

## **Requirements for the regionalization of global sustainability indicator concepts**

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### **Abstract**

Sustainability indicators are among the central pillars of the functional perspective of sustainability management, dealing with the question of how sustainable development can be measured. The formulation of quantified and terminated objectives in the form of indicators is an important instrument for sustainable analysis, political decision-making and the binding effect of a sustainability strategy. Studies on successful sustainability strategies have shown that the good governance criteria of integrated perspective as well as vertical integration and continuous monitoring and evaluation are of particular importance. In the context of good governance criterion of vertical integration the aspect of regionalization and coherence is of special relevance. At the same time, interdependencies and thus composite sustainability indices play a central role in an interlinked view of the sustainability dimensions.

This paper discusses the requirements for the regionalization of global and composite sustainability indicators. Footprint indicators (ecological, resource-related, etc.) and the planetary boundaries framework according to Rockström et al. (2009a, 2009b) are examined as illustrative examples for the adaptation to the sub-national level. The planetary boundaries show the resilience of the earth in nine indicator ranges. Humanity should act within these process limits, since exceeding these limits entails a risk for future generations. The environmental footprint indicators are comprehensive indicators that take into account the environmental impacts of domestic production and consumption.

The state of North Rhine-Westphalia, Germany's most populous region and one of the most important conurbations in Europe, is regarded as a case study. With its high energy and resource intensity and high emissions of industrial greenhouse gases, the state of North Rhine-Westphalia has great potential and at the same time, a great need to make a contribution to sustainable development.

The paper presents the possibilities and limitations of different calculation approaches in the context of the regionalization of global and composite sustainability indicators and outlines the first steps for the regionalization of the two concepts examined. The results can contribute to the (further) development of sustainability strategies at sub-national levels of government and increase comparability and coherence in a multi-stage system.

# 1 Introduction

Since the overall picture of a sustainable development is due to its abstractness characterized by lack of direct measurability, tools (indicators) are required for the measurement (Günther/Schuh 2000). Sustainability indicators are among the central pillars of the functional perspective of sustainability management, dealing with the question of how sustainable development can be measured (Schostok 2017). In this context an indicator can be understood as “a measureable part of a system” (Dalal-Clayton/Bass 2002) and in a more functional perspective as “a reductionist technique and tool” (Bell/Morse 2008). On the one hand the formulation of quantified and terminated objectives in the form of indicators is an important instrument for sustainable analysis, political decision-making and the binding effect of a sustainability strategy. Studies on successful sustainability strategies have shown that the good governance criteria of integrated perspective as well as vertical integration and continuous monitoring and evaluation are of particular importance. (ESDN n.y.; OECD 2001; UN DESA 2002; Steurer/Trattnigg 2010; Quitzow 2010; Borbonus et al. 2014, 2015) On the other hand, due to the reductive analysis function, indicators can be criticized: Indicators have an inherent context reduction function and can lead to too much simplification, especially in controversial and highly complex contexts (Bell/Morse 2008; Merry 2011; Mair et al. 2018). Indicators are regarded as objective and complete descriptions of the contexts they measure, but since the indicators are used by people or organizations with different interests, they can be guided in their informative value and are often valuable in reality and thus partly incomplete in describing the contexts they measure (Merry 2011; Porter 1995; Mair et al. 2018). Therefore indicators must comply with the quality criteria of empirical measurements. The indicator should comply with the principle of a) objectivity - the findings reflected by the indicator should be independent of the persons conducting the investigation (Häder 2015); b) reliability - being so reliable that repeated measurements of an object using a measuring instrument produce the same values (Schnell/Hill/Esser 2005); c) validity - being valid in that the measuring instrument actually measures what it is supposed to measure (ibid.).

Since different system understandings lead to different indicators, an indicator of a system should not be understood as comprehensive information about the system itself, but as a part of information that reflects how an individual or group conceives this system (Meadows 1998; Davis/Kingsbury/Merry 2015; Mair et al. 2018). Therefore in the context of good governance criterion of vertical integration the aspect of regionalization and coherence, also with regard to indicators, is of special relevance. Preliminary studies have shown a diversity and heterogeneity of indicator systems in the multi-level system of the United Nations, the European Union as well as on the national and sub-national level of the Federal Republic of Germany, which substantiates a restricted comparability among the indicators (Schostok 2015a,b; Schostok/Ulrich 2018). At the same time, interdependencies and thus composite sustainability indices play a central role in an interlinked view of the sustainability dimensions. Sustainability reporting and indicator reporting in particular has become holistic and integrative, due to the need for some indicators to address several dimensions of sustainability at the same time (Lozano/Huisinigh 2011), (Perrini/Tencati 2006). In the course of developing sustainability indicators, any interactions between indicators and SDGs and its targets must be identified and addressed.

Based on these preliminary remarks, the possibilities and limitations of different calculation approaches in the context of the regionalization of two global and composite sustainability indicator frameworks will be examined: Planetary boundaries and ecological footprint - the latter as an exemplary excerpt of the footprint family. In the following chapter 2 a short overview of the background of the research project and the case study North-Rhine Westphalia will be given. Subsequently, the two sustainability indicator frameworks are examined in chapter 3 separately from each other with regard to the regionalization for North-Rhine Westphalia. Finally, chapter 4 draws a cross-example conclusion and outlines an outlook on further research needs.

## **2 Background**

### **2.1 Sustainability Strategy of the Federal Republic of Germany and its federal states**

The sustainability strategy has a long tradition in Germany. Only one year after the publication of the European Sustainability Strategy in 2001 (Commission of the European Communities 2001), the Federal Republic of Germany published its first sustainability strategy.<sup>1</sup> In 2016, the Federal Government of Germany published a new edition of the German Sustainability Strategy (NDSG Germany 2016). The revised version of the German Sustainability Strategie is explicitly based on the SDGs (ibid.). By May 2017, a total of 35 publications were published in the framework of the interdisciplinary sustainability reporting in the federal states of Germany (Schostok 2017). This reflects the central importance of the strategies for sustainable development at the level of the federal states.<sup>2</sup>

### **2.2 Sustainability Strategy of North Rhine-Westphalia**

The state of North-Rhine Westphalia (NRW) has a highly energy- and resource-intensive economic structure and is one of the most important regions for the entire Federal Republic of Germany and also within Europe. An overview of key facts<sup>3</sup> makes clear that the state of NRW has to take on a high degree of responsibility for sustainable development and at the same time can make a significant contribution to achieving the Sustainable Development Goals (SDGs). In June 2016, the state government of North Rhine-Westphalia adopted the first sustainability strategy for North Rhine-Westphalia

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<sup>1</sup> Since that date, the Federal Republic of Germany has published a total of three progress reports (2004, 2008, 2012), five indicator reports by the Federal Statistical Office (2006, 2008, 2010, 2012, 2017) and three external peer reviews by the German Council for Sustainable Development (2009, 2013, 2018) as well as the updated sustainability strategy in 2016.

<sup>2</sup> A total of 56 documents on sustainability-related sustainability reports (sustainability strategies, progress-, indicator-, and sustainability reports as well as reviews) were published by the European Union, the Federal Republic of Germany and its federal states during the period from 01.01.2001 to 01.05.2017 (Schostok 2017).

<sup>3</sup> The state of North-Rhine Westphalia (NRW) has a highly energy- and resource-intensive economic structure and is one of the most important regions for the entire Federal Republic of Germany and within Europe. The state of NRW is the most densely populated area (525 inhabitants per km<sup>2</sup>) in Germany and with about 17.9 million inhabitants (21.7% of the German population) one of the most important urban areas in Germany and in Europe (Statistische Ämter des Bundes und der Länder 2014). The state of NRW is a national and international important economic region: 21.2% (691,5 billion euro) of German GDP were generated in NRW in 2017, these are 4.5% of European GDP (EU-28) (NRW.INVEST 2018a). A total of 15.2% of Germany's export goods are produced in NRW - this results in an export value of 181.5 billion euros in 2015 (NRW.INVEST 2016). In 2015 North Rhine-Westphalia industry accounts for 27.4% of German net electricity consumption and in 2016 emits 19% of industrial greenhouse gas emissions (GHG) in Germany (IWR 2018; LANUV 2018a).

(NRW) (State Government NRW 2016a, 2016b), that covers all three dimensions of sustainability (environmental, social, economic). Beside the strategy paper, that is also available in English (SDS NRW 2016), a central pillar of the sustainability strategy for NRW is a target and indicator system consisting of roughly 70 indicators with targets for the years 2020, 2030 or 2050 responding to 19 central areas of action in the sustainability strategy (State Government NRW 2016a, 2016b). All indicators are align to the United Nations Sustainable Development Goals (SDGs) of Agenda 2030 (UN 2015). The development of the sustainability strategy and the indicator report of NRW were scientifically accompanied by the Wuppertal Institute.

### **2.3 Accompanying Research Project by the Wuppertal Institute for Climate, Environment and Energy**

This paper is based on the partial results of the on-going scientific project "Experiences of Implementing Statewide Sustainability Strategies - Case Study: Sustainability Strategy NRW" (2016-2020) (Wuppertal Institute 2016).<sup>4</sup> Based on the example of North Rhine-Westphalia, the research project aims at exploring selected questions that typically arise during the implementation of a state-wide sustainability strategy. One research focus is the compatibility of NRW's sustainability strategy with existing sustainability strategies on UN, EU and national level, as well as to the Sustainable development Goals, with regard to the objectives and indicators used in NRW (ibid.)

The aim of this paper is to discuss the challenges of the development and regionalisation of global sustainability indicators and in particular the adaptation of the footprint indicators and planetary boundaries using the state of North Rhine-Westphalia as a case study.

## **3 Challenges for the regionalization – Case study NRW**

As already outlined in the introduction, indicators are highly important in the context of sustainability reporting. At a superordinate level, two global sustainability indicator frameworks in particular have achieved a central significance for measuring sustainable development in recent years: footprint indicators and planetary boundaries.

- Footprint indicator Family: a complementary measure of appropriation of ecological assets, greenhouse gas emissions, fresh water consumption and pollution associated with the consumption of certain products and services (Galli et al. 2013)
- Environmental footprint: "a measure of human pressure on the planet's environment in relation to resource extractions and waste emissions";
- Planetary boundaries: "a measure of the regenerative and absorptive capacity of the Earth's life-supporting systems, beyond which unacceptable environmental changes for humanity may occur" (Fang et al. 2015a).

Overridingly, the ecological footprint and the planetary boundaries can be classified in the categories of descriptive pressure indicators or critical threshold values (Fang et al. 2015b).

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<sup>4</sup> The project is funded by the Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia.

### 3.1 Footprint indicator family

The more visible the finite nature of our planet's natural resources becomes, the more urgent the question arises as to whether production and consumption in national and regional economies are moving towards a resource-saving and ecologically sustainable, i.e. green economy as the UNEP (2011) deems necessary. Answering this question requires measuring the environmental pressure associated with production and consumption activities in order to derive important information for a targeted environmental policy. National environmental statistics provide central indicators for this, but they only describe the domestic (direct) environmental pressures associated with production and consumption (e.g. direct CO<sub>2</sub> emissions of a manufacturing sector in NRW). In times of globalization, though, domestic production, and in particular domestic consumption in many economies, is partly based on products manufactured abroad (imports). Consequently, it is necessary to make use of "comprehensive" indicators that take into account the global dimension of the environmental pressures of domestic production and consumption (e.g. global CO<sub>2</sub> emissions induced by the consumption of domestically produced and imported food in NRW). These "comprehensive" indicators should also include a variety of indicators of different environmental pressures associated with an economy's production and consumption activities. Footprint indicators can be used to illustrate various environmental pressures. If several footprint indicators (e.g. ecological, carbon, nitrogen) are considered, they are also referred to as the "footprint family" (Giljum et al. 2008). Based on a literature analysis by Fang et al. (2014), the ecological dimension of sustainability is most strongly represented in the footprint concepts and in particular the ecological footprint, carbon footprint, water footprint and energy footprint.<sup>5</sup> Due to the fact that all these footprints focuses on different aspects of environmental issues, they can and should be used complementary, which would also reduce the risk of shifting the environmental impact to other impact categories (ibid.). By reporting the entire footprint family, policy makers would also have a more solid instrument at their disposal to take account of the interactions between the dimensions. In order to outline the challenges and requirements associated with the regionalization of the footprint family on a sub-national level, an exemplary deepening is first considered on the basis of the ecological footprint.

From a scientific point of view, the calculation of the ecological footprint is mainly based on two approaches: First, using the traditional Global Footprint Network (GFN) method, and second the calculation of individual footprint indicators, based on an environmentally extended input-output analysis (EE-IOA).<sup>6</sup> The conventional approach (GFN) developed by Rees/Wackernagel (1992)<sup>7</sup> calculates a single indicator, the ecological footprint. This indicator, expressed in "virtual" units of area, measures the demand on and supply of nature.<sup>8</sup> By using the EE-IOA a number of different indicators are calculated, such as the resource, energy and carbon footprint. By determining each of these indicators, the "real" global environmental impact, i.e. resource consumption, energy consumption, CO<sub>2</sub> emissions, caused by production and consumption activities is estimated. These indicators are measured in different units (tones, TJ, CO<sub>2</sub> t) and not in area equivalents.

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<sup>5</sup> A comparison of the individual footprint indicators can be found under Laurent/Owsianiak (2017), for example.

<sup>6</sup> For a summary of the approaches to the energy, carbon and water footprint, reference is made to Fang et al. (2014) as an example.

<sup>7</sup> See also Rees (1992), Wackernagel/Rees (1996).

<sup>8</sup> For a detailed discussion of the method of the ecological footprint based on the National Footprint Accounts (NFA), please refer to Borucke et al. (2013).

In order to provide an adequate information basis for (environmental) policy decisions, the selection and measurement method of the indicators is of great importance. In this context, the intention associated with the indicator needs to be clarified. Is the intention to create a general awareness of the overuse of natural resources? Or is the appropriate recording of environmental impacts taking into account the interactions between consumption and production in the economy as well as the derivation of policy recommendations in the focus? For the second intention, the calculation of specific footprint indicators based on EE-IOA and in the best case over the entire and cross-linked footprint family is preferable to the GFN calculation approach.

Based on the current data and methods of the National Footprint Account (2016) North Rhine-Westphalia has an Ecological Footprint of 5.8 gha per capita in 2012 (MKULNV NRW 2016). Converted to one calendar year, North Rhine-Westphalia covers only 68 days of its needs with its own ecosystems or its biocapacity: Thus, North Rhine-Westphalia already used up its "eco-budget" on about 8 March, the rest of the year the state lives in "ecological deficit". This places North Rhine-Westphalia in the upper third of the European footprints. (MKULNV NRW 2016) The Environmental Report NRW shows and discusses the ecological footprint in detail and vividly on ten pages. In this way, the federal state succeeds in sensibly using the ecological footprint as a communication tool for raising general awareness of human environmental consumption, positioning itself in a benchmark against other countries and deriving an understandable target figure for the necessary reduction by comparing it with the available biocapacity.

Despite its high popularity and undeniable ability as a communication tool, the concept of the ecological footprint has received much criticism, both methodological and in gauging environmental sustainability (Laurent/Owsianiak 2017; Galli et al. 2016; Van den Bergh/Grazi 2010; Fiala 2008; Lenzen et al. 2007; Ayres 2000). In part, new calculation methods for the ecological footprint have been developed which take up some of the points of criticism (see as an overview for alternative calculation methods Wiedmann/Barrett 2010). Other points of criticism remain of a fundamental nature. Taking into account the weaknesses of the ecological footprint, the calculation of various footprint indicators using an environment-related IOT for the state of North Rhine-Westphalia is to be discussed.

The EE-IOA<sup>9</sup> enables the analysis of the global environmental impacts of production and consumption patterns in the economy. For this purpose, input-output tables (IOT), resource consumption and environmental impact data from economic sectors and private households are used. IOT contain all formal economic transactions within an economy and represents the intermediate and final use of products and services in monetary units. For each sector, it shows which goods are used to produce their own products and where these products are delivered to (i.e. to which sectors and final demand areas). Using an input-output model based on this representation of all transactions within (the global) economy, it is possible, for example, to calculate how much the individual sectors produce and how many goods have to be imported so that a certain quantity of end products can be delivered to consumers (households). This also includes all upstream production in the supply chains of the sectors. Once the environmental pressures and resource consumption associated with the production are known for each sector, the (direct and indirect) environmental impacts and resource

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<sup>9</sup> IOA is already a common method for the calculation of single-dimension footprints at national level, as the overview by Fang et al. (2014) shows.

consumption caused by domestic consumption and export of domestic production can also be estimated. Since the IOT show the household consumption by product group, it can also be divided into different consumption areas (e.g. housing, mobility, nutrition). The EE-IOA therefore makes it possible to determine the direct and indirect environmental pressure and resource consumption caused by the use of each individual product group or each consumption area.

The calculation of the different footprints of global environmental impact and resource consumption associated with the consumption activities of an economy is carried out by adding the following three components:

1. the direct environmental impacts and resource consumption caused by domestic consumption of goods and services (e.g. CO<sub>2</sub> emissions due to the combustion of fuels during the transport activities of private households),
2. the direct and indirect environmental impacts and resource consumption caused by domestic production for domestic final demand (e.g. CO<sub>2</sub> emissions due to the production of cars for domestic consumption),
3. the direct and indirect environmental impacts and resource consumption associated with imported goods for production and last domestic use (e.g. CO<sub>2</sub> emissions abroad resulting from the production of imported goods).

The analysis can be carried out using a single-country input-output model or a multi-regional input-output model. However, a single country extended input-output model is only partially capable of adequately recording the environmental pressure associated with imports because the origin of the imports and destine of exports are not explicit. This would require the assumption that imported goods are produced abroad with the same production technology and the same specific environmental impact as domestic produced goods. In order to adequately record the environmental impact or resource consumption associated with imports, it is necessary to correct the related product-specific environmental impact intensities. The execution of this correction depends on the availability of the required data.

Another way to overcome this problem is to use the extended multi-regional input-output analysis (E-MRIOA). The E-MRIOA has a long tradition as an important instrument for examining the interrelationships between different economic structures and trade and their implications for a broad spectrum of social, economic and ecological issues (Többen/Kronenberg 2015).<sup>10</sup> Compared with application at international level, application at sub-national level has not yet progressed very far (ibid.). The main reason for this discrepancy is that the availability of the necessary data at the sub-national level is much more limited. Neither regional IOT nor interregional trade data are available for most countries (ibid.). In line with Wiedemann/Barrett (2010), the central obstacles to the widespread implementation of MRIO models on a sub-national level such as federal states include data availability, data processing and the relative complexity of the MRIO frameworks. However, the use of an MRIO model would increase the accuracy and completeness of the trading Ecological Footprint accounts (ibid.). It should also be noted that an MRIO framework is in line with existing UN accounting standards, would contribute to standardization of the footprint methodology and also enable the tracking of international supply chains (ibid.). Finally, it should be pointed out once again that the use of a comprehensive economic-ecological input-output model is well suited to carry

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<sup>10</sup> Of particular note here is the One Planet Economy Network Europe (OPEN:EU) project, which has integrated the ecological, carbon and water footprint in a footprint family, using an E-MRIOA (Galli et al. 2012, 2013).

out scenario simulations of the ecological and socio-economic effects of the implementation of environmental policy measures (ibid.).

The calculation of specific environmental footprints for the state of North Rhine-Westphalia (NRW) requires IOT on the one hand and data from the environmental economic accounts for NRW on the other. But as already mentioned, regional input-output tables (RIOT) for the sub-national level (federal states) are not compiled by official statistics. Due to this, it is necessary to determine the IOT using derivative methods. Boero et al. (2018) provide an overview of possible calculation approaches for the RIOT. In the case of the state of North Rhine-Westphalia (NRW), the application of such approaches would lead to the creation of an NRW-specific IOT that approximates the NRW-specific characteristics of production and consumption. Acosta/Schostok (2016) derived an expanded RIOT for North Rhine-Westphalia under the specification of a resource-specific question, which is in close interaction with the expansion of renewable energies: How will the domestic and global abiotic direct material input caused by production and consumption in NRW change, if the share of energy production (electricity and heat) based on renewable energies in NRW is above 34% in 2030 and above 50% in 2050?<sup>11</sup> The methodical approach is based on the EE-IOA for which a North Rhine-Westphalia specific "raw material consumption model" has been developed. This is a model with which the effects and characteristics of the production and consumption activities of the NRW economy can be examined specifically with regard to raw material consumption. The IOT 2010 for North Rhine-Westphalia was determined using the Cross-Hauling Adjusted Regionalization Method (CHARM) based on Kronenberg/Többen (2011) derivatively from the currently available IOT 2010 for Germany (revenue table, usage table, input-output table, import matrix) and by using further NRW specific data (sales, imports and exports from abroad, gross value added and structural use of gross domestic product).<sup>12</sup> The derivatively determined IOT 2010 for North Rhine-Westphalia approximates the characteristics of production and consumption in NRW on the one hand and the volume and composition of NRW's foreign trade relations on the other. The production sphere of NRW is divided into 38 production areas (goods and services) and domestic consumption is differentiated into four areas. NRW's exports and imports are divided into foreign trade relations with the other federal states and with other countries. All flows of goods are expressed in monetary units (million euros). The environment-related extension of IOT for North Rhine-Westphalia (row vector) refers to the consumption of energetic and non-energetic abiotic materials caused by all production and consumption activities in NRW. It therefore includes direct abiotic material input (DMI<sub>a</sub>) measured in physical units (1,000

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<sup>11</sup> The development pathways for the expansion of renewable energies (2030 > 35%, 2050 > 50%) are based on the Climate Protection Plan NRW for North Rhine-Westphalia, which „has been drawn up by the state government to meet one of the essential requirements of the state's 2013 Climate Protection Act. The Plan outlines the strategies and specific measures needed to achieve the targets for the reduction of greenhouse gas emissions set out in the Climate Protection Act. (...) The Plan is a kind of roadmap for the long-term goal of reducing greenhouse gas emissions by at least 80% between now and 2050; it sets out the options available for action and the strategic decisions to be taken in the coming years.“ (MKULNV NRW 2016b)

<sup>12</sup> For this purpose, the IOT 2010 for Germany, revised in 2014 and published by the Federal Statistical Office within the framework of the national accounts (Federal Statistical Office 2015), was used. With regard to the NRW specific data, the corresponding statistics from the State Agency IT.NRW and the Federal Statistical Office' data on the national accounts of the federal states were used. All these data sets are either available online or were made available on request by Federal Statistical Office and IT.NRW. The year 2010 was selected so that certain NRW specific values from the calculations of the climate protection plan scenarios, such as greenhouse gas emissions, can be included in the model calculation. The scenarios of the climate protection plan and the study carried out have thus taken the same base year as a basis.

tones). The  $DMI_a$  is also differentiated into 38 production areas and 4 consumer areas. In summary, this is a sound foundation for the development of a comprehensive EE-IOA for North Rhine-Westphalia, with the aim of providing a solid methodological basis for calculating the whole footprint family.

### 3.2 Planetary Boundaries

The framework of "planetary boundaries", introduced in 2009, propose global environmental limits within which humanity can safely operate (Rockström et al. 2009a). "These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes" (Rockström et al. 2009b). The foundation of the planetary boundaries is the assumption that human activities since the industrial revolution have ushered in a new geological age. The Holocene, which was characterized by stable environmental conditions, gave way to the Anthropocene<sup>13</sup> - an age in which man has become the most important factor influencing environmental changes. The stability and self-regulation of the environment, which existed in the Holocene and enabled human development, seems to be endangered by anthropogenic influence (ibid.). In order to meet the challenge of maintaining the Holocene state, nine load limits of the planet must be met: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading (ibid.). These ecological limits form the framework for the elasticity and regulatory capacity of the Earth's environmental system. If these planetary limits are not observed, there is a risk of catastrophic and irreversible environmental changes, which will also worsen the conditions of human development (ibid.). In 2015, Steffen et al. published an updated and extended analysis of the planetary boundaries framework based on the scientific findings of the past five years (Steffen et al. 2015). With the updated framework, eight out of nine earth process systems are quantified in terms of their limits that should not be exceeded. Only for the process "Introduction of novel entities" control variables and boundary values still need to be defined.

Additionally Steffen et al. (2015) introduce regional boundaries within the updated framework, which can be applied to regions such as Southern Africa or South Asian for example. In this paper, regions are defined at a lower level, i.e. a sub-national level of states in a federal political system. This raises the question: "How can a planetary quantity be applied to the evaluation of a region or a sustainable development strategy?" (Keppner 2017) The Sustainable Development Goals (SDGs) could serve as a basis for the realignment and management of the planetary boundaries framework, as they place the PB concept in the broader context of sustainable development (Häyhä et al. 2016). In Germany, in its new edition of 2016, the Federal Government refers to the Sustainable Development Goals (SDGs) and selected SDG indicators, as well as to the planetary boundaries framework (NSDS Germany 2016). Individual federal states also refer to the SDGs<sup>14</sup> as well as to the planetary boundaries<sup>15</sup>. However, it should be critically noted that the references are exclusively postulates and are thus only

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<sup>13</sup> "The Anthropocene could be said to have started in the latter part of the eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane." (Crutzen 2002).

<sup>14</sup> Thuringia (SDS TH 2018), Saarland (SDS SL 2017), (North Rhine-Westphalia (SDS NRW 2016), Lower Saxony (SDS NI 2017).

<sup>15</sup> Thuringia (SDS TH 2018), (North Rhine-Westphalia (SDS NRW 2016), Rhineland-Palatinate (SDS RP 2015).

communicated on a qualitative level. No sustainability strategy and no sustainability indicator report, neither at national nor sub-national level in Germany, makes a quantified reference to the biophysical processes of the planetary framework. One reason for this may be the reporting of the indicators themselves. There is no standard framework for indicator reporting other than the reference frame of the 230 SDG indicators provided by the United Nations (2016). And even “the most comprehensive, global sustainability process - the year 2030 Agenda - does not explicitly take into account the concept of planetary boundaries” (Keppner 2017). Additionally, unlike reporting regulations for companies and organizations<sup>16</sup> there are no specific and above all no binding reporting principles for governments. Studies prove a very heterogeneous use of indicators and also of the calculation principles, the quantification as well as the goals in correspondence with an indicators (Schostok 2015a; Schostok/Ulrich 2018). Basically, reporting is at one's own discretion. This reinforces the criticism mentioned in the introduction, that due to the fact that indicators are used by people or organizations with different interests, they can be guided in their informative value and are often valuable in reality and thus partly incomplete in describing the contexts they measure.

The Table 1 in the Appendix compares the sustainability reporting of the Federal Government of Germany and the state of North Rhine-Westphalia to the planetary boundaries framework. On the left side the planetary boundaries and the control variables according to Steffen et al. (2015) are shown. The right-hand side reflects as an excerpt the indicators from the sustainability reporting of the Federal Republic of Germany and the state of North Rhine-Westphalia, which could address the planetary boundaries, at least partially. The indicators listed are part of the current sustainability reporting, but are not yet explicitly linked to the concept of planetary boundaries as a quantification parameter and target value.

Based on the Comparison of Table 1 it can be clearly seen that in the context of sustainability reporting in Germany and NRW indicators are already calculated which may be assigned to the five planetary boundaries climate change, change in biosphere integrity, biogeochemical flows, land-system change and atmospheric aerosol loading. However it should be critically noted that the indicators do not exactly correspond to the respective control variable(s) of the planetary boundaries. For the planetary boundary of atmospheric aerosol loading, for example, the aerosol optical depth (AOD) is not measured, but parameters closely related to atmospheric aerosol loading as the emissions of air pollution by SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, NMVOC, PM2.5, PM10 are reported. For the planetary boundary of climate change, for example, all six Kyoto gases CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, SF<sub>6</sub>, HFC and PFC are reported in order to provide an almost comprehensive assessment of the emission of climate-damaging gases. For the planetary boundary of stratospheric ozone depletion, only the indicator NO<sub>2</sub> from the sustainability strategy of North Rhine-Westphalia can be assigned, although the indicator "only" represents an important precursor substance for summer ozone formation in the ground-level air layers. The sustainability reports of other federal states in Germany such as Hesse and Thuringia demonstrate that it is possible to measure the control variable O<sub>3</sub> at both sub-national and national level. There are 260 corresponding measuring stations in Germany, which are continuously monitored by the Federal Environment Agency (UBA 2017). In North Rhine-Westphalia there are 39 corresponding measuring stations, which

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<sup>16</sup> E.g. by the Global Reporting Initiative (GRI), Sustainability Accounting Standards Board (SASB), Climate Disclosure Standards Board (CDSB), International Standards Organization (ISO), International Integrated Reporting Council (IIRC).

are continuously monitored by the North Rhine-Westphalian State Agency for Nature, Environment and Consumer Protection (LANUV 2018b). As an indicator "Ozone concentration in the urban background", the measurement results are part of the Environmental Report North Rhine-Westphalia (MKULNV NRW 2016a). This would make it possible to report on ozone concentrations that can be assigned to the planetary boundary. However, it should be noted that the ozone concentration is a volumetric quantity with the unit  $\mu\text{g}/\text{m}^3$  and the planetary limit of the Stratospheric  $\text{O}_3$  concentration is expressed in the Dobson unit, which is a measure of the strength of the ozone layer. Whether the target values and long-term objectives<sup>17</sup>, established at European level and incorporated into national regulations, are sufficient to make an adequate contribution to compliance with the planetary boundary of global stratospheric  $\text{O}_3$  concentration, requires further research.

The comparison in Table 1 also shows that no corresponding or related indicators exist for three of the nine planetary boundaries Ocean acidification, Freshwater use and Introduction of novel entities within the sustainability reporting of Germany and North Rhine-Westphalia. Especially the aspect of introduction of novel entities, which also includes micoplastics in the marine environment, is important for Germany with the adjacent North Sea and Baltic Sea but also for North Rhine-Westphalia with its large river systems Rhine, Meuse, Weser and Ems which flow into the North Sea. NRW has around 720 kilometers of waterways with 120 ports, including the world's largest inland port in Duisburg, which handles around 133 million tones of goods annually (NRW.Invest 2018b). According to Röckström et al. (2009a, 2009b) and Steffen et al. (2015), there are still no clear control variables for the planetary limit of the introduction of novel entities. At this point, Germany and North Rhine-Westphalia can advocate strengthening the ecological sustainability dimension in sustainability reporting by, for example, establishing a nationwide network for measuring microplastics in the bodies of water and accelerating appropriate prevention measures. Interesting preventive measures are expected in the medium term, for example from the "eCircular" project: The project aims to avoid plastic waste through the use of digital technologies. As an initiative of Europe's largest private-public innovation partnership Climate-KIC, the project contributes to the overall goal of reducing material production to zero emissions by 2050 (Wuppertal Institute 2018; Climate-KIC 2018).

The question thus remains how national and sub-national indicator reporting can be extended to include all the indicators defined within the framework of planetary boundaries in order to comply with the concept in principle and to quantify the responsibility of the respective nation and region - how the framework of planetary boundaries can be scaled to a sub-national regional level. Despite some case studies on the regionalization of the planetary boundary framework at the national and sub-national level, there is little methodological consistency, as Häyhä et al (2016) confirmed in a previous meta-analysis. To regionalize the planetary boundaries framework on a sub-national level, one conceivable approach would be to scale the planetary boundaries per capita using the polluter pays principle. In this context, extended multi-regional input-output analysis (E-MRIOA) can play a central role, as it enables the quantification of global effects according to the polluter pays principle.

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<sup>17</sup> The assessment standards for the protection of human health are the values defined in the European Directive 2008/50/EC: target value for 2010  $120 \mu\text{g}/\text{m}^3$  for the maximum 8-hour value for a day (25 exceedances per year permitted, averaged over 3 years); long-term target:  $120 \mu\text{g}/\text{m}^3$  for the maximum 8-hour value for a day; information threshold  $180 \mu\text{g}/\text{m}^3$  as 1-hour average value; alarm threshold  $240 \mu\text{g}/\text{m}^3$  as 1-hour average value.

Based on the conference results “Making the Planetary Boundaries Concept work” a comprehensive Planetary Boundaries Science Roadmap is proposed which identifies the following key areas of research:

1. „Realization of comprehensive planetary boundaries simulation models
2. Quantification of SDG pathways within planetary boundaries
3. Research on socio-ecological complexity under conditions of planetary boundaries
4. Research on the implementation of planetary boundaries concepts in environmental and sustainability policy, businesses, sectors and regions
5. Research on the implications of planetary boundaries for concepts of natural, social, economic and political order, and associated ontologies in discourse and communication“. (Keppner 2017)

Referring to key area number four a first step could be the identification and quantification of the environmental flows of the individual control variables of the planetary boundary framework. Ryberg et al. (2018) developed a planet boundaries life-cycle impact assessment (PB-LCIA), which express the indicators of environmental metrics corresponding to the planetary boundary control variables. Ryberg et al. (2018) identify 85 environmental flows for seven of the planetary boundaries. The PB-LCIA and the environmental flows identified therein are an interesting basis not only for companies to measure their activities against planetary boundaries, but also as a basis for the regionalization of the planetary boundaries framework within the national and sub-national sustainability reporting's. A second step could be the verification the data availability and in some cases the collection of new data before the calculation and reporting of the indicators can be executed. As a conceptual model for regionalization to the sub-national level, the study "The planetary nitrogen boundary as a reference point of a national nitrogen strategy" by Hoff/Keppner (2017) can be used, which deals with the question of scaling down the planetary boundaries to the national level.

## **4 Conclusion and Outlook**

As mentioned at the beginning, sustainability reporting and indicator reporting must be holistic and integrated, as some indicators must take several dimensions of sustainability into account simultaneously. This makes it all the more important to comprehensively address global indicator concepts such as the footprint family and the planetary boundaries and to quantize them in national and sub-national sustainability reporting. Only in this way can a comprehensive picture of the interactions between the indicators and related objectives (in particular the SDGs) be mapped and the risk of shifting negative environmental impacts to other areas be minimized. In this respect, the transformation from a single-dimension to a comprehensive perspective is particularly to be emphasized. Using the state of North-Rhine Westphalia as a case study, first steps towards regionalization of these global and composite sustainability indicators have been outlined for the footprint family and for the ecological footprint in particular, as well as for the planetary boundaries framework. In this context, the footprint indicators and the planetary boundaries must be considered in a complementary relationship, because “without a reference to sustainability limits, the footprint family cannot be used to determine whether or not natural capital is being consumed in a sustainable way” (Fang et al. 2014). Methodologically, hybrid approaches such as the combination of EE-IOA and life-cycle assessment (LCA) (ibid.) are an interesting field of research to be further investigated, which could contribute to the regionalization of global sustainability indicator frameworks. There is also a need to integrate footprint indicators and planetary

boundaries into environmental sustainability assessment (ESA) (Fang et al. 2015b), not only at the national level but also at the sub-national level.

With the calculation of the ecological footprint, the state of North Rhine-Westphalia has taken a first central step towards the regionalization of global indicator frameworks, although the methodological approach would have to be readjusted in order to be able to derive concrete political measures for the mitigation of harmful environmental impacts in the future. With reference to the concept of planetary boundaries, the state of North Rhine-Westphalia can build on the indicators already used in its sustainability strategy. The operationalization and the concrete allocation of quantified and scheduled (reduction) targets is of central importance for the state of North Rhine-Westphalia in order to achieve a normative function of the indicator system. If the state of North Rhine-Westphalia succeeds in further developing this basis and closing gaps, it can play a leading role in quantifying planetary boundaries at the sub-national level.

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## Appendix

**Table 1 Comparing sustainability reporting of the Federal Government of Germany and the state of North Rhine-Westphalia to the planetary boundaries framework**

Planetary Boundaries Framework (Steffen et al. 2015)		Federal Republic of Germany (NSDS Germany 2016)	State of North Rhine-Westphalia (SDS NRW 2016)
Planetary Boundary	Control Variable(s)	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic
Climate change	Atmospheric CO <sub>2</sub> concentration, ppm	<ul style="list-style-type: none"> <li>Greenhouse gas emissions (To be reduced by at least 40% by 2020, by at least 55% by 2030, by at least 70% by 2040 and by 80% to 95% by 2050, in each case compared to 1990) <i>SDG 13</i></li> <li>Energy consumption and CO<sub>2</sub> emissions from consumption (Continuous reduction of energy consumption) <i>SDG 12</i></li> </ul>	<ul style="list-style-type: none"> <li>Greenhouse gas emissions (Reduction by at least 25% by 2020 and by at least 80% by 2050 (compared to 1990) <i>SDG 7, 13</i></li> </ul>
	Energy imbalance at top-of-atmosphere, (Watts per metre squared, Wm <sup>-2</sup> )		
Change in biosphere integrity	Genetic diversity: Extinction rate	<ul style="list-style-type: none"> <li>Species diversity and landscape quality (To be increased to the index value of 100 by 2030) <i>SDG 15</i></li> <li>Eutrophication of ecosystems (To be reduced by 35% by 2030 compared to 2005) <i>SDG 15</i></li> <li>Share of sustainably fished fish stocks in the North Sea and Baltic Sea (Fish stocks used for economic purposes to be sustainably managed in accordance with the Maximum Sustainable Yield approach by 2020) <i>SDG 14</i></li> </ul>	<ul style="list-style-type: none"> <li>Endangered species – „Red List“ (The majority of habitats and species have a favourable status of conservation: the percentage of Red List species should be reduced to 40% by 2030) <i>SDG 6, 15</i></li> <li>Diversity of species and landscape quality (Increase of biodiversity in all landscape spaces by 2030 (state-wide achievement of the best local or regional situation in the time period 1997-2015)) <i>SDG 6, 15</i></li> </ul>
	Functional diversity: Biodiversity Intactness Index (BII)		
Stratospheric ozone depletion	Stratospheric O <sub>3</sub> concentration, Dobson Units		<ul style="list-style-type: none"> <li>Nitrogen oxide (NO<sub>2</sub>) concentration (By 2030, the average annual median value of the emission concentration of is to be reduced to 40 µg/m<sup>3</sup>, even on roads in urban agglomerations) <i>SDG 6, 15</i></li> </ul>
Ocean acidification	Carbonate ion concentration, average global surface ocean, saturation state with respect to aragonite (Ω <sub>arag</sub> )		

Planetary Boundaries Framework (Steffen et al. 2015)		Federal Republic of Germany (NSDS Germany 2016)	State of North Rhine-Westphalia (SDS NRW 2016)
Planetary Boundary	Control Variable(s)	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic
Biogeochemical flows: (Phosphorus and Nitrogen cycles)	<i>Phosphorus cycle:</i> Global: Phosphorus flow from freshwater systems into the ocean Regional: Phosphorus flow from fertilizers to erodible soils	<ul style="list-style-type: none"> <li>Phosphorous in flowing waters (The benchmark values for specific types of water to be met or beaten at all monitoring points by 2030) <i>SDG 6</i></li> <li>Nitrogen surplus (Overall nitrogen surpluses for Germany to be reduced to 70 kg/ha of utilised agricultural land in the annual average from 2028-2032) <i>SDG 2</i></li> <li>Organic farming (Share of organic farming on land used for agriculture to be increased to 20% in coming years) <i>SDG 2</i></li> <li>Nitrate in groundwater – proportion of monitoring points in Germany at which the threshold of 50 mg/l for nitrate is exceeded (“50 mg/l” of nitrate in groundwater to be complied with by 2030) <i>SDG 6</i></li> <li>Nutrient inputs in coastal waters and marine waters – nitrogen input via the inflows into the Baltic (Adherence to the good conditions according to the Ordinance on the Protection of Surface Waters (annual averages for total nitrogen in rivers flowing into the Baltic shall not exceed 2.6 mg/l) <i>SDG 14</i></li> <li>Nutrient inputs in coastal waters and marine waters – nitrogen input via the inflows into the North Sea (Adherence to the good conditions according to the Ordinance on the Protection of Surface Waters (annual averages for total nitrogen in rivers flowing into the North Sea shall not exceed 2.8 mg/l) <i>SDG 14</i></li> </ul>	<ul style="list-style-type: none"> <li>Environmental condition of surface waters (All flowing water bodies will reach good environmental quality and/or a good ecological potential in accordance with the EU Water Framework Directive by 2027; With exceptions for some waters in the Rhenish brown coal area) <i>SDG 6, 15</i></li> <li>Nitrate in the ground water (Reduction of the nitrate load of all groundwater bodies to &lt; 50 mg/l by 2027 at the latest) <i>SDG 6, 15</i></li> <li>Nitrogen surplus (Reduction of the average nitrogen balance surplus to 60-75 kg N/ha by 2030) <i>SDG 2, 6, 15</i></li> <li>Ecological agriculture (Increase of the percentage of areas with organic agriculture in relation to the overall area used for agriculture) <i>SDG 2</i></li> </ul>
	<i>Nitrogen cycle:</i> Global: Industrial and intentional biological fixation of nitrogen		

Planetary Boundaries Framework (Steffen et al. 2015)		Federal Republic of Germany (NSDS Germany 2016)	State of North Rhine-Westphalia (SDS NRW 2016)
Planetary Boundary	Control Variable(s)	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic	Indicator (Target) *in brackets; <i>SDG assignment</i> *italic
Land-system change	Global: area of forested land as % of original forest cover	<ul style="list-style-type: none"> <li>Built-up area and transport infrastructure expansion (To be reduced to 30 ha minus x per day by 2030) <i>SDG 11</i></li> <li>Loss of open space in m<sup>2</sup>/inhabitant (Reduction in the loss of open space per inhabitant) <i>SDG 11</i></li> <li>Inhabitants by area occupied by built-up areas and transport infrastructure – settlement density (No reduction in settlement density) <i>SDG 11</i></li> <li>Payments to developing countries for the verified preservation or restoration of forests under the REDD+ rulebook (To be increased by 2030) <i>SDG 15</i></li> </ul>	<ul style="list-style-type: none"> <li>Portion of the purely coniferous woodlands (Increase of the stability and adaptability of the forests: reduction of purely coniferous woodlands to &lt; 20% by 2030) <i>SDG 6, 15</i></li> <li>Percentage of certified woodland – FSC and PEFC (Increase of the percentage of certified woodland in relation to the overall forests by 2030) <i>SDG 6, 15</i></li> <li>Surface area of the state-wide biotope network (In 2030, 15% of the surface area of the State will be biotope network areas) <i>SDG 6, 15</i></li> <li>Increase of the settlement and transportation areas (Limitation of land use for settlement and transportation areas to 5 ha per day by 2020. The aim is a zero net consumption in the long run) <i>SDG 2, 6, 9, 11, 15</i></li> </ul>
	Biome: area of forested land as % of potential forest		
Freshwater use	Global: Maximum amount of consumptive blue water use (km <sup>3</sup> yr <sup>-1</sup> )		
	Basin: Blue water withdrawal as % of mean monthly river flow		
Atmospheric aerosol loading	Global: Aerosol Optical Depth (AOD), but much regional variation	<ul style="list-style-type: none"> <li>Emissions of air pollutants – index of national emissions of air pollutants SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, NMVOC and PM<sub>2.5</sub> (Emissions of 2005 to be reduced to 55% (unweighted average of the five pollutants) by 2030) <i>SDG 3</i></li> <li>Share of the population with increased exposure to PM<sub>10</sub> in Germany (WHO particulate matter benchmark of an annual average of 20 µg/m<sup>3</sup> for PM<sub>10</sub> to be achieved as widely as possible by 2030) <i>SDG 3</i></li> </ul>	<ul style="list-style-type: none"> <li>Particulate Matter (PM<sub>10</sub>) concentration (By 2030, the average annual median value of the emission concentration of PM<sub>10</sub> in urban locations is to be reduced to 20 µg/m<sup>3</sup>, even on roads in urban agglomerations) <i>SDG 6, 15</i></li> </ul>
	Regional: AOD as a seasonal average over a region. South Asian Monsoon used as a case study		
Introduction of novel entities	<i>No control variable currently defined</i>		

## References

- Acosta, José F.; Schostok, Dorothea (2016): Rohstoffverbrauch und Rohstoffproduktivität - ein Zielkorridor 2030 für NRW. Bericht zum AP 4.2 im Rahmen des Zuwendungsprojektes „Konzeptionelle Analysen und Überlegungen zur Ausgestaltung einer Nachhaltigkeitsstrategie NRW aus wissenschaftlicher Sicht.“ [https://wupperinst.org/fa/redaktion/downloads/projects/NHS\\_NRW\\_AP4-2\\_Rohstoffe.pdf](https://wupperinst.org/fa/redaktion/downloads/projects/NHS_NRW_AP4-2_Rohstoffe.pdf) (accessed on 31.07.2018)
- Ayres, Robert U. (2000): Commentary on the utility of the ecological footprint concept. In: *Ecological Economics*, Vol. 32, Issue 3, pp. 347-349
- Bell, Simon; Morse, Stephen (2008). *Sustainability indicators: Measuring the immeasurable?* London: Earthscan
- Boero, Riccardo; Edwards, Brian K.; Rivera, Michael K. (2018): Regional input–output tables and trade flows: an integrated and interregional non-survey approach. In: *Regional Studies*, Vol. 52, Issue 2, pp. 225-238
- Borbonus, Sylvia; von Geibler, Justus; Luhmann, Jochen; Scheck, Hanna; Schostok, Dorothea; von Winterfeld, Uta (2014): Nachhaltigkeitsstrategien erfolgreich entwickeln – Untersuchung von Nachhaltigkeitsstrategien in Deutschland und auf EU-Ebene. In: Bertelsmann Foundation (Ed., 2014), pp. 21-300 [https://www.bertelsmann-stiftung.de/de/publikationen/publikation/did/nachhaltigkeitsstrategien-erfolgreich-entw-ckeln/?tx\\_rsmbstpublications\\_pi2%5Bpage%5D=1&cHash=90b821d569b2d188f62fb7aebea60130](https://www.bertelsmann-stiftung.de/de/publikationen/publikation/did/nachhaltigkeitsstrategien-erfolgreich-entw-ckeln/?tx_rsmbstpublications_pi2%5Bpage%5D=1&cHash=90b821d569b2d188f62fb7aebea60130) (accessed on 16.03.2015)
- Borbonus, Sylvia; von Geibler, Justus; Luhmann, Jochen; Scheck, Hanna; Schostok, Dorothea; von Winterfeld, Uta (2015): Sustainability Strategies in Germany and at the EU Level. In: Bertelsmann Stiftung (Ed., 2015): *Developing Successful Sustainability Strategies. Strategies for a Sustainable Future in Germany, Europe and Worldwide.* pp. 13-24
- Borucke, Michael; Moore, David; Cranston, Gemma; Gracey, Kyle; Iha, Katsunori; Larson, Joy; Lazarus, Elias; Morales, Juan C.; Wackernagel, Mathis; Galli, Alessandro (2013): Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. In: *Ecological Indicators*, Vol. 24, pp. 518-533
- Cole, Megan J.; Bailey, Richard M.; New, Mark G. (2014): Tracking sustainable development with a national barometer for South Africa, using a downscaled safe and just space framework. In: *PNAS*, Vol. 111, No. 42, pp. E4399-E4408
- Climate-KIC (2018): eCircular. Catalysing a switch to a circular economy through plastic waste prevention. <http://www.climate-kic.org/areas-of-focus/sustainable-production-systems/our-initiatives/ecircular/> (accessed on 31.07.2018)
- Crutzen, Paul (2002): Geology of mankind. In: *Nature*, Vol. 415. p. 23
- Dalal-Clayton, Barry; Bass, Stephen (2002): *Sustainable Development Strategies. A Resource Book.* OECD; UNDP (Ed.)
- Dao Hy, Friot Damien, Peduzzi Pascal, Bruno Chatenoux, Andrea De Bono, Stefan Schwarzer (2015), *Environmental limits and Swiss footprints based on Planetary Boundaries*, UNEP/GRID-Geneva & University of Geneva, Geneva, Switzerland. Hy, Dao; Friot, Damien, ; Peduzzi Pascal, Bruno Chatenoux, Andrea De Bono, Stefan Schwarzer (2015), *Environmental limits and Swiss footprints*

- based on Planetary Boundaries, UNEP/GRID-Geneva & University of Geneva, Geneva, Switzerland.
- Davis, Kevin E.; Kingsbury, Benedict; Merry, Sally E. (2015): The local-global life of indicators: Law, power, and resistance. In: Merry, Sally E.; Davis, Kevin E.; Kingsbury, Benedict (Eds., 2002): The quiet power of indicators: Measuring governance, corruption, and rule of law. Cambridge University Press, Cambridge, pp. 1–26
- Dearing, John A.; Wang, Rong; Zhang, Ke; Dyke, James G.; Haberl, Helmut; Hossain, Md. Sarwar; Langdon, Peter G.; Lenton, Timothy M.; Raworth, Kate; Brown, Sally; Carstensen, Jacob; Cole, Megan J.; Cornell, Sarah E.; Dawson, Terence P.; Doncaster, C. Patrick; Eigenbrod, Felix; Flörke, Martine; Jeffers, Elizabeth; Mackay, Anson W.; Nykvist, Björn; Poppy, Guy M. (2014): Safe and just operating spaces for regional social- ecological systems. In: Global Environment Change, Vol. 28, pp. 227-238
- ESDN – European Sustainable Development Network (no year): Basics of SD Strategies. <http://www.sd-network.eu/?k=basics%20of%20SD%20strategies> (accessed on 10.09.2014)
- European Directive 2008/50/EC (2008): Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=en> (accessed on 15.06.2018)
- Fiala, Nathan (2008): Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecological Economics* Vol. 67, Issue 4, pp. 519-525
- Fang, Kai; Heijungs, Reinout; de Snoo, Geert R. (2014): Theoretical exploration for the combination of ecological, energy, carbon, and water footprints: Overview of a footprint family. In: *Ecological Indicators*, Vol. 36, pp. 508-518
- Fang, Kai; Heijungs, Reinout; de Snoo, Geert R. (2015a): Understanding the complementary linkages between environmental footprints and planetary boundaries in a footprint-boundary environmental sustainability assessment framework. In: *Ecological Economics*, Vol. 114, pp. 218-226
- Fang, Kai; Heijungs, Reinout; Duan, Zheng; de Snoo, Geert R. (2015b): The Environmental Sustainability of Nations: Benchmarking the Carbon, Water and Land Footprints against Allocated Planetary Boundaries. In: *Sustainability*, Vol. 7, pp. 11285-11305
- Federal Statistical Office (2015): Fachserie 18, Reihe 2. Volkswirtschaftliche Gesamtrechnung. Input-Output-Rechnung. 2011 (Revision 2014). Erschienen am 10. August 2015, ergänzt um Tabelle 4 am 24.11.2015. [https://www.destatis.de/DE/Publikationen/Thematisch/VolkswirtschaftlicheGesamtrechnung/InputOutputRechnung/VGRInputOutputRechnung2180200117004.pdf;jsessionid=BA7F62B563F6B6F911AC53F211E7D75D.cae3?\\_\\_blob=publicationFile](https://www.destatis.de/DE/Publikationen/Thematisch/VolkswirtschaftlicheGesamtrechnung/InputOutputRechnung/VGRInputOutputRechnung2180200117004.pdf;jsessionid=BA7F62B563F6B6F911AC53F211E7D75D.cae3?__blob=publicationFile) (accessed on 16.12.2017)
- Galli, Alessandro; Giampietro, Mario; Goldfinger, Steve; Lazarus, Elias; Lin, David; Saltelli, Andrea; Wackernagel, Mathis; Müller, Felix (2016): Questioning the Ecological Footprint. In: *Ecological Indicators*, Vol. 69, pp. 224-232
- Galli Alessandro; Weinzettel Jan; Cranston, Gemma; Ercin, Ertug (2013): A Footprint Family extended MRIO model to support Europe's transition to a One Planet Economy. In: *Science of The Total Environment*, Vol. 461-462, pp. 813-818

- Galli, Alessandro; Wiedmann, Thomas; Ercin, Ertug; Knoblauch, Doris; Ewing, Brad; Giljum, Stefan (2012): Integrating Ecological, Carbon and Water footprint into a “Footprint Family” of indicators: Definition and role in tracking human pressure on the planet. In: *Ecological Indicators*, Vol. 16, pp. 100-112
- Giljum, S., Hinterberger, F. & Lutter, S. (2008): Measuring natural resource use – Context, indicators and EU policy processes. Sustainable Europe Research Institute (SERI), Background Paper 14
- Günther, Edeltraud; Schuh, Heiko (2000): Definitionen, Konzepte, Kriterien und Indikatoren einer nachhaltigen Entwicklung. <http://www.qucosa.de/fileadmin/data/qucosa/documents/868/1004077266578-7174.pdf> (accessed on 31.07.2018)
- Häyhä, Tiina; Lucas, Paul L.; van Vuuren, Detlef P.; Cornella, Sarah E.; Hoff, Holger (2016): From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged? In: *Global Environmental Change*, Vol. 40, pp. 60-72
- Häder, Michael (2015): *Empirische Sozialforschung – Eine Einführung*. 3rd edition, Springer Fachmedien Verlag Wiesbaden
- Hossain, Md Sarwar; Dearing, John A.; Eigenbrod, Felix; Johnson, Fiifi A. (2017): Operationalizing safe operating space for regional social-ecological systems. In: *Science of The Total Environment*. Vol. 584-585, pp. 673-682
- Hoff, Holger; Keppner, Benno (2017): Die planetare Stickstoff-Leitplanke als Bezugspunkt einer nationalen Stickstoffstrategie. Im Auftrag des Umweltbundesamtes. Forschungskennzahl 3714 19 100 0. [https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-08-28\\_texte\\_75-2017\\_planteare\\_stickstoffleitplanke.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-08-28_texte_75-2017_planteare_stickstoffleitplanke.pdf) (accessed on 31.07.2018)
- Hoff, Holger; Nykvist, Björn; Carson, Marcus (2014): Living well, within the limits of our planet? Measuring Europe’s growing external footprint. SEI Working Paper 2014-05. Stockholm Environment Institute, Sweden.
- IWR – Internationales Wirtschaftsforum Regenerative Energien (2018): Stromverbrauch. Nettostromverbrauch nach Sektoren. <http://www.energiestatistik-nrw.de/energie/strom/stromverbrauch> (accessed on 01.07.2018)
- Keppner, Benno (2017): Outcomes of the International Conference “Making the Planetary Boundaries Concept work”. 24 - 25 April 2017 Berlin. Organized by adelphi; Stockholm Environment Institute (SEI); Potsdam-Institut für Klimafolgenforschung (PIK). Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB); Umweltbundesamt (UBA); Deutsche Bundesstiftung Umwelt (DBU) (Eds.). [https://www.adelphi.de/de/system/files/mediathek/bilder/Outcomes\\_Planetary-Boundaries-Conference\\_Berlin-2017.pdf](https://www.adelphi.de/de/system/files/mediathek/bilder/Outcomes_Planetary-Boundaries-Conference_Berlin-2017.pdf) (accessed on 31.07.2018)
- Kronenberg, Tobias; Többen, Johannes (2013): Über die Erstellung regionaler Input-Output-Tabellen und die Verbuchung von Importen. In: Institut für Wirtschaftsforschung - IWH (Ed., 2013) *Neuere Anwendungsfelder der Input-Output-Analyse*. Beiträge zum Halleschen Input-Output-Workshop 2012, Halle (Saale)
- Kronenberg, Tobias (2011): Regional input-output modelling in Germany: The case of North Rhine-Westphalia. MPRA Paper No. 35494. <http://mpra.ub.uni-muenchen.de/35494/> (accessed on 31.07.2018)
- Kronenberg, Tobias (2009): Construction of Regional Input-Output Tables Using Nonsurvey Methods. The Role of Cross-Hauling. In: *International Regional Science Review*, Vol. 32, No. 1, pp. 40-64

- LANUV – North Rhine-Westphalian State Agency for Nature, Environment and Consumer Protection (2018a): Treibhausgas-Emissionsinventar. Nordrhein-Westfalen 2016. LANUV-Fachbericht 87.  
[https://www.lanuv.nrw.de/fileadmin/lanuvpubl/3\\_fachberichte/LANUV-Fachbericht\\_87\\_web.pdf](https://www.lanuv.nrw.de/fileadmin/lanuvpubl/3_fachberichte/LANUV-Fachbericht_87_web.pdf) (accessed on 31.07.2018)
- LANUV – North Rhine-Westphalian State Agency for Nature, Environment and Consumer Protection (2018b): Messorte der Luftqualitätsüberwachung in NRW.  
<https://www.lanuv.nrw.de/umwelt/luft/immissionen/messorte-und-werte/> (accessed on 20.07.2018)
- Laurent, Alexis; Owsianiak, Mikolai (2017): Potentials and limitations of footprints for gauging environmental sustainability. In: Sustainability Vol. 25, pp. 20-27
- Lenzen, Manfred; Borgstrom Hansson, C.; Bond, S. (2007): On the bioproductivity and land-disturbance metrics of the ecological footprint. In: Ecological Economics, Vol. 61, Issue 1, pp. 6-10
- Lin, David; Hanscom, Laurel; Martindill, Jon; Borucke, Michael; Cohen, Lea; Galli, Alessandro; Lazarus, Elias; Zokai, Golnar; Iha, Katsunori; Eaton, Derek; Wackernagel, Mathis (2016): Working Guidebook to the National Footprint Accounts: 2016 Edition. Oakland: Global Footprint Network
- Mair, Simon; Jones, Aled; Ward, Jonathan; Christie, Ian; Druckman, Angela; Lyon, Fergus (2018): A Critical Review of the Role of Indicators in Implementing the Sustainable Development Goals. In: Filho, W. Leal (Ed., 2018): Handbook of Sustainability Science and Research. World Sustainability Series, Springer, pp. 41-56
- McLaughlin, John F. (2018): Safe operating space for humanity at a regional scale. In: Ecology and Society, Vol. 23. Issue 2, Article No. 43
- Meadows, Donella H. (1998): Indicators and information systems for sustainable development: A report to the Balaton Group (p. 95). Hartland Four Corners: The Sustainability Institute
- Merry, Sally E. (2011): Measuring the world: Indicators, human rights, and global governance. In: Current Anthropology, 52(3), pp. 83-95
- MKULNV NRW – Ministry for Climate Protection, Environment, Agriculture, Nature Conservation and Consumer Protection of the State of North Rhine-Westphalia (2016a): 2016 Environmental Report North Rhine-Westphalia.  
[https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/umweltbericht\\_nrw\\_2016\\_en.pdf](https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/umweltbericht_nrw_2016_en.pdf) (accessed on 01.07.2018)
- MKULNV NRW – Ministry for Climate Protection, Environment, Agriculture, Nature Conservation and Consumer Protection of the State of North Rhine-Westphalia (2016b): Tackling climate change from the bottom up: The Climate Protection Plan for NRW at a glance.  
[https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/nrw\\_br\\_ksp\\_kurzfassung\\_engl.pdf](https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/nrw_br_ksp_kurzfassung_engl.pdf) (accessed on 01.07.2018)
- NDSD Germany – National Sustainable Development Strategy of the Federal Republik of Germany (2016): German Sustainable Development Strategy. Federal Government of Germany (Ed.).  
[https://www.bundesregierung.de/Content/DE/\\_Anlagen/Nachhaltigkeit/2017-06-20-nachhaltigkeit-neuaufgabe-engl.html;jsessionid=5C485FF55AA35996D063D341F5DEE484.s6t1?nn=507880](https://www.bundesregierung.de/Content/DE/_Anlagen/Nachhaltigkeit/2017-06-20-nachhaltigkeit-neuaufgabe-engl.html;jsessionid=5C485FF55AA35996D063D341F5DEE484.s6t1?nn=507880) (accessed on 01.07.2018)
- Nykvist, Björn; Persson, Åsa; Moberg, Frederik; Persson, Linn; Cornell, Sarah; Rockström, Johan (2013): National environmental performance on planetary boundaries. A study for the Swedish Environmental Protection Agency.

- NRW.INVEST (2016): New Opportunities in NRW. Your No. 1 Investment Location in Germany. Facts. Figures.  
[https://www.nrwinvest.com/fileadmin/user\\_upload/NEW\\_OPPORTUNITIES\\_IN\\_NRW\\_YOUR\\_NO.\\_1\\_INVESTMENT\\_LOCATION\\_IN\\_GERMANY.pdf](https://www.nrwinvest.com/fileadmin/user_upload/NEW_OPPORTUNITIES_IN_NRW_YOUR_NO._1_INVESTMENT_LOCATION_IN_GERMANY.pdf) (accessed on 01.07.2018)
- NRW.INVEST (2018a): Dynamic business location in the center of Europe.  
<https://www.nrwinvest.com/en/nrw-as-location/this-speaks-well-for-nrw/dynamic-business-location-in-the-center-of-europe/> (accessed on 01.07.2018)
- NRW.INVEST (2018b): Europe's gateway with an excellent transport infrastructure.  
<https://www.nrwinvest.com/en/nrw-as-location/this-speaks-well-for-nrw/europes-gateway/> (accessed on 01.07.2018)
- NRWSPD; Bündnis 90/Die Grünen NRW (2012): Koalitionsvertrag 2012-2017.  
[https://gruene-nrw.de/dateien/Koalitionsvertrag\\_2012-2017.pdf](https://gruene-nrw.de/dateien/Koalitionsvertrag_2012-2017.pdf) (accessed on 01.06.2017)
- OECD – Organisation for Economic Co-operation and Development (Ed., 2001): The DAC Guidelines Strategies for Sustainable Development: Guidance for Development Co-operation. <https://www.oecd.org/dac/environment-development/2669958.pdf> (accessed on 28.04.2017)
- Porter, Theodore M. (1995): Trust in numbers: The pursuit of objectivity in science and public life (p. 310). CPrinceton University Press, Chichester
- Quitow, Rainer (2010): Meta-Analyse: Nachhaltigkeitsstrategien in Politik und Wissenschaft – Querauswertung der staatlichen Nachhaltigkeitsstrategien.  
[http://www.innovative-nachhaltigkeit.de/htdocs\\_de/pdf/Analyse\\_und\\_Vergleich\\_der\\_Laender.pdf](http://www.innovative-nachhaltigkeit.de/htdocs_de/pdf/Analyse_und_Vergleich_der_Laender.pdf) (accessed on 10.09.2014)
- Rees, William E.; Wackernagel, Mathis (1992): Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy. Second Meeting of the International Society for Ecological Economics, Stockholm
- Rees, William E. (1992): Ecological Footprints and Appropriated Carrying Capacity: what urban economies leave out. *Environmental Urban*, Vol. 4, Issue 2, pp. 121-130
- Rockström, Johan; Steffen, Will; Noone, Kevin; Persson, Åsa; Chapin, F. Stuart III; Lambin, Eric; Lenton, Timothy M.; Scheffer, Marten; Folke, Carl; Schellnhuber, Hans Joachim; Nykvist, Björn; De Wit, Cynthia A.; Hughes, Terry; Leeuw, Sander van der; Rodhe, Henning; Sörlin, Sverker; Snyder, Peter K.; Costanza, Robert; Svedin, Uno; Falkenmark, Malin; Karlberg, Louise; Corell, Robert W.; Fabry, Victoria J.; Hansen, James; Walker, Brian; Liverman, Diana; Richardson, Katherine; Crutzen, Paul; Foley, Jonathan (2009a): Planetary boundaries: exploring the safe operating space for humanity. In: *Ecology and Society*, Vol. 14, Issue 2, Article 32
- Rockström, Johan; Steffen, Will; Noone, Kevin; Persson, Åsa; Chapin, F. Stuart III; Lambin, Eric; Lenton, Timothy M.; Scheffer, Marten; Folke, Carl; Schellnhuber, Hans Joachim; Nykvist, Björn; De Wit, Cynthia A.; Hughes, Terry; Leeuw, Sander van der; Rodhe, Henning; Sörlin, Sverker; Snyder, Peter K.; Costanza, Robert; Svedin, Uno; Falkenmark, Malin; Karlberg, Louise; Corell, Robert W.; Fabry, Victoria J.; Hansen, James; Walker, Brian; Liverman, Diana; Richardson, Katherine; Crutzen, Paul; Foley, Jonathan (2009b): A safe operating space for humanity. In: *Nature*, Vol. 461, Issue 7263, pp. 472-475
- Ryberg, Morton W.; Owsianiak, Mikolai; Richardson, Katherine; Hauschild, Michael Z. (2018): Development of a life-cycle impact assessment methodology linked to the Planetary Boundaries framework. In: *Ecological Indicators*, Vol. 88, pp. 250-262.

- Schnell, Rainer; Hill, Paul B.; Esser, Elke (2005): Methoden der empirischen Sozialforschung. Völlig überarbeitete und erweiterte Auflage, R. Oldenbourg Verlag München/Wien
- Schostok, Dorothea; Ulrich, Alina (2018): Sustainable Development Indicators: lack of coherence between existing Sustainability Strategies at different policy levels and the Sustainable Development Goals. Forthcoming in GAIa – ecological perspectives for science and society, Thematic Issue: Research for Sustainable Development Goals (SDGs)
- Schostok, Dorothea (2017): Konzeptionelle Vorschläge für eine kontinuierliche Nachhaltigkeitsberichterstattung. Bericht zum AP 7 im Rahmen des Zuwendungsprojektes: „Konzeptionelle Analysen und Überlegungen zur Ausgestaltung einer Nachhaltigkeitsstrategie NRW aus wissenschaftlicher Sicht“. [https://wupperinst.org/fa/redaktion/downloads/projects/NHS\\_NRW\\_AP7\\_Nachhaltigkeitsberichterstattung.pdf](https://wupperinst.org/fa/redaktion/downloads/projects/NHS_NRW_AP7_Nachhaltigkeitsberichterstattung.pdf) (accessed on 31.07.2018)
- Schostok, Dorothea (2015a): Nachhaltigkeitsindikatoren auf EU, Bundes- und Länderebene – eine Übersicht. Excel-Datei zum AP 5.1 im Rahmen des Zuwendungsprojektes „Konzeptionelle Analysen und Überlegungen zur Ausgestaltung einer Nachhaltigkeitsstrategie NRW aus wissenschaftlicher Sicht.“ Wuppertal Institute for Climate, Environment and Energy (Ed.). [https://wupperinst.org/uploads/tx\\_wupperinst/NHS\\_NRW\\_AP5-1\\_Nachhaltigkeitsindikatoren\\_Anhang.pdf](https://wupperinst.org/uploads/tx_wupperinst/NHS_NRW_AP5-1_Nachhaltigkeitsindikatoren_Anhang.pdf) (accessed on 31.07.2018)
- Schostok, Dorothea (2015b): Nachhaltigkeitsindikatoren auf EU, Bundes- und Länderebene – eine Übersicht. Bericht zum AP 5.1 im Rahmen des Zuwendungsprojektes „Konzeptionelle Analysen und Überlegungen zur Ausgestaltung einer Nachhaltigkeitsstrategie NRW aus wissenschaftlicher Sicht.“ Wuppertal Institute for Climate, Environment and Energy (Ed.). [https://wupperinst.org/uploads/tx\\_wupperinst/NHS\\_NRW\\_AP5-1\\_Nachhaltigkeitsindikatoren.pdf](https://wupperinst.org/uploads/tx_wupperinst/NHS_NRW_AP5-1_Nachhaltigkeitsindikatoren.pdf) (accessed on 31.07.2018)
- SDS NI – Sustainable Development Strategy of Lower Saxony (2017): Nachhaltigkeitsstrategie für Niedersachsen. Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz (Ed.) <https://www.umwelt.niedersachsen.de/download/112471> (accessed 10.08.2018)
- SDS NRW – Sustainable Development Strategy of North Rhine-Westphalia (2016): Sustainable Development Strategy for North Rhine-Westphalia. act now. working together towards sustainable development in NRW. State Government of North Rhine-Westphalia (Ed.). [https://www.nachhaltigkeit.nrw.de/fileadmin/download/Nachhaltigkeitsstrategie/NHS\\_EN\\_v17\\_Screen\\_Einzelseiten.pdf](https://www.nachhaltigkeit.nrw.de/fileadmin/download/Nachhaltigkeitsstrategie/NHS_EN_v17_Screen_Einzelseiten.pdf) (accessed 20.04.2018)
- SDS RP – Sustainable Development Strategy of Rhineland Palatinate (2015): Perspektiven für Rheinland-Pfalz. Nachhaltigkeitsstrategie des Landes: Fortschreibung 2015. Ministerium für Wirtschaft, Klimaschutz, Energie und Landesplanung Rheinland-Pfalz (Ed.) [https://mwvwlw.rlp.de/fileadmin/mwkel/Abteilung\\_2/8206/02\\_Nachhaltigkeitsstrategie\\_Rheinland-Pfalz/Nachhaltigkeitsstrategie\\_2015.pdf](https://mwvwlw.rlp.de/fileadmin/mwkel/Abteilung_2/8206/02_Nachhaltigkeitsstrategie_Rheinland-Pfalz/Nachhaltigkeitsstrategie_2015.pdf) S.15ff. [https://www.nachhaltigkeit.nrw.de/fileadmin/download/Nachhaltigkeitsstrategie/NHS\\_EN\\_v17\\_Screen\\_Einzelseiten.pdf](https://www.nachhaltigkeit.nrw.de/fileadmin/download/Nachhaltigkeitsstrategie/NHS_EN_v17_Screen_Einzelseiten.pdf) (accessed 20.04.2018)
- SDS SL – Sustainable Development Strategy of Saarland (2017): Gemeinsam Verantwortung tragen für heute und morgen. Nachhaltigkeitsstrategie für das Saarland. Ministerium für Umwelt und Verbraucherschutz Saarland (Ed.) <https://www.saarland.de/SID-A63C346F-8E49DF87/219917.htm> (accessed 10.08.2018)

- SDS TH – Sustainable Development Strategy of Thuringia (2018): Thüringer Nachhaltigkeitsstrategie 2018. Stand: 07.08.2018.  
[https://thueringen.de/mam/th8/tmlfun/nachhaltigkeit/thueringer\\_nachhaltigkeitsstrategie\\_2018.pdf](https://thueringen.de/mam/th8/tmlfun/nachhaltigkeit/thueringer_nachhaltigkeitsstrategie_2018.pdf) (accessed 10.08.2018)
- State Government NRW – State Government of North Rhine-Westphalia (2016a): Nachhaltigkeitsstrategie für Nordrhein-Westfalen. heute handeln. Gemeinsam für nachhaltige Entwicklung in NRW. Düsseldorf, Germany.  
[https://www.nachhaltigkeit.nrw.de/fileadmin/download/nrw-nachhaltigkeitsstrategie\\_broschuere.pdf](https://www.nachhaltigkeit.nrw.de/fileadmin/download/nrw-nachhaltigkeitsstrategie_broschuere.pdf) (accessed 20.04.2018)
- State Government NRW – State Government of North Rhine-Westphalia (2016b): Nachhaltigkeitsindikatoren Nordrhein-Westfalen. Bericht 2016. heute handeln. Gemeinsam für nachhaltige Entwicklung in NRW. Düsseldorf, Germany.  
[https://www.nachhaltigkeit.nrw.de/fileadmin/download/nachhaltigkeitsindikatorenbericht\\_2016.pdf](https://www.nachhaltigkeit.nrw.de/fileadmin/download/nachhaltigkeitsindikatorenbericht_2016.pdf) (accessed on 20.04.2018)
- Statistische Ämter des Bundes und der Länder (2014): Fläche und Bevölkerung nach Ländern. <https://www.statistikportal.de/de/bevoelkerung/flaeche-und-bevoelkerung> (accessed on 01.07.2018)
- Steffen, Will; Richardson, Katherine; Rockström, Johan; E. Cornell, Sarah; Fetzer, Ingo; Bennett, Elena M.; Biggs, R.; Carpenter, Stephen R.; Vries, Wim de; Wit, Cynthia A. de; Folke, Carl; Gerten, Dieter; Heinke, Jens; Mace, Georgina M.; Persson, Linn M.; Ramanathan, Veerabhadran; Reyers, B.; Sörlin, Sverker (2015): Planetary boundaries: Guiding human development on a changing planet. In: Science, Vol. 347, Issue 6223, Article 1259855
- Steurer, Reingard; Trattnigg, Rita (2010): Nachhaltigkeit regieren: eine Bilanz zu Governance-Prinzipien und -Praktiken. München
- Teah, Heng Y.; Akiyama, Tomohiro; Carlos, Ricardo S.; Rayo, Orlando V.; Khew, Yu T. J.; Zhao, S.; Zheng, L.; Onuki, M. (2016): Assessment of Downscaling Planetary Boundaries to Semi-Arid Ecosystems with a Local Perception: A Case Study in the Middle Reaches of Heihe River. In: Sustainability, Vol. 8, Issue 12, Article No. 1233
- UBA – Federal Environment Agency (2017): Ozon-Belastung.  
<https://www.umweltbundesamt.de/daten/luft/ozon-belastung#textpart-1> (accessed on 01.07.2018)
- UN – United Nations (2016): Final list of proposed Sustainable Development Goal indicators.  
<https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf> (accessed on 01.07.2018)
- UN – United Nations (2015): Transforming our world: the 2030 Agenda for Sustainable Development. Resolution adopted by the General Assembly on 25 September 2015. [http://www.un.org/ga/search/view\\_doc.asp?symbol=A/RES/70/1&Lang=E](http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E) (accessed on 01.06.2017)
- UN DESA – United Nations Department for Economic and Social Affairs (Ed., 2002): Guidance in preparing a national sustainable development strategy: managing sustainable development in the new millennium. Background Paper No. 13.  
<https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=90&menu=1515> (accessed on 28.04.2017)
- UNEP – United Nations Environment Programme (2011): Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers. [www.unep.org/greeneconomy](http://www.unep.org/greeneconomy) (accessed on 01.07.2018)

- Van den Bergh, J. C. J. M.; Grazi, F. (2010): On the policy relevance of ecological footprints. In: Environmental Science and Technology, Vol. 44, Issue 13, pp. 4843-4844
- Wackernagel, Mathis; Rees, William E. (1996): Our Ecological Footprint: Reducing Human Impact on the Earth. New Society, Gabriola Island, British Columbia
- Wiedmann, Thomas; Barrett, John (2010): A review of the ecological footprint indicator - Perceptions and methods. In: Sustainability, Vol. 2, Issue 6, pp. 1645-1693
- Wuppertal Institute (2018): Dematerialisation and Circularity of Plastic. Wuppertal Institute is partner in new project "eCircular" on the prevention of plastic. News 27.07.2018. <https://wupperinst.org/en/a/wi/a/s/ad/4372/> (accessed on 31.07.2018)
- Wuppertal Institute (2016): Experiences of Implementing Statewide Sustainability Strategies - Case Study: Sustainability Strategy NRW. <https://wupperinst.org/en/p/wi/p/s/pd/650/> (accessed on 31.07.2018)