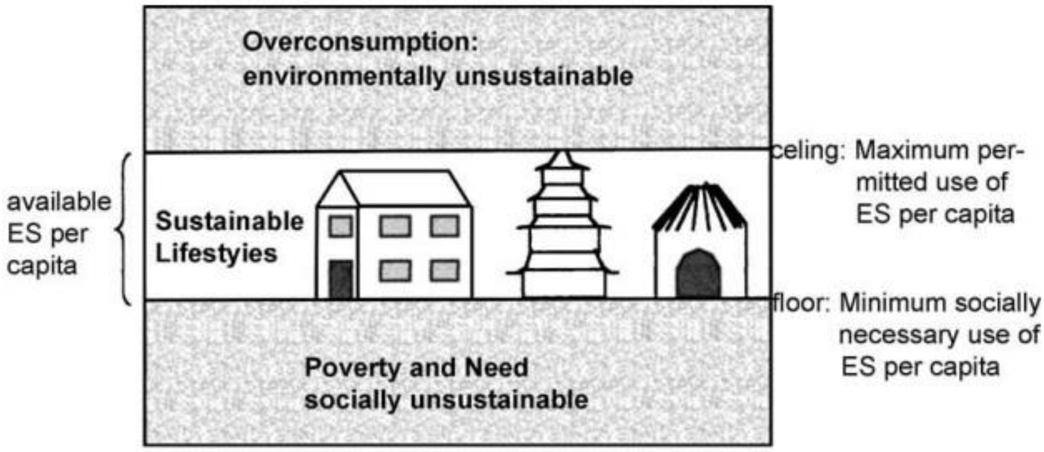
The report also conceptualizes the interlinkages between development and environment as twofold – similar to the Cocoyoc-Declaration. On the one side are essential needs which are to be satisfied. On the other side are limitations which are caused by the "state of technology and social organization" and limit the "ability of the biosphere to absorb the effects of human activities". But contrary to the Cocoyoc-Declaration these limits are seen as not absolute. When technology and social organization are improved, economic growth could follow which is essential (together with fair shares of resources) to satisfy the basic needs of all, as the Brundlandt report argues.

Environmental Space

A third predecessor is the environmental space concept which has been originally put forward by J.B. Opschoor in 1987 (building on Siebert 1982). According to the concept, there are limits to how much human pressure on resources and sinks the planet can absorb (Opschoor and Weterings 1994; Hille 1997). These limits create a space for humanity and constrain how much resources it can deplete and how much sinks it can pollute.

Spangenberg (1994) further developed the concept by adding global equity to the original conceptualization and by focusing solely on resource consumption. Environmental space then consists of both a floor and a ceiling: The ceiling is the "maximum amount of non-renewable raw materials (incl. energy), land (incl. wood) and water" that can be sustainably consumed (Spangenberg. 1994: 9). The floor is the "minimum amount" of resources necessary to "overcome need and poverty" (ibid.). Every person should be allowed the same use of environmental space (equal per capita use of environmental space). A country's share of the space is then calculated as its percentage of the world population. The merits of this conceptual model are described by Spangenberg (2002: 295): "the concept—although rather complex—can easily be communicated and used as a tool for gathering public support for sustainability policies." Figure 57 below illustrates the concept:

Figure 57: Environmental space concept (Spangenberg 2002: 298); image annotation by Spangenberg 2002



Source: Spangenberg (2002: 298)

Ecological Footprint and HDI

Finally, another predecessor to Raworth's doughnut is the combination of ecological footprints (environmental ceiling) with the HDI (social floor) (see for example the Global Footprint Network, DEZA, WWF 2008). According to the Footprint Network, combining both dimensions helps to grasp the minimal conditions for sustainable development. The difference to other predecessors lies in the use of the footprint rather than resources (as in Spangenberg's model) or carrying capacity (as in the Cocoyoc-Declaration) for the environmental dimension, and the use of the HDI for the social dimension.

Conclusions: the premises of current socio-environmental conceptual models

The brief analysis of important predecessors shows that the idea of an operating space has a long history, spanning back to the 1970s. There are various ways of creating an operating space for humanity which do not have to recur to planetary or social boundaries. Conceptualizations of the environmental pre-conditions of sustainable development can for example rest on resource consumption and pollution, solely on resource consumption or on ecological footprints. The social pre-condition can rest on minimum resources, needs or indicators of human development.

While the predecessors differ in how they specify the environmental and social dimension, they rest on several premises:

- on the assumed necessity of integrating the environmental and social factors to achieve sustainable development in the form of boundaries;
- on the dichotomy between the environmental and social pre-condition in that they represent two very different realms (humanity and nature);
- on the similarity of both in that they can be conceptualized as limits or limitations (albeit with a differing degree of absoluteness of limits);
- on the assumption of the particular communicative or political strength of a space concept for global (or regional, national, local) environmental politics (for the environmental space concept and Raworth's doughnut);
- on the assumption that avoidance targets (the limits) are enough guidance for sustainable development leaving the space open for individual pathways.

As we will see in chapter 1.6.3, Raworth's doughnut also shares these premises. But as we will show in chapter 1.6.3 and 1.6.4, these assumptions can be criticized, necessitating a re-framing of the discussion.

1.6.3 Combining planetary and social boundaries: the Doughnut Approach

One central recent combination approach is Raworth's doughnut model (Raworth 2012) which is quite influential in the planetary boundaries community, receiving almost no critique. It is referred to in major articles such as the 2015 update of the framework (Steffen et al. 2015a) and other important contributions e.g. on the SDGs and nitrogen (Hajer et al. 2015; de Vries et al. 2013). In 2017, Raworth updated the model (Raworth 2017a), identifying "seven ways to think like a 21st century economist" (book title). The framework is also often presented in public panel discussions (e.g. at TedX Athens or the Rethinking Economics Conference 2014), usually being described as a necessary extension of the PBs. It has also reached the political realm, being used by political foundations (Heinrich-Böll-Stiftung 2013), governmental agencies (Bundeszentrale für politische Bildung 2015) and governments (see Finland's vision for sustainability by 2050, Kestävä 2015). The doughnut thereby became the focal point of the debate on how to relate the PBs to the social side of sustainable development, instructing major downscaling attempts (see Cole et al. 2014; Dearing et al. 2014) and thus presents the natural starting point for reflecting on PBs and the social side. It is therefore described and evaluated in more detail below.

The doughnut approach: dimensions, indicators and illustration

The original model

Raworth invented the model of the "doughnut" as an add-on to the planetary boundaries concept. She regards the planetary boundaries as a useful starting point for grasping the natural processes on which humanity depends for sustainable development. Yet, according to Raworth, the social side is neglected in the planetary boundaries concept, which motivated her to create a model that also integrates social justice (the social boundaries). This model seeks to offer a comprehensive perspective on what she calls the biggest challenge of the 21st century: "to ensure that every person has the resources to meet their human rights, while collectively [living] within the ecological means of this one planet" (Raworth 2012, p.1).

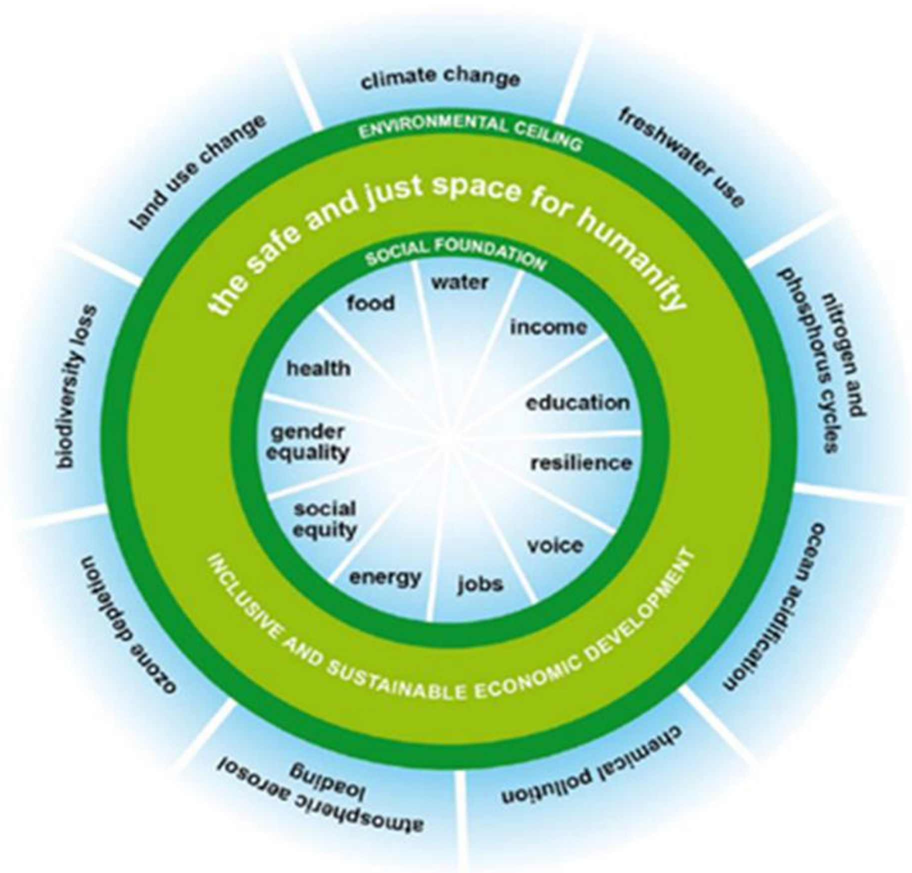
The social foundation (social ceiling) of the doughnut model consists of eleven dimensions that are premised on governments' priorities for Rio+20 (below are the eleven dimensions and corresponding, illustrative indicators; quoted from Raworth 2012):

- **Health**: measured by the population estimated to be without regular access to essential medicines;
- **Food**: population undernourished;
- **Water**: population without access to an improved drinking water source and improved sanitation;
- **Income**: population living below $1.25 (PPP) per day;
- **Education**: children not enrolled in primary school and illiteracy among 15–24-year-olds;
- **Energy**: population lacking access to electricity and clean cooking facilities;
- **Social equity**: population living on less than the median income in countries with a Gini coefficient exceeding 0.35;
- **Gender equality**: employment gap between women and men in waged work and representation gap between women and men in national parliaments;

- **Resilience**: e.g. population facing multiple dimensions of poverty; [62]
- **Voice**: e.g. Population living in countries perceived not to permit political participation or freedom of expression;
- **Jobs**: e.g. labour force not employed in decent work.

The nine dimensions of the environmental ceiling are the planetary boundaries in their original version (Rockström et al. 2009): climate change, biodiversity loss, land use change, freshwater use, nitrogen and phosphorus cycles, ocean acidification, chemical pollution, atmospheric aerosol loading, and ozone depletion.

Figure 58: Raworth's doughnut



Source: Raworth (2012: 4)

Both the social and the planetary boundaries are in a precarious state, as Raworth points out (as humanity should not remain under the minima defined as social boundaries and should not transgress the maxima defined as planetary boundaries). While significant progress can be observed in some of the dimensions of social deprivation (e.g. primary school enrolment ratios rose by nine percent from 1999 to 2009), many inequalities for instance regarding wealth, gender, ethnicity and location persist. At the same time, planetary boundaries are increasingly transgressed.

[62] For the three dimensions “resilience”, “voice” and “jobs”, Raworth included suggestions for indicators but data was not yet available.

The social and planetary boundaries are furthermore characterized by strong interdependency. Environmental problems can aggravate poverty (e.g. climate change can lead to social impacts for vulnerable societies), and poverty, in turn, can exacerbate environmental stress (e.g. as poor segments of society use resources unsustainably). Similarly, policies aiming for sustainability can exacerbate poverty (e.g. biofuel subsidies can lead to land grabbing), and policies aimed at tackling poverty can aggravate environmental problems (e.g. subsidized industrial fertilizer can lead to perturbations of the nitrogen cycle). These complex dynamics need to be considered when designing policies to ensure that both poverty eradication and environmental sustainability are promoted, as Raworth argues.

Raworth however also stresses that both sides of sustainable development can be compatible. One of the examples she cites is that providing electricity for the 19 per cent of the world's population without access to electricity could be realized with less than a 1 per cent increase in global CO_2 emissions. What is needed to achieve both environmental sustainability and social equity is a more efficient use and more just distribution of natural resources. Raworth acknowledges that the scope of policies necessary to make such an unprecedented social and economic transition is too broad to be discussed in her approach, but she emphasizes that her model offers a "global-scale compass" for achieving this goal (Raworth 2012: 5).

The 2017 update

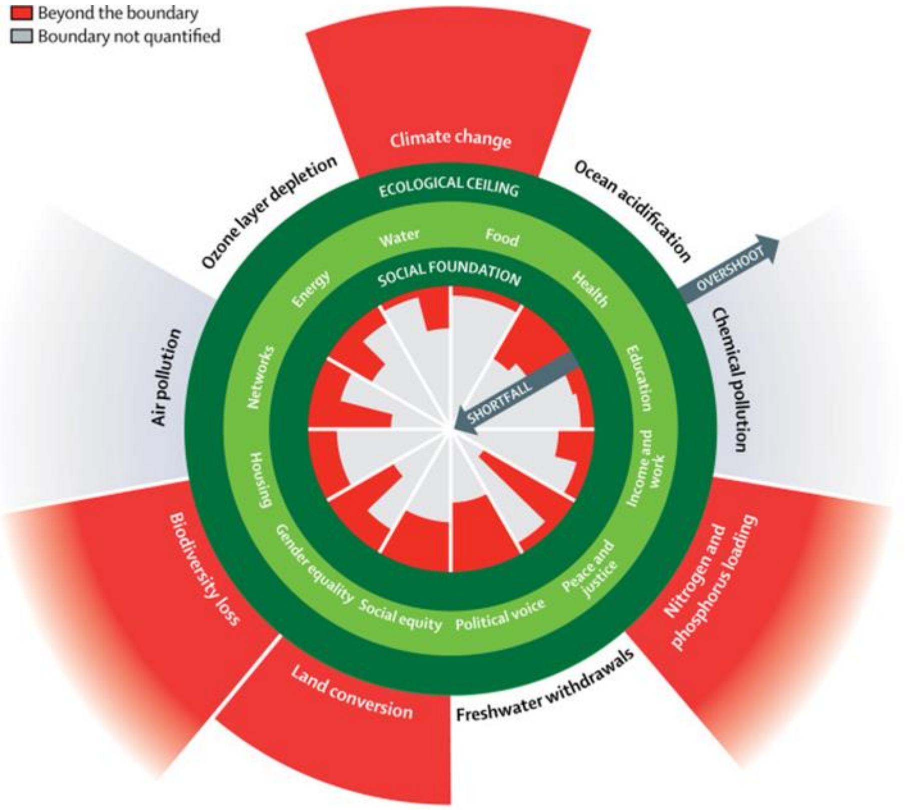
In her 2017 update, Raworth sets out to develop a new economic model, meant to provide an alternative to traditional economic theories. The underlying premise of the update is that new frames / narratives and especially new pictures are needed to persuade society to conduct business differently, not just critiquing existing models. She sees economic theory at the heart of the interdependent challenge to observe planetary boundaries and achieve social development.

Seven ideas are presented, which are thought to be "mind-shifting" (Raworth 2017a: 4), and are meant to be the tools for re-shaping economics so as to achieve ecological and social goals (the doughnut). These are:

- Change economics' goal from GDP to operating within the doughnut (safe and just space);
- Move from Circular Flow Diagrams ("self-contained market") to an "embedded economy", in which the economy is embedded in society and the Earth;
- Re-characterize human nature, going beyond rational "homo oeconomicus", integrating e.g. our social nature;
- Embrace systems thinking, rather than economic equilibrium theory;
- Re-design the economy, refraining from the Kuznets Curve, and focusing on redistributing wealth (e.g. controlled land);
- Embrace "regenerative design", meaning to "design economic policies … that unleash the extraordinary potential of the circular economy" (Raworth 2017a: 242);
- Realize our "addiction to growth" and change the economy so it can live without growth.

For the 2017 update, Raworth did not change the overall set-up of the doughnut model, but implemented several smaller changes, mainly related to renaming the categories. For the

Figure 59: The updated doughnut



Source: Raworth (2017b)

planetary side, she rephrased some of the boundaries, diverting from Steffen et al.'s 2015 article, namely "freshwater withdrawals" instead of "freshwater use", "nitrogen and phospho-rous loading" instead of "biochemical flows", "land conversion" instead of "land-system change", and "air-pollution", instead "of atmospheric aerosol loading". She also changed some of the social categories, adding "networks" (measured illustratively by "people without access to the Internet"; "people without someone to count on for help in times of trouble") and "peace and justice" (measured illustratively by level of corruption and homocide), eras-ing "resilience", and renaming "jobs" to "income and work" (measured by "population living on less than the international poverty line" and "proportion of young people … seeking but not able to find work") and "voice" to "political voice" (measured illustratively by the Voice and Accountability Index). She also relates these to the SDGs (see Raworth 2017b, Appendix).

Extending boundaries: strengths of the doughnut

Raworth's "global scale compass" is widely endorsed by the planetary boundary-community, as outlined in the previous section. Through the below described strengths, Raworth's model managed to become an often used and referenced tool for describing minimum social conditions for sustainable development in conjunction with the planetary boundaries, regarded as a necessary addendum for the planetary boundaries, being broadly legitimized and perceived useful for development discussions.

And there are several reasons why the framework has been well received:

Broad legitimation

The original framework is based on 80 Rio+20 submissions by governments and her 2017 update is based on the SDGs, reflecting topics that are widely regarded as most important social goals for the global community. These are to a large part international consensus. The framework therefore represents the international political understanding of a social minimum.

Planetary boundary foundation

The framework builds on the planetary boundaries and thus incorporates the strengths of the framework – e.g. its scientific foundation, its universal appeal and its prominence in the political and scientific arena.[63]

Filling the void and foundation for discussion

The doughnut fills a void deliberately left open by the planetary boundaries. Developmental pathways including social goals are explicitly not included in the planetary boundaries framework. The doughnut thus provides an answer to the often raised question of social justice and the planetary boundaries and the question of the interlinkages between the social and environmental pre-conditions of sustainable development. It can thus also inform discussions on interdependencies of the environment and humanity.

Further access to developmental actors

The doughnut allows to reach out to actors that focus primarily on social goals. The approach is therefore an important support in planetary boundary discussions on sustainable development as it can show that the planetary boundaries framework is generally open to the social side and that policy makers can use it for both environmental and social targets.

Focus on operating space (doughnut)

The doughnut, the safe and just operating space, is at the centre of the concept. The approach thus focuses less on limits and boundaries and therefore represents a more opportunity-oriented vision for environmental communication and policy making.

Catchy illustration and metaphor

The model offers an illustrative framework. The light colours used stress that sustainable development is a feasible task for humanity and not a frightening or irreconcilable challenge. The approach also builds on a catchy metaphor (the doughnut) which symbolizes what the safe and just operating space is intending to deliver: well-being and safety for humanity (note however that this metaphor might not be universally understood).

Limits to Boundaries: Problems of the combination approach

But notwithstanding these strengths, the framework exhibits several weaknesses which become apparent when more closely looking at the doughnut. These weaknesses refer to several aspects of the models makeup but most importantly also to the premises it shares with previous conceptualizations (see Chapter 1.6.2).

Problem of Realms

The doughnut creates two realms that are framed as opposite – the planetary and the social. But as we will argue below (chapter 1.6.4) the difference and the opposite nature of both realms can be challenged. The doughnut thus might contribute to a mis-conceptualization of the PBs and the social realm.

Problem of Complexity

By adding another realm to the illustration the PBs become over-complex resulting in even more messages. Combined, there are 20 boundaries on two different levels (nine planetary plus eleven social boundaries), with corresponding interlinkages between all these realms (planetary – planetary; social

[63] See Keppner, Benno; Kahlenborn, Walter and Teresa Sophie Rath (2016): On the communicative potential of the planetary boundaries concept.

– social; planetary – social). For environmental communication such a multi-complexity can be problematic.[64]

Problem of Hierarchy

The doughnut incorporates both environmental and social targets which, according to Raworth, can be simultaneously achieved. But conflicts between environmental and social goals are still likely to occur (e.g. when climate mitigation measures clash with social targets). In such situations, the model does not provide a rule of hierarchy which outlines criteria for the precedence of goals. According to Raworth both sides of the coin should be "taken … into account when designing policy intervention" but how they are related to each other is unclear (Raworth 2012: 18).

Furthermore, from a political perspective it appears likely that social goals will take priority (given the existential nature of e.g. the goal to eradicate hunger). But this prioritization does not sit well with the absolute character of the planetary boundaries – to avoid transgression. Also, by including social boundaries, the framework could recreate the problems that the planetary bounaries were trying to avoid – to enter into a long-lasting debate on the content of social targets.

Problem of Content

The doughnut focuses on 11 social dimensions, but many of the in chapter 1.6.2 outlined possible dimensions of a social minimum are not included, such as right to life, freedom from torture, safety etc. (see section on the conceptualization of the social minimum). This might become problematic, as it indicates an under-specification of the social minimum, only partially fulfilling the intention of creating a decent life for all.

Problem of Statism and Prioritization

Raworth's illustration leaves the question of direction of social boundary transgressions as well as the speed of these developments open, similar to the original planetary boundary illustration. This is problematic as it makes prioritization of social goals more difficult – showing the rapidity of social boundary transgression could help to deduct which of these goals should be tackled first.

Problem of Misleading Analogy

Raworth conceptualizes the social pre-condition of sustainable development as a boundary much in line with earlier conceptualizations as limits. But there is an inherently different connotation when setting social goals in analogy to the planetary boundaries. It raises the question whether there are social tipping points, which when being crossed lead to a "social regime shift" or to social unrest, demonstrations, violence, etc. While the question is valid, it is not nearly as well founded as the planetary boundaries and ecological thresholds. Indeed, it can be questioned whether social upheavals were or are to a large extent caused by remaining below or undercutting social minima. Instead it appears that relative deprivation rather than absolute deprivation is very often behind social unrest – that is the *perception* of a lack of those lifestyles, resources and goods or activities that are widely seen as the social standard within a society, rather than the lack of an absolute minimum leads to upheaval (see Gurr 1970).

Problem of persuasion

Raworth's 2017 update is based on the premise of the effectiveness of frames and pictures in the political realm. But this view might be too optimistic, given the current path-dependencies in the economic

[64] See Keppner, Benno; Walter Kahlenborn and Teresa Sophie Rath (2016): On the communicative potential of the planetary boundaries concept.

system as well as the interlinkages between authoritarian rule and economic transformation (see Richard Toye's critique, Toye 2017).

Doughnut and planetary boundary uptake in the development community

Raworth's concept was an important development for strengthening the social justice side of the plenatery boundaries and for including the questions of poverty and deprivation into the debate on guardrails for sustainable development. It thus helped to open the planetary boundaries for other broader social equity oriented circles. But the concept also exhibits several weaknesses as described above, including the problems of levels, complexity, hierarchy, content, statism and prioritization and misleading analogy.

Furthermore, the concept's impact is debatable. It certainly resonated within the academic realm, especially the planetary boundary community (see introduction to this chapter). It was also debated in the run-up to the SDG adoption in 2015: for example Raworth presented it at a Special Event of the United Nations General Assembly in 2012 (UN General Assembly 2012) and published the doughnut in the World Social Science Report 2013 (Leach et al. 2013a). The doughnut was also referenced in a report by the Sustainable Development Solutions Network (SDSN 2013b). But the doughnut was not included in the Synthesis Report of the Secretary General or the final outcome document adopted in New York 2015 (while the safe and just operating space was certainly part of the conceptualization). It is worthwhile looking more closely at the planetary boundary (and doughnut) uptake in the pre-2030 Agenda process, as understanding the critique uttered during this process helps realizing why planetary boundaries (and the doughnut) were not included in the SDGs, and what steps would be necessary to reconcile with and more firmly integrate planetary boundaries in the development community.

There are different critical voices with regards to the planetary boundaries framework observable in the run-up to the 2030 Agenda. For example, Melissa Leach, director of the Institute of Development Studies, University of Sussex, and lead author for the World Social Science report 2016, reported from the Expert Group Meeting on Science and Sustainable Development Goals which took place prior to the 2015 agreement (Leach 2013). She raised the question whether there is a "contradiction between the world of the Anthropocene, and democracy" (Ibid.). According to her, the "Anthropocene, with its associated concepts of planetary boundaries and 'hard' environmental threats and limits, encourage a focus on clear single goals and solutions" (Ibid.). Such a focus does not sit well with the diversity of different development pathways, "as a South African participant pointed out" (Ibid.). This view of a potentially un-democratic nature of the planetary boundaries is mirrored by other commentators, e.g. Roger Pielke Jr, who perceives of planetary boundaries as a "power grab", as the boundaries are set by experts and involve a hierarchy of values, trumping other sustainability dimensions (Pielke 2013).

Fred Saunders, in reflecting on the growing status of the planetary boundaries within science and the political realm, analysed the Post-2015 process with regards to the planetary boundaries (Saunders 2014). He noted "contradictory messages on planetary boundaries and development within the UN" (Saunders 2014: 829). While there is some adherence to the concept (e.g. in UNEP Geo 5; UN High-level Panel on Global Sustainability), the concept itself re-invokes a "long-standing anxiety held by Global South countries about global environmental protection being used to curtail their development aspirations" (Ibid.). Likewise, for developed countries, it appeared unlikely that they would "agree to reduction in their patterns of economic growth for environmental protection" (Ibid.). In the High Level Panel, planetary boundaries were thus often perceived as divisive. As a consequence, there was a move to "steer towards the mainstream SD debate" (e.g. the triple bottom line approach, which does not involve environmental limits). Saunders also screened the respective research literature on Rio+20 and planetary boundaries. According to Saunders, several authors concluded that the Rio+20 Conference "rejected the idea of planetary boundaries altogether" (Ibid.). The reasons are somewhat difficult to dissect, according to Saunders, as the different reports exhibited "different configurations of values, interests and ambitions", but overall the uptake in the pre-2030 Agenda process shows that the planetary boundaries are "still too controversial on a number of grounds" (Saunders 2014: 830).

In analyzing the SDGs itself, Eric Holden comes to the conclusion that the "environmental goals (Goals 12–15) are merely unquantified ambitions to 'protect','strengthen' and 'promote'" (Holden et al. 2016: 214). Clearly, the "lack of quantifiable ambitions results from not acknowledging that there are environmental limits" (Ibid.). Also, Bhattacharya, in commenting on the final outcome document of the Open Working Group on Sustainable Development Goals, argues that while "the salience of social issues in the agenda is visible … further data indicates that the emergence of an economic agenda within development is likely" as "a comparison of earlier versions of OWG documents with the final outcome document reveals that the latter contains a larger number of economic goals and targets" (Bhattacharya et al. 2014: 175).

Conclusion: ways forward and the need to re-frame planetary boundaries

It is however possible to further develop the doughnut (and the planetary boundaries) and to partially moderate the weaknesses identified above and the barriers visible in the political process at Rio+20 / the 2030 Agenda. Science could help to alleviate the problem of statism and prioritization by outlining the speed and direction of transgressions of social boundaries and by making the prioritization clearer. Furthermore, science could contribute to formulating a rule of hierarchy by setting priorities for specific planetary boundaries (e.g. climate change and biodiversity) and social boundaries (e.g. poverty reduction). Another idea forward would be to formulate a concordance rule similar to the principle of "practical concordance" in German constitutional law. This principle demands that conflicting norms should both be realized to the highest degree possible. This would mean that conflicting social and environmental goals would both need to be realized as much as possible and that trade-offs should be balanced.

Also, for the problem of the misleading analogy there are two ways forward conceivable: science could contribute to further clarifying the empirical base of social tipping points and the impacts of social regime change (see for recent developments Grimm and Schneider 2011; Werners et al. 2013), taking into account the theory of relative deprivation. Furthermore, it could be outlined that the justification for the social boundary solely rests on social equity or the international political consensus, leaving the social tipping point analogy explicitly out of the picture. For the problem of complexity, narratives could be devised that move the complex, intertwining social-environmental levels to the realm of personal experience. Such narratives could also be amended by images and illustrations depicting the interrelationship between both levels.

But several problems will prevail even when moderating them: The complexity of the model is inherent to any attempt of specifying environmental and social targets – the idea of a parsimonious model conflicts usually with the wealth of important goals (see chapter 1.6.2). Also, formulating a rule of hierarchy is not only a scientific question. It is also a political decision on the priority of social and environmental goals. This means that such a decision is bound to be conflict ridden and long-lasting. Furthermore, the problem of the misleading analogy is partially inherent in the framing of the social side of sustainable development as boundary.

Also, it is debatable whether the concept would have had more popularity without these weaknesses. Instead it appears that a central barrier is the framing of planetary boundaries and its (perceived) closeness to the limits to growth discourse. It appears therefore necessary to take a perspective that contributes to re-framing the debate which we will outline in chapter 1.6.4 below.

Such a re-framing of planetary boundaries is indeed also the path that major proponents within the planetary boundary community have taken. For example, Johan Rockström argues that the planetary boundaries are not limits to economic growth but "growth within limits"; meaning the planetary boundaries are coherent with economic growth, innovation etc. Still, the current development pathways would need to be changed to fit within the planetary boundaries (Saunders calls this approach "reflexive business as usual"; Saunders 2014: 830). For example, in the description of Rockström's book "Big World, Small Planet" the Stockholm Resilience Centre summarizes:

"Abundance within planetary boundaries requires a deep mind-shift. Not growth without limits. Not limits to growth, but growth within limits." (Stockholm Resilience Centre 2015)

Besides this re-assurance that planetary boundaries do not fundamentally conflict with economic growth, there is a second re-framing observable: to highlight the interlinkages between and the necessity to add social boundaries to the planetary boundaries in order to relate to the development community.

We believe that re-framing the planetary boundaries is indeed important for making the planetary boundaries more successful in the public realm and within political discussions but argue that social boundaries should not only be added to planetary boundaries. Rather, planetary boundaries should be portrayed as social boundaries, re-framing public discourse on planetary boundaries altogether (see the following chapter for a more detailed discussion).

1.6.4 Re-framing the debate on planetary and social boundaries

The "problem of realms" briefly mentioned above in the section on "limits to boundaries" indicates a deeper challenge for conceptualizing the doughnut: how to create a model that refrains from creating dichotomies between social and environmental realms and takes into account the deep interlinkages between both. To reframe the debate, the different worlds which environmental and social policy-makers inhabit have to be taken into account and the constructed dichotomy between planetary and social boundaries has to be analysed more closely.

Social boundaries and social development

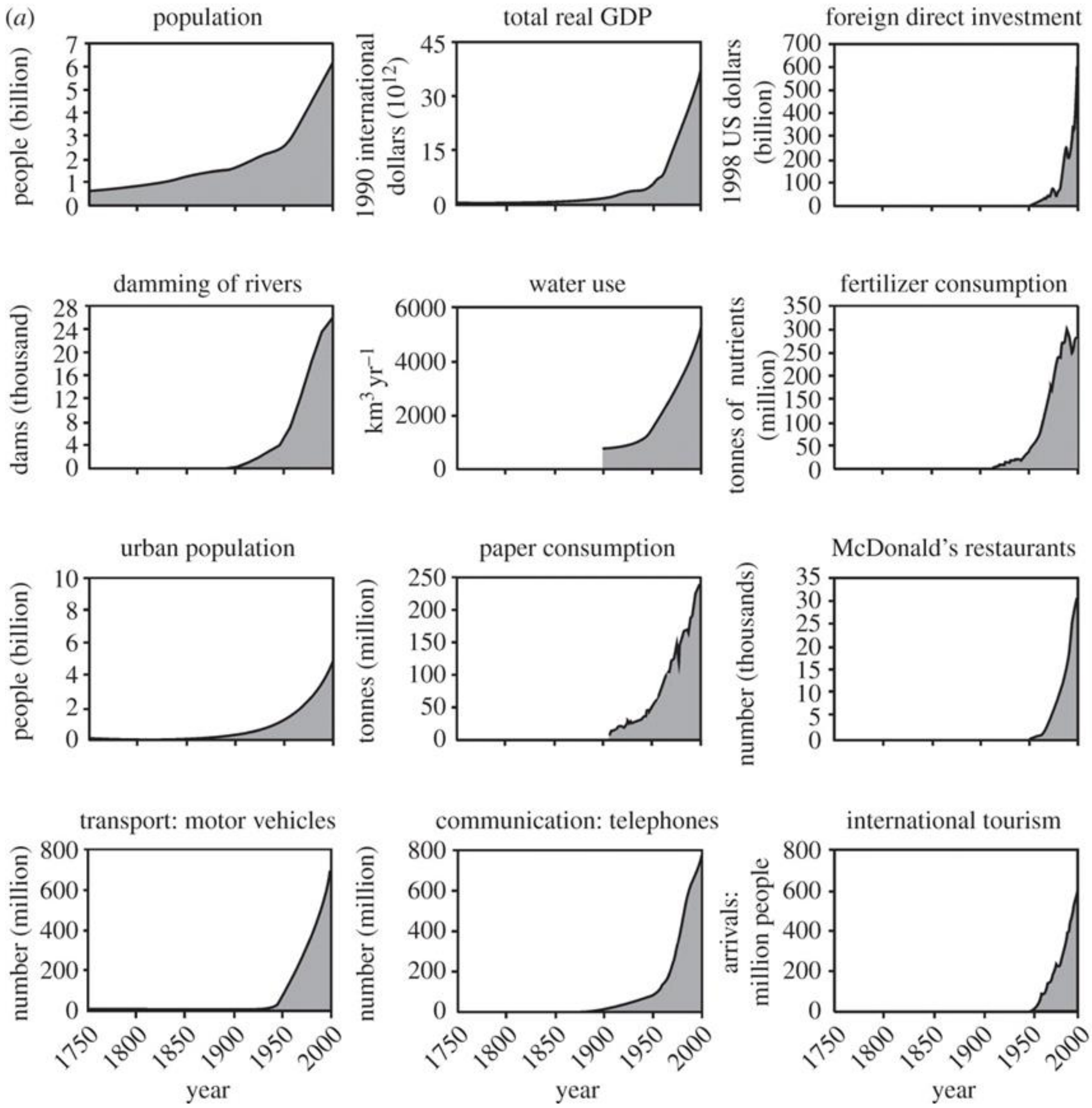
The PB discourse is to a considerable extent based on the Anthropocene debate. Respective publications from the Anthropocene field show the development of several human-induced environmentally-damaging factors, such as rapidly increasing resource consumption (Steffen et al. 2007; Steffen et al. 2011b). For example, Steffen et al. illustrate the "great acceleration" (Steffen et al. 2007: 617) by visualizing central aspects of human activities that impact the environment or are drivers or human pressures. In doing so, these publications substantiate the danger of transgressing the planetary boundaries supporting the planetary boundaries framework. According to this line of argumentation, the exponential increase of environmental impacts entails risks, as these illustrations signify the growing pressure on the planetary boundaries which may lead, according to Rockström et al. to "human induced environmental disasters at continental to planetary scales" (Rockström et al. 2009).

These conclusions are mirrored in other environmental assessments. The Millenium Ecosystem Assessment asserts that 15 ecosystem services are degrading, that is less benefits are provided to humans. These include the loss of provisioning services (e.g. genetic resources, fresh water), regulating services (e.g. air quality regulation; erosion regulation) and cultural services (e.g. spiritual and religious values, aesthetic values) (Millenium Eocsystem Assessment 2005: 7). Monetarizing parts of these loss, Costanza et al. estimate the total (economic) loss of ecosystem services caused by land use change alone as 4.3 to 20.2 trillion per year (Costanza et al. 2014).

Similarly, the UN Global Environmental Outlook 5 notes that "the impacts of complex, non-linear changes in the Earth System are already having serious consequences for human well-being", including for food security through climate variability and extreme weather events, health impacts through land system change / deforestation (e.g. malaria), and impacts on human security (e.g. reduction in available resources) (UNEP 2012: 208). For climate change, the latest IPCC assessment report highlights impacts on human systems, including on “food production” and “livelihoods, health and/or economics” (IPCC 2014a: 7); future impacts could lead to “long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems” (IPCC 2014a: 8).

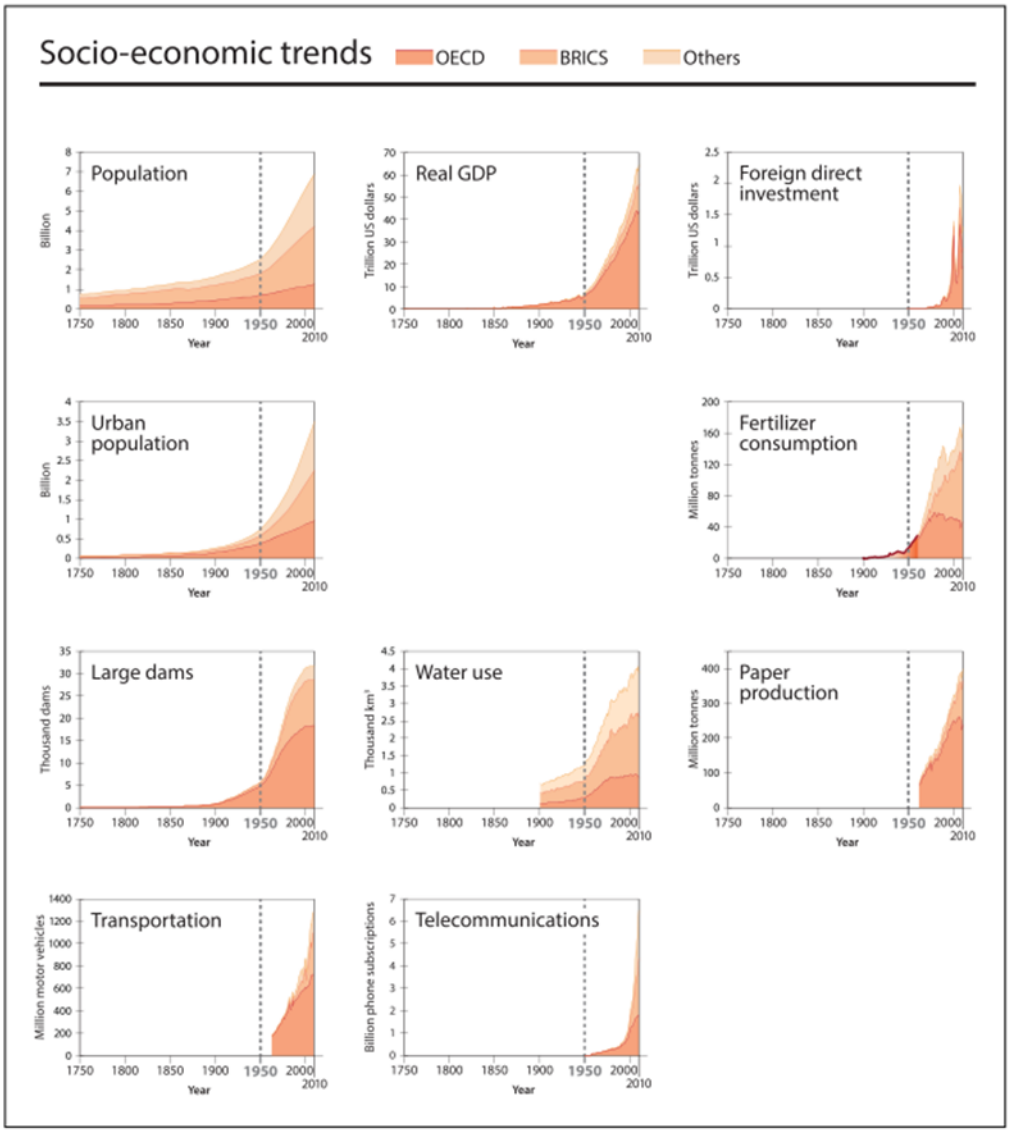
The world in which environmental policy-makers operate is thus marked by a multitude of assessments, publications, illustrations that highlight the risks associated with the Anthropocene and the current form of social metabolism. Figure 60 below and the 2015 disaggregated update by Steffen et al. in Figure 61 are one of these many examples, showing the exponential increase in e.g. population numbers, total real GDP, water use and paper consumption.

Figure 60: The Great Acceleration: socio-economic trends



Source: Steffen et al. (2011b: 851)

Figure 61: Updated Illustration; socio-economic trends



Source: Steffen et al. (2015b: 86)

The world in which development policy-makers operate looks very different. This is for example visible in major development assessment documents. The MDG progress report 2015 for example undertaken by an inter-agency and expert group and supported by large development organizations, such as the World Bank, UN Children's Fund, the World Health Organization and others, "based on a master set of data" argues that "unprecedented efforts have resulted in profound achievements" (United Nations 2015). According to the report, "extreme poverty has declined significantly over the last decades"; the working class has increased by the factor 3; the number of undernourished people has "fallen by almost half" (Ibid.: 4). The report also notes progress in universal primary education ("primary school net enrolment rate in developing regions reached 91 percent"), in promoting gender equality (e.g. "many more girls are now in school compared to 15 years ago")(Ibid.: 5), reducing child mortality, improving maternal health and combatting HIW/Aids.

The Human Development Report 2016, drafted by the United Nations Development Programme, highlights as achievements "a drop of more than two-thirds" in the "global extreme poverty rate" (UNDP 2016: 26). Also, mortality decreased and "between 1990 and 2015 2.1 billion people gained access to improved sanitation" (UNDP 2016: 27). According to the report further "rapid progress is possible", as "the world has the resources, the technology and the expertise to overcome human deprivations" (UNDP 2016: 39). This vision is shared by the 2030 Agenda for Sustainable Development, the most comprehensive and universally accepted development agenda, which aims "to end poverty and hunger everywhere; to combat inequalities within and among countries; to build peaceful, just and inclusive societies; to protect human rights and promote gender equality and the empowerment of women and girls; and to ensure the lasting protection of the planet and its natural resources" until 2030 (Introduction, para 3). This Agenda is deemed as ambitious, but also as achievable when "working tirelessly for the full implementation of this Agenda by 2030" (Introduction, para 2).

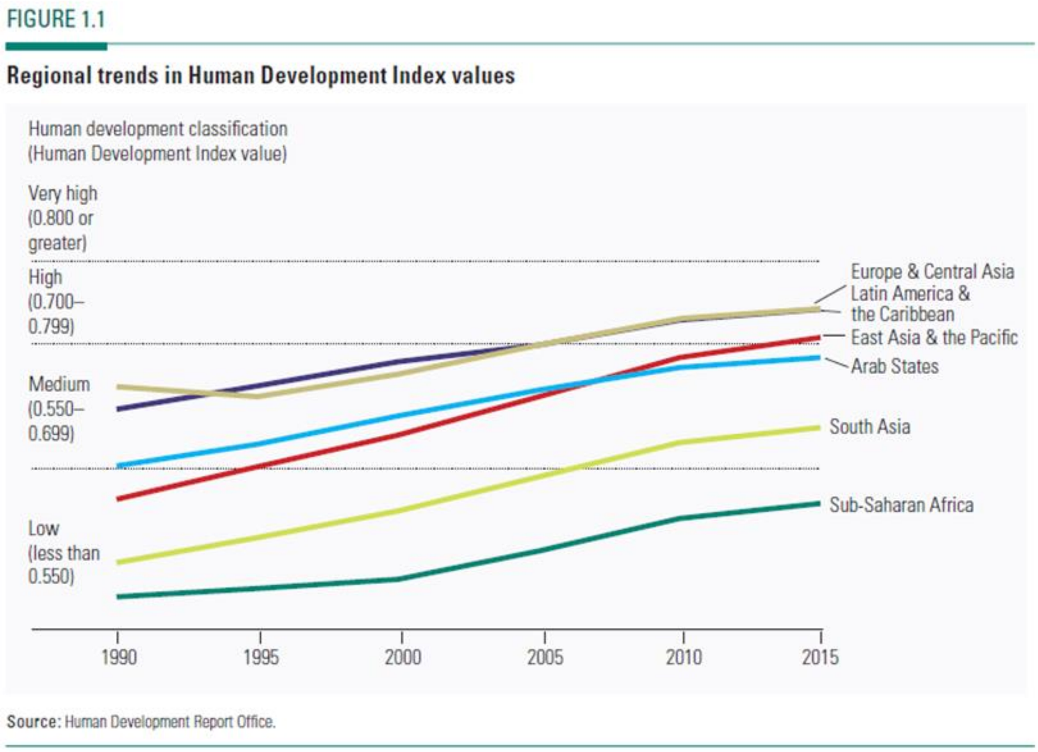
Furthermore, progress is also noted for specific regions, such as Africa and Asia and the Pacific. The UN Economic Commission for Africa, working together with the African Union, the African Development Bank Group and UNDP for a report on MDG progress in Africa, states that "Africa has made considerable progress towards achieving the Millennium Development Goals despite challenging initial conditions" (UN Economic Commission 2015). The continent has "achieved impressive gains", in the areas of education, gender, child and maternal deaths, and reducing HIV/Aids prevalence, according to the report. Considerable progress is also noted for Asia and the Pacific, as a report by UNDP, the Asian Development Bank and UNESCAP argues: "Asia and the Pacific, with more than half of global population, and some of its most dynamic economies, has helped drive the world towards major successes. And where the targets have been missed there has been substantial progress that can serve as a launching pad for the Sustainable Development Goals" (UNESCAP 2015). In South Asia, the "extreme poverty rate [fell] from 44.5 percent in 1990 to 15 percent in 2013" (UNDP 2016: 39). Also, despite the financial crisis "average incomes rose among the poorest 40 percent between 2008 and 2013".

For development policy-makers, the world thus looks very different. This is not to say that inequalities and other persistent challenges aren't mentioned. For example the ISSC, IDS and UNESCO highlighted ongoing intra-societal inequalities (ISSC, ISD, UNESCO 2016). Challenges are also noted in the other mentioned documents. For example, the MDG progress report also mentions gender inequality, intra-societal gaps between rich and poor, persistence of poverty, violent conflicts and environmental degradation (United Nations 2015: 4). The Human Development Report also notes "lingering deprivations and inequalities" as challenges that remain alongside the achievements that have been made (UNDP 2016: 27). But within these documents, these challenges persist alongside large and widespread social improvements.

This progress is also often visualized. For example, the following Figure 62 shows regional improvements in UNDP's HDI. Figure 63 visualizes progress visible in publically available aggregated data from the last 130 years.[65] These illustrations depict improvements in the realms of poverty reduction, education, hunger, health, peace and justice, gender equality, energy as well as water and sanitation.

[65] These illustrations have been compiled and generated for this paper (see Annex for a comprehensive list of sources).

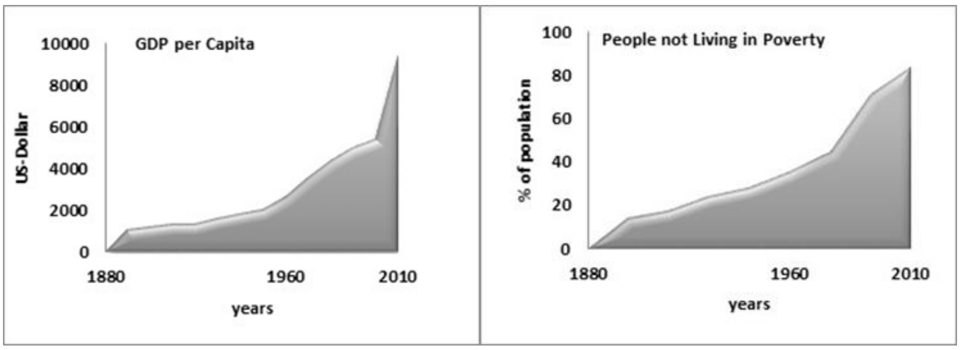
Figure 62: Snapshot from Human Development Report 2016, showing regional trends in HDI values



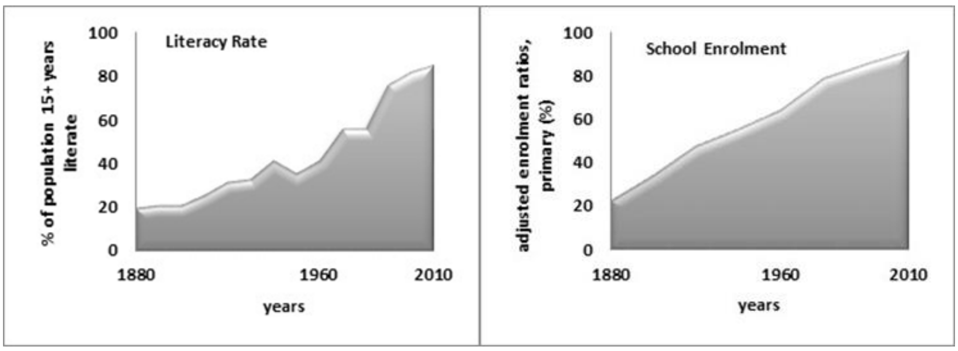
Source: UNDP 2016

Figure 63: Trends in global well-being (1880-2010)

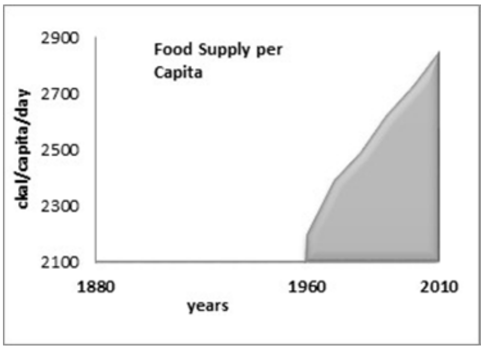
No Poverty

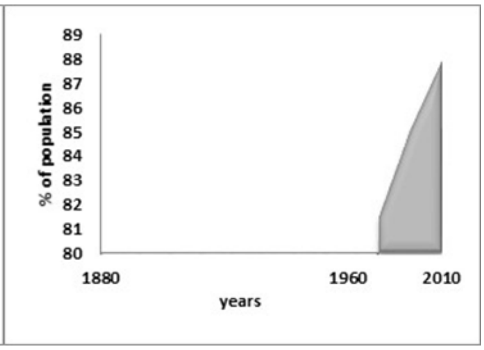


Quality Education

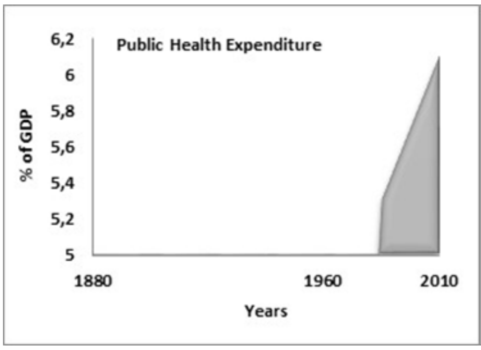


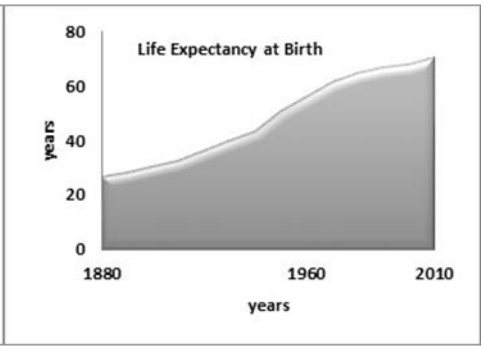
Zero Hunger



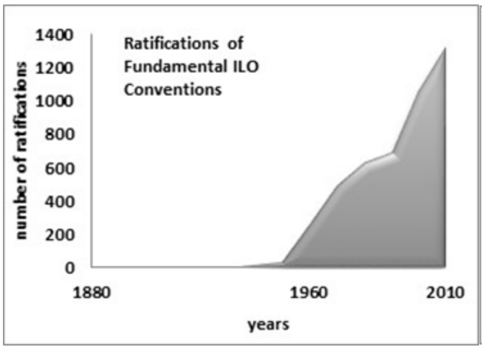


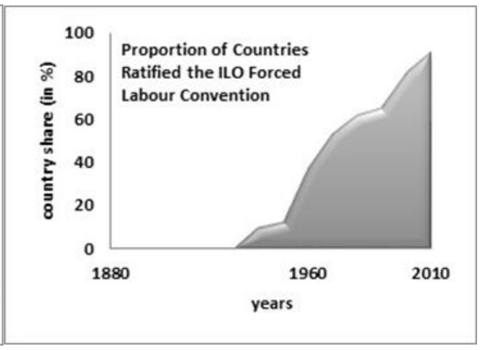
Good Health



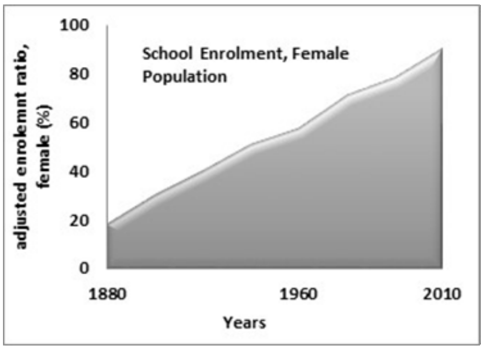


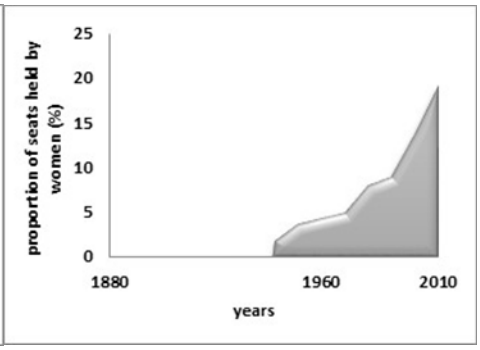
Strong Institutions



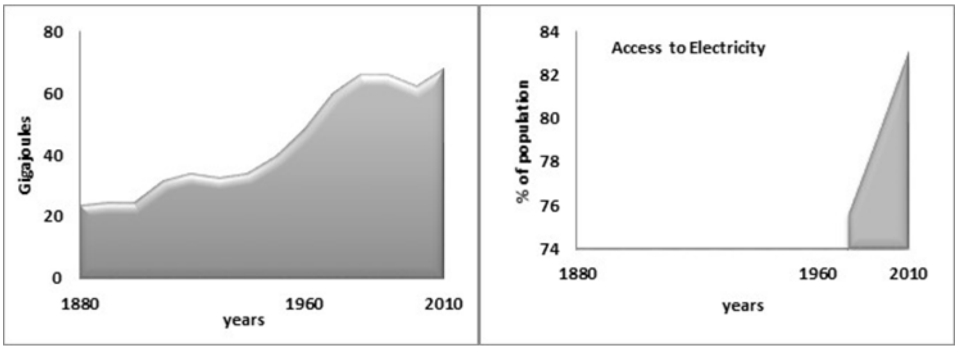


Gender Equality

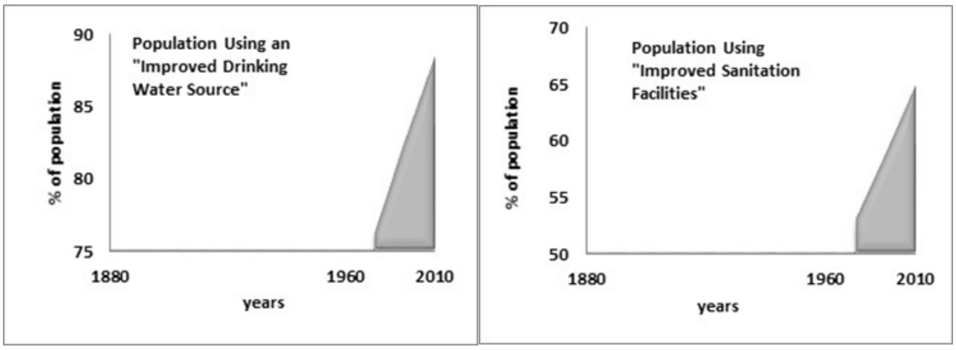




Affordable Energy



Access to Water and Sanitation



Sources: see Annex

Figure 63 shows: despite the rapid increase in the size of the world population global well-being also increased substantially. According to these illustrations and associated data, there are now far less people living in poverty, the literacy rate increased and life expectancy at birth has multiplied. These numbers did not rise exponentially but they clearly show an upward trend. Even more so, for some of the dimensions, the development is close to reaching 100 percent of its intended goal - see e.g. school enrolment.

Furthermore, for many, humanity has moved into the "age of humans" (Anthropocene) in yet another sense: not only are we according to some authors capable of profoundly altering geological conditions and processes (e.g. Ellis 2011), we also developed the ability of transforming the environment in a way that allows us to increasingly reduce environmental limitations (such as food and water availability) and other environmental conditions which have rendered lives difficult and risky. For example agricultural societies modified and managed ecosystems in order to increase crop yield and were thus able to feed a much larger population. Humanity is in this sense not only living in the Anthropocene in the geological understanding, but also in a sociological sense in that we utilize our shaping power for human progress and that we have created social systems that have eased the detrimental forces of nature. Earle Ellis for example argues (Ellis 2011):

"Ever since early humans discovered fire and the benefits of collaborative systems such as collective hunting and social learning, human systems, not the classic biophysical limits that still constrain other species, have set the wider envelope for human population growth and prosperity."

For developed countries this characterization is now almost universally taken for granted and therefore often not even perceived. But for the vast majority of humanity it presents a novel condition they just experienced or are about to experience. Through the lens of social and development policy-makers humanity entered a development path which was considered difficult or even impossible hundred years ago. For example Ruth deFries et al. argues (deFries et al. 2012):

"Although Earth's life support systems set the broad envelope for human survival, societies evolve, adapt to and sometimes alter this broad envelope to overcome many biophysical constraints and to correct negative environmental consequences. For example, a long series of ingenious technologies building on millennia of incremental understanding expanded the human carrying capacity over the last 12,000 years through plant breeding, irrigation, crop rotation, and synthetic nitrogen fixation"

Hence, from a social perspective and for these authors, the future offers many opportunities. The numerous problems world politics is confronted with now, including various civil wars, migration fluxes, financial crises, the political struggle within the EU or China's economic slowdown, veil the fact that for the majority of people their lives are changing, often for the better and that tens of thousands get access to running water or electricity every day. Moreover, in addition to providing basic needs, there is a rise of the world's middle class, not only securing survival but also a certain degree of wealth and well-being. This phenomenon thus signifies a two-fold social revolution: escaping poverty and entering into prosperity. For example, Mario Pezzini, Director of the UNDP Development Centre has argued along these lines (Pezzini 2011):

"The increase in average incomes and the fall in levels of absolute poverty, in particular during the last decade, suggest that an increasing proportion of the world's population is neither rich nor poor by national standards but finds itself in the middle of the inome distribution. In 2009 the middle class included 1.8 billion people, with Europe (664 million), Asia (525 million) North America (338 million) accounting for the highest number of people belonging to this group. Even in Africa, where middle class's growth has not been very robust, it has nonetheless been noticeable and contributed to increased domestic consumption in many countries"

Against the backdrop of excessive resource use for human progress, some environmental scientists point to the limits of our current concept of growth – supported in their argumentation by the planetary boundaries concept – and call for a fundamental change in our understanding of "progress". Unsurprisingly, natural scientific criticism and environmental visions resulting thereof on the one hand, and developmental and socio-political wishes and visions on the other hand easily conflict. In a world that desires to end hunger and poverty for millennia and that now has this goal closer in reach, a "wake-up call" regarding environmental boundaries does not fit well. This does of course not mean that there is a lack of good will. For the last two decades, debates on sustainable development and efforts to combine social and environmental concerns emerged and the recent SDGs further support these endeavours. Furthermore, the development and socio-political community is well aware of the fact that environmental factors can compromise social progress. But this will most likely not change the fact that the future will primarily be understood through the lens of social and developmental goals. Despite the fact that socio-political progress is linked to increased environmental burdens, the willingness to hear a message that expounds that the current path is too risky and fatal in the long-run is relatively small given the many irrefutable development-related successes: in other words, social success appears to trump looming environmental risks. This is the situation the environmental policy perspective needs to bear in mind.

The social character of planetary boundaries

The planetary boundaries are usually framed as scientifically secured boundaries for humanity. For example, Rockström et al. argue: "We have identified nine planetary boundaries and, *drawing upon current scientific understanding*, we propose quantifications for seven of them" (Rockström et al. 2009; highlighted by authors). And Steffen et al. argue for the need of a new paradigm, integrating development and maintenance of the Earth system (Steffen et al. 2015a: 736; highlighted by authors): "The planetary boundary (PB) framework contributes to such a paradigm by *providing a science-based analysis* of the risk that human perturbations will destabilize the ES [Earth system] at the planetary scale." The planetary boundaries are thus intended to offer a scientific foundation for policy-makers, allowing them to underpin their environmental targets with scientific evidence.

It is however possible to take another, different perspective on the planetary boundaries. The planetary boundaries can also be interpreted as indicating limits of the current growth model or limits of our current model for generating prosperity – this deduction is already present in the planetary boundaries as they suggest boundaries for development. Furthermore, the planetary boundaries do not only include the message that some environmental burdens are too large. Implicitly, they also judge on the related economic and social drivers of these problematic developments. This becomes very clear when looking at the illustrations on the great acceleration which do not only show environmental impacts but also drivers such as population growth (see Figure 61). The concept does not suggest whether for instance green growth, de-growth or other paths should be followed but the signal the planetary boundaries send against the continuation of the current growth model is clear. Rockström and Sachs for example argue for a sustainable development trajectory, involving "six major structural transformations" (Rockström and Sachs 2013: 7). These are an "energy transformation", "food security transformation", "urban sustainability transformation", "population transformation", "biodiversity management transformation" and the "private and public governance transformation" (Rockstörm and Sachs 2013). From this perspective the planetary boundaries are not so much natural scientific boundaries but indeed social boundaries.

Furthermore, the ambivalent character of the planetary boundaries becomes even more apparent when considering on what basis the concept is founded. It is clear that the planetary boundaries show Earth-systemic processes, demonstrating the „boundary level that should not be transgressed if we are to avoid unacceptable global environmental change [which] is here defined in relation to the risks humanity faces in the transition of the planet from the Holocene to the Anthropocene" (Rockström et al. 2009, p.2). But the decision that and why this Holocene-like state should be preserved is normative: the demarcations are made because the possibility to ensure the continued existence of our social systems is tied to these environmental preconditions. This is also acknowledged within the planetary boundaries community. For example, Sarah Cornell writes (Cornell 2015):

"The authors of the papers do indeed take a normative position about the sustainability of societies and the state of the Earth system – and they make that position clear"

Similarly, Rockström et al. (2009: 32) argue:

"Determining a safe distance involves normative judgments of how societies choose to deal with risk and uncertainty"

Although the planetary boundaries certainly have a natural scientific core, the before outlined aspects show that setting them is after all normative and based on social values. This even more renders the planetary boundaries as social boundaries. In that sense, the planetary boundaries are the science-based attempt to ensure that our social systems and our societies can continue to function in the future. The main goal is not the preservation of a specific state of the environment, but to preserve the human society and their social systems. Respecting the planetary boundaries means preserving the social foundation in the long run.

The concept's core message therefore largely corresponds with the social boundaries (as developed by Raworth 2012). The main difference between planetary boundaries and social boundaries is perhaps not that the former focuses on environmental aspects. As Rockström et al. pointed out, the goal is "to maneuver in the pursuit of long-term social and economic development within the stability domain provided by the observed resilience of the Earth System in the Holocene" (Rockström et al. 2009, p.20). The main difference between the two is thus that the planetary boundaries are defined in a way that looks farther into the future, seeking to guarantee the possibility for sustaining our social minimum standards for very long time spans ("future generations").

Re-framing the planetary as social: challenges and opportunities

"Re-framing" the planetary as social builds upon the social character of planetary boundaries. It means to communicate planetary boundaries as social boundaries in public, political and scientific discourse. In contrast to Raworth's model, the realms that planetary boundaries and social boundaries inhabit are thought as being two sides of the same coin. Such a "re-framing" offers opportunities as well as new challenges.

In general, it mirrors other conceptualizations which unify, bring together or more closely relate the environmental and social realms. For example, Wallimann has pointed out that "environmental policy is social policy", as "both are but two aspects of the same coin – if sustainability is the goal" (Wallimann 2013). The Integrated Environmental Programme 2030, put forward by the Federal environmental ministry, argues similarly that "environmental policy needs to be social policy, much stronger as in the past" (BMUB 2016a: 29; own translation)[66].

Also, within the research community on socio-ecological systems and resilience (one of the building blocks of PBs), humans (or human systems) are firmly integrated. For example, Young (2008) summarize the increasing integrated analysis of human and ecological systems:

"Studies of resilience, vulnerability, and adaptability have moved forward in tandem from analyses focusing either on ecological systems or on social systems toward holistic conceptualizations and models of socio-ecological systems (SESs) …, social-ecological systems …, or coupled human–environment systems …."

Similarly, in Earth system science, human systems are integrated. Thus, Earth system science concerns "the study of the Earth System with an emphasis on observing, understanding and predicting global environmental changes involving interactions between land, atmosphere, water, ice, biosphere, *societies*, technologies and economies" (Leemans 2010; emphasis added).

To re-frame the planetary boundaries as social boundaries is thus not entirely new, but mirrors other attempts to further integrate or even unify environmental and social realms and policy responses. The "re-framing" takes these ideas and projects it on planetary boundaries. Several implications arise.

Socially re-framed planetary boundaries could, on the one hand, imply new challenges. One challenge lies in the fact that environmental activists, especially those from the "deep ecology" school might feel disconnected from such a framing, as it does not present nature as a value in itself. This challenge is e.g. visible in the discourse on ecosystem services, where some authors have criticized the ecosystem services concept as "neo-liberal" or as putting a price on nature, thereby perpetuating the problem that has led to environmental degradation in the first place (compare e.g. Büscher 2012). A second challenge could be that the legitimacy connected with framing planetary boundaries as "scientific" might be undermined. As a result, planetary boundaries could appear arbitrary and less as founded on Earth system and resilience science as well as environmental history.

On the other hand, re-framed planetary boundaries could imply opportunities. The re-framed discourse on planetary boundaries and social boundaries appears less dichotomous. Instead the planetary boundaries and social boundaries are thought of as lying on the same level, being separated mainly through the time dimension (as the social nature of both boundaries dominates other differences such as the biophysical vs. social categorization). Breaking up the dichotomy reduces the tension between both and precludes interpretations focusing mainly on trade-offs and conflicting environmental and developmental targets. It thus becomes possible to argue from the very beginning that the

[66] The German version reads: «Umweltpolitik muss viel stärker als in der Vergangenheit Gesellschaftspolitik sein, die den Menschen und der sozialen Gemeinschaft dient, neue Leitbilder für Wohlstand, Teilhabe und Lebensqualität prägt und zugleich Demokratie, Gerechtigkeit und Freiheit stärkt» (BMUB 2016a: 29).

planetary boundaries and the social boundaries are on the same side of the coin and that environmental and social policies are fighting for a common cause. This re-framing brings the two worlds of developmental and environmental perspectives together: by showing that we are on the same playing field with both perspectives and that we are not in two different worlds when debating the planetary boundaries.

Furthermore, the planetary boundaries can create new inputs to the development debate – as they focus on the more long-term risks for humanity and are oriented towards the future (future transgressions, future regime shifts, etc.), they can add to the debate which tries to alleviate the immediate social deprivation and poverty. Respecting the planetary boundaries then means a social investment for the future. It also means being aware of the implications of future population developments. The idea is not to contrast the boundaries but to realize their time spans. It is about a world that provides favourable living conditions today and tomorrow.

Moreover, when planetary boundaries are described as social boundaries in the discourse, it can be shown that the planetary boundaries should not only be debated in the realm of environmental politics or with a focus on the environmental aspects. There are many other characteristics of the planetary boundaries with social implications (as argued above): the normative safe operating space for example, or the future dimension, delineating what risks societies are willing to take. These are all aspects that we can only reflect and answer together with social development.

Also, conceptualizing the planetary boundaries as social boundaries in the discourse opens the opportunity to focus more on the safe operating space. A safe operating space is then not about when we face the collapse but up until when and how we can develop. As both planetary boundaries and social boundaries are social, the discussion focuses less on limits but on ensuring our well-being and focusing on present and future risk for that well-being.

Framing the planetary boundaries as social also means that developing and improving the planetary boundaries at the same time further specifies social boundaries. The planetary boundary community therefore also contributes to the social boundaries and to the social cause in general. This does not necessarily mean a new self-understanding of the planetary boundary community as the planetary boundary framework already intended to contribute to sustainable development, but it means a self-assurance as being at the same time a researcher on the cause of social well-being and the planetary boundaries.

1.6.5 Where are we heading? Applying socially re-framed planetary boundaries

Based on the argumentation outlined above this chapter reflects on how the re-framing could be used for environmental politics and how it relates to ongoing debates on the SDGs and SDG implementation and the regionalization of the planetary boundaries. It is based on the assumption that the benefits of re-framing outweigh the challenges, as both mentioned challenges could be addressed. The first challenge could e.g. be remedied by pointing out the necessity for environmental politics to relate to the social cause, to succeed in the wider political realm. Framing planetary boundaries as social therefore does not mean to devalue nature, but to better further its cause in the political arena. The second challenge could e.g. be addressed by increasing the social legitimacy of the planetary boundaries, e.g. through public participation in co-developing the framework.

Planetary as social boundaries: implications and ways forward for environmental politics

The reframing of planetary boundaries as social boundaries underlines the modern self-understanding of environmental politics – that environmental protection essentially serves a social cause. In this picture, environmental politics becomes ever more social, having as central goal to safeguard humanity. The tasks to fulfill this goal are manifold – they involve for example to raise awareness of the Anthropocene and planetary boundary transgression and to implement transformative measures on all scales for staying within the safe operating space, as highlighted e.g. in the Integrated Environmental Programm 2030 (BMUB 2016a).

The two ideas of "social impact" and "social investment" outlined in more detail below are helpful in fulfilling this task, building on the social nature of planetary boundaries. Both are already present in the planetary boundaries community and are worthwhile to consider and extend further. The idea of "social impact" for example, is raised in the concept (see e.g. Rockström et al. 2009), when speaking about the consequences of transgressing boundaries, but not fully addressed (e.g. in terms of risks, cost/benefits, monetary costs, etc.). The idea of "social investment", is not directly mentioned in the planetary boundaries community, but builds on the idea of "Green investments" or "sustainable finance", the large investments necessary for a sustainability transformation.

Social Impact

The rationale of "social impact" is to outline that and how transgressing the boundaries can lead to negative social consequences. Social impacts are thus understood as the repercussions of living outside of the safe operating space. They signify a decrease in social well-being as result of planetary boundary transgressions. They thus also impact on the achievement of social goals. Such impact could be expressed differently, e.g. in terms of monetary costs, or health costs, in terms of loss of ecosystem services, in terms of risks for human security / livelihoods / economic sectors etc., similarly to climate change impact assessments. Expressing planetary boundaries transgression in these terms is beneficial for environmental politics, as it highlights the large societal transformation challenge connected to planetary boundary transgressions and could thus prove to be powerful communication tool.

To describe and measure these impacts presupposes different scientific developments: first, the interlinkages between different planetary processes need to be more fully understood, to outline the precise interlinkages between planetary boundary transgressions and well-being. Furthermore, many of these social impacts are likely to occur in the future, when thresholds are crossed. Hence, we need to be better able to identify such impacts (e.g. through better forecast, monitoring and rapid reaction). To move forward, the analysis of social impacts could also build on environmental economics to start quantifying the costs of planetary boundary transgression and comparing them with the costs of reducing these transgressions through e.g. political measures. There is already existing research on global environmental change which could be screened together with research on interlinkages between ecosystem services and poverty reduction and prevention (see e.g. Millennium Ecosystem Assessment 2005; TEEB 2010; Stern et al. 2006; Sandifer et al. 2015; Fisher et al. 2013). Building on these findings, the costs of planetary boundary transgression could be analysed. It could also be analysed whether social goals / social minima are impacted, whether all social goals / societal groups / social realms are equally impacted, whether these impacts lie on different scales, e.g. on the local or global level, or when exactly these impacts on social goals will occur. There are already starting points visible in the debate. For example, Steffen et al. have proposed to extend the ecosystem services frameworks to more strongly include earth system goods and services (in the three realms of regulating, supporting and provisioning services) (Steffen et al. 2011b). Transgressing the planetary boundaries could then imply a profound change of the Earth system, decreasing the goods and services available for humans thus signifying a social impact of the planetary boundaries.

Social Investment

The concept of social investment builds on the idea of a social impact of planetary boundary transgression as well as the notion that the planetary boundaries should be best understood as a "budget".[67] It highlights that investing in the planetary boundaries is essentially a social endeavour, preventing hu-

[67] Commentary Georgina Mace during the Planetary Boundaries Conference Berlin, 2017.

manity from decreasing the earth system goods and services through planetary boundary transgression. This concept is useful to strengthen policy measures designed to keep humanity within the safe operating space because it renders these measures as social policy. The concept can thus help to generate additional legitimacy for environmental politics and could increase the coherence between environmental and social policies (see Wallimann 2013). “Social investment” would mean to take the planetary boundaries as starting point for a sustainability transformation, which requires large-scale investments, e.g. in greener technologies, energy efficiency etc., to stop or reverse ecosystem service loss.

Three different questions would need to be tackled when further developing the concept of social planetary boundary investment. The first question is where to invest. Planetary boundary social investment could use the earth system goods and services idea outlined before. Investment would then mean to ensure that these goods and services are continuously available to humanity. A necessary way forward for developing this idea would be to further specify the precise earth system goods and services for example by screening existing research and by creating a typology.

A second question is how to invest. Here it would be necessary to further analyze which investments appear to be effective for maintaining earth system goods and services. Such an analysis could draw on previous knowledge of ecosystem management and on the effectiveness of environmental policy measures for respective boundaries and for global environmental change (see for example Schindler and Hilborn 2015).

A third question is which social co-benefits arise when investing in planetary boundaries. The idea would be to analyze the complex system of social development for positive consequences of an investment in the planetary boundaries. Specifying these co-benefits helps to show that social investment is indeed beneficial for humanity.

Planetary as social boundaries: implications for the SDG debate

A second area of application for re-framed planetary boundaries is the SDG implementation. The adoption of the SDGs by the General Assembly in New York 2015 has been widely heralded as success, formulating 17 goals for all countries worldwide and setting 169 targets for achieving these goals. While there are several problems with the overarching system of the SDGs (such as their consistency, implementability and measurability; see ICSU/ISSC 2015), they nevertheless offer a great opportunity for fostering sustainable development, as they are universally legitimized[68] and can be used to steer progress on all levels of governance, mainstreaming sustainable development in all policy sectors, complementing the window of opportunity opened by the 2015 Paris Agreements. SDG implementation is now more strongly underway in Germany, e.g. through the update of the German Sustainable Development Strategy.

This reframing of planetary boundaries as social boundaries could inform the SDG implementation both on the international level (represented by the High Level Forum) and the national level (national implementation process), and could also help to “bring the planetary boundaries back in”, that is to address some of the perceived and previously described shortcomings of the planetary boundaries. For the national implementation, the re-framed planetary boundaries can support the formulation of the SDG implementation strategy, to provide a frame for the respective implementation chapters and to provide further reference points. It could for example be outlined that the planetary boundaries are

[68] Note however that the SDGs are not binding international law (being a General Assembly Resolution), in contrast to the 2015 Paris agreement.

a form of social investment (see section below). The strategy could highlight that the planetary boundaries are themselves social and that transgressing them risks harmful feedbacks for other social goals such as eradicating poverty and deprivation.

More specifically, the re-framed understanding of planetary boundaries could e.g. inform the debate on sustainable urban development and the New Urban Agenda. In October 2016, the Habitat III conference will take place. It is the first UN world summit after the adoption of the SDGs and the Agenda 2030 and will reflect inter alia how cities can support the SDGs and how the New Urban Agenda and the SDGs can complement each other. When downscaled to the urban scale (see section below) and when reframed as social boundaries, the planetary boundaries could be used to increase the pressure for a stronger commitment to urban transformation by outlining how for example urban consumption has contributed to pressure on the planetary boundaries and how further transgressing the PBs might have detrimental effects for societies in the future.

Planetary as social boundaries: implications for the regionalization of the safe and just operating space

Another important debate where the re-framed understanding of planetary boundaries as social boundaries can be useful is the regionalization of the planetary boundaries. So far the regionalization for the social justice aspects of the planetary boundaries is implemented by relying on Raworth's doughnut model, adapting this concept to the local situation. For example, Dearing et al. (2014) apply the concept to China, to illustrate the safe and just operating space for two rural areas. Cole et al. (2014) apply it to South Africa, in order to evaluate the applicability of the approach for the national level and to develop a national barometer, combining 20 indicators and boundaries using a decision-based process.

But using Raworth's approach for downscaling entails several weaknesses as outlined in chapter 1.6.4. Therefore, future downscaling attempts should take the reframing into account. This objective can be illustrated in three areas where future downscaling should be heading.

A first way forward further develops the method of defining a safe and just operating space, taking the re-framing of planetary boundaries into account. As planetary boundaries are inherently normative and social (see chapter 1.6.4), it is not enough to scientifically and politically debate boundaries. Such far reaching decisions on a country's future course need to be publically discussed to evaluate what risks societies are willing to take and what social goals they strive for. Therefore, any attempt to relate the planetary boundaries to the regional, national and local level should include participatory elements (see Sayers and Trebeck 2015). For example, South Africa is currently undertaking a comprehensive process to determine the ecological reserve (the minimum amount of water needed for ecological functioning in rivers) based on scientific research but also on socio-economic considerations and the views of relevant stakeholders in each river catchment.

A second way forward applies this understanding of planetary and social boundaries to other cases (1) on different scales (such as to regions, nations, administrative levels or the municipal level) and (2) with different environmental and social characteristics (such as countries higher or lower on the Human Development Index-Ranking and differing with regards to their environmental performance). The idea is to begin the evaluative assessment and to further strengthen the concept.

Such comparisons are currently underway for downscaled versions of Raworth's doughnut. For example, Cole et al. downscale the safe and just operating space to the provincial level in South Africa (Cole et al. *forthcoming*). But such downscalings should also take the re-framed understanding of planetary as social boundaries into account, for example by further developing national barometers that refrain from creating a dichotomy or by testing its usefulness for environmental communication on downscaled levels.

Illustrative narrative for social impacts: Access to Drinking Water & Overuse of Freshwater

Lake Chad decreased by 95% between 1963 and 2001. The United Nations Environment Programme estimated that the decrease is related both to climate change as well as to needs for irrigation water (Lake Chad Basin Commission 2016). Poor human management such as unsustainable irrigation contributed to the situation which now not only deprives people of their livelihoods but also hampers access to safe drinking water and proper sanitation.

Globally, eleven percent of the world's population (783 million people) live without access to an improved source of drinking water (UN Water 2013). Almost universally (albeit to varying degrees), water is wasted and consumption per capita increases. The world's use of renewable water resources grew six-fold in the last century while the population tripled. Future population growth and a concomitant increased demand for water together with continued water mismanagement will entail serious consequences for both people and their access to water as well as for the environment.

Overuse of freshwater reserves hence leads to negative social impacts with direct human costs today – access to water – as well as in the future if this resource is not managed more sustainably. This process of interlinked environmental and social systems is also backed up by research. Researcher Rockström et al. argued in 2009 that there are nine important conditions for sustainable development (the planetary boundaries) – among them not to cross the boundary for freshwater use. These planetary boundaries can also be understood as social boundaries as the overuse of freshwater in the example above shows – a transgression of the freshwater boundary will entail detrimental implications for people's access to water.

Sources: Lake Chad Basin Commission (2016); UN Water (2013)

Conclusion: the application of re-framed planetary boundaries

In general, the safe and just operating space approach has widely influenced the operationalization of planetary boundaries and the integration of social goals (framed as boundaries) within the planetary boundaries community. One of the major advantages of Raworth's doughnut has been to re-affirm the social cause with regards to planetary boundaries. This paper argues for upholding and extending the social boundaries idea, using this momentum, re-framing the planetary boundary discourse. This paper has formulated some of the benefits of such a re-framing. We believe that environmental policy-making could benefit from this framing, e.g. with regards to SDG implementation, or generally for communicating the large investment needs for sustainability transformations as well as the social impacts of planetary boundary transgression.

1.6.6 Annex

Sources for Figure 63: Trends of Global Well-Being

"GDP per capita" is based on a combination of two datasets: 1890-1990 van Zanden et al.(2014), 2000-2010 World Bank Data, Indicator GDP per capita, current USD.

"People not Living in Poverty" is based on a combination of two datasets: 1890-1980 Bourguignon and Morrisson (2002), 1985-2010 World Bank Data, Indicator Poverty Headcount 2011 PPP, 1.9USD/day.

"School Enrollment" is based on a combination of two datasets: 1880-1960 Barro and Lee (2015), 1970-2010 World Bank Data, Indicator adjusted net enrollment rate, primary, both sexes (%).

"Literacy Rate" is based on a combination of two datasets: 1880-1980 van Zanden et al. (2014), 1985-2010 UNESCO Institute of Statistics, Indicator adult literacy rate, population 15+years, both sexes (%).

“Food Supply” and “Population which does not suffer from malnutrition” are based on the dataset of FAOstat. ”Life Expectancy at Birth” is based on a combination of two datasets: 1880-1990 van Zanden et al. (2014), 1995-2010 World Bank Data, Indicator Life expectancy at birth, total years.

“Public Health Expenditure” is based on the dataset of the World Bank, Indicator Health expenditure (% of GDP).

”Ratifications of Fundamental ILO Conventions” and “Proportion of Countries Ratified the ILO Forced Labour Convention” are based on the Normlex dataset of the International Labour Organization.

“School Enrolment Female Population“ is based on the combination of two datasets: 1880-1960 Barro and Lee (2015), 1970-2010 World Bank Data, Indicator adjusted net enrollment rate, primary, female (%).

”Women in National Parliaments” is based on the Cross-national Dataset of Paxton, Pamela/Green, Jennifer/Hughes, Melanie, Inter-university Consortium for Political and Social Research [distributor], ICPSR Study no. 24340.

“World Energy Consumption per Capita” is based on the data of Smil (2010), the population data is provided by HYDE (History Database of the Global Environment; PBL Netherlands Environmental Assessment Agency 2016).

“Access to Electricity” is based on World Bank Data, Indicator access to electricity (% of population).

“Population Using an Improved Drinking Water Source” is based on World Bank Data, Indicator improved water source (% of population with access).

“Population Using Improved Sanitation Facilities” is based on World Bank Data, Indicator improved sanitation facilities (% of population with access).

1.7 Planetary Boundaries and Burden Sharing

1.7.1 Introduction: planetary boundaries and global ecological justice

The planetary boundaries concept was formulated in 2009 by an international scientific expert team led by Johan Rockström and has subsequently sparked great interest, especially in the environmental / sustainability sciences, but also among policy-makers, within civil society and increasingly also among multinational companies. The concept defines globally aggregated boundaries for nine different Earth system processes. It sets a scientifically informed environmental ceiling for human operations and thus re-interprets the 'sustainability trias'[69] by setting absolute boundaries for human resource consumption and emissions.

Given the fact that the concept now informs several national sustainability strategies, regional environmental programmes (EC 2014) and the formulation and implementation of the 2030 Agenda, the concept potentially has much larger implications which go beyond a pure scientific discussion on how best to achieve sustainable development.

This paper discusses the concept's significance for the discussion of global ecological justice. As today's world is marked by profound inequality in terms of causes and effects of and vulnerability to environmental change, access to and consumption of resources, progress with regards to ecological justice is of great importance. And furthering it requires not only action on the ground (e.g. bottom up pressure through social movements and civil society) but also new concepts and ideas that help to envision a just world, map and monitor the current status with regards to this vision, and develop new pathways to achieve this vision.

To shed light on the planetary boundaries concept's implications for global ecological justice, this paper analyzes the different notions of justice the planetary boundaries concept induces. To do so it first defines major distinctions of ecological justice and burden sharing. It subsequently looks at the discourse both in the scientific community that defines and develops the concept and within the German political sector to discern how the concept has been related to questions of justice. Looking at the science discourse helps understand how main proponents of the concept connect it to justice. The major debate on the concept occurred within academia (see Keppner et al. 2016). German governmental discourse is selected as Germany's Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety is one of the forerunners of planetary boundaries mainstreaming, and the German governmental system is thus a good case for analyzing how the concept is related to global ecological justice / burden sharing in practice. This paper finally raises the question what burden sharing could mean in the context of each planetary boundary.

This paper is part of a larger project on the operationalization of planetary boundaries, funded by the German Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety and the German Environment Agency (FKZ 3714 19 100 0). Previous papers published in this project assess the potential contribution of the planetary boundaries for the German Integrated Environmental Programme 2030 and a German Integrated Nitrogen Strategy, as well as its conceptual foundations, its potential for environmental communication, its relation to social boundaries and ways to downscale the planetary boundaries and use them for environmental benchmarking (e.g. illustrating the externalization of environmental impacts).

1.7.2 Global ecological justice and burden sharing: definitions

Three distinct definitions of justice are useful for the discussion of the planetary boundaries concept. *Distributive* justice refers to a state where each referent object of justice (e.g. an individual or nation-

[69] Social, ecological and economic sustainability.

state) has what is due to her (a specific benefit or burden or a specific right or duty) on grounds of a distributive principle such as equality or want. *Corrective* justice implies to change an unjust state which has been brought about by an action of an agent such as an individual or nation state and has harmed the referent object of this respective action. *Procedural* justice requires that *the way* of how a distribution of benefits or burdens is formulated is fair (Fleurbaey et al. 2014, Ikeme 2003).

Ecological justice applies these distinctions to environmental benefits and burdens / rights and duties. *Distributive* ecological justice for example refers to an equal distribution of access rights to an environmental good such as water. *Corrective* ecological justice would e.g. imply the (moral) duty for a state to compensate another state for polluting a shared lake. *Procedural* ecological justice would mean to install a fair process for determining who has access to water.

A problem of *global* justice arises whenever at least one of four conditions are present (directly quoted after (Brock 2017)):

- Actions stemming from an agent, institution, practice, activity (and so on) that can be traced to one (or more) states negatively affects residents in another state.
- Institutions, practices, policies, activities (and so on) in one (or more) states could bring about a benefit or reduction in harm to those resident in another state.
- There are normative considerations that require agents in one state to take certain actions with respect to agents or entities in another. Such actions might be mediated through institutions, policies, or norms.
- We cannot solve a problem that affects residents of one or more states without co-operation from other states.

Global ecological justice is therefore concerned with actions of an agent in one state leading to environmental burdens for individuals in another state (such as transboundary pollution), policies etc. that could reduce such actions, the moral reasons why pollution need to be reduced (e.g. to equitable distribution of risks of pollution) and the need of and pathways for cooperation to solve transboundary pollution.

Whenever an issue of global ecological justice arises, the global community is faced with the question, who is to contribute what to reduce the pollution. Prominently, global action on climate change subsumes this question under the notion of 'burden sharing'. Burden sharing in the climate change debate "refers to sharing the effort of reducing the sources or enhancing the sinks of greenhouse gases … as well as sharing the cost burden associated with mitigating / adapting to environmental change" (IPCC 2014).

Several burden sharing principles and mechanisms for operationalizing these have been discussed (IPCC 2014), based e.g. on egalitarian considerations (equal individual right to pollute), the sovereignty principle (right of nations to pollute), the horizontal principle (similar development status = similar burden sharing obligations), the vertical principle (ability to pay) and the "polluter pays" principle (burden relative to emissions, including historical emissions) (Ringius et al. 2002). These principles have very different implications for how burden sharing is to be carried out.

1.7.3 Planetary boundaries and global ecological justice & burder sharing: science discourse

Method

To understand how the nexus between the planetary boundaries concept and global ecological justice has been framed in the scientific community, a comprehensive analysis of the core scientific contributions that define and develop the planetary boundaries concept was undertaken. The timeframe for the analysis was September 2009 to April 2018. In total, 33 articles were selected and analyzed (see

Annex for the complete list of selected publications). Articles were chosen when their abstracts refer to justice or synonyms of justice as well as the planetary boundaries concept.

Findings

Most of the analyzed articles did not focus on global ecological justice – articles instead focused on different core themes listed in Table 15.

Table 15: Core themes

Core themes within non-nexus contributions		
Agenda 2030 (3)	Agriculture (1)	Anthropocene (7)
Biosphere (1)	Climate change mitigation (2)	The definition of the planetary boundaries concept (2)
Ecosystem management (2)	Future Earth (1)	Global environmental change research (1)
Global water assessments (1)	Health (1)	Oceans (1)
Operationalization of planetary boundaries (1)	Resilience (2)	

Source: from authors, adelphi

Within those articles that discussed both in conjunction, there were four different ways observable how the planetary boundaries concept was connected with global ecological justice.

The first perspective – the neutrality perspective – highlights that the planetary boundaries concept in itself does not consider justice, it is a neutral concept and "does [not] … take into account the deeper issues of equity and causation" (Steffen et al. 2015). The concept functions as a frame in which questions of distribution, such as how much nitrogen emissions are permitted per capita, can be discussed: "While planetary boundaries emphasize the urgency of environmental problems, the concept does not address the distributional issues and opportunities linked to access to environmental resources and services" (Hajer et al. 2015).

The second perspective – the synergy perspective – focuses on the benefits when simultaneously respecting planetary boundaries and justice (Steffen and Stafford Smith 2013). One example is reducing the release of nitrogen in countries above the nitrogen boundary and increasing the use of nitrogen in countries below the boundary.

The third perspective – the safe and just operating space perspective – takes both thoughts further and argues that the 'neutral' biophysical planetary boundaries need to be amended by social boundaries as a logical extension of the concepts rationale "of protecting human wellbeing" as "human wellbeing depends fundamentally upon each person having claim to the natural resources required to meet their physiological needs" (Dearing et al. 2014).

The fourth perspective – the grass-roots perspective – demands to look more closely at the local level when distributing fair shares of the safe operating space: "Beyond global questions over sharing of the safe operating space there arise more local questions" (Leach et al. 2012). This means to look in more detail at the effects of a specific distribution, in particular whether such a policy favours "the interests of the most marginal groups" (Leach et al. 2012). An example is the spread of irrigated agriculture which could from one angle increase food production and boost economic growth, but could also "destroy the livelihoods of marginal groups such as pastoralists and women farmers" (Leach et al. 2012).

This perspective implies to take into account context criteria when "negotiating a consensual ethical and political basis for allocating the 'safe operating space'" (Clift et al. 2017).

Burden sharing was discussed in five of the 33 documents, but only in one instance connected to the planetary boundaries concept (Steffen et al. 2011). Other articles highlighted that instead of burden sharing, the concept of opportunities should be pursued, as "burden" implies a negative connotation (Bai et al. 2016; Richardson et al. 2009) and that upscaling "of local dynamics" instead of downscaling of planetary boundaries should be undertaken (Verburg et al. 2016: 9).

Looking at these perspectives through the lens of the three **distinctions of justice**, several points are apparent for the core scientific community:

- Distributive justice is a main theme discussed in terms of fair shares of the safe operating space;
- Corrective justice is not currently discussed in connection with the planetary boundaries concept;
- Procedural justice is discussed with regards to the procedure of allocating fair shares (see the contribution of (Clift et al. 2017)).

1.7.4 Planetary boundaries and global ecological justice & burden sharing: German governmental discourse

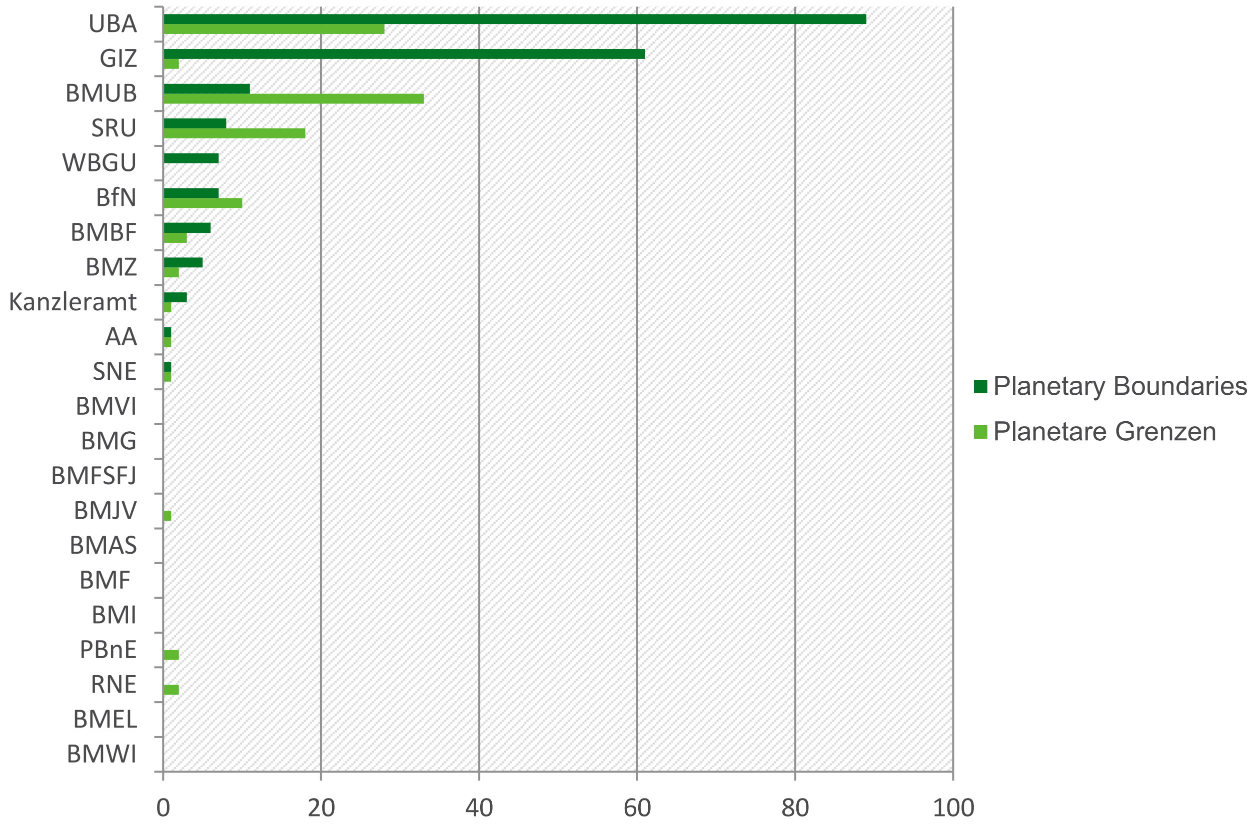
Method

To understand how the nexus between the planetary boundaries concept and global ecological justice was framed in the political realm, publications of all German federal ministries as well as institutions that are central for the German sustainability discourse were analyzed. In total 22 organizations were screened. Documents that mention "planetary boundaries" and "Planetare Grenzen" were searched for references of "justice" and related synonyms. Documents that mention both were selected and analyzed (in total 65 documents were screened).

Findings

As described in a previous paper on the German planetary boundary discourse, the concept is increasingly referred to in the German political arena. The analysis for this paper reveals that the political discourse is mainly driven by eight central actors, especially the German environmental agency and ministrythe Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, the BMZ and GIZ, as well as advisory agencies (WBGU and SRU). There are many political institutions that have never mentioned or used the concept publically (see Figure 64).

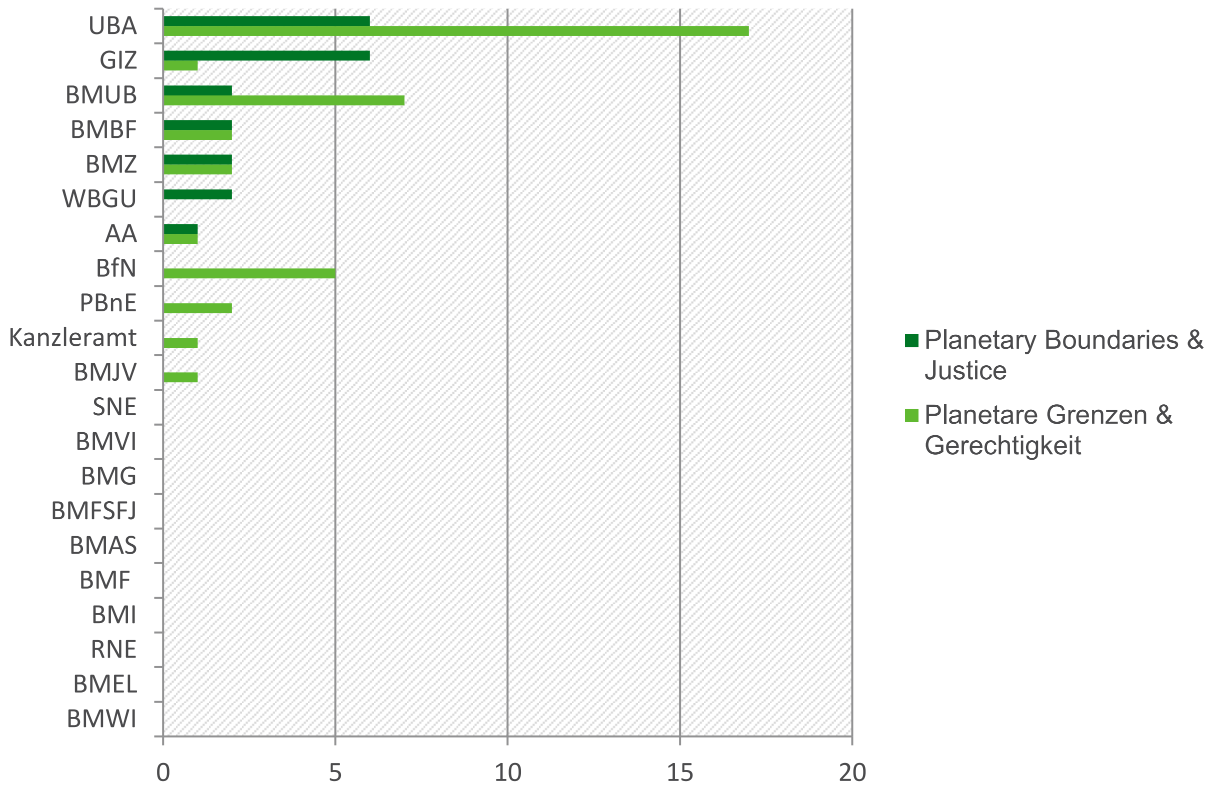
Figure 64: Publications by actor (in absolute numbers, search results for "planetary boundaries" and "Planetare Grenzen")



Source: from authors, adelphi

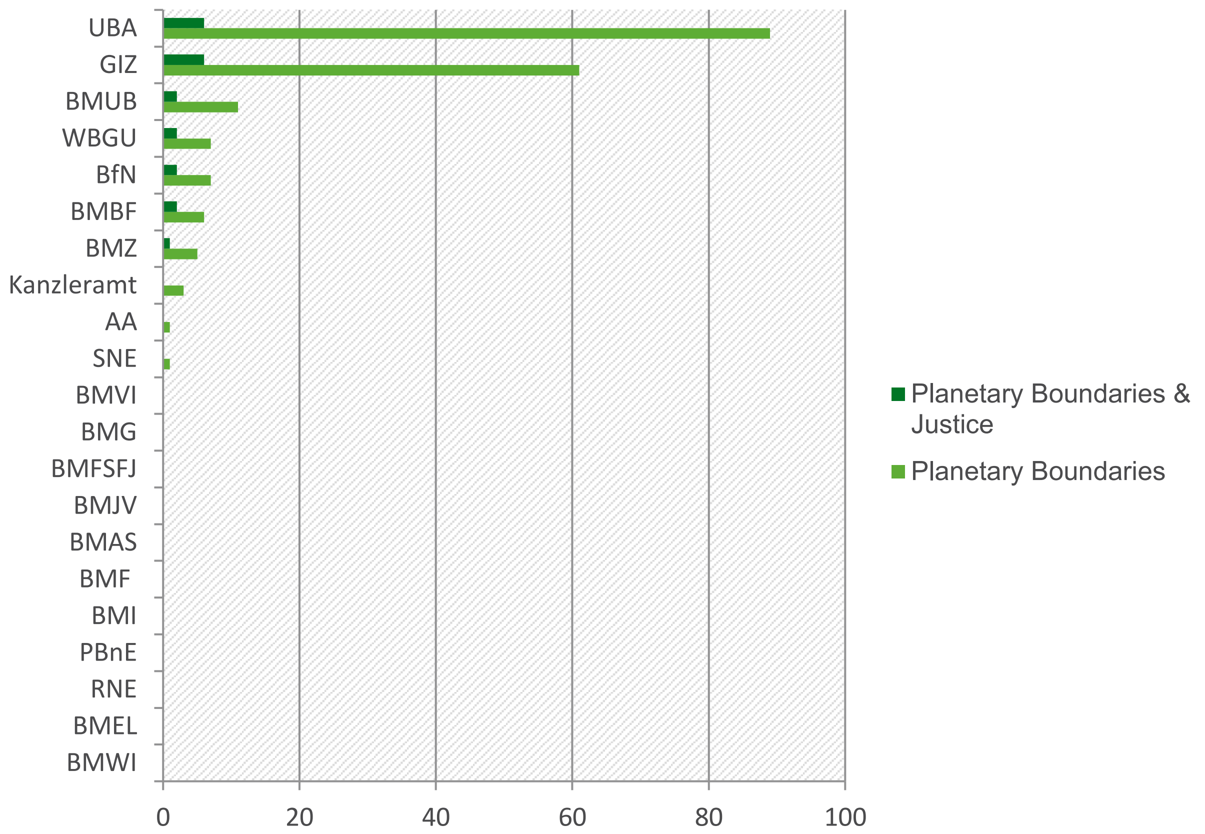
Within these documents "justice" or related keywords are rarely found in documents that mention the concept of planetary boundaries (see Figure 65 and Figure 66). This suggests that the concept is so far only loosely and not explicitly connected to questions of justice. There is thus far no real planetary boundaries justice discourse visible. This is also true for burden sharing which is not yet connected to the planetary boundaries concept.

Figure 65: Number of in-text occurrence of “justice” references in documents which mention “planetary boundaries” and “Planetare Grenzen” or synonyms (absolute numbers)



Source: from authors, adelphi

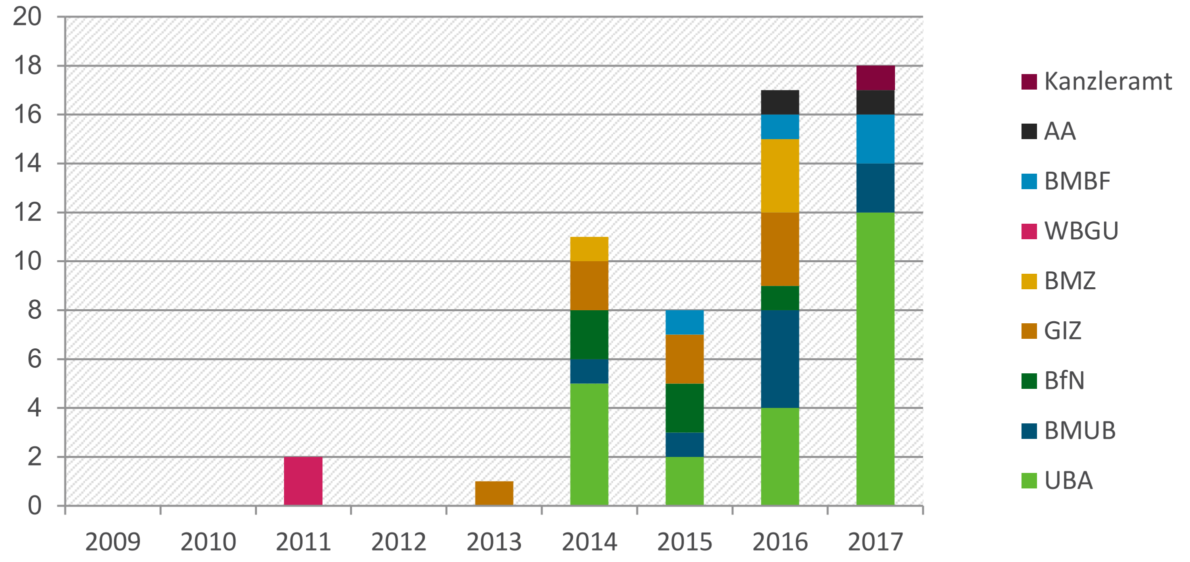
Figure 66: Comparison between planetary boundaries and justice, number of publications



Source: from authors, adelphi

The analysis of documents that refer to both planetary boundaries and justice shows (see Figure 67) that it took roughly four years until there were more documents that refer to both. There were less documents in 2015 and again an increase in 2016 and 2017.

Figure 67: Trends in publications on planetary boundaries and justice in the German governmental discourse



Source: from authors, adelphi

A more detailed analysis of 65 selected documents in which "planetary boundaries" and justice keywords occur in the same document reveals that in the majority of these documents both concepts are not directly interlinked. Rather, justice questions are separately discussed. There are some instances where planetary boundaries are discussed in relationship to justice, mainly in documents by the BMUB, UBA and SRU.

In a first perspective visible in the discourse, planetary boundaries are seen as precursor for justice (see for example (BMUB 2016): 25). They are interpreted as the foundation for the achievement of other social goals, such as a world with less violent conflicts, less poverty and dignity for all. Respecting planetary boundaries therefore is a necessary step for a more just world; but planetary boundaries are not providing the means for deciding on how such a world can be created. This perspective is very close to the neutrality perspective in the science discourse.

In a second perspective, planetary boundaries are interlinked with distributional justice, especially the distribution of fair per-capita access rights to resources and the fair distribution of detrimental effects on the environment (Umweltbundesamt 2016). The concept sets the absolute boundary of fair resource use and thus provides (at least in the case of climate change) for a global budget to be distributed equitably.

A third perspective, connects the concept of "ecological boundaries" to procedural justice, in particular participation in the normative aspects of the concept such as defining the risk societies are willing to take and setting sub-global targets (see for example (SRU 2012): 21).

The analysis shows that the concept indeed invited different interpretations of how the planetary boundaries concept is connected to global ecological justice.

1.7.5 Planetary boundaries and distributive justice: further potential

This chapter focuses on the question of distributive justice and planetary boundaries. First, core principles that have been used in the literature for allocating resource rights or duties to conserve are described in more detail. Subsequently, their application to the planetary boundaries concept is discussed. Both steps aim to contribute to answering the question what burden sharing could mean in the context of the planetary boundaries.

1.7.5.1 Principles of distributive justice for planetary boundaries burden sharing

Principles of distributive justice intend to guide national decision-making in a situation where the protection of the environment requires strong global efforts including limiting resource use while human development and access to resources need to be simultaneously guaranteed. As Lucas and Wilting (2018) summarize, countries differ strongly with regard to their development stage, the impacts of global environmental change they face, their capacity to handle environmental problems as well as the degree to which they contributed to an environmental problem. For example, the multidimensional poverty index which integrates the dimensions health, education and standard of living shows vast differences with regard to the developmental level of individual countries and regions (UNDP and Oxford Poverty and Human Development Initiative 2019). Furthermore, as the 2015 IPCC synthesis report has highlighted, risks caused by climate change are “unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development” (IPCC 2014: 13). Countries also have different financial resources available to adapt to a changing environment. Principles of distributive justice aim to allocate resource rights and conservation duties, taking these differences into account.

Commonly used principles stem from the climate change debate (Ringius et al. 2002; Höhne et al. 2013; van den Berg et al. 2019; Fleurbaey et al. 2014). According to the **egalitarian** or equality **principle**, each individual has an equal right in resource use, respectively an equal right to “pollute or to be protected from pollution” (Ringius et al. 2002) as each individual has equal “moral worth” (Lucas and Wilting 2018: 13). For example, each person has the same right to use land, water or the atmosphere. As per the **sovereignty principle,** each *country* has an equal right in resource use / to pollute / be protected from pollution, while the “level of emissions constitutes a status quo right” (Ringius et al. 2002: 5). This principle builds on the notion of sovereignty underlying international law, where states are primary holders of rights and duties. It implies for example for climate change, to “allow or reduce emissions proportionally across all countries to maintain relative emission levels between them” (Ringius et al. 2002: 5).

The **vertical** or capability **principle** holds that countries have duties to conserve in relation to their capacity to contribute to addressing the environmental issue at hand. Capacity is usually interpreted as ability to pay understood as financial resources at hand. For example, wealthier countries are assumed to have a higher capability in conserving biodiversity and should thus carry larger costs associated with global conservation. The **right to development** principle also relates to a countries development state, but focuses on the consumption requirements (meeting the needs of the population). According to this principle, poorer countries have lower duties to conserve. For example, least developed countries are allowed to formulate less ambitious targets for land use reduction. As per the **polluter pays** or responsibility **principle** conservation requirements arise in relation to the degree to which a country has caused an environmental problem. This means countries have a higher responsibility to solve an environmental problem, if they contributed to the problem to a larger degree.

1.7.5.2 Planetary boundaries and “fittingness” of distributive justice principles

When applying these principles to the planetary boundaries concept characteristics of the concept such as the definition of the respective boundary need to be taken into account (Häyhä et al. 2016; Lucas and Wilting 2018).

As a general observation, the planetary boundaries concept is particularly apt for a budget approach to burden sharing where individual countries receive fair shares of the global budget as the concept defines global values which create a “safe operating space” to be shared (Lucas and Wilting 2018). However, for some boundaries such as the biosphere integrity boundary and the land system change boundary it can be debated how meaningful such a fair share is. For biosphere integrity, a fair share would for example mean “number of species extinct per country” or “fair share of impacts on biodiversity intactness” and for land system change a “fair share of deforestation”.

The political efforts related to the respective boundary could function as starting points for application of the boundary. For the biosphere boundaries a potential referent object for burden sharing better suited might be the effort associated with protecting large ecosystems and local changes / ecosystems in general, as well as the effort for preventing species extinction. For example, under the convention on biological diversity, the Nagoya protocol was agreed upon by the member states which entails provisions on “access to genetic resources and the fair and equitable sharing of benefits arising from their utilization” (Secretariat of the Convention on Biological Diversity 2011: 1). Thus, instead of sharing the biodiversity boundary budget, the principles are applied to this particular effort, focusing for example on genetic resources and rights to access them. For land system change a potential referent object might be the effort associated with policies that contribute to less land consumption and less land intensive production.

In addition to this observation, two different levels can be distinguished when applying the principles of distributive justice to the planetary boundaries concept.

Criteria for selecting planetary boundaries for application of distributive justice principles

The first level relates to the question which planetary boundaries to select for application of the principles of distributive justice. Not all planetary boundaries appear to be equally apt for selection.

A first criterion for selection is the **status of the definition of the planetary boundary**. The novel entities boundary, the atmospheric aerosol boundary as well as the functional diversity part of the biosphere integrity boundary do not yet have control variables. The application of principles of distributive justice is in this case difficult as it is not clear what the resource right or the conservation duty is that needs to be distributed.

A second criterion for selection is the **criticality** of the global environmental problem. The ozone boundary refers to an environmental problem with lower criticality due to the efforts undertaken under the Montreal protocol. Hence, it appears to be less urgent to apply principles of distributive justice to this environmental problem.

A third criterion for selection is **interlinkages between boundaries**. The ocean acidification boundary is closely linked to the climate change boundary. Application of principles of distributive justice should thus focus on climate change as the overarching environmental problem.

Principles of distributive justice

The second level relates to the principles directly; they are not equally apt for burden sharing with regards to the planetary boundaries concept. The following subsection entails preliminary thoughts on the fittingness of each principle for the planetary boundaries concept.

The *equality principle* implies that each individual has the same duty to conserve. But this appears to be only just if each person has the same control on the environmental problem at hand. Otherwise, a person that has no or low control over the environmental problem would be similarly treated as a person with high control. The principle thus fits best to the climate change boundary as greenhouse gas emissions by each person worldwide contribute similarly to the climate change problem and reducing these would reduce the problem similarly.

The *sovereignty principle* implies that differences in the individual and country-specific responsibility for an environmental problem are not so high or responsibility for it cannot easily be ascertained.

Thus, it is prudent to rely on the sovereignty principle which is established within international law for ascertaining responsibility for sharing efforts and simply treats states equally. When applying this principle to the planetary boundaries the question arises whether responsibility for the environmental problem underlying the boundaries cannot be identified. This question is difficult to answer in general. However, it appears that for the boundaries some degree of responsibility can be identified. For example, for the land boundary, land system change in one country can be traced back to consumption in other countries, e.g. the consumption in Switzerland (compare Würtenberger et al. 2006). Thus, the principle appears to be less suitable for application.

The *vertical principle* relates the duty to conserve to a country's capability, measured in ability to pay. It assumes that the costs of solving an environmental problem matter greatly. In general, it appears that conservation with regards to all boundaries is associated with higher costs. Hence, the principle should be generally taken into account.

The *polluter pays* principle presupposes a situation where large differences exists in the question who has contributed to an environmental problem in the past (more importance) as well who contributes currently. This is certainly true with regards to global environmental change. However, the planetary boundaries differ in whether their control variable is defined as cumulative or annual. Some boundaries are not cumulative: The control variables of the N/P boundary are defined as yearly "P flow from freshwater systems into the ocean" and as "industrial and intentional biological fixation of N" per year (Steffen et al. 2015). Also, the control variable of the freshwater use boundary has an annual budget. For these boundaries, the question of responsibility arises "annually". For example, a country's N fixation in 2012 does not impact the distribution of N-budget in 2017. For these boundaries, the problem of historic contribution therefore does not arise in the same sense as for the climate change boundary where greenhouse gas emissions in the past reduce the available budget.

Summarizing, when applying these criteria and when looking at the implications of each principle for the planetary boundraies, it can be concluded that burden sharing in the context of the planetary boundaries concept fits well to a budget approach. Nevertheless, it seems reasonable to also apply effort sharing to boundaries for which budgets cannot be easily defined, i.e. the biosphere integrity boundary. Furthermore, planetary boundaries best suited for application of the distributive justice principle are (currently) climate change, biosphere integrity, land system change, freshwater use and biogeochemical flows, as the ozone boundary has low criticality, ocean acidification is closely connected to the climate boundary and the control variables of the novel entities and aerosol boundaries are not yet defined.

While the equality or per-capita principle fits best to the climate change boundary, for other boundaries the question of control or influence arises when applying the concept. The vertical principle and the right to development principle appear to fit well to applying the planetary boundary concept. In contrast the sovereignty principle seems less suitable as for the environmental problems underlying the planetary boundaries concept more or less clear responsibilities can be identified. The historical principle can best be applied to the climate change boundary, in which it is well established in the discourse of effort sharing and historical emissions can be quantified.

The brief analysis shows that the concept of planetary boundaries can have added value for burden sharing as it helps approximate who should contribute to solving global environmental problems. Nevertheless, not all principles appear to be equally fit for application.

1.7.6 Conclusion and recommendations

This paper analyzed the different notions of justice the planetary boundaries concept induces and highlighted further potential for burden sharing and planetary boundaries. To do so it first defined major distinctions of ecological justice and burden sharing. There are three distinctions that are in principle useful for the discussion of the planetary boundaries concept:

- *Distributive* justice refers to a state where each referent object of justice (e.g. an individual or nation-state) has what is due to her (a specific benefit or burden or a specific right or duty) on grounds of a distributive principle such as equality or want.
- *Corrective* justice implies to change an unjust state which has been brought about by an action of an agent such as an individual or nation state and has harmed the referent object of this respective action.
- *Procedural* justice requires that *the way* of how a distribution of benefits or burdens is formulated is fair.

The paper subsequently looked at the discourse in the scientific community that defines and develops the concept to understand how main proponents of the concept connect it to justice. Within the science discourse *distributive justice* is a main theme discussed in terms of fair shares of the safe operating space; *corrective justice* is not currently discussed in connection with the planetary boundaries concept; *procedural justice* is discussed with regards to the procedure of allocating fair shares.

In addition, German governmental discourse was analysed as Germany's Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety is one of the forerunners of planetary boundaries mainstreaming and the discourse thus represents a good case for analyzing how the concept is related to burden sharing in practice. The analysis shows that the concept indeed invited different interpretations of how the planetary boundaries concept is connected to global ecological justice:

- In a first perspective visible in the discourse, planetary boundaries are seen as *precursor for justice*. They are interpreted as the foundation for the achievement of other social goals, such as a world with less violent conflicts, less poverty and dignity for all.
- In a second perspective, planetary boundaries are *interlinked with distributional justice*, especially the distribution of fair per-capita access rights to resources and the fair distribution of detrimental effects on the environment.
- A third perspective, connects the concept of "ecological boundaries" to *procedural justice*, in particular participation in the normative aspects of the concept such as defining the risk societies are willing to take and setting sub-global targets.

As a last step, further potential for distributive justice and planetary boundaries was analysed to contribute to the question what burden sharing could mean for each planetary boundary. Planetary boundaries best suited for application of the distributive justice principle are (currently) climate change, biosphere integrity, land system change, freshwater use and biogeochemical flows. Distributive justice principles best suited for the framework are, based on the preliminary analysis, the equality or per-capita and responsibility principle (climate change boundary) as well as the vertical and the right to development principle (all planetary boundaries). Further research should analyse the implications of distributive justice principles for the respective boundaries in more detail, for example by looking at case studies of resource use.

1.7.7 Annex

1.7.7.1 Documents, science discourse

No	Document
1	Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: A safe operating space for humanity. In: Nature 461:7263, pp 472–475.

No	Document
2	Rockström, Johan; Will Steffen; Kevin Noone; Asa Persson; F. Stuart Chapin; Eric F. Lambin; Timothy M. Lenton; Marten Scheffer; Carl Folke; Hans Joachim Schellnhuber; Bjorn Nykvist; de Wit, Cynthia A.; Terry Hughes; van der Leeuw, Sander; Henning Rodhe; Sverker Sorlin; Peter K. Snyder; Robert Costanza; Uno Svedin; Malin Falkenmark; Louise Karlberg; Robert W. Corell; Victoria J. Fabry; James Hansen; Brian Walker; Diana Liverman; Katherine Richardson; Paul Crutzen and Jonathan A. Foley 2009: Planetary Boundaries: Exploring the Safe Operating Space for Humanity. In: Ecology & Society 14:2, p 32.
3	Steffen, Will; Katherine Richardson; Johan Rockström; Sarah E. Cornell; Ingo Fetzer; Elena M. Bennett; Reinette Biggs; Stephen R. Carpenter; Wim de Vries; de Wit, Cynthia A.; Carl Folke; Dieter Gerten; Jens Heinke; Georgina M. Mace; Linn M. Persson; Veerabhadran Ramanathan; Belinda Reyers and Sverker Sörlin 2015: Planetary boundaries: Guiding human development on a changing planet. In: Science 347:6223, p 1259855.
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9	Griggs, David; Mark Stafford-Smith; Owen Gaffney; Johan Rockstrom; Marcus C. Ohman; Priya Shyamsundar; Will Steffen; Gisbert Glaser; Norichika Kanie and Ian Noble 2013: Policy: Sustainable development goals for people and planet. In: Nature 495:7441, pp 305–307.
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22	Rockström, Johan; John Williams; Gretchen Daily; Andrew Noble; Nathanial Matthews; Line Gordon; Hanna Wetterstrand; Fabrice DeClerck; Mihir Shah; Pasquale Steduto; Charlotte de Fraiture; Nuhu Hatibu; Olcay Unver; Jeremy Bird; Lindiwe Sibanda and Jimmy Smith 2017: Sustainable intensification of agriculture for human prosperity and global sustainability. In: AMBIO 46:1, pp 4–17.
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1.7.7.2 Documents, governmental discourse

No	Document
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2	Auswärtiges Amt (2017): Preventing Crises, Resolving Conflicts, Building Peace.
3	BfN (2014): 5. Erfahrungsbericht 2014 zu umweltbezogenen Nachhaltigkeitsindikatoren.
4	BfN (2016): Die Energiewende im Spannungsfeld energiepolitischer Ziele, gesellschaftlicher Akzeptanz und naturschutzfachlicher Anforderungen
5	BfN (2015): Artenschutz-Report 2015. Tiere und Pflanzen in Deutschland.
6	BfN (2014): Management of land- and seascapes: for people and nature.
7	BfN (2015): Naturkapital und Klimapolitik.
8	BMBF (2015): Bekanntmachung. Richtlinie zur thematischen Förderung (Modul II) im Rahmen des Konzepts „Bioökonomie als gesellschaftlicher Wandel“.
9	BMBF (2016): Käte Hamburger Centers – international cutting-edge research in the humanities.
10	BMBF / Bundesregierung (2017): Leitlinien für das neue EU-Rahmenprogramm für Forschung und Innovation.
11	BMBF / Bundesregierung (2017): Fortschritt durch Forschung und Innovation Bericht zur Umsetzung der Hightech-Strategie.
12	BMJV (2016): Rede von Ulrich Kelber, Parlamentarischer Staatssekretär beim Bundesminister der Justiz und für Verbraucherschutz auf der Dialogkonferenz am 19. Januar 2016 in Bonn zur Fortschreibung der nationalen Nachhaltigkeitsstrategie.
13	BMUB (2018): Planetare Belastbarkeitsgrenzen. www.bmub.bund.de/WS4559 [13.07.2018].
14	BMUB (2016): Hendricks: “Es ist Zeit für eine neue, gestärkte Umweltpolitik”. Rede von Dr. Barbara Hendricks zum Integrierten Umweltprogramm 2030.
15	BMUB (2016): Keynote von Dr. Barbara Hendricks beim Umweltbeirat der chinesischen Regierung.
16	BMUB (2016): 30 Jahre Bundesumweltministerium: Wir bohren weiter dicke Bretter!
17	BMUB (2017): Bundesregierung beschließt ersten Stickstoffbericht.
18	BMUB (2014): Rede von Dr. Barbara Hendricks an der Humboldt-Universität Berlin.
19	BMUB (2015): Statement von Rita Schwarzelühr-Sutter bei den Verhandlungen der Vereinten Nationen zur Post 2015-Agenda
20	BMZ (2016): A new global social contract. Keynote speech by Former Federal President of Germany Horst Köhler.
21	BMZ (2016): Berlin Recommendations for the Cities of Tomorrow.

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22	BMZ (2014): Die Zukunftscharta „EINEWELT – Unsere Verantwortung“.
23	BMZ / Bundesregierung (2016): Bericht der Bundesregierung zum High-Level Political Forum on Sustainable Development 2016.
24	GIZ (2013): Mobilising Investment for Inclusive Green Growth in Low-Income Countries.
25	GIZ (2016): Modules on Sustainable Agriculture (MOSA) – Reader.
26	GIZ (2014): Shifting Paradigms. Unpacking Transformation for Climate Action.
27	GIZ (2016): The Political Economy of Extractive Resources.
28	GIZ (2016): Synergies and trade-offs between green growth policies and inclusiveness.
29	GIZ (2015): Benefits of a Green Economy Transformation in Sub-Saharan Africa.
30	GIZ (2014): GIZ Reihe – Forschung trifft Praxis. Planetarische Grenzen und die Post-2015 Agenda.
31	GIZ (2016): Agricultural development policy: a contemporary agenda.
32	Kanzleramt (2017): Rede von Bundeskanzlerin Merkel beim Jahresempfang für das Diplomatische Corps am 13. Juli 2017.
33	PBNE (2017): Bericht des parlamentarischen Beirates für nachhaltige Entwicklung (Arbeitsbericht der 18. Wahlperiode).
34	PBNE (2017): Stellungnahme des Parlamentarischen Beirates für nachhaltige Entwicklung zur Deutschen Nachhaltigkeitsstrategie 2016
35	SRU (2012): Umweltgutachten 2012. Verantwortung in einer begrenzten Welt.
36	SRU (2016): Umweltgutachten 2016.
37	SRU (2015): Stickstoff: Lösungsstrategien für ein drängendes Umweltproblem
38	SRU (2012): FFU. Nachhaltiges Wirtschaften in den Grenzen des Wachstums – 40 Jahre Politikberatung. Vortrag Prof. Dr. Martin Jänicke.
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40	SRU (2013): Das 7. Umweltaktionsprogramm: Gut leben innerhalb der Belastbarkeitsgrenzen des Planeten. Vortrag Dr. Christian Hey.
41	SRU (2011): Ökologische Leitplanken setzen, natürliche Lebensgrundlagen schützen – Empfehlungen zum Fortschrittbericht 2012 zur nationalen Nachhaltigkeitsstrategie.
42	UBA (2015): Elemente einer erfolgreichen Ressourcenschonungspolitik.
43	UBA (2015): Green Economy: Nachhaltige Wohlfahrt messbar machen unter Nutzung der umweltökonomischen Gesamtrechnungs(UGR) Daten.
44	UBA (2016): Schwerpunkte 2016.
45	UBA (2014): Leida Rijnhout. Presentation. Resource Efficiency Forum, Berlin 10-11 of November.

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50	UBA (2014): 2nd European Resources Forum, Berlin. Minutes from the European Resources Forum 2014. Day 2.
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54	UBA (2017): Große Transformation und die Medien – Alternativen zum Wachstum als Leitbild der Kommunikation.
55	UBA (2017): Übergang in eine Green Economy: Systemische Hemmnisse und praktische Lösungsansätze.
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58	UBA (2017): Nachhaltigkeit 2.0 – Modernisierungsansätze zum Leitbild der nachhaltigen Entwicklung. Abschlussbericht.
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60	UBA (2017): Narrative und Diskurse in der Umweltpolitik: Möglichkeiten und Grenzen ihrer strategischen Nutzung.
61	UBA (2017): Soziale Aspekte des Natur- und Umweltschutzes – Band II : Soziale Aspekte der Umweltpolitik.
62	UBA (2017): Soziale Aspekte des Natur- und Umweltschutzes – Band I : Umweltgerechtigkeit.
63	UBA (2017): Die Managementregeln der Nachhaltigkeitsstrategie.
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2 Focus issues

In addition to cross-sectional themes such as environmental communication and burden sharing, the project also adressed political focus topics, exploring for example how the planetary boundaries concept can support the formulation of a national integrated nitrogen strategy and the Integrated Environmental Programme 2030.

2.1 Entry points

Within the research project, entry points for mainstreaming the planetary boundaries concept in the political arena were examined in several workshops. These workshops focused on the interlinkages between resource use efficiency and the planetary boundaries concept as well as the connection between the planetary boundaries concept and the sustainable development goals. The input papers for these two workshops are included below.

2.1.1 Planetary boundaries and resource efficiency: pathways for a sustainable future? (workshop summary)

Planetary boundaries delineate a safe operating space for humanity but refrain from proposing pathways for sustainability. Resource use efficiency (RUE) can be such a pathway, but doesn't come with any targets (and hence may cause non-sustainable outcomes). Complementing each other, RUE can contribute to the operationalization of PBs, while the PBs can guide RUE by providing an overarching global frame and legitimizing RUE.

The planetary poundaries concept does not directly address RUE, but identifies nine Earth System conditions vital for sustainable development. The specific means to stay within this safe operating space are deliberately left open, as the intention is to provide guardrails, not specific pathways. But for the political realm the question of operationalization and implementation of the planetary boundaries is central: how can the planetary boundaries be integrated with existing scientific insights on natural resource, their scarcities and use efficiency, and how can they be aligned with concrete political experiences and requirements? And what added value does the framework provide for achieving resource efficiency and sustainability goals? Leading planetary boundaries and natural resource scientists and German and European policy makers provided insights on these questions in a joint workshop on planetary boundaries and RUE in February 2016 in Berlin. This paper synthesizes the results and contributes to a further discussion on the interlinkages and potential synergies between both concepts.

Resource Use Efficiency for staying in the Safe Operating Space?

Improved resource efficiency can help to stay within the safe operating space, i.e. ensuring human well-being and development, while reducing pressure on natural resources and the environment (decoupling). For example, increasing the efficiency of synthetic fertilizer application in the agricultural sector can lower pressures on the N-planetary boundary while also reducing health impacts (eutrophication; nitrate in groundwater) and potentially improving food security. Similarly, increasing water productivity in irrigation, e.g. by closing yield gaps, can reduce impacts on the freshwater use planetary boundary and at the same time lower water scarcity and improve water security. However, that requires integration with additional approaches that limit the total resource use and account for potential externalities: RUE is an important element of sustainability pathways, but requires a complementary budget approach such as the planetary boundaries, in order to constrain overall resource use to a sustainable level.

Politically, RUE targets contribute to planetary boundary operationalization at the national and regional level. RUE provides a positive vision and opportunities for planetary boundaries, highlighting the power of human ingenuity, transformation, technology and a pathway to a Green economy. Also, when operationalizing planetary boundaries, policy-makers can build on existing RUE targets. For example, planetary boundary operationalization can rely on the national targets to double resource productivity by 2020 with a 1994 baseline (German Sustainable Development Strategy) and to increase the recycling rate for municipal waste to 65% by 2020 (German Ressource Efficiency Programm, ProgRess II). Both of these targets, if implemented, can reduce pressure on several environmental processes and boundaries, e.g. land, water and climate. At the EU-level, planetary boundary operationalization can build on e.g. the Resource Efficiency Flagship, the Circular Economy Action Plan and targets for minimizing municipal and packaging waste.

However, to move back into and ensure a safe operating space for humanity, RUE improvements are not enough, they need to be complemented by other elements, such as transformative and innovative production systems, infrastructure, changing preferences and lifestyles, institutional reform, policy coherence and implementation. The current state of the planetary boundaries – some of which have already been transgressed - shows the massive global challenge and urgent demand for transformative changes with respect to other drivers such as consumer behavior and through other political measures complementing current RUE approaches (e.g. energy transition; taxation and subsidies). Furthermore, rebound effects can partially consume or even overcompensate RUE gains e.g. by lowering prices for goods and thus increasing demand, necessitating an effective policy mix complementing RUE.

Planetary Boundaries for Improving Resource Use Efficiency?

Planetary boundaries provide an additional legitimization at large scale, for resource efficiency measures beyond the usual local to national arguments. Planetary boundaries describe large-scale and systemic environmental risks (related to the functioning of the Earth system) and are a wakeup call for increased efforts at all scales, including through improved RUE. For example, the transgression of the planetary boundary for climate change justifies to drastically improve energy efficiency to minimize the risk for crossing the threshold.

Planetary boundaries support resource efficiency strategies. They inform policy processes by providing additional large-scale targets, and with that they can support policy coherence across scales, and being systemic targets also between environmental processes. Ongoing political strategy formulations such as the German Integrated Nitrogen Strategy and the Integrated Environmental Program highlight the benefits of taking into account planetary boundaries, such as relying on science based assessments for Earth System stability, accounting for external and large-scale effects, and ensuring long-term prosperity within boundaries.

The planetary boundaries can guide RUE implementation towards sustainable pathways, along which total, consumption-based footprints stay within the safe operating space. Planetary boundaries highlight the need to extend the system boundaries of RUE measures beyond national territories to also account for external environmental pressures through consumption and associated imports of commodities such as soy and palm oil. They signify a global responsibility for planet and people.

Ressource Use Efficiency and Planetary Boundaries: The Role of Science and Policy-making

Operationalization of the planetary boundaries (and RUE) for policy making at national or European level requires entry points, i.e. ongoing policy processes, along which scientists and policy makers can develop a dialogue and co-design, co-develop and apply new knowledge. An example from Germany for such a policy process is the development of an Integrated Nitrogen Strategy, which has been informed by the planetary boundaries on vertical integration (aligning national with European and global nitrogen-related goals and policies) and horizontal integration (spelling out and quantifying co-constraints or co-benefits with other environmental goals along the nitrogen cascade and along supply chains, and consequences for policy coherence). A European entry point is the Circular Economy Action Plan (related to food waste, water reuse, fertilizer use etc.). Future strategy formulation and review, e.g. on the German Resource Efficiency Program ProgRess III, should extend resource efficiency targets to account for all planetary boundary relevant resources, such as phosphorus, nitrogen, CO_2, water, land and biodiversity. Furthermore, future targets need to adequately reflect the large scale risks described by the planetary boundaries.

Another ongoing process which needs to be informed by the planetary boundaries is the 2030 agenda and the national SDG implementation. The principles of universality and integration inherent to the SDGs, require this process to be informed by the planetary boundaries about the global environmental safe operating space and the international and global effects of domestic action. Again, RUE is one important element in decoupling development goals from resource use and environmental pressure (and hence achieve all goals and targets in concert). Downscaled integrated scenarios can inform sustainable pathways towards 2030.

SDG implementation also has to account for challenges and opportunities related to globalization, including trade (external footprints, sustainable sourcing, sharing of knowledge and technology, development cooperation etc.) – this is captured e.g. in SDG 8.4. on overall resource efficiency, SDG 12 on sustainable consumption and production and SDG 17 on global partnership.

2.1.2 Thesenpapier: Möglichkeiten und Grenzen des Konzepts der Planetaren Grenzen für die nationale Umwelt- und Nachhaltigkeitspolitik: Integriertes Umweltprogramm und Implementierung der Agenda 2030 (Fachdialog)

2.1.2.1 Hintergrund

- Die neun Planetaren Grenzen[70] (Planetary Boundaries) betreffen physikalische, chemische und biologische Prozesse des Erdsystems. Dies sind im Einzelnen: Klimawandel, Verlust der Integrität der Biosphäre, Landnutzung, Wassernutzung, biogeochemische Flüsse, Ozeanversauerung, atmosphärische Aerosolbelastung, stratosphärischer Ozonverlust, Einführung neuer Umweltsubstanzen.
- Aufbauend auf Vorläufer- und verwandten Konzepten wie „limits to growth", „carrying capacity", „critical loads", „tolerable windows" fasst das Konzept der Planetaren Grenzen den Stand der Wissenschaft zu großmaßstäbigen, systemischen Umweltgrenzen bzw. Leitplanken[71] zusammen und definiert darüber einen globalen nachhaltigen Entwicklungsraum („safe operating space"[72]).
- Für die Planetaren Grenzen ist der historische Klima- und Erdsystemzustand (das Holozän) die Referenz (siehe Abbildung 68 unten für die Diskussion um die Bewahrung des Holozänartigen Erdsystemzustands). Das wissenschaftliche Konzept der Planetaren Grenzen weist auf die Risiken hin, die mit einem Verlassen des bisherigen Holozänzustands und des Safe Operating Space verbunden sind.
- Im Anthropozän[73] mit seiner seit den 50er Jahren voranschreitenden „großen Beschleunigung" weltverändernder menschlicher Aktivitäten (Steffen et al. 2015b) geraten das natürliche Erdsystem und seine Sub-Systeme immer stärker unter Druck (siehe Abbildung 69 unten für den

[70] Im nachfolgenden wird «Planetare Grenzen» mit «Planetaren Grenzen» abgekürzt.

[71] Leitplanken (eine sinngemäße Übersetzung von „Planetary Boundaries") begrenzen einen nachhaltigen Entwicklungsraum sozial-ökologischer (Mensch-Umwelt) Systeme, innerhalb dessen unerwünschte oder gar katastrophale Entwicklungen aller Wahrscheinlichkeit nach vermieden werden können. Der Begriff wurde ursprünglich für das Klimasystem entwickelt (WBGU 1995).

[72] Der safe operating space bezeichnet den durch die Planetaren Grenzen definierten „sicheren" Handlungsraum, innerhalb dessen wahrscheinlich eine nachhaltige Entwicklung möglich ist.

[73] Der Begriff Anthropozän bezeichnet ein zusätzliches neu definiertes geologisches Erdzeitalter, in welchem der Mensch zu einem „entscheidenden Einflussfaktor auf die biologischen, geologischen und atmosphärischen Prozesse der Erde geworden ist" (Crutzen 2002).

Zusammenhang zwischen Megatrends, Erdsystemzustand und Planetaren Grenzen). Dabei drohen für die Menschheit essentielle Funktionen und Ökosystemdienstleistungen verloren zu gehen, und es kann bei Überschreitungen kritischer Grenzwerte zu unerwarteten und gravierenden Folgen, bis hin zu sogenannten „regime shifts“ (abrupten Reaktionen), kommen (siehe Abbildung 70 unten für eine Illustration verschiedener potenzieller selbststabilisierender Zustände des Erdsystems; siehe Abbildung 71 unten für zwei illustrative Fälle der Festlegung planetarer Grenzen – bei glattem Verlauf eines Erdsystemzustandes und bei Vorliegen eines Kipp-Punktes).

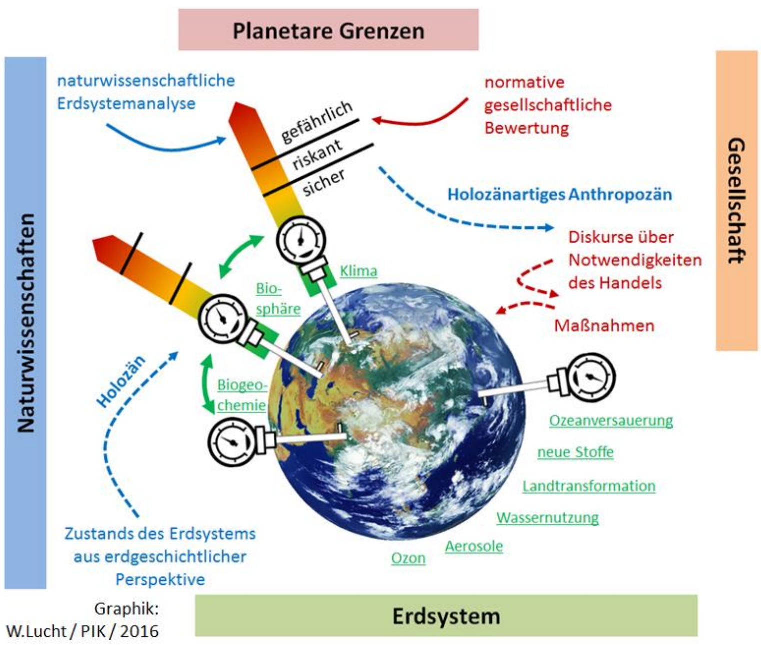
- Wenngleich die Forschung stetig voranschreitet, z.B. bzgl. der Regionalisierung einiger planetarer Grenzen, sind diese noch nicht vollständig quantifiziert (gar nicht oder sehr unzureichend quantifiziert sind: neue Umweltsubstanzen, atmosphärische Aerosolbelastung sowie der Verlust der Integrität der Biosphäre).
- Darüber hinaus bestehen noch erhebliche Unsicherheiten bezüglich der jeweiligen Lage und Dynamik der kritischen Grenzwerte (z.B. Skalierungseffekte und kumulative Effekte lokaler Grenzwertüberschreitungen), Reaktionen (und Trägheiten) des Erdsystems und dessen Teilsystemen bei Grenzüberschreitungen, einzuhaltender Sicherheitsabstände von den Grenzwerten („Leitplanken“) und Interaktionen zwischen den einzelnen Grenzen und den ihnen zugrunde liegenden Prozessen. Dabei ist zu betonen, dass bei der Bestimmung der Planetaren Grenzen das Vorsorgeprinzip („precautionary principle“) angewandt wird. Die Planetaren Grenzen definieren einen sicheren Abstand von kritischen Grenzwerten oder Leitplanken, innerhalb dessen das Risiko bekannter oder unbekannter Veränderungen auf ein akzeptables Maß begrenzt bleibt.[74]
- Aus naturwissenschaftlicher Perspektive wird neben diesen Unsicherheiten auch kritisiert, dass die Kritikalität der Grenzwerte zu wenig belegt sei, sie möglicherweise gar nicht existieren oder zumindest nicht an den genannten Punkten liegen würden und die vorgeschlagenen Kontrollvariablen nicht ausreichten sowie die komplexen Wechselwirkungen zwischen den betreffenden Umweltsektoren und Prozessen (und damit der systemische Charakter der Grenzwerte) nicht genügend beachtet würden. Weiterhin wird kritisiert, dass möglicherweise nicht alle genannten Grenzen Relevanz für das Erdsystem hätten, sondern einige sich lediglich auf lokale kontext-spezifische Prozesse bezögen.
- Daneben ist das Konzept auch aus politik- und sozialwissenschaftlicher Perspektive kritisiert worden. So wird angemerkt, dass die Planetaren Grenzen falsche Signale senden könnten, insofern als Ressourcen weiter ausgebeutet und die Umwelt bis zur Erreichung der Grenzen verschmutzt werden könnten (Schlesinger 2009); seien die Grenzen erst einmal überschritten, könne sich Fatalismus einstellen (vgl. Brook und Bradshaw 2013).
- Aus demokratietheoretischer Sicht wird kritisiert, das Konzept sei inhärent antidemokratisch (Leach 2013; Pielke, Jr. 2013; für Gegenargumente vgl. Galaz 2013). Die Planetaren Grenzen erzeugten – zusammen mit dem Anthropozän-Konzept – top-down Ziele und Lösungen unter Verweis auf wissenschaftliche Autorität. Unterschiedliche Deutungen der globalen Umweltveränderungen und unterschiedliche Entwicklungswege würden so unterminiert. Gesellschaftlich

[74] Dieser Sicherheitsabstand von den kritischen Grenzwerten ist u.a. deshalb erforderlich, weil die genaue Lage der kritischen Grenzwerte noch nicht oder zumindest nicht genügend genau bekannt ist (wissenschaftliche Unsicherheiten), weil das Erdsystem und seine Teilsysteme mit Verzögerung auf anthropogene Störungen reagieren (z.B. Erwärmung der Ozeans, Schmelzen des Grönlandeises), weil positive Rückkopplungen möglich sind (z.B. Auftauen von Permafrost und die damit einhergehende Beschleunigung des Klimawandels) und weil gesellschaftliche Reaktionen (Nachhaltigkeitstransformationen) Zeit benötigen und ebenfalls mit Unsicherheiten behaftet sind.

notwendige Aushandlungsprozesse zwischen Umwelt-, Sozial-, Wirtschafts- und weiteren Zielen würden vom Vorrang der Umweltziele abgelöst (vgl. auch Nordhaus et al. 2012).

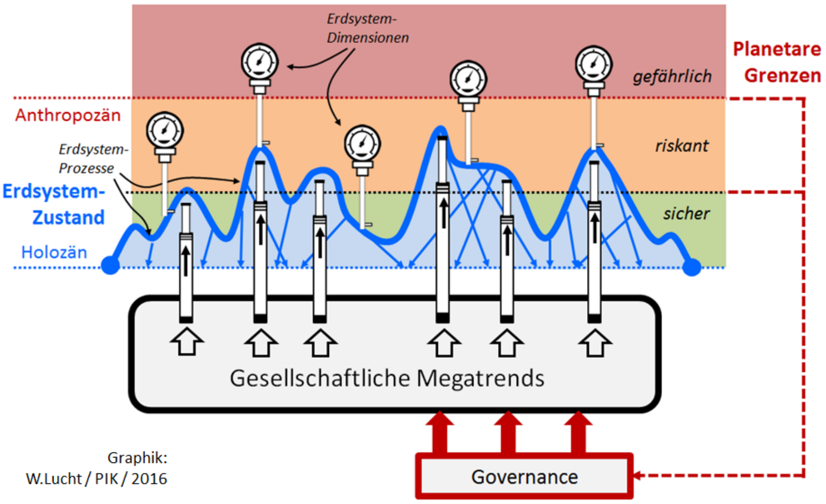
- Die Grundausrichtung des Ansatzes wird teils als „millenaristisch" kritisiert (Rayner 2013): so werde mit der immer knapper werdenden Zeit argumentiert (Katastrophe kurz bevorstehend) zusammen mit einer immer stärkeren Verdichtung des Raumes (als Erdsystem). Als Ergebnis würden die politischen Vorschläge der Befürworter der Planetaren Grenzen als einziger Weg aus der bevorstehenden Apokalypse präsentiert. Dies verberge
- die stark normative Natur dieser Grenzen (z.B. Holozän als Referenzrahmen oder die Definition akzeptabler Risiken)
- Für die internationale Umweltpolitik sei das Konzept eher hinderlich, da auf zu viele verschiedene Grenzen fokussiert werde; stattdessen sollten Klimawandel, Ozeanversauerung und Biodiversitätsverlust im Mittelpunkt stehen (Lewis 2012), was teilweise im von Steffen et al. (2015) revidierten Konzept Berücksichtigung findet (Klimawandel und Verlust der Biosphärenintegrität als „core boundaries").

Abbildung 68: Schema des Zusammenwirkens naturwissenschaftlicher Analyse und normativer Festlegungen in der Diskussion um die Bewahrung eines Holozän-artigen Erdsystemzustands im Anthropozän.



Quelle: W. Lucht, PIK, 2016, unveröffentlicht

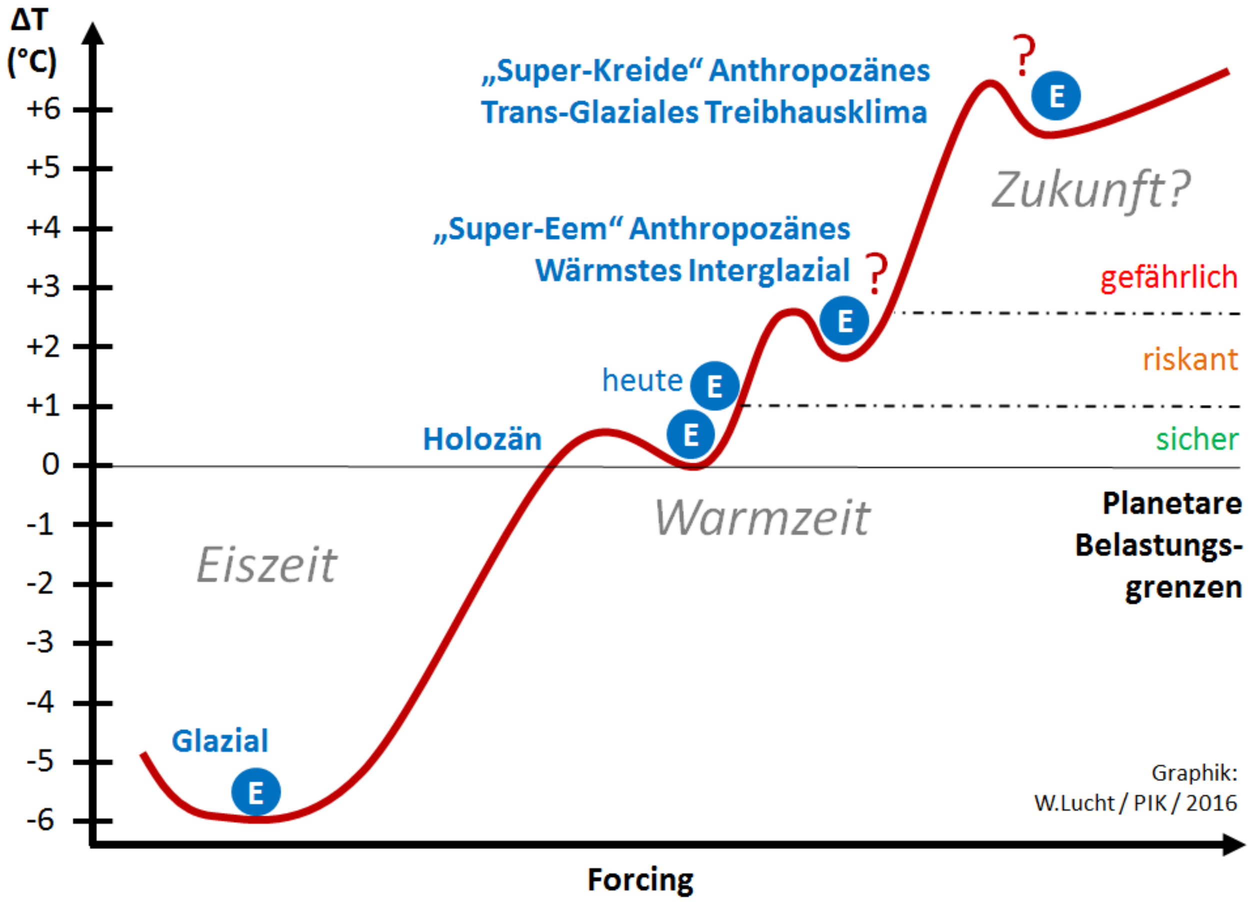
Abbildung 69: Gesellschaftliche Megatrends verändern erdsystemare Zustandsgrößen und damit das gesamte Erdsystem (blaue Linie, Abweichung vom horizontalen Naturzustand des Holozän) [75]



Quelle: W. Lucht, PIK, 2016, unveröffentlicht

[75] Solchen Veränderungen wirken erdsystemare Prozesse teilweise entgegen, wodurch Verzerrungen entstehen (dünne blaue Pfeile). Bei zu starker Veränderung droht das Erdsystem sich ganz vom selbststabilisierten Holozän zu lösen. Planetare Grenzen werden für verschiedene signifikante Messgrößen im Erdsystem definiert.

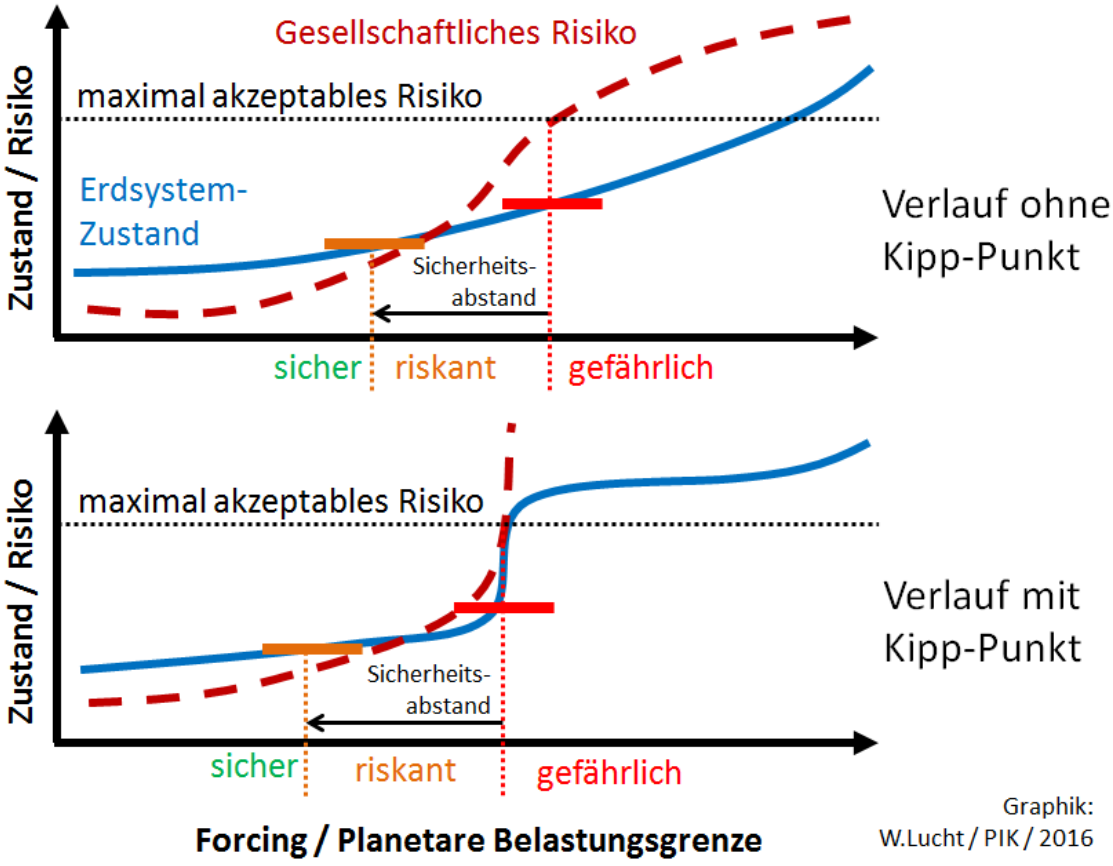
Abbildung 70: Vereinfachte Illustration verschiedener potenzieller selbststabilisierender Zustände des Erdsystems[76]



Quelle: W. Lucht, PIK, 2016, unveröffentlicht

[76] Die Fluktuationen des Erdsystems im Pleistozän scheinen durch definierte glaziale und interglaziale Zustände charakterisiert (es existieren komplexe Zwischenzustände). Das Holozän ist ein aus astronomischen Gründen ungewöhnlich robuster und lange anhaltender Zustand. Die Existenz eines wärmeren, der Zwischeneiszeit des Eem plakativ ähnlichen Zustands wärmer als das Holozän ist spekulativ, entspricht aber der Obergrenze der Temperatur aller Zwischeneiszeiten. Ob die Temperatur eines der Kreidezeit entsprechenden eisfreien Niveaus auf hohem Niveau stabil sein kann, ist unbekannt. Die Eiszeitzyklen wären jedoch durchbrochen. Sowohl das Super-Eem als auch die Super-Kreide wären ebenso Formen des Anthropozän wie ein anthropogen hergestelltes Holozän.

Abbildung 71: Zwei illustrative Fälle für die Festlegung planetarer Grenzen[77]



Quelle: W. Lucht, PIK, 2016, unveröffentlicht

2.1.2.2 Rolle der Planetaren Grenzen in der Agenda 2030 und der Neufassung der Deutschen Nachhaltigkeitsstrategie

- Das Konzept der Planetaren Grenzen ist kein expliziter Teil der Agenda 2030. Zentrale Begriffe des Konzeptes (boundaries, Earth system etc.) finden sich in der Resolution der VN-Generalversammlung nicht wieder und es wird kein spezifisches, direkt auf dieses Konzept bezogenes Ziel ausgewiesen (wie beispielsweise von WBGU 2014 und Brandi 2015 vorgeschlagen).
- Allerdings verweisen diverse Ziele (SDGs bzw. deren targets) auf die Erdsystemprozesse und Umweltkompartimente, die von den Planetaren Grenzen abgedeckt werden (z.B. SDG 6 zu Wasser, SDG 13 zum Klimawandel, SDG 14 zu Ozeanen oder SDG 15 zu terrestrischen Ökosystemen; vgl. Häyhä et al. 2016).
- Außerdem hat die Agenda 2030 eine ähnliche Ausrichtung wie die Planetaren Grenzen: Beide sind systemisch angelegt und betonen die Notwendigkeit integrativer Ansätze und Umsetzungen für die Erreichung der SDGs / targets bzw. die Einhaltung der Planetaren Grenzen (Häyhä

[77] Oben bei glattem Verlauf eines Erdsystemzustands als Funktion eines anthropogenen Forcings mit glattem, aber anders geformtem funktionalen Verlauf des gesellschaftlichen Risikos (welches ggf. auch nichtlineare Übergänge oder Kipp-Punkte enthalten könnte); unten bei Vorliegen eines Kipp-Punktes im Erdsystemzustand, an dessen Folgen Gesellschaften sich nicht anpassen können (möglich sind auch funktionale Verläufe mit abruptem Anstieg, aber noch endlichem Risiko). Der Verlauf der erdsystemaren Veränderungen und zugehörigen gesellschaftlichen Risiken sind größtenteils nur mit einiger Unsicherheit bekannt, insbesondere bezüglich der Lage von Kipp-Punkten.

et al. 2016). Damit können die Planetaren Grenzen für die Umsetzung der Agenda 2030 und der SDGs in Deutschland und in der EU eine wichtige Rolle spielen, indem sie einen ökologischen Handlungsraum (safe operating space) für die stärker sozialpolitisch bzw. wirtschaftspolitisch orientierten Ziele schaffen. Außerdem können siePolitikintegration und -kohärenz fördern: a) vertikal, indem sie Maßnahmen zwischen unterschiedlichen Ebenen koordinieren (Global – EU – Bund – Länder), sowie b) horizontal, indem sie (z.B. auf nationaler Ebene) Maßnahmen in unterschiedlichen Politikfeldern und für unterschiedliche Umweltkompartimente koordinieren (auch als „dashboard Funktion" der Planetaren Grenzen bezeichnet).

- ► Vertikale Koordination bedeutet auch, dass die einzelnen nationalen Beiträge (nationally determined contributions – NDCs) in ihrer Summe das jeweilige globale Ziel nicht überschreiten dürfen, wie z.B. die Summe der NDCs für Treibhausgasemissionen zur Einhaltung des 2° bzw. 1,5° Klimaziels.
- ► Räumlich explizit dargestellte Planetare Grenzen (siehe unten: Operationalisierung) erlauben zudem die Bestimmung der u.U. unterschiedlichen Kritikalität externalisierter Umweltauswirkungen in verschiedenen Weltregionen (so sind z.B. die von deutschen Konsummustern ausgehenden Entwaldungen in anderen Weltteilen nicht überall gleichermaßen kritisch für das Erdsystem und für die SDGs zu Klima und Biodiversität).
- ► Damit können die Planetaren Grenzen auch eine Operationalisierung nachhaltiger Konsum- und Produktionsmuster unterstützen, wie sie in SDG 12 und in der Deutschen Nachhaltigkeitsstrategie gefordert wird.
- ► Die Planetaren Grenzen können auch die nationale und EU-SDG-Lückenanalyse unterstützen („gap analysis"; vgl. Niestroy 2016), indem sie als Benchmarks genutzt werden, um die Effektivität bestehender Politiken (und die Umsetzung einzelner Maßnahmen) für einzelne Umweltkompartimente zu bewerten (Schritt 3 einer Lückenanalyse). Hierzu müssen die Planetaren Grenzen jedoch zunächst herunterskaliert und räumlich explizit gemacht werden (siehe unten: Operationalisierung).

2.1.2.3 Rolle der Planetaren Grenzen im Integrierten Umweltprogramm 2030 (IUP)

- ► Das Konzept der Planetaren Grenzen ist für das IUP in Teilen Grundlage: so wird die Einhaltung der Planetaren Grenzen als die zentrale Herausforderung für die nationale Umweltpolitik formuliert (Kap. 1.3). Im weiteren Verlauf des IUPs wird teils auf das Konzept rückverwiesen[78].
- ► Insgesamt werden die Planetaren Grenzen an einigen Stellen nicht in die weitere Diskussion eingebunden[79]. Zu überlegen wäre, das Konzept der Planetaren Grenzen in der weiteren Kommunikation und in der Umsetzung auch für die Darstellung der Schlüsselbereiche Energieversorgung, Mobilität, Landwirtschaft (2.2.1 – 2.2.3) sowie der Minderung weltweiter Umweltauswirkungen (3.3) und aller Schwerpunkte (auch in Kap. 4.1, 4.3 und 4.4) zu verwenden. Dies könnte dabei helfen,darzustellen, welchen Beitrag die Maßnahmen in diesen Bereichen für die zentrale Herausforderung der Einhaltung der Planetaren Grenzen leisten können.

[78] Die Planetaren Grenzen werden verwendet in: Vorwort; Kurzfassung; Abschnitt „Gut Leben 2050" ; Kap. 1.4 (aktueller politischer Rahmen); Kap. 2.1 (Umweltpolitik als Gesellschaftspolitik); Kap. 2.2.4 (Konsum und Ressourcennutzung); Kap. 3.2 (Wirtschafts- und Finanzpolitik); Kap. 4.2 (zukunftsfähige Landwirtschaft); Kap. 4.5 (Internationale Umweltpolitik).

[79] Die Planetaren Grenzen werden nicht verwendet in : Kap.1.1, 1.2, 1.5 (umweltpolitische Erfolge; aktuelle Aufgaben; IUP); Kap. 2.2, 2.2.1, 2.2.2, 2.2.3 (Schlüsselbereiche; Energieversorgung; Mobilität; Landwirtschaft) ; Kap. 3.1, 3.3, 3.4, 3.5 (Umweltpolitik des Bundes; weltweite Umweltauswirkungen Deutschlands; neues Wohlfahrtsverständnis; Unterstützung nachhaltigen Handelns); Kap. 4.1, 4.3, 4.4 (Umwelt und klimaverträglich wirtschaften; Mobilität; Gesunde Lebensbedingungen); Kap. 5 (Bürgerdialog).

- Die Planetaren Grenzen dienen im IUP argumentativ dazu, den Primat der Umwelt vor Sozialem und Ökonomie herauszustellen – „Klar ist: Ökonomische und soziale Ziele müssen künftig im Rahmen ökologischer Grenzen verwirklicht werden" (IUP, ii) – und den Zustand der Umwelt in Deutschland und global zu verdeutlichen (IUP, i-ii).
- Wissenschaftliche Debatten und Unsicherheiten werden im IUP nicht angesprochen. Es wird dargestellt, dass die Planetaren Grenzen „einerseits auf naturwissenschaftlichen Erkenntnissen, andererseits auf der Anwendung des Vorsorgeprinzips" basieren; die Planetaren Grenzen werden (außer den noch nicht quantifizierten Grenzen) als „verlässliche Einschätzung" der Risiken interpretiert, vor denen die deutsche und globale Gesellschaft steht (implizit S. 11).
- Das IUP folgt einer ganz bestimmten Deutung der Planetaren Grenzen. Die Ursachen der Grenzüberschreitung liegen laut IUP u.a. im Bevölkerungswachstum, wachsendem Wohlstand, Urbanisierung, Konsum, Verkehr, Landwirtschaft, der Wirtschaftsweise etc. Die Folgen der Grenzüberschreitung werden u.a. formuliert als Risiken für „wirtschaftlichen Wohlstand" und „sozialen Frieden", für Ökologie / Wirtschaft / Gesellschaft, als Gefährdung der nachhaltigen Entwicklung durch „abrupte und möglicherweise un¬umkehrbare Beeinträchtigungen der Lebensbedingungen auf der Erde". Als zentrale Mittel für die Einhaltung der Planetaren Grenzen werden die sozial-ökologische Transformation und transformative Umweltpolitik identifiziert.
- In der Außendarstellung des BMUB zum IUP nehmen die Planetaren Grenzen ebenfalls eine zentrale Rolle ein, z.B. in der Pressemitteilung und der Rede der Bundesministerin (vgl. BMUB 2016b, BMUB 2016c). Im medialen Diskurs nach der Veröffentlichung des IUPs spielten die Planetaren Grenzen keine große Rolle. Im Zentrum der medialen Aufmerksamkeit standen vor allem die Idee eines „zweiten Preisschildes" sowie die agrarpolitischen Aussagen des IUPs und die Debatte um ein Initiativrecht für das BMUB (vgl. bspw. Tagesschau 2016).
- Teils wird die Verankerung der Planetaren Grenzen im IUP medial auch kritisch aufgegriffen: So wird kritisiert, das Programm lege nicht klar genug dar, wo die Grenzen liegen, verwende nur eine Quelle (Rockström et al. 2009) und stelle nicht plausibel dar, dass eine Krisensituation vorliege, die „radikale Grenzziehungen" nötig mache (Hentrich 2016).

2.1.2.4 Möglichkeiten der Operationalisierung der Planetaren Grenzen

- Um die Planetaren Grenzen wie oben beschrieben zu nutzen, z.B. im Rahmen des IUP oder auch in der Nachhaltigkeitsstrategie, bedarf es der Operationalisierung.
- Diese Operationalisierung erfordert ein Herunterskalieren (downscaling) auf den jeweiligen Maßstab von Politik und Umweltmanagement, also eine räumlich explizite Darstellung der Planetaren Grenzen. Erst damit werden ein Mainstreaming und die Integration mit kontextspezifischen lokalen Umwelt- und Nachhaltigkeitszielen möglich.
- Der erste Schritt vor einer solchen Operationalisierung sollte immer eine Überprüfung sein, ob und ggf. welche Planetaren Grenzen mittels Mainstreaming tatsächlich einen Mehrwert im jeweiligen Kontext schaffen können. Diese Überprüfung sollte, wie auch alle weiteren Schritte der Operationalisierung, durch Wissenschaftler und Wissenschaftlerinnen sowie andere Stakeholder gemeinsam erfolgen.
- Diese gemeinsame Operationalisierung der Planetaren Grenzen sichert gleichzeitig die wissenschaftliche Untermauerung sowie die Relevanz des Prozesses und die Legitimität der erforderlichen normativen Entscheidungen. Weiterhin verspricht ein solches „co-design" und eine „co-production" (Mauser et al. 2013) auch die Zielgenauigkeit der Anwendung der Planetaren Grenzen zu verbessern.
- Zu den normativen Entscheidungen bei der Operationalisierung und der Weiterentwicklung der Planetaren Grenzen gehören u.a. die Festlegung akzeptabler Risiken (der Überschreitung

von Planetaren Grenzen und damit verbundener Folgen) und fairer Allokationen der globalen Planetaren Grenzen-Werte.

- Obwohl die verschiedenen Planetaren Grenzen unterschiedlich definiert sind und unterschiedliche Eigenschaften haben (z.B. in Hinblick auf ihre Wirkungsskalen, die Bedeutung räumlicher Muster und ihre Kontext-Spezifizität), zeichnet sich eine verallgemeinerbare Vorgehensweise bei der Operationalisierung ab, die etwa folgende Schritte umfassen kann:
    - Herunterskalieren und Allokation der globalen Werte auf einzelne Regionen, Länder oder Bevölkerungsgruppen;
    - Einbeziehung der zeitlichen Dynamik beim Herunterskalieren – je nach Planetare Grenze (wichtig z.B. für Emissionsreduktionspfade für die Planetare Grenze für Klimawandel);
    - Nutzung der herunterskalierten Planetaren Grenze als Benchmark für den gegenwärtigen Umweltzustand (environmental performance) oder die erwartete Verbesserung durch neue Strategien, Politiken etc. (sind diese z.B. ausreichend, um den globalen Zielen zu genügen?). Dieses Benchmarking sollte sowohl produktionsbasiert (also auf den nationalen Umweltzustand bezogen) als auch konsumbasiert (also auf die gesamten Umweltauswirkungen im Inland und Ausland bezogen) erfolgen. Nur ein konsumbasiertes Benchmarking erfasst die volle nationale Verantwortung für die mögliche Überschreitung von Planetare Grenzen, und erst wenn die konsumbasierten Umwelt-Fußabdrücke[80] zurück gehen, kann von einer Entkopplung (siehe Green Economy) die Rede sein;
    - die Ergebnisse aus den vorhergehenden Schritten können für einen Abgleich neuer (z.B. nationaler) Strategien, Politiken etc. mit den durch die Planetaren Grenzen beschriebenen globalen Umweltzielen genutzt werden.
- Eine solche Operationalisierung der Planetaren Grenzen kann bereits zum jetzigen Zeitpunkt beginnen, ohne erst weitere wissenschaftliche Fortschritte abzuwarten. Operationalisierung und wissenschaftliche Weiterentwicklung der Planetaren Grenzen bedingen und fördern sich gegenseitig.

Beispiel für die Operationalisierung der Planetaren Grenzen für Deutschland: Stickstoff-Planetare Grenze

Die Planetary Boundary für Stickstoff liegt laut Steffen et al. (2015) bei einer anthropogenen Erzeugung von 62 Megatonnen (Mt) reaktiven Stickstoffs (Nr) pro Jahr. Downscaling dieses globalen Wertes auf alle Ackerflächen der Welt ergibt einen zulässigen Maximalwert von 41 kg pro ha und Jahr, was für Deutschland mit einer Ackerfläche von ca. 12 Millionen ha einer zulässigen Gesamtmenge von ca. 0,5 Mt entspricht (bei einer gleichmäßigen Verteilung des globalen Wertes auf alle 7.4 Milliarden Menschen von denen 80 Millionen in Deutschland leben, kommt man auf eine ganz ähnliche zulässige Gesamtmenge für Deutschland). Dem steht gegenwärtig in Deutschland ein tatsächlicher Wert von 2,6 Mt gegenüber. Die vom SRU geforderte Reduzierung des N-Überschusses um 50 % (von gegenwärtig ca. 100 auf zukünftig 50 kg pro ha) würde lediglich eine Reduktion um ca. 0,85 Mt auf 1,75 Mt bewirken, also auf einem Wert der immer noch um mehr als 200 % über der herunterskalierten PB für Stickstoff liegt. Aus Sicht der PBs sind also wesentlich ambitionierte Reduktionsziele, als gegenwärtig in Deutschland diskutiert, erforderlich.

[80] Footprints oder Fußabdrücke stellen die Umweltauswirkungen menschlichen Handelns und menschlicher Konsummuster dar, sowohl lokal bzw. national, als auch extern d.h. über den Handel in anderen Regionen verursacht

Zusätzlich zu den innerhalb Deutschlands („produktionsbasiert“) erzeugten Mengen reaktiven Stickstoffs, wird auch in anderen Ländern Nr für die Produktion und den Export landwirtschaftlicher Güter nach Deutschland erzeugt. Dieser externene N-footprint Deutschlands wird über die sogenannte konsumbasierte Berechnung oder konsumbasierte footprints mit erfasst. „Konsumbasiert“ umfasst alle in Deutschland konsumierten Güter und Dienstleistungen und die dafür im Inland und Ausland insgesamt erzeugte Menge an Nr. Da Deutschland ein starker Nettoimporteur von Biomasse und Agrarprodukten ist, ist die konsumbasierte Nr Erzeugung erheblich höher als die produktionsbasierte. Erste Berechnungen am PIK mittels Multi-Regionaler Input-Output Analysen haben ergeben, dass Deutschlands externer N-footprint fast doppelt so hoch ist wie der interne. Dadurch ist der von Deutschland insgesamt verursachte Druck auf die Planetary Boundary für Stickstoff wesentlich höher, als es die Zahlen für Nr Erzeugung innerhalb Deutschlands (interner N-footprint) wiedergeben. Die sich ergebenden Reduktionsverpflichtung Deutschlands zur Einhaltung der PB-N steigen damit ebenso an.

2.1.2.5 Kommunikationspotenzial der Planetaren Grenzen

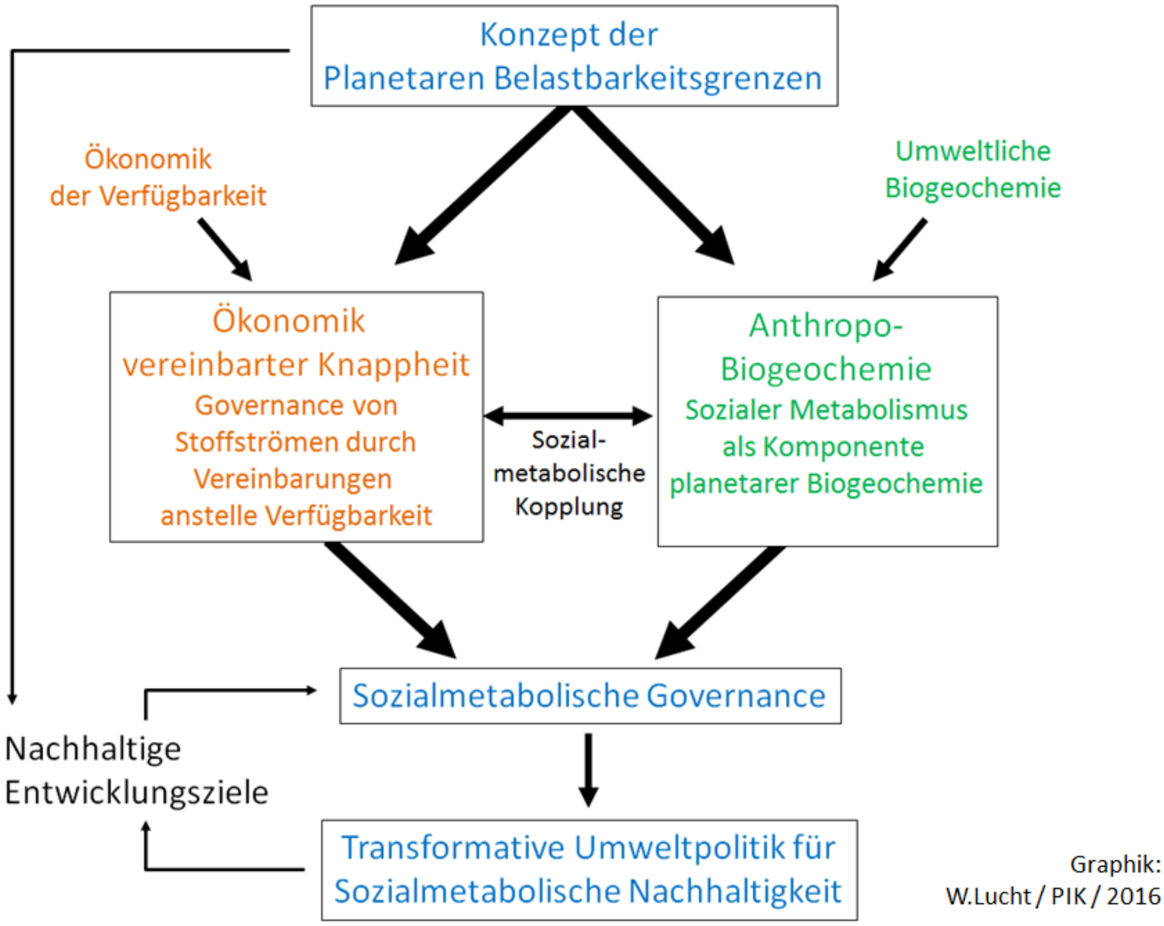
- Die Planetaren Grenzen werden häufig als kommunikative Erfolgsgeschichte bzw. als kommunikativ besonders durchschlagskräftiges Konzept dargestellt (vgl. Lalasz 2013; Cornell 2015; Pisano and Berger 2013).
- Diese Einschätzung ist teils auch zutreffend. So hat das Konzept eine einfache und universale Botschaft, ist metaphorisch („Grenzen“) und visuell recht ansprechend (vgl. zentrale Illustration oben), es baut auf dem wissenschaftlichen Stand auf und hat mit prominenten wissenschaftlichen Vertretern glaubwürdige „Botschafter“ (bspw. den Umweltpreisträger der DBU, Johan Rockström).
- Das Konzept hat außerdem verschiedene Kernbotschaften, die für die Umweltpolitik zentral sind (siehe S. 1-2 dieses Thesenpapieres). In der Kommunikation mit Zielgruppen (Wissenschaft, Politik, Wirtschaft, Bevölkerung) können die Planetaren Grenzen darauf aufbauend verschiedene Funktionen erfüllen: als Weckruf, Motivationsinstrument, Referenzpunkt, Fokuspunkt, Kommunikationsplattform, begrifflicher und kontextueller Rahmen und als Legitimierungs-Tool.
- Das Konzept hat insgesamt (noch) einen eher geringen kommunikativen Impact. Es wird zwar zunehmend kommunikativ eingesetzt, besonders im politischen Raum (durch Regierungen, politische Stiftungen, Zivilgesellschaft), wird jedoch in den Massenmedien nur sehr vereinzelt aufgegriffen.
- Das Konzept verändert außerdem kaum bestehende Diskurse. Es fügt sich ein in existierende Debatten und dient hier unterschiedlichen Zwecken – bspw. dazu, globale Herausforderungen zu illustrieren, den Konflikt zwischen Entwicklung und Nachhaltigkeit darzustellen, den globalen Zustand der Umwelt abzubilden. Teils werden die Planetaren Grenzen auch in Zusammenhang mit Klimaflüchtlingen, Friedenspolitik, Ressourcenkonflikten oder sogar dem Überleben der Menschheit gesetzt.
- Die Planetaren Grenzen weisen verschiedene kommunikative Probleme auf: Sie sind komplex, teils auch missverständlich (z.B. Unterschied zwischen Grenzen und Kipp-Punkten). Sie sind wenig in Zeit und Raum konkretisiert. Die Priorisierung einzelner Grenzen ist teils unklar, ebenso wie es die Folgen des Konzeptes sind. Die Öffentlichkeit wird im Konzept wenig einbezogen. Die Sprache ist größtenteils technisch, teils noch stärker apokalyptisch. Die Illustration ist noch nicht ganz überzeugend (missverständliche Farbwahl; fehlende Dynamisierung).
- Um den kommunikativen Impact der Planetaren Grenzen zu erhöhen, ist weitere Forschung notwendig (z.B. Quantifizierung der grauen Felder in der Illustration), außerdem sollte die visuelle Sprache weiterentwickelt werden (Interaktionen zwischen den Grenzen, weniger statische Darstellung, bessere Farbwahl).
- Narrative können genutzt werden, um das Konzept in konkretere Botschaften zu übersetzen, die wesentlich näher an der Erfahrungswelt der Bevölkerung sind, bspw. indem auf einzelne

Aspekte der Planetaren Grenzen fokussiert wird – z.B. Kipp-Punkte und Regime Shifts und die Interaktion der Grenzen – und die möglichen Folgen der Grenzüberschreitungen für Beispielfälle illustriert werden.

2.1.2.6 Sozio-ökonomische Anschlussfähigkeit der Planetaren Grenzen

- Das Konzept der Planetaren Grenzen dient der nachhaltigen Entwicklung. Es ist inhärent konzipiert als Antwort auf die Frage, wie globale Wohlstandsverbesserungen erreicht werden können, ohne die natürlichen Grundlagen dafür zu gefährden. Es ist damit dem Ziel nach schon sozio-ökonomisch ausgerichtet (siehe auch Abbildung 72 unten für die Wirkung des Konzepts der Planetaren Grenzen auf die Wissenschaftsrichtungen der Erdsystemanalyse und Makroökonomie des Globalen Wandels).
- Das Konzept und die bisherige Forschung gibt noch keine ausreichende Antwort auf die zukünftigen sozio-ökonomischen Auswirkungen der Grenzüberschreitungen. Für die Legitimität des Konzepts und Durchschlagskraft auch im politischen Raum wäre eine solche Darstellung essentiell.
- Das Konzept der Planetaren Grenzen nennt selbst keine originär sozialpolitischen Ziele (wie bspw. Armutsbekämpfung) – es formuliert „Vermeidungsziele" (Umwelt-Zustände, die nicht eintreten sollen), lässt indes die Frage der politischen Maßnahmen und Entwicklungswege innerhalb des Umweltraumes (bewusst) offen.
- Soziale Ziele können ergänzt werden, um so einen doppelten Rahmen für menschliche Entwicklung zu setzen (vgl. Raworth 2012; Dearing; …), ähnlich zu früheren Konzeptualisierungen (vgl. z.B. Cocoyoc-Erkläung oder das Umweltraum-Konzept; Opschoor und Weterings 1994; Hille 1997; Spangenberg et al. 1994).
- Werden solche (auch soziale Grenzen genannte) Ziele hinzugefügt, können verschiedene Probleme für die Umweltpolitik entstehen:
  - Soziale und Umwelt-Ziele könnten als gegensätzlich aufgefasst werden (Dichotomien), obwohl beide der Entwicklung und Wohlfahrt dienen (in unterschiedlichen Zeithorizonten);
  - Die zentrale Grafik der Planetaren Grenzen wird überkomplex;
  - Es entstehen Spannungen und Hierarchiekonflikte (trade offs) zwischen den sozialen und Umweltzielen;
  - Umweltziele könnten in der Umsetzung zugunsten sozialer Ziele zurückstehen.
- Die Einbeziehung sozialer Ziele stärkt aber auch das Konzept:
  - Das Konzept der Planetaren Grenzen wird noch wesentlich um die (wichtige) Dimension der sozialen Gerechtigkeit ergänzt;
  - Es wird anschlussfähiger an Akteure mit (bisher) rein sozial- bzw. entwicklungspolitischer Ausrichtung;
  - Die Planetaren Grenzen werden anschlussfähig an verschiedene SDGs, bspw. SDG 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-Being), 4 (Quality Education) etc.
  - Synergien zwischen Maßnahmen für Umwelt- und soziale Ziele können besser identifiziert und dargestellt werden.

Abbildung 72: Wirkung des Konzepts der planetaren Belastungsgrenzen auf die zwei im internationalen Diskurs dominanten Wissenschaftsrichtungen der Erdsystemanalyse und der Makroökonomie des Globalen Wandels.[81]



Quelle: W. Lucht, PIK, 2016, unveröffentlicht

2.2 Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie[82]

Zusammenfassung

Die planetaren Leitplanken (Planetary Boundaries; PBs) beschreiben einen sicheren Handlungsraum („*safe operating space*"), innerhalb dessen mit hoher Wahrscheinlichkeit die Funktionsfähigkeit des Erdsystems in einer für den Menschen günstigen Konstellation erhalten bleibt. Damit können sie die vertikale Integration einer nationalen Stickstoffstrategie mit globalen Nachhaltigkeitskriterien und

[81] Neue Ökonomiken der konsensualen Knappheit von Ressourcen ersetzen Analysen der ökonomischen Wirkungen physischer Knappheit, ein fundamentaler Wandel der Analyse ökonomischer Instrumente. Aus der klassischen Erdsystemmodellierung auf biogeochemischer Grundlage wird eine globalskalige Anthropobiogeochemie, in welcher die Gesellschaften des Menschen als Komponenten biogeochemischer Kreisläufe berücksichtigt werden. Die Verbindung zwischen Ökonomie und Anthropo-Biogeochemie erfordert eine sozial-metabolische Theorie der Gesellschaften, welche bislang nicht verfügbar ist. Das Ziel der Einhaltung der Planetaren Grenzen erfordert jedoch sozial-metabolische Governance mit dem Ziel sozial-metabolischer Nachhaltigkeit. (Quelle: W. Lucht, PIK, 2016, unveröffentlicht).

[82] Siehe auch die separate Veröffentlichung des gleichen Textes als: Hoff, Kahlenborn, Keppner (2017): Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie. Veröffentlicht vom Umweltbundesamt, Reihe: Texte 75/2017.

Umweltzielen - und damit auch die internationale Kooperation - unterstützen. Für eine solche Operationalisierung und Anwendung der planetaren Leitplanken sind die globalen planetare Leitplanken-Werte herunterzuskalieren, räumlich explizit darzustellen (*downscaling*) und für den jeweiligen Kontext zu übersetzen. Erst dann können sie als Richtwerte (*benchmarks*) dienen, mit denen der nationale Ist-Zustand der Umwelt zu vergleichen ist, und nationale Strategien gegebenenfalls entsprechend angepasst werden können (*mainstreaming of the PBs*).

Die planetare Leitplanke für Stickstoff (N-PB) wird von Steffen et al. (2015) mit 63 Millionen Tonnen pro Jahr angegeben. Diese Leitplanke, die gegenwärtig global um den Faktor 2 überschritten wird, bezieht sich nur auf die beabsichtigte Erzeugung und Freisetzung von reaktivem Stickstoff über biologische Fixierung und Düngeranwendung. Sie umfasst nicht die unbeabsichtigten Freisetzungen über Verbrennungsprozesse. Die vorliegende Studie leitet daraus für Deutschland eine Stickstoff Leitplanke von 0,5 – 0,7 Millionen Tonnen pro Jahr ab, je nachdem ob der globale Wert bezogen auf Deutschlands Anteil an der globalen Landwirtschaftsfläche oder bezogen auf Deutschlands Anteil an der Weltbevölkerung herunterskaliert wird. Diesem *benchmark* aus PB-Sicht steht ein gegenwärtiger realer Wert von ca. 2,3 Millionen Tonnen gegenüber. Wenn man zusätzlich die, aufgrund deutschen Konsums und entsprechender Nettoimporte landwirtschaftlicher Produkte, im Ausland verursachten Stickstofffreisetzungen (*external footprints*) mit berücksichtigt, liegt dieser Wert noch deutlich höher.

Eine solche Anwendung der N-PB weist darauf hin, dass die bisherigen - zumeist noch nicht einmal erreichten - deutschen und europäischen Stickstoffziele aus Sicht globaler Nachhaltigkeitskriterien nicht ambitioniert genug sind. So würde z.B. die Einhaltung der EU *emission ceilings directive* nur zu einer Reduktion des gegenwärtigen Wertes um knapp 0,5 Millionen Tonnen führen. Selbst bei vollständiger Umsetzung der vom Sachverständigenrat für Umweltfragen (SRU) und vom Umweltbundesamt (UBA) geforderten Halbierung des N-Überschusses auf landwirtschaftlichen Flächen, würde die auf Deutschland herunterskalierte N-PB noch immer um ca. 200 % überschritten. Zu ihrer Einhaltung wären zusätzliche Emissionsminderungen in der Landwirtschaft und darüber hinaus (v.a. in den Sektoren Energie, Transport und Industrie) erforderlich.

Eine Erhöhung der Effizienz der Stickstoffnutzung (*nitrogen use efficiency* - NUE) auf allen Ebenen und über die gesamte Wertschöpfungskette stellt einen wichtigen Hebel zur Erreichung verschiedener Umwelt- und Nachhaltigkeitsziele dar. Neben der Verminderung der Stickstofffreisetzung in die Umwelt lassen sich zusätzliche Verbesserungen (*co-benefits*) z.B. in Bezug auf Land, Wasser, Energie, Ernährungssicherheit und andere Entwicklungsziele wie sie in den SDGs benannt sind, erreichen. Durch Erhöhung der Ressourceneffizienz kann der in die Umwelt freigesetzte Anteil des eingesetzten Stickstoffs reduziert werden. Da die N-PB über maximal zulässige Umweltkonzentrationen definiert ist, kann sie bei erhöhter Ressourceneffizienz höher angesetzt werden.

Entscheidend für die vertikale Integration von deutschen und internationalen Umweltzielen und Nachhaltigkeitskriterien ist der „Dreiklang" aus i) Verringerung der Stickstofffreisetzung innerhalb Deutschlands, ii) Reduktion des (handelsbedingten) deutschen Stickstoff-*footprints* im Ausland sowie iii) internationale Kooperation für eine verbesserte Stickstoffnutzung und Ressourceneffizienz in allen Bereichen, z.B. über Investitionen, Entwicklungszusammenarbeit und Wissens- und Technologietransfer. Dieser Dreiklang entspricht auch dem Leitbild der nationalen Implementierung der SDGs, innerhalb Deutschlands unter gleichzeitiger Beachtung dieser Ziele auch im Ausland (*implementation in, by and with Germany*). Anknüpfungspunkte für eine verbesserte vertikale Politikkohärenz von national über regional bis global sind z.B. die gemeinsame europäische Agrarpolitik, internationale Handelsabkommen sowie die verschiedenen multilateralen Umweltabkommen.

Aus der Operationalisierung und Anwendung der N-PB für die integrierte nationale Stickstoffstrategie ergeben sich umgekehrt auch Hinweise für die Weiterentwicklung der planetaren Leitplanke selber, z.B. in Hinblick auf deren Erweiterung über den Landwirtschaftssektor hinaus. Weiterentwicklung der

PBs und deren Anwendung müssen iterativ und wechselseitig erfolgen. Dazu sollte die Stickstoffstrategie dynamisch weiterentwickelt werden, so dass neues Wissen (z.B. aus der Begleitforschung) kontinuierlich eingepflegt werden kann („*adaptive management*“). Entsprechend dem systemischen Charakter des PB Konzepts und der Komplexität des Stickstoffkreislaufs, bedarf dies eines umfassenden Dialogs mit Partnern aus allen relevanten Sektoren, gemäß dem Future Earth Prinzip von „*co-design* & *co-production* of *relevant knowledge*“, d.h. in wechselseitiger Abstimmung zwischen Politikern, Entscheidungsträgern und Wissenschaftlern.

Summary

The planetary boundaries (PBs) delineate a safe operating space within which the Earth system is likely to maintain its functions as life support system for humanity. With that the planetary boundaries also support the vertical integration of the German Nitrogen Strategy with global environmental and sustainability criteria and goals, and with that also international cooperation. For such an operationalization and application of the planetary boundaries, the global values need to be downscaled, made spatially explicit and translated for the respective context. Only then can they serve as benchmarks for the national environmental performance, and enable institutional improvements e.g. of national strategies accordingly (i.e. mainstreaming of the planetary boundaries).

The planetary boundary for nitrogen (N-PB) was quantified by Steffen et al. (2015) to be 63 million tons per year. This boundary, which is currently exceeded globally by a factor of 2, only refers to the intentional fixation, i.e. production and release of reactive nitrogen through biological nitrogen fixation and application of fertilizer. It does not include the unintended fixation or release from combustion processes. This study derives for Germany a national boundary of 0.5 – 0.7 million tons per year, depending on the downscaling algorithm, either per capita or per area (Germany's fraction of global population or of global agricultural area). The real current fixation rate of reactive nitrogen in Germany amounts to 2.3 million tons per year. When including Germany's consumption-based external nitrogen footprints (which is a net importer of agricultural commodities) this value is even higher.

Such an application of the N-planetary boundary shows that the current German and European nitrogen-related environmental goals (even if they were met) are not sufficiently ambitious from a global perspective. Full compliance with the EU emission ceilings directive for example, would only lower the current value by about 0.5 million tons. Even an implementation of the SRU/UBA goal of reducing N-surpluses on agricultural land by 50%, would still result in transgression of the downscaled N-planetary boundary by about 200%. Additional emission reductions in agriculture and beyond (in particular in the energy, transport and agricultural sectors) would be required in order to meet the downscaled N-planetary boundary.

Important for achieving various environment and sustainability goals will also be an increase in nitrogen use efficiency (NUE) at all levels and all along the value chains. This can also generate a number of *co-benefits*, e.g. related to land, water, energy, food security and other development objectives as specified in the SDGs. A higher NUE reduces the fraction of nitrogen applied that is released into the environment. Since the N-planetary boundary is defined through maximum concentrations in the environment, the N-planetary boundary can be relaxed, i.e. raised if NUE increases.

Vertical integration of the Germany's and international environmental and sustainability objectives can follow the triple goal of i) reducing N-emissions within Germany, ii) reducing Germany's trade-related external N-footprint in other regions and iii) international cooperation for improved N-use and NUE e.g. via foreign investments, development cooperation, and knowledge- and technology transfer. This triple goal also resembles the implementation mode of the SDGs in, by and with Germany, i.e. meeting the goals domestically while at the same time promoting them also internationally. Entry points for improved vertical policy coherence from national to regional and global are for example the

EU Common Agricultural Policy, international trade agreements and various multilateral environment agreements.

The operationalization and application of the N-planetary boundary for the German Integrated Nitrogen Strategy can also help to improve the N-planetary boundary itself, e.g. expanding its coverage beyond the agricultural sector. Further development of the N-planetary boundary and its application have to go hand in hand. For that, the national Nitrogen Strategy should to be developed dynamically, continuously incorporating new knowledge (e.g. from accompanying research) as it becomes available (adaptive management). According to the systemic nature of the planetary boundary concept and the complexity of the nitrogen cycle, comprehensive dialogues are required with partners from all relevant sectors, following the Future Earth principles of co-design & co-production of relevant knowledge by policy and decision makers and scientists.

2.2.1 Einleitung

Die vorliegende Studie enthält Empfehlungen zur Berücksichtigung des Konzepts der planetaren Leitplanken[83] (Planetary Boundaries, PBs; Rockström et al. 2009, Steffen et al. 2015a) zur Erarbeitung einer Nationalen Integrierten Stickstoffstrategie.[84] Ziele der Studie sind i) ein Herunterskalieren der globalen Leitplanke auf den nationalen Maßstab, ii) Eignung der vorhandenen Grenzwerte und Richtlinien um die globalen Leitplanken ausreichend zu berücksichtigen, iii) eine Übersicht über bestehende Modelle welche den gegenwärtigen und zukünftigen Umweltzustand in Bezug auf die verschiedenen Stickstoffdimensionen darstellen können, iv) Ansätze zur Institutionalisierung und Operationalisierung der gewonnenen Ergebnisse und v) Darstellung der Stärken und Schwächen des PB Konzepts in diesem Kontext.

Die Studie ist im Rahmen des UFO-Plan Vorhabens „Planetare Grenzen – Anforderungen an die Wissenschaft, Zivilgesellschaft und Politik“ (FKZ 3714 19 100 0) erstellt worden. Sie baut auf zuvor vorgelegten Inputpapieren (Hoff et al. 2015a, b) auf und führt die dort vorgeschlagenen Ansätze und Vorschläge weiter aus. Gleichzeitig wurden die Ergebnisse des Expertenworkshops „*Developing a National Nitrogen Strategy*“ (26./27. 11.2015 in Berlin) berücksichtigt, bei dem die Planetary Boundaries vorgestellt und ihre Anschlussfähigkeit für die nationale Stickstoffstrategie diskutiert wurden. Hier kam es in Ansätzen zu einem ersten Brückenschlag zwischen Wissenschaft und Anwendung bzw. *„co-design & co-production of relevant knowledge“*[85] wie von Future Earth gefordert (siehe dazu auch Cornell et al. 2013).

Während die zahlreichen vorliegenden Publikationen zum Thema Stickstoff (z.B. UBA 2009, Sutton et al. 2011, Sutton et al. 2013a, UBA 2015a, SRU 2015) sich vor allem mit der horizontalen Integration, d.h. Prozessen und Wechselwirkungen der verschiedenen Stickstoffverbindungen über die verschiedenen Umweltkompartimente und Sektoren hinweg, befassen, konzentriert sich dieses Inputpapier mit seinen Vorschlägen zur Anwendung bzw. Operationalisierung des Planetary Boundaries-Konzepts auf die **vertikale Integration**: Es stellt die Anforderungen an eine nationale Stickstoffstrategie aus der globalen Perspektive dar, wie sie sich aus dem Planetary Boundaries-Konzept und in Hinblick auf eine umfassende Nachhaltigkeitstransformation ergibt. Dabei wird auch auf Deutschlands Verpflichtungen im Rahmen der 2015 verabschiedeten Sustainable Development Goals (SDGs) Bezug genommen, siehe z.B. die SDGs und targets 6.3 *reduce water pollution,* 8.4 *improve resource efficiencies,* 12.4*. reduce chemicals release to air, water and soil, to minimize adverse impacts on human health and environment*

[83] Wir übersetzen hier „Planetary Boundaries“ mit „Planetare Leitplanken“, was deren Zielsetzung, einen sicheren Handlungsraum oder *safe operating space* zu beschreiben, besser trifft, als die Übersetzung „Planetare Grenzen“.

[84] Alle Ergebnisse dieses Forschungsvorhabens werden auf der Website des Planetary Boundaries Network unter pb-net.org verfügbar gemacht.

[85] www.futureearth.org/impact

sowie 15.5 *reduce degradation of natural habitats*. Dieses Inputpapier macht Vorschläge zur integrierten Implementierung stickstoffrelevanter SDGs, auch mit Blick auf die Universalität der SDGs innerhalb UND außerhalb Deutschlands (siehe dazu auch Dawkins et al. 2016).

Wie in den o.g. Publikationen ausführlich beschrieben, ist der **Stickstoffkreislauf** sehr komplex. Er umfasst zahlreiche Quellen, Verbindungen, Reaktionen und Transportwege der verschiedenen Stickstoffverbindungen durch alle Umweltkompartimente (die sogenannte Stickstoffkaskade) und entsprechende Auswirkungen der N-Freisetzung auf Mensch und Umwelt. Die vielfältigen und systemischen Wechselwirkungen (siehe z.B. Erisman et al. 2013), über verschiedene Sektoren und räumliche und zeitliche Skalen hinweg, erfordern entsprechend konsistente und systemische Umweltziele.

Reaktiver Stickstoff (N_r), d.h. alle Stickstoffverbindungen außer N_2, wird vor allem zur Ertragssteigerung in der Landwirtschaft für die Versorgung der wachsenden und anspruchsvoller werdenden Weltbevölkerung mit Nahrungsmitteln und anderen Biomasse-basierten Produkten benötigt. Reaktiver Stickstoff wird (beabsichtigt) entweder industriell oder durch biologische N-Fixierung erzeugt. Anthropogen hat sich die Erzeugung von N_r gegenüber der natürlichen Rate mittlerweile vervierfacht (Vitousek et al. 2013). Dabei stellt sich die Situation in den verschiedenen Weltregionen sehr unterschiedlich dar: In einigen Regionen ist zu wenig Stickstoff verfügbar, was die landwirtschaftliche Produktion einschränkt, in anderen zu viel, was zu negativen Auswirkungen auf Umwelt und menschliche Gesundheit führt. Auch innerhalb Deutschlands und Europas gibt es große räumliche Unterschiede (> Faktor 10) in Bezug auf den in der Landwirtschaft über biologische N-Fixierung erzeugten und als Dünger angewandten Stickstoff und die anschließende Freisetzung vor allem in Form von Ammoniak (NH_3) und Nitrat (NO_3) in die Umwelt (Leip et al. 2011). Im Mittel endet nur ca. 1/3 (35 %) der erzeugten und angewendeten Menge in geernteten Marktprodukten, ca. **2/3 des landwirtschaftlichen Stickstoffs werden in die Umwelt freigesetzt** (UBA 2009, Sutton et al. 2013a, UBA 2015a). Die Landwirtschaft ist auch in Deutschland für etwa zwei Drittel der Freisetzung von N_r in die Umwelt insgesamt verantwortlich (Leip et al. 2011, UBA 2015a) - und entsprechend erreicht Deutschland unter 34 OECD-Ländern nur Platz 26 (Kroll 2015) in Bezug auf seine N- (und P-) Überschüsse. In geringerem Maße wird N_r zudem in Form von Stickstoffoxid (NO_x)-Emissionen durch Verbrennungsprozesse in die Umwelt freigesetzt.

Zu den physikalischen, geochemischen und ökologischen **Umweltauswirkungen** von freigesetztem N_r zählt großmaßstäbig insbesondere die Bildung anoxischer Zonen (*dead zones*) in den Weltmeeren – welche auch eine der Grundlagen für die ursprüngliche Definition der Planetary Boundary für Stickstoff (N-PB) durch Rockström et al. (2009) war. Diese anoxischen Zonen finden sich besonders in Küstenregionen flussabwärts von landwirtschaftlichen Gebieten mit kritisch hohen Stickstoffeinträgen (s. Abbildung 73 und Selman et al. 2008). Die Anzahl und das Ausmaß solcher *dead zones* haben laut Selman et al. (2008) seit Mitte des vergangenen Jahrhunderts um ein Vielfaches zugenommen. In Regionen mit gegenwärtig steigenden Stickstoffüberschüssen ist entsprechend von einer weiteren Zunahme und Ausbreitung solcher Zonen auszugehen. In Europa finden sich solche Zonen gegenwärtig v.a. in der nördlichen Adria, den dänischen Küstengewässern und allgemein entlang der Ostseeküste (Billen et al. 2011). Am Beispiel der Ostsee wird deutlich, dass solche großmaßstäbigen Umweltprobleme nur durch internationale Kooperation und aufeinander abgestimmte nationale Umweltziele gelöst werden können.

Zu den großmaßstäbigen Umweltauswirkungen von freigesetztem N_r gehören weiterhin der Beitrag zur Klimaerwärmung (N_2O-Moleküle haben ein 265-fach höheres Treibhauspotential als CO_2) und die Zerstörung von stratosphärischem Ozon durch N_2O. Zu den regionalen und lokalen Umweltauswirkungen gehören: Partikelbildung in der Atmosphäre, Oxidierung von Bodenkohlenstoff aufgrund der Düngewirkung von N_r, Einträge mit dem Regen in Böden, Gewässer und terrestrische und aquatische Ökosysteme und deren Versauerung und Eutrophierung, Verschmutzung des Trinkwassers sowie Luftverschmutzung und bodennahe Ozonbildung (photochemischer Smog), mit den entsprechenden Folgen für Ökosysteme, für deren Stabilität und Funktion sowie für die menschliche Gesundheit. Die Umweltauswirkungen reichen je nach Eigenschaften der jeweiligen N-Verbindung und des Umweltmediums unterschiedlich weit. So können z.B. atmosphärische N-Transporte über 1000 km weit, und damit auch über Landesgrenzen hinaus, reichen (Hertel et al. 2011).

Einige dieser Prozesse bzw. zugrunde liegende N_r -Verbindungen sind zudem sehr langfristig bzw. langlebig[86], insbesondere der Verbleib von N_2O in der Atmosphäre sowie N-Verbindungen in maritimen *dead zones* und in tiefen Grundwasserleitern. Zudem akkumuliert N_r in einigen Umweltkompartimenten. Über die sogenannte Stickstoffkaskade kann einmal freigesetztes und im Allgemeinen sehr mobiles N_r mehrfache bzw. additive Folgewirkungen über mehrere Umweltkompartimente hinweg haben (Erisman et al. 2013). Entsprechende Verlagerungen von Problemen zwischen Umweltkompartimenten werden auch als *pollution swapping* bezeichnet (UBA, 2009). Horizontal und vertikal integrierte systemische Umweltziele müssen solche Kaskadeneffekte über die verschiedenen Umweltkompartimente und N_r -Verbindungen hinweg berücksichtigen. Das PB Konzept trägt den mit solchen langfristigen, komplexen und noch nicht im Einzelnen bekannten Wechsel- und Folgewirkungen und den damit verbundenen Unsicherheiten durch Anwendung des Vorsorgeprinzips und entsprechend vorsichtige Leitplankensetzung Rechnung (siehe Kapitel 2.2.2). Dieses Vorsorgeprinzip ist entsprechend auch auf die nationale Stickstoffstrategie zu übertragen.

Neben den von dem PB Konzept betonten horizontalen (sektorübergreifenden) und vertikalen (skalenübergreifenden) Wechselwirkungen gilt es eine weitere wichtige Dimension zu berücksichtigen, nämlich die **Wechselwirkungen über Regionen** hinweg. Neben den weitreichenden atmosphärischen Transporten von Luftschadstoffen ist dafür vor allem der rasch zunehmende Welthandel (1/3 des in der Landwirtschaft eingesetzten Stickstoffs und der damit erzeugten Produkte gelangt in den Welthandel, Lassaletta et al. 2014) verantwortlich, welcher Deutschland und Europa zu einem starken und weiter wachsenden Nettoimporteur für stickstoffintensive landwirtschaftliche Produkte gemacht hat (Oita et al. 2016, Eggers 2016). Dadurch wird die Einhaltung von Umweltzielen innerhalb Europas zunehmend mit der Umweltfreisetzung von reaktivem Stickstoff (und anderen schädlichen Verbindungen sowie der Ressourcen(über)nutzung) in anderen Regionen „erkauft“ (Hoff et al. 2014). Bei der Quantifizierung solcher räumlichen Externalitäten („*footprints*“) von deutschen und europäischen Konsummustern gibt es noch erhebliche Unsicherheiten.

Eine Rangfolge der **Kritikalität** oder, soweit bekannt, der Schadenskosten der erhöhten Stickstoffkonzentrationen in den verschiedenen Umweltkompartimenten sieht nach Experteneinschätzung etwa folgendermaßen aus (Sutton et al. 2011, Erisman et al. 2013, Sutton pers. comm., Bodirsky pers. comm.):

1. Bodennahe Luftverschmutzung (Feinstaub, Ozon) und dadurch verursachte Gesundheitsschäden (z.B. Krebs, Asthma)
2. Anoxische Zonen in den Meeren (*dead zones*)
3. Eutrophierung von Gewässern und Meeren, wie der Ostsee und damit verbundene Produktivitäts- (Fischerei, Tourismus, Lebensqualität) und Biodiversitätseinbußen
4. Klimawirkung durch das Treibhausgas N_2O
5. Oxidierung und damit Verlust von Bodenkohlenstoff [87]
6. Nitratbelastung von Gewässern mit entsprechenden Gesundheitsschäden

[86] Zum Zusammenhang zwischen räumlichem Maßstab und Langfristigkeit der Umweltauswirkungen von Stickstoff siehe auch Abbildung 2-3 in SRU 2015.

[87] Durch verstärkten Metabolismus im Boden bei erhöhten Stickstoffgaben.

7. N-Eintrag in (v.a. noch N-arme) terrestrische Ökosysteme (wie z.B. Hochmoore) und deren damit verbundene Gefährdung
8. Ozonzerstörung in der Stratosphäre („Ozonloch“)

Diese Rangfolge bezieht sich auf die Auswirkungen gegenwärtiger Freisetzungen reaktiven Stickstoffs. Mögliche zukünftige Veränderungen (wie z.B. zu erwartende Verminderungen der Aerosolbelastung bei zunehmend strengeren Umweltauflagen oder mögliche Folgewirkungen der Überschreitung lokaler Umweltgrenzwerte oder der globalen N-PB sind hier noch nicht berücksichtigt (letztere sind, wie auch für die meisten anderen PBs, noch nicht hinreichend abgeschätzt). Auch variiert die Rangfolge je nach Experten und der persönlichen Gewichtung der Auswirkungen geringfügig. Auf alle Fälle übersteigen die Umweltschadenskosten in ihrer Summe den ökonomischen Nutzen der Stickstoffdüngung in der Landwirtschaft (Sutton et al. 2011). Umgekehrt ist der ökonomische Nutzen der Einhaltung von N-Schutzzielen, v.a. in Bezug auf verbesserte menschliche Gesundheit, bis zu 40 mal höher als die dabei entstehenden Kosten (Salomon et al. 2016).

Die vorliegende Studie beschreibt in Kapitel 2.2.2 die Planetaren Leitplanken und die Möglichkeiten zu deren Herunterskalieren für die Anwendung auf der nationalen Ebene. In Kapitel 2.2.3 wird dann dargestellt, wie die herunterskalierte N-PB bereits vorhandene nationale und regionale Stickstoff-Grenzwerte ergänzen kann, mit dem Ziel vertikal integrierter Stickstoffziele. Kapitel 2.2.4 stellt die verschiedenen vorhandenen wissenschaftlichen Simulationsmodelle und ihre Anwendung zur Bestimmung integrierter Stickstoffziele kurz vor. Anschließend werden in Kapitel 2.2.5 die Stärken und Schwächen des PB Konzepts in Hinblick auf solche Stickstoffziele einander gegenüber gestellt. Und schließlich fasst Kapitel 2.2.6 die vorhandenen Ansätze zur Operationalisierung und Institutionalisierung der N-PB zusammen.

2.2.2 Die Planetaren Leitplanken und Möglichkeiten des Herunterskalierens auf die nationale Ebene

Das Konzept der Planetaren Leitplanken (Planetary Boundaries - PBs) beschreibt nachhaltige Domänen (einen „***safe operating space***“) der Nutzung natürlicher Ressourcen bzw. der Emission von potentiell schädlichen Substanzen oder der Modifikation von Ökosystemen (Rockström et al. 2009, Steffen et al. 2015a). Gemäß dem Vorsorgeprinzip wird ein Sicherheitsabstand von möglichen kritischen Grenzwerten im Erdsystem oder dessen Subsystemen, wie dem Klimasystem oder der Biosphäre, definiert. Bei Überschreitung dieser Grenzwerte würde die Wahrscheinlichkeit für Mensch und Umwelt nachteiliger Änderungen des Systemzustands inakzeptabel hoch[88] - siehe dazu Hoff et al. 2015a).

Das PB-Konzept hebt die vielfältigen Wechselwirkungen zwischen verschiedenen großmaßstäbigen Umweltprozessen hervor und bestätigt damit die in den meisten bisherigen Publikationen zum Thema Stickstoff betonte Notwendigkeit der **horizontalen Integration** von Umweltzielen über verschiedene Umweltbereiche hinweg (siehe Hoff et al. 2015a, b). So sind auf globaler Ebene z.B. Wechselwirkungen von Stickstoff mit den Bereichen Biosphärenintegrität[89], Ozon, Aerosole, Land und Klima wichtig. Dahinter stehen zahlreiche Interaktionen reaktiven Stickstoffs mit anderen Substanzen und Prozessen wie Biodiversitätsverlust, Abbau der Ozonschicht, Aerosolbildung, aber auch Landnutzungs- und Klimawandel und Land- und Wasserressourcendegradation und -knappheit (Erisman et al. 2013), mit den jeweils entsprechenden PBs. Die PBs stellen somit systemische Umweltleitplanken dar, welche auf die zahlreichen Wechselwirkungen von reaktivem Stickstoff (N_r) in der Umwelt hinweisen.

[88] Der Begriff „inakzeptabel“ beinhaltet immer auch eine normative Komponente, die der gesellschaftlichen und politischen Abstimmung bedarf.

[89] Die Forderung des SRU (2015), dass die Ziele der nationalen Stickstoffstrategie sich an der Belastbarkeit der Ökosysteme orientieren müssen, spiegelt das zentrale PB-Motiv: „reconnecting to the biosphere“ (Folke et al. 2011) wider.

Der wichtigste Mehrwert der Nutzung bzw. Operationalisierung des PB-Konzepts bei der Entwicklung der nationalen Stickstoffstrategie erwächst aber aus der Ergänzung der horizontalen Integration um eine vertikale Integrationskomponente, d.h. der Abstimmung nationaler und regionaler (insbesondere europäischer) Umweltziele, wie sie in Kapitel 3 aufgeführt sind, mit globalen Leitplanken. Umgekehrt können die bei der Entwicklung und Implementierung der nationalen Stickstoffstrategie gewonnenen spezifischen (*bottom-up*) Erfahrungen die Weiterentwicklung der globalen Leitplanken bzw. Planetary Boundaries unterstützen. Entscheidend ist dabei die Integration von *bottom-up* und *top-down* Ansätzen und Umweltzielen. Ziel dieser horizontalen und vertikalen Integration ist letztlich eine verbesserte **Politikkohärenz.**

Die nationale Stickstoffstrategie sollte entsprechend vertikal und horizontal koordinierte multi-dimensionale Umweltziele aufweisen, welche auch mit übergeordneten Zielen konsistent sind, wie z.B. dem Integrierten Umweltprogramm 2030 (BMUB 2016a) und der Deutschen Nachhaltigkeitsstrategie (Bundesregierung 2017) als Umsetzungsrahmen der Agenda 2030 für nachhaltige Entwicklung (UN 2015) bzw. auf europäischer Ebene mit dem 7. Umweltaktionsprogramm (EC 2014), aber auch mit anderen nicht direkt umweltbezogenen Politikzielen. Als Negativbeispiel fehlender Politikkohärenz wird häufig auf die zusätzlichen Stickstoffbelastungen verwiesen, wie sie aus ungenügend koordinierten Bioenergie- und Klimaschutzstrategien erwachsen können (siehe z.B. EPA 2011).

Mit Bezug auf die in der Einleitung genannten negativen Auswirkungen von Stickstofffreisetzungen in die Umwelt, insbesondere die kumulativen Folgewirkungen von Ressourcen- und Ökosystemdegradation, auf die Resilienz des Erdsystems und seiner Sub-Systeme, hatten Rockström et al. (2009) eine **Planetare Leitplanke für die beabsichtigte Freisetzung von reaktivem Stickstoff** (*intentional N-fixation*[90]) von 35 Teragramm bzw. 35 Millionen Tonnen pro Jahr (35 Mt N_r yr^{-1}) vorgeschlagen. Diese Begrenzung auf ca. 25 % der tatsächlichen gegenwärtigen anthropogenen Freisetzung von reaktivem Stickstoff war ausdrücklich als erste Abschätzung („*first guess*“) gedacht.

Die Weiterentwicklung dieser *first-guess* Stickstoff-Leitplanke (im folgenden N-PB genannt) durch de Vries et al. (2013) und nachfolgend durch Steffen et al. (2015) baut auf den maximal vertretbaren Grenzwerten kritischer Stickstoffverbindungen in den jeweiligen Umweltmedien bzw. **Schutzgütern** auf[91]. Dies sind im Einzelnen:

- Atmosphäre: 1 - 3 µg NH_3 m^{-3} (abgeleitet von der Schadwirkung auf Flechten und höhere Pflanzen);
- Trinkwasser: 50 mg NO_3 l^{-1} oder 11.3 mg NO_3-N l^{-1} (gemäß WHO Gesundheitsstandards);
- aquatische Ökosysteme: 1.0 - 2.5 mg N l^{-1} (basierend auf ermittelten ökotoxikologischen Wirkungen anorganischer N-Verbindungen);
- Treibhauseffekt bzw. ein zusätzlicher Strahlungsantrieb (*radiative forcing*) von maximal 1 W m^{-2}, anteilig für den gegenwärtigen Beitrag von N_2O zum Treibhauseffekt.

Entsprechend ergeben sich, je nach betrachtetem Schutzgut und kritischer Stickstoffverbindung, durch Rückrechnung von der jeweiligen Maximalkonzentration auf die global zulässige Gesamtfreisetzung von N_r verschiedene Werte für die N-PB, die von 20 - 130 Mt pro Jahr reichen[92]. Gemäß dem PB-inhärenten Vorsorgeprinzip ist dasjenige Schutzgut maßgeblich, welches den niedrigsten globalen Grenzwert einfordert. Das ist in diesem Fall der Wert von 20 Mt N yr^{-1}, der sich durch Rückrechnung aus der zulässigen atmosphärischen N_2O Konzentration in Hinblick auf den Treibhauseffekt ergibt. Da aber die

[90] Die beabsichtigte landwirtschaftliche Freisetzung bzw.“intentionally fixed reactive N to agricultural systems” umfasst sowohl die Ausbringung von industriellem Dünger als auch die biologische N-Fixierung.

[91] Die aufgelisteten Werte werden so auch vom SRU (2015) genutzt, siehe dort Tabelle 2-2.

[92] Den Berechnungen der N-PB von de Vries liegt zugrunde, dass in Regionen, in denen die oben genannten Grenzwerte für einzelne Umweltkompartimente bereits überschritten sind, die Belastung reduziert werden muss, jedoch in Regionen in den diese Grenzwerte noch nicht erreicht sind, trotzdem kein weiterer Anstieg erlaubt ist. Wenn man diese Bedingung mildern und Anstiege in schwach belasteten Regionen erlauben würde, ergäbe sich ein höherer globaler Wert für die N-PB.

Klimawirkung von Stickstofffreisetzungen bereits durch die PB-Klima mit abgedeckt wird, haben Steffen et al. (2015), gemäß de Vries et al. (2013), den nächsthöheren Wert für die **N-PB** gewählt. Dies ist der Wert, der sich aus dem Wasserqualitätskriterium zur Vermeidung der Eutrophierung, Versauerung und von negativen Auswirkungen auf aquatische Ökosysteme ergibt. Wenn die N-Konzentration in Gewässern als Kontrollvariable für die N-PB dient und (gemäß Vorsorgeprinzip) der untere Wert dieser Variable von 1 mg N l^{-1} gewählt wird, ergibt sich eine maximal zulässige **globale biologische Fixierung und Düngeranwendung in der Landwirtschaft** von **62 Millionen Tonnen (Mt) Nr pro Jahr.** Dies entspricht etwa der Hälfte der tatsächlichen gegenwärtig jährlich in landwirtschaftlichen Systemen und für landwirtschaftliche Systeme fixierten und angewandten Menge.

Diese Leitplanke bezieht sich nur auf die beabsichtigte zusätzliche (industrielle und landwirtschaftliche) Erzeugung und Freisetzung von reaktivem Stickstoffs (welche ca. ¾ der gesamten anthropogenen Freisetzung in die Umwelt von N_r ausmacht). D.h. „unbeabsichtigte“ Freisetzungen (v.a. aus Verbrennungsprozessen) sind in der N-PB nicht mit erfasst.

Für die Nutzung bzw. Operationalisierung der PBs für die nationale Stickstoffstrategie ist ein **räumlich explizites downscaling** der hier beschriebenen globalen Leitplanke erforderlich. Für verschiedene PBs werden unterschiedliche *downscaling*-Verfahren angewendet bzw. vorgeschlagen: vollständig globale PBs, d.h. solche mit gut durchmischten globalen Pools (wie Klima und Ozon) können aus biophysikalischer Sicht gleichmäßig über alle Länder verteilt werden, da es keine Rolle spielt, wo die Freisetzung von Schadstoffen in die Umwelt erfolgt. Beim downscaling anderer PBs hingegen, wie z.B. der Land-PB, welche den Verlust an Waldflächen begrenzt, sind räumliche Muster der lokalen bzw. nationalen Beiträge zur globalen Leitplanke zu berücksichtigen – im Falle der Land-PB spielt es für die Auswirkung auf das Erdsystem eine erhebliche Rolle, wo welche Art von Wald (tropischer, temperierter, borealer Wald) verloren geht. Für die N-PB ist zusätzlich auch noch der lokale Kontext der N-Freisetzung zu berücksichtigen, welcher das Umweltverhalten und die großmaßstäbigen Auswirkungen und Wechselwirkungen mit anderen PBs mitbestimmt (Häyhä et al. 2016).

Ansätze zum Herunterskalieren von PBs und zum Vergleich des Ist-Zustand mit der herunterskalierten PB (benchmarking):

Der oben genannte globale Maximalwert für die zusätzliche anthropogene Erzeugung von reaktivem Stickstoff („industrielle und biologische Fixierung“ von N2) von 62 Mt yr^{-1}, kann auf unterschiedliche Weise herunterskaliert und räumlich explizit gemacht werden, z.B. in Form von:

- flächenbezogenen **Länderwerten**, welche entweder von der gesamten Fläche oder von der landwirtschaftlichen Fläche des jeweiligen Landes im Verhältnis zur globalen Landfläche ausgehen (oder alternativ statt auf Flächen auch auf den landwirtschaftlichen Ertrag bezogen werden können);
- **Pro-Kopf-Werten** bezogen auf den Anteil, den das jeweilige Land an der Weltbevölkerung hat (hier kann noch weiter zwischen *equal-per-capita* Verteilung und anderen Verteilungen die etwas dem Prinzip der *common-but-differentiated-responsibility* folgen, unterschieden werden).

Der Vergleich des Ist-Zustandes der Freisetzung von N_r mit der (pro Kopf) herunterskalierten N-PB kann wiederum auf zweierlei Weise erfolgen, entweder:

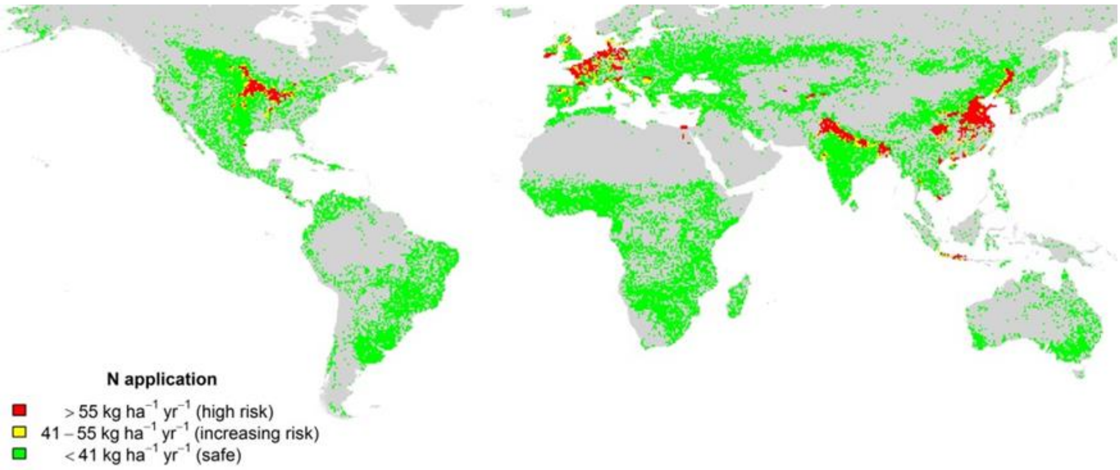
- produktionsbasiert (oder territorial), wobei nur N_r Freisetzungen innerhalb des jeweiligen Landes berücksichtigt werden, oder
- konsumbasiert, wobei auch N_r Freisetzungen in anderen Region aber ausgelöst vom Konsum und Importen des jeweiligen Landes berücksichtigt werden..

1) Downscaling auf flächenbezogene Länderwerte und entsprechendes Benchmarking

Flächenbasiertes *downscaling* kann entweder auf die gesamte Landesfläche oder auf die landwirtschaftliche Fläche in Verhältnis zur gesamten globalen (eisfreien) Landfläche bezogen werden, oder ggf. auch auf die landwirtschaftlichen Erträge des Landes. So sind z.B. Deutschlands landwirtschaftliche N-Applikationsraten pro landwirtschaftliche Flächeneinheit ca. 60 % höher als in Europa insgesamt, 100 % höher als es dem weltweiten und 1000 % höher als es dem afrikanischen Durchschnitt entspricht. Gleichzeitig sind die Hektarerträge für Getreide in Deutschland fast doppelt so hoch wie im europäischen und fast fünfmal so hoch wie im afrikanischen Durchschnitt (FAOSTAT). Entsprechend steht Deutschland im internationalen Vergleich wesentlich besser da, was seinen Beitrag zur Überschreitung der N-PB betrifft, wenn der globale Wert gemäß den nationalen Erträgen verteilt wird als wenn die Verteilung auf Basis der Landesfläche erfolgt.

Steffen et al. (2015) haben den globalen N-PB Wert (dessen Unsicherheitsbereich von 62 bis 82 Mt N_r pro Jahr reicht) auf die gesamte landwirtschaftliche Fläche bzw. Ackerfläche verteilt. Aus der Division des globalen PB Wertes durch die globale Ackerfläche ergibt sich eine **zulässige biologische Fixierung und Düngeranwendung von Stickstoff in Höhe von 41 bis 55 kg ha^{-1} yr^{-1}.** Deren Einhaltung bzw. Überschreitung ist in Abbildung 73 räumlich explizit dargestellt.

Abbildung 73: Kritikalität der gegenwärtigen biologischen Fixierung und Düngeranwendung von Stickstoff auf Ackerflächen, gemäß einheitlich flächenbezogen herunterskalierter N-PB. NB: der Begriff „application" wird hier ungenau verwendet.



Quelle: Steffen et al. (2015a, SI)

Unschwer zu erkennen sind die hotspots der biologischen Fixierung und Düngeranwendung von N_r in Deutschland und Europa (sowie in Nordamerika, China und Indien). Die PBs, in ihrer Funktion als vereinfachte Darstellung komplexer Umweltprozesse und –grenzen, erheben nicht den Anspruch vollständiger und endgültiger Quantifizierung, sondern stellen lediglich erste Abschätzungen kritischer Umweltgrenzen im globalen Maßstab dar. Dies wird im Falle von Stickstoff z.B. daran deutlich, dass Steffen et al. (2015) die N-PB nicht in Hinblick auf umweltrelevante Freisetzung von Überschüssen (in Deutschland zur Zeit knapp 100 kg ha^{-1} yr^{-1}, UBA 2015a), sondern in Form absoluter landwirtschaftlicher Fixierungs- und Anwendungsraten („additional industrial & biological fixation") definiert haben. Diese liegen, wie in Kapitel 1 dargestellt, um fast die Hälfte höher als die Überschüsse.

Bei einer Ackerfläche Deutschlands von ca. 12 Mha (knapp 1 % der globalen Ackerfläche, FAOSTAT) entspricht die Erzeugung von 41 kg N_r ha^{-1} einer maximal zulässigen Gesamtmenge von ca. 0,5 Millionen Tonnen (Mt) reaktiven Stickstoffs[93]. **Der für Deutschland herunterskalierten N-PB (0.5 Mt) steht eine tatsächliche biologische Fixierung und Düngeranwendung in Deutschland von 2,3 Mt**

[93] Während sich die N-PB lediglich auf Ackerflächen bezieht, wird in Deutschland (anders als in den meisten anderen Weltregionen) Stickstoff auch auf Weideflächen ausgebracht. Die gesamte landwirtschaftliche Fläche Deutschlands beträgt ca 17 Mha.

N_r **gegenüber** („beabsichtigte" zusätzliche anthropogene Erzeugung reaktiven Stickstoffs über Mineraldünger (1,8 Mt), -, biologische N-Fixierung (0.2 Mt) [94] und Futtermittelimporte (0.3 Mt)- UBA 2015a). Wenn, wie in Kapitel 1 dargestellt, ca. 2/3 der erzeugten und angewendeten Menge reaktiven Stickstoffs, also ca. 1,5 Mt, nicht in Marktprodukten, sondern als Überschüsse in die Umwelt freigesetzt werden, würde die vom SRU (2015) geforderte Reduzierung des N-Überschusses um 50 % (von gegenwärtig knapp100 auf zukünftig 50 kg ha^{-1}) einer Reduktion der gegenwärtigen Erzeugung und Anwendung von 2,3 Mt um ca. 0,8 Mt bzw. einer verbleibenden Erzeugung von ca. 1,5 Mt entsprechen, also einem Wert der immer noch um 200 % über der herunterskalierten N-PB liegt.

Zusätzlich zu der bis hierher geschilderten gleichmäßigen Verteilung des globalen Grenzwerts auf alle Länder, könnten andere Verteilungskriterien für die Operationalisierung der PB herangezogen werden, z.B. **historische N-Freisetzungen**, sofern es sich um persistente Verbindungen handelt, die in der Umwelt akkumulieren. Beständige N-Verbindungen sind zum einen N_2O, das in der Atmosphäre eine Verweildauer von mehr als 100 Jahren hat, und zum anderen längerfristig im tiefen Grundwasser oder in Sedimenten festgelegtes N_r , dessen Verweildauer je nach Dynamik über 500 Jahre betragen kann (Grundwasser kann somit auch noch lange nach Ende der ursprünglichen anthropogenen Freisetzung weiter Stickstoff in die Flüsse und damit auch in die Küstenzonen eintragen). N-Verbindungen in den übrigen Umweltkompartimenten haben zumeist nur eine sehr kurze Lebensdauer und sind somit für eine mögliche historische Verantwortung irrelevant. Die erforderlichen Daten sind jedoch noch nicht global konsistent verfügbar, so dass die Berücksichtigung „historischer Schulden" bei der Verteilung des global erlaubten Wertes auf einzelne Länder zur Zeit noch nicht möglich ist.

Im Prinzip wäre auch ein weiteres Herunterskalieren der ermittelten Länderwerte für die erlaubte N-Freisetzung auf die sub-nationale Skala wünschenswert, um unterschiedlichen kontext-spezifischen Vorbelastungen und Vulnerabilitäten von Böden, Gewässern und Ökosystemen in verschiedenen Landesteilen Rechnung zu tragen. Aber auch dafür fehlt es noch an flächendeckenden konsistenten Daten. Absolute Länderwerte wie sie hier vorgeschlagen werden, sind vor allem dann zielführend wenn es um kumulative großmaßstäbige und internationale Umweltauswirkungen, wie die von N-Einträgen in die Ost- oder Nordsee oder Beiträge zum Klimawandel, geht.

2) Downscaling auf Pro-Kopf-Werte und produktionsbezogenes (territoriales) benchmarking

Das *downscaling* der PB relativ zur jeweiligen Bevölkerung (pro Kopf) nimmt stärker Bezug auf die Bevölkerungsdichte und damit auch auf die Ernährungssicherheit, als es die o.g. Länderwerte tun. Eine global einheitliche Pro-Kopf-Allokation globaler Maximalwerte, d.h. gleiche Emissionsrechte für alle, sind auch in anderen Fällen (z.B. in den Klimaverhandlungen) zur Anwendung gekommen. Im Falle der N-PB von 62 Mt N_r pro Jahr, ergibt die gleichmäßige Verteilung auf ca. 7 Milliarden Menschen eine **zulässige Pro-Kopf-N-Erzeugung und Anwendung in der Landwirtschaft von 8,8 kg pro Jahr**[95]. Diesem Pro-Kopf-Grenzwert steht in Deutschland ein **Ist-Wert von fast 30 kg** gegenüber (die o.g. 2,3 Mt geteilt durch 80 Millionen Einwohner). Pro-Kopf gerechnet ergibt sich damit ebenfalls eine ca. 200 %ige Überschreitung der herunterskalierten N-PB. Die hier ermittelte Überschreitung der N-PB (deren Definition auf der Vermeidung von Schadwirkungen in Gewässern beruht) manifestiert sich auch auf der regionalen Ebene, weshalb die Europäische Kommission Deutschland vor dem Gerichtshof der EU verklagt, weil es versäumt hat, strengere Maßnahmen gegen die Gewässerverunreinigung durch Nitrat zu ergreifen. (Pressemitteilung der Europäischen Kommission vom 28. April 2016). Entscheidend beim PB downscaling und benchmarking ist eine Abstimmung der verschiedenskaligen

[94] Hierin ist in der für Deutschland genannten Zahl allerdings auch die Fixierung durch andere, nicht landwirtschaftliche Ökosysteme enthalten.

[95] Abnehmend mit weiter wachsender Weltbevölkerung.

Grenzwerte aufeinander. Zahlreiche andere europäische Länder sowie China, Indien, Brasilien, Indonesien und andere weisen ähnlich hohe Pro-Kopf-Werte auf wie Deutschland (Nykvist et al. 2013). Dies wird auch durch das N-*footprint network*, z.B. von Leach et al. (2012) bestätigt.

Die meisten Länder Sub-Sahara Afrikas hingegen haben landwirtschaftliche N-Freisetzungsraten von weniger als 2 kg pro Kopf und Jahr (Nykvist et al. 2013) - was oft einer Verarmung der Böden (*nutrient mining*) und einer unzureichenden Nahrungsmittelproduktion und prekären Ernährungslage führt. In diesen Ländern ist also eine Erhöhung der biologischen N-Fixierung und Düngeranwendung erforderlich, was für die Einhaltung der globalen N-PB noch stärkere Reduktionsverpflichtungen der übrigen Länder bedeutet. Die extremen nationalen Unterschiede bei der Über- (oder Unter-)schreitung der herunterskalierten N-PB haben also auch eine ethische Dimension für das *downscaling* und Verteilen der globalen Leitplanke bzw. PB auf einzelne Länder , mit Bezug auf das Recht auf angemessene Ernährung für alle.

Wichtig aus Ernährungssicht ist in diesem Zusammenhang, dass die WHO eine Aufnahme von ca. 3 kg N (in Form von Proteinen und Aminosäuren) pro Kopf und Jahr empfiehlt (WHO 2007). Dieser Wert ist mit der landwirtschaftlichen Nr -Erzeugung über die Effizienz der Stickstoffnutzung (*Nitrogen Use Efficiency, NUE*) in allen Schritten entlang der Wertschöpfungskette verknüpft. Je höher diese NUE, desto mehr des angewendeten N wird in Produkte umgesetzt und genutzt bzw. vom Menschen aufgenommen, und desto weniger wird in die Umwelt freigesetzt. In Deutschland werden – wie oben beschrieben – weniger als 20 % der in der Landwirtschaft erzeugten und angewendeten Menge Stickstoffs durch den Menschen mit Nahrungsmitteln aufgenommen. Der NUE kommt damit eine zentrale Rolle bei der Einhaltung der N-PB bei gleichzeitiger Ernährungssicherung zu. Die aufgeführten Pro-Kopf-Allokationen der N-PB sind „produktionsbezogen“, d.h. sie beschränken sich auf die territoriale landwirtschaftliche N_r Erzeugung und Anwendung innerhalb des jeweiligen Landes, ohne die mit Importen verbundenen Freisetzungen zu berücksichtigen.

3) Downscaling auf Pro-Kopf-Werte und konsumbezogenes benchmarking

Eine konsumbezogene Berechnung berücksichtigt zusätzlich zur produktionsbezogenen (territorialen) N_r Erzeugung und Freisetzung im Inland auch die mit Importen von Nahrungs- und Futtermitteln verbundene Mengen die im Ausland erzeugt und freigesetzt werden. In Anbetracht der rasch wachsenden Importe und Nettoimporte von Nahrungs- und Futtermitteln durch Deutschland und Europa (s. z.B. von Witzke und Noleppa 2010, Lugschitz et al. 2011), wird die externe, in den Produktionsländern bei der Exportproduktion anfallende N-Freisetzung und die damit verbundene dortige Umweltauswirkung zunehmend wichtiger. Wenn diese mit dem deutschen oder europäischen Konsum verbundenen externen Mengen zusätzlich zu den nationalen territorialen Werten berücksichtigt werden, fallen die Überschreitungen der herunterskalierten N-PB bzw. die Beiträge zur Überschreitung der globalen N-PB noch deutlicher aus als unter 1) und 2) dargestellt. Gleichzeitig erhöht die N-Zufuhr mit Futtermittelimporten die N-Überschüsse in der Landwirtschaft und letztlich in der Umwelt hierzulande weiter. Futtermittelimporte sind in Deutschland für 10 % der Gesamtfreisetzung von N_r in die Umwelt verantwortlich, europaweit für 2 % (UBA 2015a).

Für die Quantifizierung von Fernwirkungen nationaler Konsummuster über den Welthandel, d.h. die Externalisierung von N-Freisetzung und Umweltauswirkungen werden v.a. *sogenannte environmentally extended Multi-Regional Input-Output* (MRIO) Modelle verwendet (siehe z.B. Wiedmann und Barrett 2013, Tukker et al. 2014). Damit lassen sich konsistent konsumbezogene interne und externe *footprints* bestimmen. Diese erfassen die gesamten internationalen Produktions- und Wertschöpfungsketten vom Feld bis zum Konsumenten. Galloway et al. (2014) und das N-*footprint* tool (www.n-print.org) weisen ebenfalls darauf hin, dass konsumbezogene N-*footprints* für Europa deutlich höher ausfallen als rein territoriale oder produktionsbezogene[96].

Erste Berechnungen zu konsumbezogenen N-*footprints* Deutschlands durch Eggers (2016) ebenfalls mittels MRIO, weisen darauf hin, dass der externe, also im Ausland wirksam werdende Anteil des konsumbezogene N-*footprints* fast doppelt so hoch ist wie der interne Anteil. Dieses Ergebnis ist konsistent mit den Berechnungen zu anderen landwirtschaftlichen *footprints* bzw inputs, nämlich Land und Wasser (Hoff et al. 2014). Das heißt, ein großer (und vermutlich weiter wachsender) Teil des Drucks deutscher Konsummuster auf die entsprechenden N-, Land- und Wasser-PBs erwächst nicht in Deutschland selber, sondern in anderen Ländern, bei der Exportproduktion für den deutschen Konsum. Entsprechend **fällt Deutschlands nationale Reduktionsverpflichtung bei Anrechnung seiner extern verursachten Erzeugung von** N_r **noch stärker aus,** , als dies unter 1) und 2) dargestellt worden ist. Vorschläge dazu bedürfen allerdings noch einer weiteren detaillierten und soliden quantitativen Analyse von konsumbezogenen N-footprints für Deutschland.

Aus solchen MRIO Analysen, in Kombination mit landwirtschaftlichen Produktivitätsdaten und N-Intensitäten der Produktion in den jeweiligen Erzeugerländer, lassen sich auch Möglichkeiten ableiten, wie sich Produktions- und Handelsmuster so optimieren ließen, dass der Druck auf die jeweilige PB minimiert wird. Dabei müssen aber auch kontext-spezifische relevante Umwelteigenschaften berücksichtigt werden, im Falle von Stickstoff z.B. bestehende Vorbelastungen und die Vulnerabilität von Böden, Gewässern und Ökosystemen (die grünen Regionen in Abbildung 73 zeigen lediglich an, dass dort die einheitlich herunterskalierte PB noch nicht überschritten ist. Das bedeutet nicht unbedingt, dass dort keine lokalen N-Grenzwerte überschritten werden). Weiterhin ist bei solchen Überlegungen zu berücksichtigen, dass sich je nach PB unterschiedliche Lösungen bzw. räumliche Muster für die Optimierung ergeben können. So haben Dawkins et al. (2016) z.B. festgestellt, dass Deutschland Soja z.T. aus wasserknappen Regionen Brasiliens importiert, so dass eine weitere Steigerung der dortigen Exportproduktion (die aus Sicht der N-PB möglicherweise sinnvoll erscheint) zu einer weiteren Verschärfung der Wasserknappheit führen dürfte.

Zusätzlich zu den unter 1), 2) und 3) genannten biophysikalischen Kriterien für das *downscaling* und benchmarking der N-PB, können auch sozio-ökonomische, ethische und normative Aspekte berücksichtigt werden (die z.T. oben auch schon genannt wurden), wie Ernährungssicherheit, realistische und faire Allokationsregeln für globale PB Werte (z.B. differenzierte Pro-Kopf-Werte) sowie historische „Schulden" bzw. Beiträge zur heutigen Belastung mit persistenten Verbindungen. Damit werden Konzepte wie *equity*[97]*, fair shares* und *common but differentiated responsibility* wichtig. Wenn solche normativen oder ethischen Kriterien herangezogen werden, sind auch Zielkonflikte zwischen kurz- und langfristigen Zielen zu lösen, wie sie aus anderen internationalen Umweltabkommen oder -konventionen wie der Klimarahmenkonvention bekannt sind (siehe z.B. Raupach et al. 2014 oder Steininger et al. 2015). Hier lohnt sich eine gründliche Analyse der in anderen Bereichen gemachten Erfahrungen für den Stickstoffsektor.

Neben der Dynamik der PBs selber (als Teil der Erdsystemdynamik) lassen Trends wie Bevölkerungswachstum, sich ändernde Konsum- und Ernährungsmuster, landwirtschaftliche Transformation oder auch das weitere Anwachsen des Welthandels dynamische Regeln für das Herunterskalieren von PBs

[96] Im Klimabereich werden neuerdings auch hybride footprint-Ansätze verfolgt, die zwischen produktions- und konsumbezogen liegen, siehe z.B. Kander et al. (2015). Deren Nutzbarkeit für Stickstoff ist zu prüfen.

[97] *equity* Prinzipien können z.B. sein i) *egalitarian*: gleiche Rechte bzw. pro-Kopf Allokationen für alle, ii) *polluter pays*: stärkere (ggf. auch historische) Emissionen oder Nutzungen resultieren in höheren Reduktionsverpflichtungen, iii) *capacity*: besser ausgestattete / wohlhabendere Länder übernehmen größere Reduktionsverpflichtungen, iv) inter-generationelle Gerechtigkeit, v) status quo (*grandfathering*) Rechte.

und damit das Setzen von nationalen N-bezogenen Umweltzielen – im Einklang mit nachhaltigen Entwicklungszielen - sinnvoll erscheinen.

Unabhängig von gewählten Kriterien und Ansätzen für das *downscaling* und *benchmarking* der N-PB auf die nationale Ebene ist Ländern mit geringer landwirtschaftlicher Produktivität aufgrund geringen Düngereinsatzes und damit in Zusammenhang stehender Unterernährung eine Zunahme der N-Nutzung, d.h. ein höherer Anteil an der N-PB (62 Tg yr^{-1}) zuzugestehen. In Anbetracht der Tatsache, dass der Einsatz von Stickstoffdünger innerhalb und zwischen Weltregionen um einen Faktor 10 und mehr (pro Flächeneinheit) variiert (s.o.), weisen Steffen et al. (2015) und Mueller et al. (2014) darauf hin, dass in einer globalen N-Umverteilung (weg von Überschuss- hin zu Defizitgebieten) erhebliche **Chancen** liegen, die Ernährung der Weltbevölkerung bei gleichzeitiger Reduktion der Gesamtumweltbelastung (und Einhaltung der N-PB) zu sichern. Van Grinsven et al. (2013) argumentieren analog für eine Umverteilung von landwirtschaftlicher Produktion innerhalb Europas. Die praktische Umsetzung solcher Überlegungen würde allerdings eine Reihe von gravierenden Maßnahmen erfordern, insbesondere neue Formen der Kooperation und zusätzliche Nachhaltigkeitskriterien für den Welthandel, aber auch Steigerungen *der Nitrogen Use Efficiency* (NUE) und Reduktionen von Verlusten entlang der gesamten Wertschöpfungskette (siehe dazu Bodirsky et al. 2014).

2.2.3 Verwendbarkeit vorhandener Grenzwerte und der Planetary Boundary als Grundlage für die Bestimmung integrierter nationaler Stickstoffziele

Integrierte nationale Umweltziele müssen die Multi-Dimensionalität des Stickstoffs entlang der jeweilige Umweltpfade und der Stickstoffkaskade abbilden. Dazu müssen diese Ziele sowohl mit vorhandenen anderen nationalen Umweltzielen („horizontal") konsistent sein (und diese ggf. aktualisieren), als auch mit regionalen und internationalen Umweltzielen („vertikal"), hier v.a. mit EU-Zielen, aber auch mit globalen Zielen und Leitplanken, insbesondere der N-PB in ihrer herunterskalierten Form (siehe Kapitel 2.2.2). Integrierte Stickstoffziele anderer Länder können für die Bestimmung nationaler Ziele ebenfalls herangezogen werden (siehe z.B. de Vries 2001 und Erisman 2001[98] für die Niederlande).

Vorhandene Stickstoff-Ziele für die verschiedenen Umweltmedien sind:

1) Land und terrestrische Ökosysteme

- N-Überschuss auf landwirtschaftlichen Flächen < 70 kg ha^{-1} im Fünfjahresmittel 2028-2032, gemäß der Deutschen Nachhaltigkeitsstrategie (Bundesregierung 2017); der N-Überschuss liegt gegenwärtig in Deutschland bei knapp 100 kg (im Fünfjahresmittel 2008-2012: 95 kg, Jahreswert 2014: 84 kg, europaweit bei ca. 50 kg)
- **N-Überschuss auf landwirtschaftlichen Flächen < 50 kg ha^{-1}**, gemäß **SRU/UBA-Vorschlag**, entspricht einer Reduktion um 0,8 Mt pro Jahr (von 2,3 auf 1,5 Mt) (SRU 2015; UBA 2015a)
- N-Ausbringung < 120-150 kg ha^{-1} (EU Verordnung über tierische Nebenprodukte 1774/2002)
- N-Ausbringung mit Dung < 170 kg ha^{-1} (EU Nitrat Richtlinie 91/676/EEC)
- **Reduktion von Ammoniak um -39 % und von Stickstoffoxiden um -69 %** ab 2030 gegenüber 2005; ausgehend von jährlichen NH_3-Emissionen von ca. 0,6 Mt und NO_x Emissionen von ca. 1,2 Mt in Deutschland (UBA 2015c), bedeutet dies eine Reduktionen von 0,45 Mt N pro Jahr, wovon NH_3-N knapp 0,2 MT und NOx-N gut 0,25 Mt ausmacht (**EU Richtlinie über nationale Emissionshöchstmengen (emission ceilings directive)**, 2003/35/EC, Umrechnungsfaktoren von NH_3 in N und von NO_x in N aus UBA 2009)

98 die eine 50-70 % Reduktion des Stickstoffinputs in der Landwirtschaft für erforderlich halten.

- Minderung des Anteils der Ökosystemflächen, die von Eutrophierung betroffen sind, um 49 % (Europäische Kommission 2005)
- Flächenanteil der ökologischen Landwirtschaft von 20 % gemäß der Deutschen Nachhaltigkeitsstrategie (Bundesregierung 2017)
- "By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity" (globales Aichi target der Biodiversitätskonvention)

2) Wasser, Gewässer und aquatische Ökosysteme

- 75 %ige Eliminierung von Stickstoff in Kläranlagen (EU Abwasserrichtlinie EEC 1991)
- 50 mg NO_3 l^{-1} bzw. 11,3 mg N l^{-1} (WHO Richtlinie für Trinkwasser)
- Guter Gewässerzustand (EU Wasserrahmenrichtlinie)
- **< 2,6 und 2,8 mg N l^{-1} in Küstengewässern**, gemäß **Verordnung zum Schutz der Küstengewässer** (**BLMP** 2011)
- Minderung der deutschen Stickstoffeinträge in die Ostsee um 12 % bis 2021, HELCOM, Übereinkommen zum Schutz der Meeresumwelt des Ostseegebietes (1992)
- Ostseeweite Einträge < 0,8 Mt N pro Jahr, was für Deutschland einer anteiligen Reduktion von weniger als 0,01 Mt pro Jahr bzw. ca. 10 % der gegenwärtigen nationalen Einträge entspricht (Ostseeaktionsplan, 2007)
- „Regional abgestimmte Stickstoffminderungsziele für die Nordsee in Analogie zu den Minderungszielen für die Ostsee" gemäß SRU N-Gutachten (die deutschen Einträge in die Nordsee liegen um einen Faktor 10 höher als die in die Ostsee)
- **Minderung der deutschen N-Flüsse in die Nordsee um 30 – 48 % bis 2021**, dies entspricht bei gegenwärtigen Frachten von ca. 0,215 Mt einer Reduktion um 0,065 – 0,1 Mt N pro Jahr (**BLMP** 2011)

Zahlreiche der oben genannten, bereits gültigen Umweltziele werden bislang nicht erreicht (Implementierungsdefizit), so dass es in der nationalen Stickstoffstrategie gleichermaßen um die Setzung neuer (vertikal und horizontal) integrierter Ziele, wie auch um die Umsetzung bereits bestehender Ziele gehen sollte. Nur wenige der oben genannten nationalen und regionalen Umweltziele lassen sich direkt mit der herunterskalierten N-PB (siehe Kapitel 2.2.2) vergleichen oder auf diese abstimmen[99]. Dies hat zum einen mit der Herleitung der PBs zu tun (diese beziehen sich auf die Funktionsfähigkeit des Erdsystems, nicht auf spezifische lokale oder nationale Umweltziele), zum anderen aber auch mit der Komplexität des Stickstoffkreislaufs und der entsprechenden Schwierigkeit, die aus der N-Freisetzung resultierenden Transporte, Reaktionen, Konzentrationen und Auswirkungen verschiedener N-Verbindungen in den jeweiligen Umweltkompartimenten quantitativ darzustellen. Die in der obenstehenden Liste fettgedruckten Umweltziele geben erste Anhaltspunkte für eine mögliche Abstimmung bzw. vertikale Integration mit der herunterskalierten N-PB:

- die Verringerung des N-Überschusses auf landwirtschaftlichen Flächen auf < 50 kg ha^{-1}, gemäß SRU/UBA-Vorschlag, entspricht einer Reduktion der absoluten N_r Erzeugung in der deutschen Landwirtschaft von ca. 2,3 auf 1,5 Mt N_r und verfehlt damit die herunterskalierte N-PB (maximal 0,5 Mt) pro Jahr bei weitem;

[99] Die Notwendigkeit der Harmonisierung von Nachhaltigkeitszielen über die verschiedenen räumlichen Skalen hinweg, findet sich z.B. auch bei der Implementierung der Sustainable Development Goals

- die Werte der EU Richtlinie über nationale Emissionshöchstmengen (Reduktion von Ammoniak um -39 % und von Stickstoffoxiden um -69 %) entsprechen einer Reduktion in Deutschland um ca. 0,45 Mt N_r pro Jahr; ein Großteil dieser zu reduzierenden Emissionen stammt allerdings aus der Landwirtschaft, so dass die Umsetzung des SRU/UBA Vorschlags sich mit dieser EU Richtlinie überschneidet und die beiden Reduktionswerte nicht einfach aufsummiert werden können;
- die Grenzwerte von 2,6 bzw. 2,8 mg N l^{-1} zum Schutz von Küstenökosystemen liegen deutlich höher als der der N-PB zugrunde liegende Wert für Oberflächengewässer von 1.0 mg l^{-1} (de Vries et al. 2013). Auch wenn kein direkter Vergleich dieser beiden Werte möglich ist, deutet sich auch hier eine stärkere Reduktionsverpflichtung aus Sicht der N-PB an. Auch dieser Grenzwert überschneidet sich mit der Reduktion landwirtschaftlicher N-Freisetzung, da ca. 1/3 der landwirtschaftlichen N-Freisetzung letzten Endes in die Küstengewässer gelangt (UBA 2105a).
- Minderung der deutschen N Flüsse in die Nordsee um 30 – 48 %, was einer Reduktion um 0,065 – 0,1 Mt N_r pro Jahr entspricht. Dieses Ziel ist v.a. durch Reduktion landwirtschaftlicher Einträge zu erreichen, und stellt daher keinen eigenständigen additiven Beitrag zur Einhaltung der N-PB, über den SRU/UBA Vorschlag (< 50 kg ha^{-1} Stickstoffüberschuss) hinaus, dar.

Aus diesem ersten Vergleich von vier bestehenden Umweltzielen mit der herunterskalierten N-PB lässt sich bei aller Komplexität des Stickstoffkreislaufs trotzdem gut erkennen, **dass die neu zu entwickelnden integrierten N-Ziele in Deutschland strikter gefasst** (und vor allem auch umgesetzt) **werden müssen, um den Ansprüchen der herunterskalierten N-PB zu genügen**. Dies gilt umso mehr, wenn die externe N-Erzeugung und Freisetzung im Ausland für den deutschen Konsum (Nettoimporte), mit auf Deutschlands Budget angerechnet berücksichtigt wird (siehe konsumbasierte Pro-Kopf-Werte in Kapitel 2.2.2).

Landwirtschaftliche Importe (v.a. von Futtermitteln) sind, über Ihre externen Auswirkungen auf die N-PB hinaus, innerhalb Deutschlands für 12 % der Stickstoffzufuhr in den Agrarsektor verantwortlich (UBA 2015b). Dies unterstreicht die Notwendigkeit, die mit Importen verbundenen Stickstoffflüsse in der deutsche Stickstoffstrategie zu berücksichtigen.

Als Nettoexporteur von gasförmigen N_r -Verbindungen über Atmosphärentransporte (0,3 – 0,4 Mt N pro Jahr, UBA 2015a, Leip et al. 2011) kann Deutschland zudem durch die o.g.nationalen Emissionsreduktionen zur Einhaltung der herunterskalierten N-PB und von Stickstoffzielen in anderen Ländern und Regionen beitragen.

Vertikale Integration nationaler Umweltziele mit der N-PB und den o.g. EU-Zielen bedeutet auch, einen Einzugsgebiets-Ansatz zu verfolgen, welcher N- (und P-) Zuflüsse so begrenzt, dass anoxische Zustände in Küstengewässern und Meeren vermieden oder rückgängig gemacht werden. Dies erfordert die Abstimmung mit allen Anrainern in Hinblick auf differenzierte kontext-spezifische N-Freisetzungsgrenzen und entsprechende internationale Politikkohärenz. Das UBA schlägt dazu vor, entsprechende Grenzwerte in der Oberflächengewässer VO festzuschreiben (Geupel pers. comm.).

Um der besonderen Kritikalität von N_r in Gewässern (siehe Kapitel 2.2.1) Rechnung zu tragen, schlagen Nykvist et al. (2013) vor, DIN (*dissolved inorganic nitrogen*) als Universalindikator für Wasserqualitätsziele zu verwenden (nach welchem der Rhein laut Liu et al. 2012, mit zu den international am stärksten verschmutzten Gewässern gehören würde).

Da die Umweltauswirkungen von reaktivem Stickstoff sehr kontext-spezifisch sind, ist ein weiteres ***downscaling*** globaler und nationaler Grenzwerte **auf die subnationale Ebene** sinnvoll. Auf sub-nationaler Ebene sind zusätzliche**, lokale kontext-spezifische Umwelteigenschaften** zu berücksichtigen. Für Böden können dies beispielsweise die Pufferkapazität gegenüber Versauerung, Denitrifikationsraten oder N-Rückhaltevermögen bzw. Auswaschungsraten (und damit Einträge ins Grundwasser) sein:

je nach lokalen Bodeneigenschaften, z.B. Sand- oder Wassergehalt oder Durchwurzelungstiefe, wären dann nationale Umweltziele (wie z.B. das SRU/UBA Ziel von 50 kg N Überschuss pro ha) entsprechend räumlich differenzierter darzustellen. Andere kontext-spezifische Kriterien können z.B. sein: Vorbelastungen bzw. lokale *hotspots*, die Selbstreinigungskapazität aufnehmender Gewässer, die Vulnerabilität von Ökosystemen gegenüber erhöhten N-Konzentrationen oder auch agro-ökologische Bedingungen und Produktivität. Solch eine kontext-spezifische kleinräumige Differenzierung von Umweltzielen kann auch für kurzlebige gasförmige N-Verbindungen sinnvoll sein, wenn sich diese aufgrund ihrer kurzen Lebensdauer nicht gleichförmig in der Atmosphäre verteilen.

Aus den bisherigen Kapiteln wird deutlich, dass parallel zur (Weiter-)entwicklung der Stickstoffstrategie **begleitende Forschung** auf allen Ebenen erforderlich ist: zum einen ist das Verständnis von Transport, Reaktionen, Umwandlungen Wechselwirkungen und Auswirkungen verschiedener N-Verbindungen in der Umwelt zu verbessern, um eine bessere Vergleichbarkeit und Abstimmung der verschiedenen Umweltziele (und bestehender Zielkonflikte bzw. *tradeoffs*) in den jeweiligen Umweltkompartimenten und über alle Skalen hinweg zu ermöglichen und ein *pollution swapping* (eine Verschiebung der Verschmutzung in andere Umweltkompartimente) zu vermeiden; zum anderen ist eine verbesserte Quantifizierung der stickstoffbezogenen internationalen Auswirkungen deutscher Konsummuster und Importe erforderlich; und schließlich ist eine Abschätzung der wichtigsten und effektivsten Interventionsmöglichkeiten Deutschlands im Sinne der N-PB (sowie anderer globaler Grenzwerte und Umweltziele) vorzunehmen, z.B. in den Bereichen Agrar- und Handelspolitik, aber auch Änderungen deutscher Konsummuster. Für die integrierte Stickstoffstrategie sollte der gleiche „Dreiklang" wie für die nationale Implementierung der *Sustainable Development Goals* (SDGs) gelten, nämlich einer Umsetzung der Ziele 1) national innerhalb der Landesgrenzen, 2) international durch Verminderung der externen auf deutschen Konsummustern und Importen beruhenden *footprints*, und 3) international durch Kooperation in den Bereichen Entwicklungszusammenarbeit, Investitionen und Wissens- und Technologietransfer.

Kurz zu erwähnen sind hier auch die möglichen **positiven Umweltauswirkungen** von Stickstofffreisetzungen, v.a. der Düngungseffekt und die entsprechend erhöhte pflanzliche Nettoprimärproduktion, auch in nicht landwirtschaftlichen Ökosystemen[100] und damit einhergehende stärkere Kohlenstoffsequestrierung (einschließlich biomasse-basiertes Carbon Capture & Storage - CCS, das gegenwärtig auch stickstofflimitiert ist, siehe z.B. Smith und Torn 2013). Dieser Effekt kann zunächst die Klimaerwärmung verlangsamen (*cooling effect*). Ebenso können die Bildung N-haltiger Aerosole, der N_r -bedingte Abbau von Methan und die verminderte Treibhausgas-Freisetzung aus der Viehwirtschaft aufgrund N-haltiger Futtermittel die Klimaerwärmung verlangsamen. Erisman et al. (2011) gehen davon aus, dass diese kurzfristigen Kühleffekte gegenwärtig die N-bedingte Klimaerwärmung (v.a. über das Treibhausgas N_2O) in etwa ausgleichen. Die wesentlich längere Lebensdauer und höhere Klimawirksamkeit von N_2O lässt jedoch ein Aufrechnen von Kühl- und Erwärmungseffekten verschiedener N-Verbindungen gegeneinander und die Berücksichtigung dieser positiven Umweltauswirkungen bei der Setzung von N-bezogenen Umweltzielen nicht angeraten erscheinen.

2.2.4 Übersicht über relevante Modelle zur Unterstützung integrierter N-Umweltziele

Wie zuvor dargestellt, besteht die zentrale Herausforderung bei der Entwicklung und Begründung von horizontal und vertikal integrierten Umweltzielen darin, alle wichtigen Bestandteile des komplexen N-Kreislaufs von seinen Quellen über die Umweltpfade und (z.T. systemischen) Reaktionen und Wechselwirkungen der verschiedenen Stickstoffverbindungen bis hin zu den Auswirkungen auf Mensch und Umwelt zu erfassen und die Ziele entsprechend evidenzbasiert zu formulieren und schließlich zu implementieren.

[100] Dies ist z.B. für die immer zahlreicher werdenden nationalen Bioökonomie- und Biomassestrategien von Bedeutung.

Simulationsmodelle werden eingesetzt, wenn räumliche oder zeitliche Einschränkungen bezüglich der Verfügbarkeit von Beobachtungsdaten bestehen, sowie zur Verbesserung des Verständnisses der Prozesse und Wirkungszusammenhänge. Insbesondere lassen sich mit Hilfe von Modellen die Auswirkungen und Wechselwirkungen verschiedener Triebkräfte, Interventionen und Grenzwerte und die entsprechenden Umweltsystemantworten simulieren und entsprechende Zukunftsszenarien erstellen. Unter dem Gesichtspunkt der vertikalen Integration, für welche die Nutzung der PB bei der Erstellung der nationalen Stickstoffstrategie v.a. steht, können Simulationsmodelle skalenübergreifende systemische Antworten auf die Implementierung von Umweltzielen mittels entsprechender Maßnahmen, einzeln und in Kombination, abschätzen. Dazu gehören auch die Beiträge zur Einhaltung bzw. Überschreitung der N-PB.

Entsprechend der Komplexität des Stickstoffkreislaufs sind für solche Abschätzungen horizontal und vertikal integrierte Modelle erforderlich. Im Rahmen dieses Input Papers ist keine eigenständige Stickstoffmodellierung möglich, sondern es kann nur übersichtsartig dargestellt werden, welche Arten von Modellen sich eignen, um integrierte Simulationen des Umweltverhaltens verschiedener Stickstoffverbindungen in verschiedenen Umweltkompartimenten (und der Stickstoffkaskade) durchzuführen und dabei die Wirksamkeit von Umweltzielen in Hinblick auf die menschliche Gesundheit, die Erhaltung der Umweltqualität und die Einhaltung der N-PB (sowie umgekehrt Einschränkungen, welche aus der N-PB erwachsen) zu untersuchen.

Folgende Klassen von Modellen zur Stickstoffmodellierung lassen sich unterscheiden:

1. Globale Langzeit-, Erdsystem- und Szenarienmodelle, welche Triebkräfte von N-Emissionen wie Nachfrageänderungen und Auswirkungen von großmaßstäbigen Anpassungsmaßnahmen darstellen. Dazu gehören z.B. das PBL Image Modell und das PIK MagPie Modell

2. Impaktmodelle wie z.B. das PIK LPJmL Modell, welches die großmaßstäbigen Wechselwirkungen von Stickstoff mit natürlicher und landwirtschaftlicher Vegetation konsistent mit Wasser und Kohlenstoffflüssen darstellt,[101] aber auch Modelle, welche diese spezifisch für bestimmte Landschaften, Einzugsgebiete oder terrestrische oder aquatische Ökosysteme (z.B. das PIK SWIM Modell) oder auch die Auswirkungen auf die menschliche Gesundheit darstellen

3. Transport- und Reaktionsmodelle, welche Umweltpfade und Reaktionen und Umwandlungen von Stickstoffkomponenten darstellen (z.B. das WUR Miterra Modell);

4. Integrierte Managementmodelle wie IIASA GAINS und das Thünen RAUMIS Modell, welche auch Mitigationsmaßnahmen mit darstellen und oft in der Politikberatung eingesetzt werden, so z.B. GAINS in der Klimapolitik und RAUMIS in der Agrar- und Umweltpolitik.

Wie bereits vom UBA (2014) festgestellt, kann keines der verfügbaren Modelle die Vielzahl der Reaktionen und Wirkungspfade in allen Umweltkompartimenten und auf allen räumlichen Skalen umfassend simulieren. Für die evidenzbasierte quantitative und räumlich explizite Begründung einer integrierten Stickstoffstrategie im Kontext der N-PB ist daher zum einen eine Weiterentwicklung integrierter Modelle, zum anderen eine kombinierte Anwendung von verschiedenen Modellen der o.g. Klassen (*coupling* oder *soft-coupling*), erforderlich. Hierbei sind z.T. sehr unterschiedliche räumliche und zeitliche Skalen zu überbrücken. Wichtig ist dabei eine Integration von bottom-up und top-down Ansätzen. Die Grundlagen dafür legt gegenwärtig vor allem eine Expertengruppe des International Nitrogen Management System (INMS),[102] welche auch eine integrierte internationale Stickstoffstrategie erarbeitet. Das INMS schlägt vor, die folgenden Modellklassen ergänzend bzw. in Kombination mit den oben genannten zu verwenden: hydrologische Modelle, Vegetationsmodelle, landwirtschaftliche Bodenqualitäts-

[101] Andere globale Vegetationsmodelle (wie das Orchidee Modell) beschränken sich zumeist auf natürliche Vegetation.

[102] www.inms.international/

und Ertragsmodelle, Livestock-Modelle, Wasserqualitätsmodelle, Emissionsmodelle für Luftschadstoffe, Luftqualitätsmodelle, Modelle der menschlichen Gesundheit.

Darüber hinaus sind zur Erfassung der Externalisierung von, N-Freisetzung und Umweltauswirkungen (externalisierter Druck auf die N-PB, ggf. auch andere PBs) durch den Welthandel zusätzlich *environmentally extended* multi-regionale *Input-Output* (MRIO) Modelle anzuwenden (siehe z.B. Wiedmann und Barrett 2013, Tukker et al. 2014).

Da die genannten Modelle laufend weiterentwickelt werden und sich damit die Simulation und Quantifizierung der relevanten Prozesse verbessert, sollte die nationale Stickstoffstrategie flexibel genug sein, um an den jeweils aktuellen Stand der Wissenschaft angepasst werden zu können („*adaptive management*“).

2.2.5 Darstellung der Stärken und Schwächen des PB-Konzeptes im Hinblick auf Stickstoff-bezogene nationale Umweltziele

Die PBs beschreiben aus Sicht der Erdsystemwissenschaften großmaßstäbige Umwelt- und Nachhaltigkeitskriterien, die bei der Erarbeitung einer nationalen Stickstoffstrategie berücksichtigt werden sollten. Der risikobasierte Ansatz der PBs zielt darauf ab, innerhalb des *safe operating space* zu bleiben und die Überschreitung kritischer Grenzwerte mit nachteiligen Folgen für Mensch und Umwelt zu vermeiden.

Die Anwendung des PB-Konzepts und die ersten Ansätze zum *downscaling* der Stickstoff Leitplanke (siehe de Vries et al. 2013, Eggers 2016, Häyhä et al. 2016) erlauben es, die bereits in zahlreichen anderen Publikationen dargestellte horizontale Integration (zwischen N-Verbindungen, Umweltkompartimenten und Sektoren) um die vertikale Integration zwischen den verschiedenen räumlichen Skalen bzw. Levels zu ergänzen. Dabei stellt die Konsistenz von Umweltzielen über räumliche und zeitliche Skalen (Prozesse und Wechselwirkungen im Erdsystem und dessen Sub-Systemen erfolgen oft über wesentlich längere Zeiträume als lokale bis regionale Prozesse) eine erhebliche Herausforderung an Wissenschaft und Anwendung dar. Der integrative Ansatz des PB-Konzepts erlaubt die Erkundung möglicher Synergien und Zielkonflikte (*tradeoffs*), hier insbesondere vertikal zwischen nationaler, regionaler und globaler Skala und über Regionen hinweg und damit auch systemische Lösungen und verbesserte Politikkohärenz. Dabei werden auch Externalisierungseffekte, wie sie mit der Globalisierung und dem Welthandel verbunden sind, vom PB-Konzept konsistent mit erfasst.

Das den PBs inhärente **Vorsorgeprinzip** legt globale Umweltleitplanken so fest, dass auch unter Berücksichtigung aller Komplexitäten und Unsicherheiten Störungen des Erdsystems mit kritischen Auswirkungen auf den Menschen und die Umwelt nach Möglichkeit vermieden werden. Dieses Vorsorgeprinzip ist entsprechend auch auf die Operationalisierung (bzw. das *downscaling*) der N-PB für die nationale Stickstoffstrategie anzuwenden. Ein weiteres charakteristisches Element der PBs ist der starke Bezug auf die Biosphäre ***(„reconnecting to the biosphere***“), welcher insbesondere in der PB zu *biosphere integrity* zum Ausdruck kommt, aber auch allgemeiner durch den starken Bezug auf sozial-ökologische Systeme und Ökosystemdienstleistungen. Hierauf sollte, wie auch vom SRU (2015) gefordert, die nationale Stickstoffstrategie aufbauen.

Der im PB-Konzept für jede einzelne Leitplanke definierte *safe operating space* ist für die nationale integrierte Stickstoffstrategie anhand der N-PB multi-dimensional darzustellen: Dafür muss er konsistent für den deutschen Kontext und die verschiedenen Umweltkompartimente herunterskaliert und räumlich explizit gemacht werden, wobei sowohl horizontale als auch vertikale Wechselwirkungen zu berücksichtigen sind. Beim **Herunterskalieren** (*downscaling*) können verschiedene Verfahren angewandt werden, so z.B. ein Herunterskalieren **auf Länderwerte oder Pro-Kopf-Werte**. Bei letzterem sollten auch konsumbezogene externe Umweltauswirkungen mit berücksichtigt werden. Die Auswahl der Methode zur Allokation der PBs auf einzelne Länder oder Regionen hängt von der jeweiligen Anwendung und Zielsetzung sowie von normativen und ethischen Kriterien ab. Je nach gewählter *downscaling* Methode und den dabei angewandten biophysikalischen, sozio-ökonomischen und ethischen Kriterien, könnte es also unterschiedliche PB-konforme nationale Umweltziele bzw. eine Spannbreite von Zielen geben (Häyhä et al. 2016). Diese sind gemeinsam mit den relevanten Stakeholdergruppen so abzuwägen, dass kontext-spezifische, aber gleichzeitig N-PB konforme Lösungen mit möglichst wenig Zielkonflikten (*tradeoffs*) gefunden werden. Wie in Kapitel 2.2.4 dargestellt, erwachsen weitere Unsicherheiten aus der Wahl der Simulationsmodelle, welche beim *downscaling* der PBs und ggf. der Szenarienerstellung zum Einsatz kommen. Über das *downscaling* auf die nationale Ebene hinaus, können weitergehende **sub-nationale Differenzierungen** sinnvoll sein, welche zusätzlich **kontext-spezifische Bedingungen** (z.B. Vorbelastungen, Pufferkapazitäten, Vulnerabilitäten etc.) berücksichtigen. Eine solche höhere räumliche Auflösung verhindert auch, dass lokale *hotspots* in Ländermittelwerten verloren gehen. Für diese feinere räumliche Differenzierung ist eine entsprechende umfassende und konsistente Datenbasis erforderlich, zu N-Emissionen und Immissionen (wie z.B. aus dem UBA PINETI Projekt[103]), aber auch zu Eigenschaften von Gewässern, Böden, (Agrar-) Ökosystemen und ggf. auch sozio-ökonomischen Bedingungen. Damit wird dann auch die konsistente Integration von top-down und bottom-up Ansätzen möglich.

Neben den methodischen **Unsicherheiten,** wie sie mit der Operationalisierung und dem *downscaling* der PBs einhergehen, sind auch die globalen PBs selber mit zahlreichen Unsicherheiten behaftet, z.B. bezüglich der Definition und genauen Lage der kritischen Grenzwerte, die den PBs zugrunde liegen (und die nicht empirisch ermittelt werden können) und der erforderlichen Sicherheitsabstände von diesen. Weitere Unsicherheiten im PB Konzept liegen in den (irreversiblen?) biophysikalischen und letztlich auch sozio-ökonomischen Reaktionen bei Überschreitung dieser Grenzwerte, den zeitlichen Dynamiken und verzögerten Antworten im Erdsystem (auch was das Wirksamwerden von Maßnahmen betrifft) und den Wechselwirkungen und Rückkopplungen (*feedbacks*) der PBs untereinander.

Eine weitere Kritik am PB-Konzept bezieht sich darauf, dass es den **natürlichen Erdsystemzustand als Referenz** verwendet und erlaubte anthropogene Abweichungen von diesem natürlichen Zustand aus definiert. Unter den Bedingungen des Anthropozäns reichte diese Referenz möglicherweise nicht mehr aus, heißt es in dieser Kritik. So muss z.B. für die Ernährung der Weltbevölkerung erheblich über die natürliche N-Fixierung hinausgegangen werden um die Nahrungsmittelproduktion entsprechend der wachsenden Nachfrage zu erhöhen. Dieser Kritik am natürlichen Referenzzustand ist am besten durch eine realistische Operationalisierung und ein entsprechendes räumlich explizites Herunterskalieren der globalen N-PB und durch Integration der herunterskalierten PB mit lokalen *bottom-up* Nachhaltigkeitskriterien (unter Einbeziehung der Ernährungssicherung) zu begegnen.

Grundsätzlich beschreibt das PB-Konzept selber aber nur **wissenschaftlich abgeleitete biophysikalische Umweltleitplanken**, jenseits derer die Resilienz (Anpassungs- und Transformationsfähigkeit) und Funktionsfähigkeit des Erdsystems gefährdet sind. Das PB- Konzept nimmt keinen direkten Bezug auf sozio-ökomische oder politische Nachhaltigkeitsziele oder *human securities* oder den Schutz menschlicher Gesundheit, welche (neben dem Schutz von Ökosystemen) ein zentrales Anliegen von integrierten Stickstoffzielen sein muss. Solche sozio-ökonomischen (bottom-up) Ziele müssen komplementär zu den PBs für die relevanten Skalen formuliert werden (siehe z.B. Raworth 2012, Cole et al. 2014, Dearing et al. 2014).

Zum Teil wird auch als Schwäche des PB-Konzepts genannt, dass es lediglich Leitplanken, jedoch **keine Lösungsansätze** (und keine Treiber des Wandels) darstellt. Jedoch ergibt sich aus dem PB Konzept die Notwendigkeit verbesserter Ressourceneffizienz, z.B. Stickstoffeffizienz, um die Einhaltung der Leitplanken bei gleichzeitiger Sicherung der menschlichen Bedürfnisse (*human securities*) zu gewährleisten (für eine detailliertere Darstellung siehe unten).

[103] Pollutant INput and EcosysTem Impact.

Stickstoff-Effizienz als Lösungsansatz

Im Rahmen eines Projektworkshops (Planetary Boundaries and Ressource Efficiency, 29. Februar 2016 in Potsdam) wurde die Komplementarität von PBs und Ressourceneffizienz herausgearbeitet: auf der einen Seite benötigen die PBs Lösungsansätze, wie z.B. verbesserte Ressourceneffizienz, auf der anderen Seite benötigen Ansätze zur Verbesserung der Ressourcennutzungseffizienz Grenzen wie die PBs, ohne die sie nachteilige Folgen haben können, wie der sogenannte rebound Effekt belegt (verbesserte Ressourceneffizienz führt u.U. zu insgesamt höherem Ressourcenverbrauch). So schlagen z.B. Sutton et al. (2013b) als aspirational goal eine Erhöhung der Stickstoffeffizienz (oder Nitrogen Use Efficiency - NUE) um 20 % vor. Das SDSN 2013a schlägt als Beitrag zur Erreichung der Sustainable Development Goals (SDGs) eine 30 %ige Erhöhung der NUE über die gesamte Wertschöpfungskette vor. Auch die SDGs selber sehen (in target 8.4.) explizit die Erhöhung der Ressourceneffizienz vor, was auch zu co-benefits in anderen Sektoren führt. Anders als die übrigen Ressourceneffizienzen[104], wie etwa die von Land, ist die NUE global jedoch seit Mitte des vergangenen Jahrhunderts global stark (um fast 50 %) zurückgegangen (Bouwmann et al. 2013). Zu den Maßnahmen zur Steigerung der NUE, die in einer integrierten Stickstoffstrategie eine wichtige Rolle spielen sollte, gehören z.B.: recycling, cascading resource use, Rückgewinnung aus Abfallprodukten, closing the loop, circular economy und N-effizientere integrierte landwirtschaftliche Produktionssysteme (einschließlich Viehzucht). Dies kann z.B. über ökologische Landwirtschaft und sog. nachhaltige Intensivierung (Ertragssteigerungen ohne den Druck auf die Umwelt zu erhöhen) erreicht werden. Weiterhin könnten dazu auch Maßnahmen auf der Nachfrageseite zählen, wie veränderte Ernährungsgewohnheiten (insbesondere verminderter Fleischkonsum, da tierische im Vergleich zu pflanzlicher Nahrungsmittel- und Kalorienproduktion mit einer um den Faktor 4 geringeren N-Ressourceneffizienz erfolgt, Sutton et al. 2013b) sowie die Reduktion von Verlusten und Abfällen entlang von Wertschöpfungsketten. Veränderte Ernährungsgewohnheiten können auch aus der Perspektive anderer PBs (co-benefits) und aus Gesundheitssicht motiviert werden. Für Stickstoff gilt, wie in Kapitel 3 aufgeführt, eine empfohlene maximale Aufnahme von 3 kg pro Person und Jahr (WHO 2007). Mit solchen umfassenden Ansätzen zur Erhöhung der Ressourceneffizienz entlang der gesamten Wertschöpfungsketten und daraus resultierender besserer Einhaltung von Umweltzielen (und letztlich der N-PB) kann langfristig die Resilienz sozial-ökologischer Systeme erhöht und eine Nachhaltigkeitstransformation unterstützt werden.

Letztlich kann das PB-Konzept jedoch nur flankierende übergeordnete Handlungsempfehlungen aus globaler Sicht und im Sinne einer vertikalen Integration geben, welche die Formulierung spezifischer nationaler Ziele unterstützen. Die Festlegung von integrierten nationalen Stickstoffzielen muss v.a. kontext-spezifische Aspekte und Interessen berücksichtigen. Dabei können z.B. integrierte nationale Stickstoffbudgets, wie sie von UNECE (2013) entwickelt werden, Unterstützung leisten oder auch *critical loads* (und entsprechende Teilziele) für die Umweltkompartimente Gewässer (auch Grundwasser), Luft und Ökosysteme, wie sie z.B. von Erisman et al. (2001) und de Vries et al. (2001) für die Niederlande bestimmt wurden.

2.2.6 Handlungsempfehlungen für eine nationale Stickstoffstrategie

Die planetaren Leitplanken verdeutlichen einen sicheren Handlungsraum, innerhalb dessen ein geringes Risiko für die Destabilisierung des Erdsystems mit nachteiligen Folgen für die Menschheit besteht (Steffen et al. 2015a). Wie in Kapitel 2.2.1 dargestellt, können die planetaren Leitplanken die horizontale und vertikale Integration anleiten und die integrierte Umsetzung der nachhaltigen Entwicklungsziele (SDGs) in Deutschland unterstützen. Dieses Kapitel soll nun darlegen, welche operativen Schritte

[104] Für den Begriff "Ressourcen" siehe Roadmap for a Resource Efficient Europe, dort werden genannt: abiotische Ressourcen (wie Mineralien und Metallen), biotische Ressourcen (alle Arten von Biomasse einschließlich landwirtschaftlicher Produkte) und Umweltmedien (z.B. Land und Wasser).

angezeigt erscheinen, um der normativen Intention der planetaren Leitplanken für die Stickstoff-Dimension Geltung zu verschaffen, nämlich das Erdsystem stabil und innerhalb der N-PB zu halten.

Charakterisierung des Nr-Problems aus politikwissenschaftlicher Sicht

Um geeignete politische Handlungsempfehlungen abzuleiten, muss zuerst die Problemlage im Stickstoffbereich kurz charakterisiert werden (die Charakterisierung folgt dabei in wesentlichen Punkten dem Ansatz von Young 2008).

Wie zuvor bereits dargestellt (vgl. Kapitel 2.2.1), sind die Eintragungswege für Stickstoff in die Umwelt vielfältig und es existieren vielfältige Treiber (politische Rahmenbedingungen, technologische Entwicklungen, Entwicklungen auf der Nachfrageseite) und Verursacher (u.a. Landwirtschaft, Energieerzeugung und Verkehr). Außerdem wirkt sich auch die nationale, regionale und weltweite Bevölkerungsentwicklung auf künftige Stickstoffeinträge aus – dies ergibt sich unter anderem aus dem Zusammenhang des Stickstoffproblems mit der Landwirtschaft und Ernährung.

Daneben ist das Stickstoffproblem dadurch gekennzeichnet, dass es ein Kollaborationsproblem darstellt – das heißt, dass, für die internationale Ebene betrachtet, deutliche Anreize für einzelne Staaten existieren, von vereinbarten Regelungen abzuweichen. Das Kollaborationsproblem im Stickstoffbereich existiert aber auch auf kleineren räumlichen Skalen, so auf der europäischen Ebene beim Eintrag von Stickstoff in die Nord- und Ostsee sowie bei Luftverschmutzung durch Stickstoff. Selbst innerstaatlich tritt dieses Problem auf.

Die Emission von reaktivem Stickstoff ist ferner als räumlich explizites Problem einzuschätzen, das heißt, das Problem ist ortsgebunden, manifestiert sich in unterschiedlichen Kontexten unterschiedlich und muss deshalb einzeln in unterschiedlichen Regionen bearbeitet werden (vgl. Young 2008). Damit wird die Regelkonformität von Akteuren in Hotspots wichtig.

Zudem kennzeichnet die N_r-Problematik auch die Gefahr von regionalem bzw. lokalem abruptem Wandel ökologischer und sozial-ökologischer Systeme durch Stickstoffeinträge (bspw. durch Eutrophierung). Mögliche Reaktionsfristen sind damit teils kurz und gleichzeitig auch nicht vorhersehbar.

Die in Kapitel 2.2.2 angesprochenen Hauptregionen der Stickstoffemissionen verweisen schon auf besonders wichtige Stakeholder – insbesondere die USA, die EU-Mitgliedstaaten und Staaten in Ost- und Südasien (u.a. Indien, China, Indonesien). Gleichzeitig ist abzusehen, dass sich die Hauptregionen in Zukunft ausweiten oder verschieben könnten – beispielsweise könnte Afrika durch die absehbare Bevölkerungsentwicklung (Vereinte Nationen 2015) und landwirtschaftliche Entwicklung bzw. nationale Landwirtschaftsplanung zunehmend eine Rolle spielen. Die Hauptregionen der Stickstoffemissionen sind deshalb als sich dynamisch weiter verändernd zu betrachten. Damit ist auch die internationale Akteurslage zumindest auf die Dauer nicht feststehend.

Die zahlreichen hier aufgezeigten Facetten zeigen, dass es sich insgesamt nicht nur von der Thematik her, sondern auch von der Struktur her (räumliche und zeitliche Skalen, Akteursgruppen und Interessenlagen, Handlungsoptionen etc.), um eine hochkomplexe, im Sinne von einfachen Lösungen nicht zugängliche, Gesamtproblematik handelt.

Dem steht gegenüber, dass das Problemverständnis vieler wesentlicher Akteure im N_r-Bereich noch wenig ausgeprägt ist, besonders im Vergleich zur Klimawandelproblematik – das Thema ist weder stark auf der nationalen, noch auf der europäischen, noch auf der internationalen Agenda vertreten. Zwar sind erste Anzeichen für eine stärkere Problemwahrnehmung erkennbar (als Beispiele seien hier das Stickstoffgutachten des SRU und das Forschungsprojekt International Nitrogen Management System genannt) (Reay et al. 2011), doch sind dies nur allererste Ansätze. Künftige Konflikte über die Interpretation des Problems sind dabei jetzt schon absehbar – die erkennbar wichtigste Konfliktlinie wird international der Zusammenhang der N_r-Emissionen mit der weltweiten Nahrungsproduktion sein; europäisch und national werden die hohen ökonomischen Kosten einer N_r-Reduktion für die wichtigen Verursachergruppen (Landwirtschaft, Verkehr, Industrie und Energieerzeugung) die Problemwahrnehmung sicher entscheidend beeinflussen.

Zumindest existieren für verschiedene Bereiche, die vom N_r-Problem berührt werden, bereits Regelungen. So etwa für den Bereich der Biodiversität die Biodiversitätskonvention, für den Klimawandel die Klimarahmenkonvention, für die Auswirkungen des Stickstoffs für Luft und Wasser das Übereinkommen über weiträumige grenzüberschreitende Luftverunreinigung und das Übereinkommen zum Schutz und zur Nutzung grenzüberschreitender Wasserläufe und internationaler Seen (vgl. SRU 2015; Bull 2011).

Zu nennen sind auch eine Vielzahl von Richtlinien[105] der Europäischen Union (siehe Oenema 2011); ihre Effektivität variiert zwar je nach Sektor, für die recht wichtige Nitrat-Richtlinie haben Velthoff et al. aber gezeigt, dass diese zur Verringerung der Gewässer-Verunreinigungen durch die Landwirtschaft beigetragen hat (Velthof et al. 2014). Gemeinsam ist den verschiedenen Regelungsansätzen, dass sie sektoral angelegt, das heißt nicht hinreichend aufeinander abgestimmt sind, und oftmals nicht konsequent umgesetzt werden und nur begrenzt wirksam sind.

Allgemein gilt, dass die bisherigen Ansätze zur Problemlösung ungenügend sind, wie das SRU-Gutachten (SRU 2015) konstatiert: EU-Ziele werden verfehlt, existierende Umweltziele und Politiken mit Einfluss auf Stickstoffemissionen sind nicht immer konsistent, Synergiepotentiale zwischen bestehenden Instrumenten werden noch unzureichend genutzt. Der Grund hierfür liegt laut dem SRU-Gutachten in politischen und institutionellen Faktoren: in der privilegierten Rolle der Landwirtschaft, dem Einfluss wirtschaftlicher Interessengruppen (in den betroffenen Bereichen Verkehr, Landwirtschaft, Energieerzeugung, Industrie), existierenden Pfadabhängigkeiten, beispielsweise in der Agrarpolitik sowie bestehenden Strukturen in der Verwaltung. Eine Lösung des Problems durch einen einmaligen Regulierungsschritt im Bereich des Stickstoffeintrages ist aufgrund der geschilderten Komplexität nicht möglich.

Um aus dieser Situation eines sehr schwer fassbaren Problems, einer noch unzureichenden Problemwahrnehmung und einem unzulänglichen Instrumentarium herauszukommen, sind diverse Schritte erforderlich. Neben der in anderen Publikationen schon behandelten horizontalen Integration (siehe Kapitel 2.2.1) bedarf es erstens der besseren vertikalen Integration über alle Ebenen hinweg, um so die Politikkohärenz zu verbessern, und zweitens der verbesserten Institutionalisierung der N_r-Problematik. Beide Prozesse können durch die N-PB und allgemein den Planetary Boundaries Ansatz unterstützt werden.

Handlungsempfehlungen für die vertikale Integration

Deutschland sollte darauf hinarbeiten, das Stickstoffproblem als Umweltproblem auf allen Ebenen stärker auf die Agenda zu setzen (zu „*mainstreamen*“), insbesondere im Zusammenwirken mit weiteren Hauptemittenten. Für eine nationale Stickstoffstrategie bedeutet dies, dass beim Framing eine rein nationale Problembetrachtung und Problembearbeitung zu vermeiden ist. Vielmehr sollte auch für andere Staaten sichtbar werden, dass Deutschland eigene Anstrengungen als Beitrag zur europäischen und weltweiten Problemlösung sieht und letztlich europäische und weltweite Schritte nötig sind, um dem Problem gerecht zu werden. Dieses Framing kann durch den Rückgriff auf die Planetaren Leitplanken und die N-PB unterstützt werden, indem der eigene Beitrag innerhalb und außerhalb Deutschlands in Bezug zur weltweiten Herausforderung gesetzt wird, die durch das Überschreiten der N-PB schon verdeutlicht wird.

[105] Die einzelnen Richtlinien sind unter anderem: ambient air quality - 2008/50/EC; integrated pollution, prevention and control - 2008/1/EC; national emissions ceilings - 2001/81/EC; water framework directive - 2000/60/EC; urban wastewater treatment directive - 91/271/EEC; nitrates directive - 91/676/EEC; marine strategy framework directive - 2008/56/EC; directive on the protection of groundwater - 2006/118/EC.

Allerdings sollte hierbei beachtet werden, dass die Kontrollvariable für die N-PB rein auf die beabsichtigte industrielle sowie die zusätzliche biologische Stickstoff-Fixierung unter Nichtbetrachtung der Beiträge anderer Verursacher (z.B. unbeabsichtigte Stickstoffemissionen durch Verfeuerung fossiler Energieträger in der Industrie und dem Verkehr) abstellt. Politisch könnte so durch das alleinige Zurückgreifen auf den Ansatz der planetaren Leitplanken eine integrierte Stickstoffstrategie Gefahr laufen, vom Verursacher Landwirtschaft als unzureichend kritisiert zu werden, da Beiträge anderer Emittenten nicht in der Kontrollvariable der N-PB auftauchen. Deshalb sollte schon beim Framing dargelegt werden, dass die N-PB für die Darstellung nur ein erster wichtiger Schritt ist. In der Strategie selbst sollte in Bezug auf die N-PB außerdem noch auf die Beiträge anderer Verursacher hingewiesen werden.

Beim nationalen Framing ist außerdem die Ernährungsfrage immer mit zu bedenken, da hier international, gerade von Entwicklungsländern, Gegenwind zu erwarten ist. Die planetaren Leitplanken können hier im Sinne der „*planetary opportunities*" kommuniziert werden (DeFries et al. 2012): Globale Möglichkeiten ergeben sich beispielsweise durch die Umverteilung von Stickstoff von Überschussgebieten in Gebiete mit Defiziten, wiewohl eine solche Umverteilung auch vor praktischen Problemen steht (beispielsweise ist der genaue Mechanismus einer Umverteilung unklar). Hier sollte verdeutlicht werden, dass Begrenzungen des Stickstoffüberschusses nicht zwangsläufig zu verringerter Ernährungssicherheit führen, sofern die notwendige Stickstoff-Fixierung für die weltweite Ernährung mit in die Setzung von Grenzwerten aufgenommen wird (siehe hierzu auch de Vries et al. 2013; Van Grinsven et al. 2013) und sofern auch Alternativen zur Nutzung von fixiertem Stickstoff bedacht werden (Razon 2015).

Beim nationalen Framing sollte weiterhin der Beitrag der N-PB für die Umsetzung der nachhaltigen Entwicklungsziele (*Sustainable Development Goals,* SDGs) verdeutlicht werden; dazu zählen vor allem die drei Punkte i) Verringerung der Stickstoffbelastung innerhalb Deutschlands, ii) Reduktion der deutschen N-*footprints* im Ausland, wie sie durch Importe verursacht werden, sowie iii) internationale Kooperation für eine verbesserte Ressourceneffizienz. Die Einhaltung der planetaren Stickstoffleitplanken kann die Umsetzung verschiedener einzelner Ziele der SDGs unterstützen, dies sollte ebenfalls in der Strategie verdeutlicht werden. Dazu gehören unter anderem:

- Target 6.3: Verbesserung der Wasserqualität – hier kann die Einhaltung der Planetary N-Boundary unter anderem durch die Verminderung der Stickstoffeinträge in Gewässer zur SDG-Umsetzung beitragen
- Target 8.4: Verbesserung der Ressourceneffizienz – hier unterstützt die Einhaltung der Planetary N-Boundary die SDG-Umsetzung, sofern dies durch Verbesserung der Nutzungseffizienz von Stickstoff erreicht wird.
- Target 12.4: Verbesserung des Chemikalienmanagements und Reduzierung der Freisetzung von Chemikalien in Luft, Wasser und Boden – die Einhaltung der Planetary N-Boundary erfordert eine Verringerung der Stickstoff-Freisetzung
- Target 15.5: Reduzierung des Biodiversitätsverlustes – die Einhaltung der Planetary N-Boundary kann zur Verminderung der negativen Auswirkungen für Arten beitragen.

Die SDGs und die Planetary Boundaries stehen in einem Wechselverhältnis: die Einhaltung der N-PB unterstützt die Umsetzung der SDGs, gleichzeitig tragen die SDGs zur Einhaltung der Planetaren Leitplanken bei (vgl. bspw. SDG 12 „*Responsible Consumption and Production*", deren einzelne Ziele unter anderem das nachhaltigere Management und die effizientere Nutzung von Ressourcen wie beispielsweise auch Dünger ist).

Ein Ergebnis des erwähnten Framings der Stickstoffstrategie, also der Bezugnahme der N_r-Problematik auf die planetaren Leitplanken (und die SDGs) könnte auch die Forderung nach einer Förderung von Alternativen zu Mineraldünger sein, beispielsweise die ökologische Landwirtschaft, (Razon 2015) sowie die verbesserte Effizienz der Düngernutzung über u.a. Management- und Trainingsmaßnahmen und verstärktes Recycling (*circular economy*). Grundsätzlich scheinen aber Alternativen zum Mineraldünger allein bisher nicht in der Lage zu sein, die Ernährung der Weltbevölkerung vollständig zu sichern (Razon 2015).

Um im Rahmen der Stickstoffstrategie die vertikale Dimension gleich mitzudenken und eine vertikale Integration zu fördern, gibt es zahlreiche Ansatzpunkte für eine stärkere Politikkohärenz im Themenfeld N_r zwischen verschiedenen Ebenen. Zu diesen Ebenen gehören aus der Perspektive der Politikkoordination die Ebene der Bundesländer, die nationale Ebene, die EU-Ebene und die internationale Ebene. Ziel muss es auch hier sein, ein gemeinsames Problemverständnis und eine gemeinsame Sprache für alle Ebenen zu schaffen. Von allen Ebenen muss das Stickstoffproblem erst einmal als solches anerkannt werden und darauf Bezug genommen werden.

Auf der Ebene der **Bundesländer** ist ein zentraler Anknüpfungspunkt für die Politikkoordination die Umweltministerkonferenz. Hier existieren bereits verschiedene Arbeitsgemeinschaften mit Bezug zur Stickstoffthematik – so die Arbeitsgemeinschaft für Bodenschutz (LABO), für Immissionsschutz (LAI), für Wasser (LAWA) und für Klima, Energie, Mobilität, Nachhaltigkeit (BLAG KliNa). Ebenso wichtig sind die Landwirtschaftsministerien auf Länderebene. Die Stickstoffstrategie sollte hier darlegen, dass das Stickstoffproblem eine gemeinsame Aufgabe ist, zu deren Bearbeitung auch die Bundesländer und insbesondere die Landwirtschaftspolitik in den Bundesländern ihren Beitrag leisten muss. Auch hier kann die N-PB als Richtschnur fungieren; in der Strategie könnte darauf verwiesen werden, dass die Bundesländer zur Lösung der planetaren Herausforderung ihren Beitrag leisten müssen – eng abgestimmt mit dem deutschen Gesamtbeitrag.

Ein zentraler Anknüpfungspunkt für die **EU-Ebene** ist die Gemeinsame Europäische Agrarpolitik (GAP). Die GAP ist einer der wichtigsten Treiber innerhalb der N_r-Problematik (SRU 2015). Sie wurde zwar für den Zeitraum 2014-2020 reformiert, die Überarbeitungen sind allerdings als nicht weitgehend genug zu bewerten (vgl. SRU 2015; KLU 2013). Die Stickstoffstrategie könnte hier auf die zentrale Rolle der GAP hinweisen und darauf verweisen, dass das Erreichen nationaler Stickstoff-Ziele auch von Entwicklungen auf EU-Ebene abhängt und dass weitere Reformanstrengungen nötig sind. Ein zentraler Hebel hierfür wäre auch das 7. Umweltaktionsprogramm der EU, das sich schon in seinem Titel („Living well within the limits of our planet") zu den Planetaren Leitplanken bekennt. Die Stickstoffstrategie könnte hier argumentieren, dass dieses Bekenntnis der EU nun auch in andere europäische Politikbereiche integriert werden müsste – also eben gerade in den Landwirtschaftsbereich für die N-PB.

Auf der **internationalen Ebene** finden sich noch zahlreiche weitere Anknüpfungspunkte für die Politikintegration. Ein möglicher Ansatzpunkt lässt sich aus der zentralen Rolle des Handels mit landwirtschaftlichen Produkten ableiten. Da gerade landwirtschaftliche Erzeugnisse die mit einem hohen N_r-Überschuss verbunden sind, einen hohen Exportanteil aufweisen (Lassaletta et al. 2014), wird sich auf die Dauer natürlich für viele Staaten die Frage stellen, ob sie weiterhin bereit sind, Produkten die in der Herstellung stark umweltbelastend (und gleichzeitig oftmals hoch subventioniert) sind, den ungehinderten Zugang zu den eigenen Märkten zu ermöglichen. Marktzugangskriterien, wie sie die EU im Bereich der (nachhaltigen) Biomasseproduktion befürwortet, könnten beispielsweise künftig auch von außereuropäischen Importländern europäischer Lebensmittel gefordert werden. Der Globalisierung im Bereich der Agrargüter kann künftig mithin eine wichtige Rolle bei der Regulierung der N_r-Problematik zukommen, sofern hierzu die richtigen Geleise gelegt werden – und die Stickstoffstrategie kann auch hier einen ersten Beitrag leisten, etwa indem sie die weitere Beleuchtung dieser Frage einfordert.

Ein weiterer wichtiger Anknüpfungspunkt und ein zentraler Akteur für eine N_r-Lösung auf globaler Ebene ist die Ernährungs- und Landwirtschaftsorganisation der Vereinten Nationen (FAO), speziell mit Blick auf eine verbesserte Koordination zwischen Stickstoffreduktions- und Entwicklungszielen –

hier ist die Thematik teilweise bereits präsent, beispielsweise in Form der jährlichen Ermittlung von zu erwartender Düngernachfrage und -angebot (vgl. FAO 2015) (diese jährliche Ermittlung könnte künftig mit Blick auf ein erstes N_r-Monitoring ausgebaut werden) sowie dem Bericht „*Building a common vision for sustainable food and agriculture*" (FAO 2014). Die Rolle der FAO und deutsche Einwirkungsmöglichkeiten hierauf sollten ebenso in der Stickstoffstrategie adressiert werden wie das Committee on World Food Security, insbesondere mit Blick auf das Global Strategic Framework for Food Security and Nutrition. Wiederum kann das Konzept der Planetaren Leitplanken einen guten gemeinsamen Bezugspunkt darstellen, denn es verdeutlicht, dass Ernährungssicherheit (Food Security) ohne eine Einhaltung der N-PB nicht möglich ist.

Ein dritter Anknüpfungspunkt auf internationaler Ebene für die verbesserte Koordination von Politikzielen ergibt sich aus dem Zusammenhang von Klimawandel und Stickstoff. Dabei spielen negative Klimawirkungen durch N_2O-Emissionen und unbeabsichtigte positive Klimawirkungen durch den „*cooling effect*" eine Rolle. Gleichzeitig existieren Synergie-Effekte zwischen Anpassung an den Klimawandel, Klimaschutz und Stickstoffpolitiken, da die Treiber des Klimawandels und der Freisetzung von Stickstoff ähnlich sind (bspw. sich ändernde Konsummuster und Energienutzung; vgl. Erisman 2011). Im Kyoto-Protokoll ist N_2O bereits als Treibhausgas aufgenommen, auch in den „*intended nationally determined contributions*" bspw. der EU und ihrer Mitgliedsstaaten zum 2015 verabschiedeten Paris-Abkommen wird N_2O erwähnt. Bisher fehlen aber noch Stickstoffpolitiken, welche auf die Auswirkung der Stickstoffemissionen für den Klimawandel fokussieren. Es wäre zu überlegen, spezifische Stickstoffminderungsansätze (z.B. Stickstoffmanagement) in die Klimawandeldiskussion einzubringen. Hier sollten die positiven Synergieeffekte einer Stickstoffminderung für den Klimawandel verdeutlicht werden zusammen mit den negativen Umweltauswirkungen, auch für bspw. Biodiversität und Wasserqualität, die Stickstoffemissionen mit sich bringen. Für die Illustrierung der Wechselwirkungen zwischen Stickstoffkreislauf und Klimawandel könnte dabei auch auf den Ansatz der Planetaren Leitplanken (Stickstoff- und Klimaleitplanke) zurückgegriffen werden.

Handlungsempfehlungen für eine Institutionalisierung

Vieles spricht dafür, eine weitere Institutionalisierung im Bereich der N_r-Problematik anzustreben. Die eingangs geschilderte, sehr komplexe Problemlage lässt erwarten, dass es eines prominenten Akteurs (anzudenken wäre beispielsweise Deutschland oder die Europäische Union) und eines verbindlichen Sets von Regelungen bedarf, um zu substantiellen Fortschritten zu kommen. Wichtige erste Aspekte, die im Rahmen einer solchen Institutionalisierung aufzugreifen sind und die für eine Problemlösung in einem Politikkontext, wie er im N_r-Bereich vorliegt, eine hohe Bedeutung besitzen, sind u.a.:

- beständiges Monitoring und ein Compliance-Mechanismus

Wichtig für die effektive Problembearbeitung ist ein Compliance-Mechanismus, da das Stickstoffproblem, wie oben beschrieben, als Kollaborationsproblem zu werten ist. Konkret vorstellbar als Compliance-Mechanismen sind beispielsweise periodische Berichte – z.B. zu Stickstoffüberschüssen und konkreten Stickstoffminderungsmaßnahmen. Ebenso ist ein beständiges, unabhängiges Monitoring zentrale Aufgabe für die Problembearbeitung, da Anreize für die Nicht-Beachtung existierender Regelungen bestehen.

- Koordination bestehender Regelungen

Wichtig ist es außerdem, bestehende Regelungen in Bezug zueinander zu setzen, denn die institutionelle Bearbeitung des Stickstoffproblems hat Auswirkungen für andere institutionelle Arrangements und umgekehrt. Hierfür können auch die Planetary Boundaries eingesetzt werden: Sie können anzeigen, für welche Umweltbereiche Wechselwirkungen existieren und sie können mithelfen, die für die Koordination wichtige gemeinsame Sprache zu entwickeln.

- Früherkennung, Frühwarnung und beständige Anpassung

Schließlich ist auch die Früherkennung, Frühwarnung und beständige Anpassung existierender Regelungen zentral, denn durch das N_r-Problem ergibt sich, wie oben dargestellt, die Gefahr von regionalem bzw. lokalem abruptem Wandel ökologischer Systeme durch Stickstoffeinträge (siehe hierzu auch Galaz et al. 2008 und das im Ansatz der planetaren Leitplanken verankerte Vorsorgeprinzip).

Der Weg einer Institutionalisierung ist weit. Angesichts der skizzierten Problemlage besteht, wie schon geschildert, eine zentrale Voraussetzung darin, zuallererst eine gemeinsame Problemwahrnehmung aller für die Problemlösung wichtigen Akteure auf den verschiedenen Ebenen zu schaffen. Hiervon ist man zurzeit sicher noch weit entfernt. Dabei muss es darum gehen, dass von möglichst vielen Akteuren das Problem als solches anerkannt wird – dass also einerseits überhaupt wahrgenommen wird, dass reaktiver Stickstoff verschiedene Umweltprobleme verursacht (siehe hierzu Kapitel 2.2.1) und andererseits auch anerkannt wird, dass zur Verringerung der Umweltauswirkungen politische Maßnahmen nötig sind. Schon an dieser Stelle kann das Konzept der planetaren Leitplanken einen wichtigen Beitrag leisten, weil es keine Verursacher benennt, aber die Untragbarkeit der aktuellen Situation (im wahrsten Sinn des Wortes) auch bildhaft gut transportiert.

Um Problemwahrnehmung und Problemanerkennung zu forcieren, ist es weiterhin wichtig, eine gemeinsame „Problemsprache" zu finden, die allen Akteuren zugänglich ist. Auch hier kann der Ansatz der Planetaren Leitplanken nützlich sein: Das Konzept der Planetaren Leitplanken bildet einen leicht verständlichen Rahmen, der auch für Akteure zugänglich ist, für die die N_r-Problematik bisher eher weniger stark auf der Agenda steht. Zwar deckt das Konzept aktuell nur Teile der Problematik ab, aber dessen ungeachtet bietet es einen Startpunkt und einen Rahmen für eine gemeinsame Diskussion auch sehr unterschiedlicher Communities.

Für Fortschritte in Richtung verstärkter Institutionalisierung ist es weiterhin wichtig, die Stickstoff-Thematik in verschiedene Foren zu tragen und dort zu kommunizieren. Die Planetaren Leitplanken und die N-PB können diese Kommunikation unterstützen, indem sie etwa verdeutlichen, dass Risiken für die Resilienz des gesamten Erdsystems durch das Übertreten der N-PB entstehen. Verschiedene Foren für eine Vertiefung der Debatte zur N_r-Problematik wurden oben schon genannt, wie etwa die FAO oder UNFCCC. Weitere wichtige Diskussionsplattformen sind sicher UNEP (welches das Konzept der Planetaren Leitplanken bereits verwendet; vgl. Dao et al. 2015) und Future Earth als Forschungsplattform (an die sich über das Forschungsthema „Dynamic Earth" anknüpfen lässt).

Eine eigenständige Institutionalisierung der Stickstoffproblembearbeitung beispielsweise in Form einer eigenen globalen Stickstoff-Organisation kann aufgrund der bisherigen geringen Problemwahrnehmung und -anerkennung nur ein Fernziel (Zielhorizont 15 Jahre) sein. Wenn aber bei einer Vielzahl von Akteuren die Einsicht reift, dass das Stickstoffproblem einer verbesserten Zusammenarbeit und einer effektiveren Problemlösung bedarf, ist dieses Ziel sicher erreichbar.

Um die weitere Institutionalisierung voranzutreiben, ist die Stärkung des internationalen Forschungsprogramms „Towards an Establishment of an International Nitrogen Management System" (INMS) zu empfehlen, da die Veröffentlichung der Forschungsergebnisse des INMS ein Zeitfenster für erste mögliche Institutionalisierungsschritte bietet (voraussichtlich 2019). Dieses Forschungsprogramm untersucht den globalen und regionalen Stickstoffkreislauf und analysiert regionale, nationale und lokale Management-Maßnahmen (INMS 2015). In der INMS ist bereits eine Vielzahl der wichtigsten Akteure versammelt, darunter: die Global Environment Facility, UNEP, die International Nitrogen Initiative, das Centre for Ecology & Hydrology, the Global Partnership on Nutrient Management, Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, Convention on Biological Diversity, OECD, the Task Force on Reactive Nitrogen, Future Earth und das EU Nitrogen Expert Panel. In dieser bereits bestehenden Initiative zeigen sich folglich schon Ansätze einer internationalen Partnerschaft zur Stickstoffproblembearbeitung. Deutschland sollte die Initiative unterstützen, beispielsweise indem das Forschungsprogramm in der nationalen integrierten Strategie als einer der wichtigsten neuen internationalen Ansatzpunkte benannt wird. Anzudenken wäre auch einen PB-basierten Ansatz in den Prozess im INMS einzubringen.

Welcher weitere Institutionalisierungsweg sich letztendlich ergeben kann bzw. angestrebt werden sollte, ist zurzeit noch nicht abzuschätzen. Der Bereich der Erneuerbaren Energien hat aber mit der stark von Deutschland vorangetriebenen Gründung der International Renewable Energy Agency (IRENA) aufgezeigt, wie ein solcher Institutionalisierungspfad gezielt über einen längeren Zeitraum verwirklicht werden kann – mit der Schaffung von Diskussionsräumen, dem Platzieren von Themen, der Ansprache von Akteuren etc. Analog lässt sich auch eine Agenda für den N_r-Bereich aufzeichnen.

3 Ways Forward

3.1 Next steps for the political sector

3.1.1 Objectives

The concept of „planetary boundaries" forms an implicit – and increasingly also explicit – part of sustainability strategies and environmental policies (for example, in Germany, Finland and Switzerland). The concept has great potential for sustainability and risk governance in the public and private sphere, in particular for increasing policy and strategy coherence, communicating with expert groups, stakeholder groups and the broader public, supporting negotiations on global-scale targets for various environmental processes and influencing sub-global targets, as well as for mapping externalized environmental impacts. This potential needs to be further developed in a broad variety of conceptual, communicative and cooperative processes supported by policy to make the concept known and accepted, and to make it work.

Careful, contextualized, sophisticated communication and „operationalization" of the concept needs to be a key objective in the political arena.

The concept should be linked to (and embedded within) existing social and economic discourses. This can be done in particular by building a coherent narrative around the concept that frames the integrity of planetary systems and processes as necessary conditions for human dignity, livelihoods, economic prosperity and global peace. The relationship between planetary boundaries and the Anthropocene could also be further highlighted in order to create context.

The most comprehensive, global-scale sustainability process – the 2030 Agenda – does not explicitly take the concept of planetary boundaries into account. This is reflected in the difficulties that arise when implementing, operationalizing and downscaling the planetary boundaries concept for benchmarking and mainstreaming beyond communication purposes. Yet the concept reinforces the idea and purpose of the Sustainable Development Goals (SDGs) by emphasizing that a safe operating space is an indispensable condition for human wellbeing, a healthy planet and a steady economy.

Politically, the implications of a transition from the Holocene to the Anthropocene should be brought to the fore, in particular its consequences for security, justice, inclusiveness and prosperity, and for safe and just spaces on a global and local level. The planetary boundaries concept should be stressed as a complementary and supportive approach, in particular for the implementation of the SDGs.

The concept is still evolving and, as a set of environmental quality and risk norms, not yet fully quantified.

„Operationalization research" is evolving, and applications for sub-global contexts are growing, but there is not yet a „ready-to-go kit" for applying the concept in the political realm. Thus, there is a need for flexible interpretation within the planetary boundary framework of the parameters most relevant for different geographical scales and governance realities, in order to encourage the active engagement of policymakers.

For example, combining and lin- king the concept with bottom-up footprint work along global value chains, concepts of driving forces and environmental pressures, regionally and locally specified definitions of boundary systems and safe spaces is currently underway. This would appear to be as necessary as enhancing the link to concepts of social needs, distributional equity and economic prosperity. The risks that could arise when crossing planetary boundaries, and the associated dynamics and reversibility, should be further investigated and highlighted, and the insecurities involved should be described in a transparent manner.

3.1.2 Next steps

Dialogue

The dialogue process around planetary boundaries should be continued in a sophisticated manner, focusing on scientific, communicative, educational, political and societal issues. This dialogue can build on previous conferences and workshops such as those held in Geneva (2013)[106] and Brussels (2014)[107] and especially on the conference in Berlin in 2017. The dialogue process should be supported by policymakers.

In the political sector, especially within Europe, a dialogue should be initiated (or stepped up) between European, national and regional governments with the objective of elaborating on the political dimensions and potentials of the concept and how it can be integrated and operationalized. The idea of an exchange between European Union member states concerning the design of national policies and a potential 8th EU Environmental Action

Programme, possible contributions to a renewed European Sustainability Strategy, and the implementation of the 2030 Agenda could be taken up within the EU, the European Sustain- able Development Network (ESDN) and the European Environmental Agency (EEA).

Dialogues in the academic, business and civil realms could be supported by policy, national foundations and associations. Focus issues might include, for example: emergent planetary systems risks for the insurance, business and financial sector; the innovative and cooperative potential of the enhancement of safe and just spaces, both globally and locally; and the communicative and educative potential of planetary systems thinking.

Political action

Integration of the planetary systems („Earth as a complex system") idea into the 2030 Agenda could greatly advance the implementation of the SDGs at a national, European and UN level. The notion of a „safe and just space" could represent a politically sound path for connecting planetary boundaries with the 2030 Agenda. A scientifically informed political process should evaluate and inform the Agenda 2030 and its sub-global sustainability strategies referring to the concept of safe and just spaces; the Global Sustainability Report of the UN, relevant reports by UN Environment and related projects such as the Global Risks Report of the World Economic Forum (and the World Business Council for Sustainable Development) could begin connecting planetary boundaries with the 2030 Agenda. Further negotiations and development of sustainability targets and indicators on an international, national and regional level should form part of this process.

Policymakers should strive for operationalizing policy instruments that bend back the „hockey stick" trends that have emerged since the onset in the 1950s of the Great Acceleration phase of drivers and pressures impacting the integrity of the planetary systems. We need a politically initiated societal debate about a socio-ecological market economy, welfare models and new measuring approaches, taking into account the Anthropocene, planetary systems, global footprint and safe and just space approaches.

Research and education

Increased research efforts are needed into the governane challenge arising from the planetary boundaries concept and the strategies and policies needed to stay within the safe operating

[106] Workshop in Geneva, November 3-5, 2013 on „Planetary boundaries and environmental tipping points: What do they mean for sustainable development and the global agenda?"

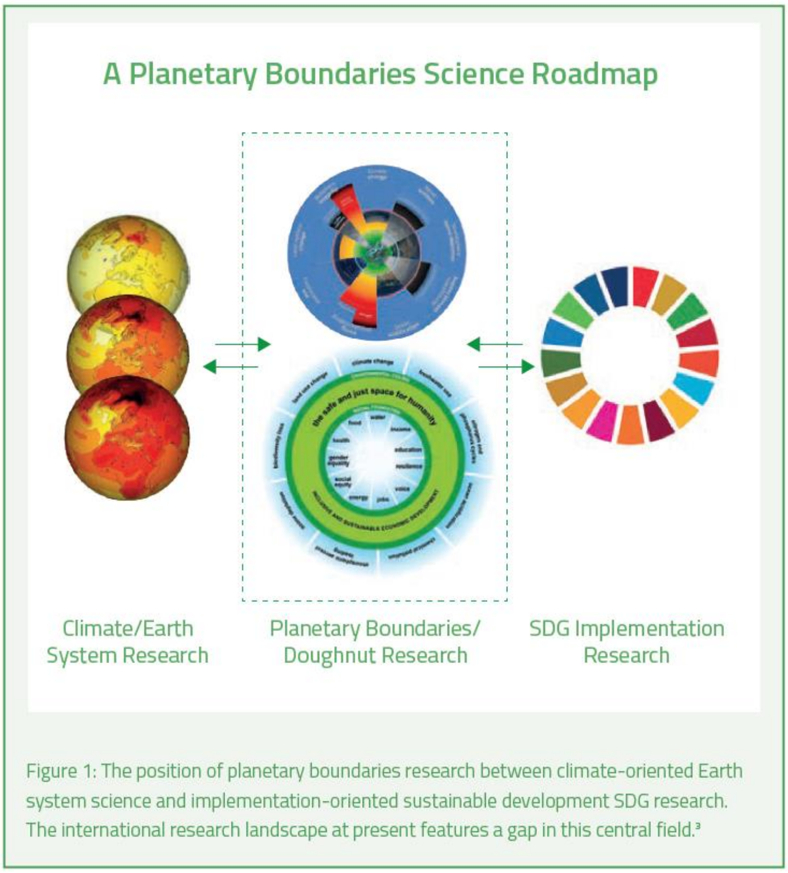
[107] Workshop in Brussels, January 23-24, 2014 on „Safe operating space – Current state of the debate and considerations for national policies".

space. More research is also needed into how to effectively implement these strategies and policies from a global perspective, including suitable formats for dialogue on scientific policy and identifying options or reforms to curricula (for example, in the field of political and business economics).

3.2 Next steps for the scientific community

The planetary boundaries framework has become increasingly important in environmental policymaking on both a national and an international level. It underpins the UN's Sustainable Development Goals (SDG) process (2015), as well as some national policy agendas such as Germany's Integrated Environment Programme and Germany's National Sustainable Development Strategy (both 2016).

Figure 74: The position of planetary boundaries research between climate-oriented Earth system science and implementation oriented sustainable development SDG research



Source: from authors, PIK

Nonetheless, the international landscape of research into planetary boundaries features some large gaps that are hampering the more advanced application, operationalization and communication of the framework in strategic policymaking, sustainability evaluation of business practices and the general public debate. The plane- tary boundaries research community, although expanding, is still relatively small. Available funding is not geared toward advancing the concept for operational applications. Efforts in modeling and data analysis require more focus on increasing the practical utility of the framework and its underlying challenges for economic theory, socio-metabolic governance and normative choice. This situation slows down the required strategic tie-ins between sustainable development and Earth system analysis in support of increased, targeted policy coherence.

Planetary boundaries research is situated between the more traditional climate-oriented Earth system sciences and implementation-oriented sustainability/SDG science. The scope of analysis is widened from a focus mainly on climate and its impacts to the whole of the Earth system, particularly the integrity of the biosphere. From the perspective of case-oriented socio-ecological SDG research, it elaborates the properties defining a safe operating space for social and economic development and the opportunities this space offers for implementation of the SDGs. Figure 74 illustrates the central position of planetary boundaries research between SDG research and climate-centered Earth system research.

The concept of planetary boundaries is characterized by several aspects:

- Multi-topical, systemic approaches
- Transformative implications of planetary boundary maintenance and transgression in the context of the SDG agenda
- Governance of socio-metabolic flows

Commonly asked questions include, for example: What are the dynamics of planetary boundary processes and how fast are we approaching the thresholds? What happens once we transgress boundaries? Why do we not see the effects of transgression yet? What are the synergies and tradeoffs for staying within planetary boundaries? How can a planetary quantity be applied to the evaluation of a region or a sustainable development strategy?

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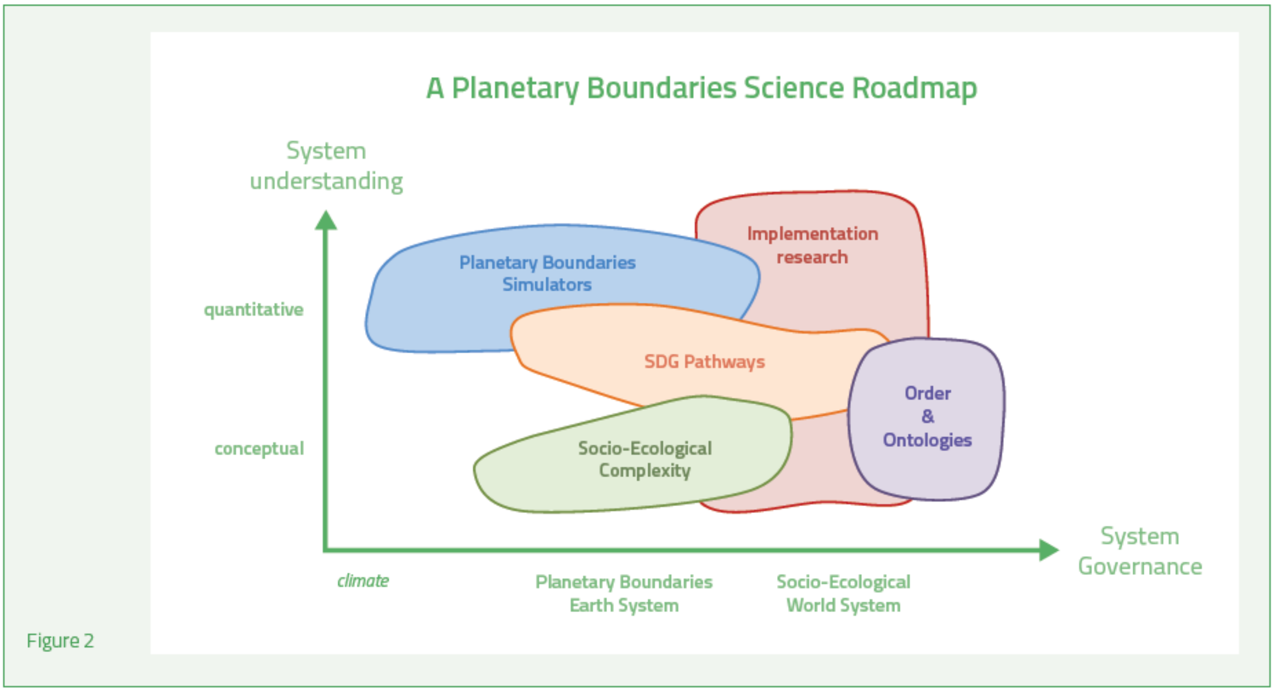
Figure 75: A Planetary Boundaries Science Roadmap (system understanding and system governance)



Source: from authors, PIK

Figure 75 presents the outlines of a topical roadmap for planetary boundaries research, identifying the following key areas of research:

- Realization of comprehensive planetary boundaries simulation models
- Quantification of SDG pathways within planetary boundaries
- Research on socio-ecological complexity under conditions of planetary boundaries
- Research on the implementation of planetary boundaries concepts in environmental and sustainability policy, businesses, sectors and regions
- Research on the implications of planetary boundaries for concepts of natural, social, economic and political order, and associated ontologies in discourse and communication

Additionally, a number of international procedural actions are suggested in support of operationalizing the planetary boundaries framework for the purpose of policymaking.

3.2.1 Planetary boundary simulators

The simulation of planetary boundaries and their dynamic interactions with the Earth system require adapted types of models, centered among other things on the marine and terrestrial biogeochemistry, biodiversity, the effects of agriculture and other land use, environmental pollution, and coupled to atmosphere-ocean models.

Key new research areas are:

- A whole system approach in which biosphere integrity (not just climate) is central
- Treatment of human societies as dynamic biogeochemical components („anthropo-biogeochemistry")
- Planetary boundary interactions, hotspots and teleconnections
- Nexus research (land-ocean, land-water-energy-agriculture, and so on)
- Emphasis on tipping element interactions shaping the planetary boundaries framework

3.2.2 SDG pathways

Quantifying pathways that meet the socio-economic objectives of development while staying within planetary boundaries is an important task when evaluating sustainability strategies. With respect to a number of sectors (for example, water, food, energy), integrated assessment models have begun to simulate such SDG pathways (see, for example, the Sustainable Development Solutions Network's (SDSN) initiative The World in 2050 – TWI2050).

Key new research areas are:

- The socio-economic feasibility of normative paths (including long term)
- Quantifying SSPs (shared socio-economic pathways; benchmarking against planetary boundaries)
- Economics of socio-metabolic and technological governance
- Non-monetary (social and environmental) metrics
- Synergies and tradeoffs between SDG objectives and maintaining and/or achieving safe and just operating spaces

3.2.3 Socio-ecological complexity

The co-evolving World-Earth system is a complex socio-ecological system expected to display properties such as bifurcations, tipping points, state transitions, limit cycles, and the emergence of macro-patterns and macro-dynamics. To a large extent, established Earth system and integrated assessment models fail to capture these properties due to their specific approaches. The preconditions under which a simultaneously safe and just operating space exists, from the viewpoint of complexity science, is a topic of critical importance.

Key new research areas are:

- Preconditions for the existence and resilience of safe and just operating spaces
- Co-evolutionary planetary-scale socio-ecological dynamics and tipping points
- Topology and attainability of desirable states
- Resilience and interaction metrics, definitions and concepts
- Agency, networking, and complexity in socio-ecological dynamics

3.2.4 Implementation research

The interfaces of planetary boundaries research with policymaking, business and the broader public are decisive for their operationalization, and represent a topic of research in themselves. Such research also addresses the normative dimensions of the concept, such as concepts of risk, precaution and cultural preferences, as well as the challenges of policy coherence across sectors and spatial scales.

Key new research areas are:

- Science-society interfaces, translation, and integration into decision-making cycles
- Global footprints: teleconnections and socio-metabolic externalities
- Environmental justice, security, legitimacy, cooperation and institutions
- Resolving up-scaling and downscaling dilemmas, systemic and cross-scale policy coherence, and actor, interest and institutional analyses
- Interlinkages with the circular economy, the green economy
- Learning and education, initiatives and social engagement

3.2.5 Orders and ontologies

If the concept of planetary boundaries is to become more prevalent in the public discourse, it is very important that its implications for the dimensions of socio-cultural discourse are considered. Also of central importance is the issue of language and images, their implications, associations, sub- texts and opportunities. Key new research areas are:

- Planetary boundaries and new natural, social, cultural and political orders/mindsets
- Methods for advancing shared meaning through common language
- Reconnecting with the biosphere: ethical, spiritual, religious, philosophical, and moral aspects
- Risk discourse and precaution, opportunity and transformation narratives

3.2.6 Procedural actions

A number of international initiatives and actions supporting operationalization the concept of planetary boundaries in policymaking are recommended:

- Regular planetary boundary Assessments (including SDG evaluation), national/sectoral assessments
- Dialogue platforms with business / finance
- “Costs of inaction” reports and research gap anylysis
- An international advisory group on concepts and definitions
- Cooperation on modelling, scenarios and data cube (Future Earth, TWI2050, SDSN, etc.)

3.3 Next steps for the private sector

The planetary boundaries conference underlined both the challenges for private sector operationalization and the progress that has been made since the concept was first established in 2009. The main challenges comprise developing methodologies to downscale and translate the global concept to the scale of companies and to embed it in companies' operations so as to influence their performance on corporate sustainability – in a way that goes beyond merely referring to it in corporate responsibility reports.

Since 2009, several companies have embarked on the operationalization of planetary boundaries, relating their corporate activities to the concept. Overall, however, implementation is still in its infancy. This is despite important steps having been taken, especially under the Action 2020 plan formulated by the World Business Council for Sustainable Development.

3.3.1 Added value

The conference underlined that the planetary boundaries concept has added value for sustainable businesses. First, there is the communication side of the framework. The concept creates a narrative, a story, which puts sustainable business activity in a much larger context – that of safeguarding humanity. Companies can use the concept as a tool for raising awareness both internally and externally:

- Internally, they can use it to put the risks the concept highlights on the managing board's agenda (planetary boundaries as risk management)
- Externally, they can use it to showcase their commitment to sustainability and to build consumer trust by coupling references to the concept with credible steps aimed at implementing sustainability measures across the entire value chain.

Second, there is the content of the concept itself. The concept helps determine the main sustainability dimensions that companies should take into account (a comprehensive sustainability dashboard), as well as highlighting their interlinkages (the systemic nature of the framework). For some planetary boundaries, the concept suggests a global budget and formulates global-scale performance indicators. Potentially, the concept can thus support the formulation of science-based targets for companies. As current methodologies for downscaling are still evolving and not yet fully functional, directly deriving targets from the concept on a larger scale is not yet feasible. Furthermore, it is crucial to take the company's context into account when relating the planetary boundaries concept to actual business activity (co-development).

3.3.2 Next steps

Several objectives are important for further operationalizing the concept. Scientifically, an initial objective would be to continue developing methodologies for downscaling, and to further strengthen the concept. It is also important to analyse existing corporate responsibility standards, such as the standards developed by the Global Reporting Initiative (GRI), the UN Global Compact, the European Commission (Eco-Management and Audit Scheme, EMAS), ISO14001, and footprinting standards, such as 14040, regarding their relationship to and (compatibility with) planetary boundaries. This is important because these standards are one of the main entry points for operationalization. To support such an analysis, it would be helpful to conduct interviews with standard organizations and companies. It is also crucial to discern where, and how, the planetary boundaries concept has already been applied in market overviews, and to develop further strategies for incorporating it into business operations.

A second objective would be to support companies in implementing the concept. In this regard it is important to develop argumentations and narratives focusing on the added value for businesses of incorporating the planetary boundaries concept – in other words, a business case. Furthermore, guidance as to how to implement the concept is crucial, for example through a planetary boundaries compass, by incorporating forerunners („flagships“) for specific boundaries, and by translating the concept into concrete terms for the business world. When supporting companies it is especially important to relate the concept‘s core messages to the existing corporate language and corporate sustainability instruments. The planetary boundaries concept should be framed as complementary to existing standards.

To further incorporate the concept in small and medium-sized enterprises (SMEs), it would be very beneficial to relate the innovations already undertaken by SMEs to the overarching concept (for example, in the form of a "good practice guide"). Many companies, including SMEs, already implicitly promote the planetary boundaries concept by developing and using innovative technologies and production processes to improve their environmental performance. Such an analysis could also facilitate the exchange of innovative ideas between companies, or inspire those who want to take their engagement in environmental protection further.

A third objective would be to further disseminate the concept. For this, it is central to raise awareness among companies. In particular, the concept needs to be connected to other dialogue processes of relevance for the private sector, such as socially and environmentally sustainable procurement (Kompass) and „CSR made in Germany“, as well as SEED and SDG implementation. It is also important to use existing communication channels to contact SMEs and larger companies. Continuous dialogue focusing on the further co-development of planetary boundaries is thus an important next step when working with chambers of industry and commerce, insurance companies and trade associations, for example, as well as with businesses, the scientific community and the political sector.

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