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Eco-Factors for International Company Environmental Management Systems

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Abstract: Environmental management systems (EMS) require the assessment of environmental aspects to ensure that organizations recognize their most relevant impacts on the environment. The ecological scarcity method (ESM) provides weighting factors for environmental flows (pollutants and resources), called eco-factors (EF), applicable in the assessment of environmental aspects. EF are based on a distance-to-target approach, displaying the ratio of the current state to the respective policy targets for environmental flows. The ESM has been developed for Switzerland; however, for site-specific application beyond Switzerland, national EF are desirable. This publication presents a systematic procedure for the derivation of EF in an international framework, based on the investigation of eight countries worldwide and comprehensive data research. As a novel feature, the grouping of EF into sets is introduced, according to the character of the underlying policy target: legally based, intended policy, or expert recommendation. Overall, 134 EF for six environmental issues were calculated and applied in a case study from Volkswagen AG. An in-depth analysis identifies the differences between national EF and between sets of EF and discusses the implications for EMS. From the findings, general conclusions for future development and the application of EF in an international context of company management are derived.

Keywords: environmental scarcity method; eco-factors; environmental management systems; environmental aspects; weighting; policy targets



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1. Introduction

Environmental management systems (EMS) have evolved since the 1990s; the European Union's eco-management and audit scheme (EMAS) and the standard ISO 14001 are widely-used international schemes. Since 2001, first by the revision of the EMAS [1] and later by the revision of ISO 14001, the requirement for an organization to identify and evaluate its environmental aspects has been introduced [2], thereby promoting that organizations recognize their effective impacts on the environment and focus measures on the most significant aspects. The approach to assess the relevant environmental aspects is largely left to the individual organization [3–8]. A divergent and low-structured procedure for the assessment of environmental aspects, however, encompasses drawbacks as to comparability, reproducibility, and transparency.

In 2003, the Volkswagen AG (VW) introduced the so-called SEBU approach (i.e., a system for identification and impact assessment of environmental aspects) in its EMS, which is based on the systematic procedure for the assessment of environmental aspects developed by Gernuks et al. [9]. Since then, SEBU has been continuously used within VW production sites across Europe. It comprises two parts: the identification of the

relevant environmental aspects and the derivation of environmental targets based on this assessment. The latter part involves the technical experts at the company's production sites in order to incorporate their expert knowledge and raise their awareness of environmental issues. To foster this process, the approach for the identification of relevant aspects is expected to be scientifically substantiated and, at the same time, easy to communicate. Based on these requirements, Gernuks et al. [9] proposed the ecological scarcity method (ESM) for the evaluation of environmental aspects. ESM was developed in Switzerland and provides weighting factors, the so-called eco-factors (EF), which are based on a distance-to-target approach, i.e., the ratio of the current state to a desired state of the environment. The EF in ESM have been derived for Switzerland, i.e., are based on Swiss framework conditions [10,11]. However, they are also used outside Switzerland, as few national EF in other countries exist. In the 1990s, adaptations of ESM were carried out for Japan [12] (updated later [13]), Sweden and Norway [14]. Single EF for Thailand (primary energy, greenhouse gases, freshwater resources) were developed in a study on biofuels [15]. EF for Germany [16], Germany and Russia [17], and for the European Union (EU) were also published [18,19]. Recently, international EF for three environmental issues have been calculated based on data from international organizations [20].

For the assessment of production sites, the EF for the respective countries where a site is located are desirable in order to reflect the national framework conditions towards which an EMS should be oriented. Due to the lack of EF for most countries worldwide, VW has launched several projects to derive national EF for a broad scope of environmental issues for countries where its production sites are located. While the first projects provided EF for Germany and the EU [18,19], this publication reports EF for eight countries outside Europe.

The novelty of this publication in contrast to former approaches [12–20] lies in (i) the development of a systematic procedure for all steps of selecting data sources and deriving EF, and (ii) an in-depth analysis of the significance and differences of EF for diverse nations and the related implications of their application in EMS. The benefits of this systematic procedure are, on the one hand, high transparency and reproducibility of all steps for the calculation EF, including the retrievability of data sources, and on the other hand a clear reasoning for the selection of policy goals describing the desired state of the environment. Based on this systematic procedure and the joint investigation of eight independent countries (in contrast to a focus on the domestic viewpoint of single countries as in earlier publications), differences in the definition and terminologies of environmental flows and also in national target-setting on environmental issues can be revealed. The discussion highlights the outcomes of the resulting EF and the consequences of their application in the EMS of multinational companies based on a case study from VW. Thus, conclusions can be drawn regarding the challenges and perspectives for the application and further development of the ESM in the international context.

2. Materials and Methods

2.1. The Ecological Scarcity Method

The idea of ecological scarcity was introduced by Müller-Wenk in 1978 in an early concept for the environmental management of companies [21]. Based on this idea, the ESM has been elaborated in subsequent publications [10,11,22]. In ESM the current and desired states of the environment are expressed as flows for a reference area, denoted as “current flow” and “critical flow”. The term “flow” notably covers pollutants and resources, i.e., physical flows of substances or materials, but in general, every environmental impact that can be expressed as a quantity per unit in time can be defined as a flow. Ecological scarcity “is determined as a function of the limited carrying capacity of the environment in relation to anthropogenic impacts (critical flow) and of the effective extent of these impacts (current flow) upon the environment” [11]. From this distance-to-target approach, EF are calculated as weighing factors for the respective environmental flows. EF are expressed as eco-points (EP) per unit of pollutant emission or resource extraction. Multiplying real flows, e.g., from a production site, with their corresponding EF, converts them into the common

unit of EP, providing the possibility to aggregate the results for multiple environmental flows to a single-score value.

The calculation algorithm for EF was first defined by Frischknecht et al. [22] as described in Equation (1):

$$EF = (1 \times \text{UBP}/F_k) \times (F/F_k) \times c [\text{UPB}/\text{physical unit} \times \text{a}] \quad (1)$$

where F is the current flow, F_k is the critical flow, c is $10^{12}/\text{a}$ (dimensionless number, adjusting EF to a convenient range of magnitude), and UPB is EP. In Equation (1), the notion of distance-to-target or ecological scarcity is displayed by the ratio of F to F_k . The larger the current flow (i.e., the current state of pollution) and the smaller the F_k (i.e., the level which is termed to be critical for the environment), the higher the EF will be, attributing increased weight to the respective flow. The first term, $1/F_k$, provides a normalization to the critical flow, accounting for the fact that even in the case of the same ratio of F/F_k , the impact of one substance may be higher, which is displayed by its critical flow as denominator [22]. The critical flow, a proxy for the desired state of the environment, is derived from policy goals which are usually defined on the national level. Thus for practical reasons, the ESM specifies the flows for the reference area of a nation, which also enables the use of national statistics to identify current flows [22].

With the update of ESM in 2006 [10], the expression of the formula has been reformulated to the current structure displayed in Equation (2):

$$EF = K \times \left(\frac{EP}{F_n} \right) \times \left(\frac{F}{F_k} \right)^2 \times c \quad (2)$$

In Equation (2), the denomination of F , F_k , c , and their units stays the same as in Equation (1). In addition, a normalization flow, F_n , is introduced, which is defined as the current flow F_n “of the region to which the eco-factor is to apply” [10]. For the Swiss EF, this is the national territory of Switzerland. However, according to Frischknecht et al. [10], temporal and geographical/spatial differentiation is possible for regionalized EF calculation. Above this, the main motivation for the above reformulation has been the intention to make the formula compliant to the structure of life cycle impact assessment (LCIA), a phase of life cycle assessment (LCA) as described in the international standards ISO 14040/44. The latest update of ESM also introduces a revised classification of pollutants and resources [11], in view of complying with the concept of midpoint indicators applied in LCIA. Formerly, EF for single substances had been grouped according to the environmental compartment, now the grouping is performed along with environmental impacts and issues. However, as Frischknecht et al. [11] point out, policy targets taken from laws often relate to individual pollutant emissions, not impacts. Thus, the grouping of EF comprehends impact-based groups (e.g., climate change, ozone layer depletion) and thematic based groups (e.g., air pollutants, energy resources), in total 19 groups.

It should be noted, however, that despite the formal compliance of Equation (2) to the procedural structure of LCIA, there are fundamental differences as to how environmental impacts are evaluated. LCIA, according to ISO 14044, is based on the application of a characterization model for the respective impact category. This characterization model connects flows into the environment by a natural science-based cause-effect chain to impacts derived from the current scientific knowledge. Using this model, so-called category indicators are calculated, whose dimension is specified by the selected characterization model. Comparing the category indicator results for different products, services or organizations reveals the one with the lowest environmental impacts. In contrast, the ESM only accounts for impact assessment indirectly by assuming that a natural science-based evaluation of the impacts has been taken into account in the process of setting policy targets, which are used to derive critical flows.

2.2. Approach for Calculation of Country Specific Eco-Factors

Eight countries were selected based on the location of production sites of VW: Argentina, Brazil, China, India, Mexico, Russia, South Africa, and the US. These countries make up nearly half of the world's population (47.9%) and cover 36.7% of its land area. The production sites are integrated into the global organization and brand structure of VW, so that framework conditions, as well as the technological level of production, can be seen to be similar worldwide. This is documented by the VW Multisite Certification, which was established for 24 VW brand production sites [23].

The general methodological approach follows the current ESM as described above [11]. The list of EF to be worked out is adopted from Ahbe et al. [16] for the EF for Germany. This selection is substantiated by the general environmental importance and the specific relevance of the environmental indicators to automotive production sites. At the operational level, this adoption ensures a largely homogeneous list of EF for application in EMS at all production sites of a multinational company worldwide. Still, inevitably, some modifications had to be taken due to the switch to an international framework.

For normalization, in literature, different options are discussed as to the choice of region and the consequences of such choices [20]. Here, in view of the intended application in production sites, current national flows were used for normalization, i.e., normalization was performed for the respective countries. This mirrors the perspective of the region in which the production site is located and which is affected by its emissions.

3. Systematic Procedure for Derivation of Eco-Factors

3.1. Overview

The systematic procedure is presented in Figure 1. It encompasses the four steps described in detail below:

Step 1: Identification of data sources for current flows.

Step 2: Selection of policy targets for critical flows.

Step 3: Elaboration of the specific calculation approach for each EF.

Step 4: Assignment of the calculated EF to sets.

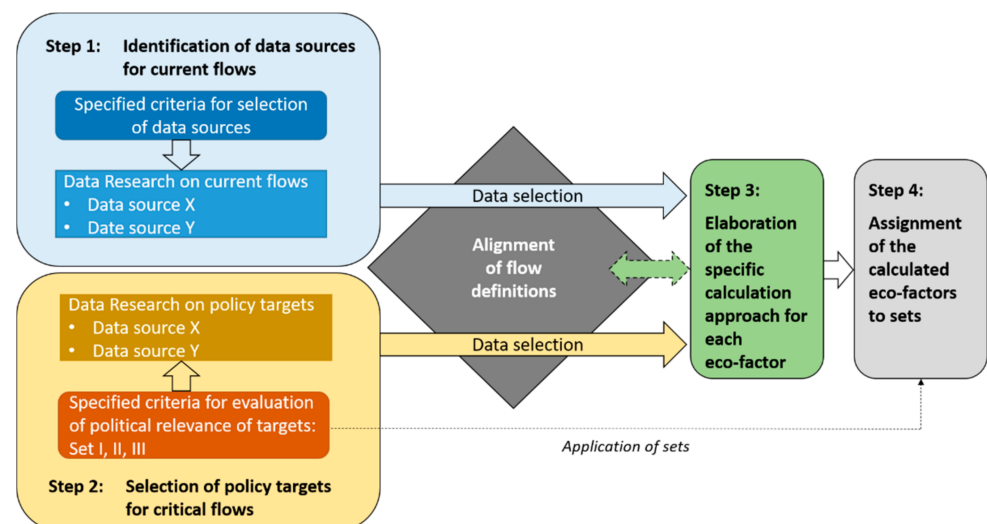


Figure 1. Systematic procedure for derivation of eco-factors.

While steps 1–3 are performed for each eco-factor individually, in step 4, for application in ESM, all calculated EF for the eight countries are grouped into sets according to the classification of policy targets performed in step 2.

Steps 1 and 2 comprise two parts: first, the specification of criteria for the selection of data sources and policy goals, respectively; second, the actual search for data, including the documentation of data sources and access to data. This distinction between criteria and

data search is a basic feature for transparency as well as reproducibility and is the basis for the future updating of data.

Steps 1 to 3 are connected iteratively by the alignment of flow definitions. This became necessary, as the first screening of data sources revealed divergent definitions and terminologies for flows between the investigated eight countries or between current flows and policy goals for one country. This is also the reason why definitions or terminology of single-resulting EF are diverging from Frischknecht et al. [11] and/or Ahbe et al. [16].

3.2. Step 1: Identification of Data Sources for Current Flows

3.2.1. Selection of Data Sources

For current flows, data on environmental emissions in different media (air, water, soil), as well as other flows (energy, waste), on the national level are sought. In case there are no data on emission flows are available, other environmental data are needed, e.g., data on concentration levels, together with supplementary data in order to calculate the respective flows. Data sources should generally be selected as to the criteria of providing the most recent national data based on quality assurance procedures. Following these criteria, national statistic agencies are a primary source for current flows, providing data from national or sub-national statistical data collection. However, for many environmental issues, notably climate change and air pollutants, these national data are regularly transferred into international statistics. These provide a convenient way for accessing data, together with an additional level of quality assurance and homogenization of data. In some cases, research agencies also provide quality-assured compilations of these statistics together with tools or compiled tables to access data in a structured way.

Thus, the selection of data sources has been based on comprehensive web-based research via the websites of institutions that provide respective quality-assured data sources, e.g., United Nations (UN), Organization for Economic Co-operation and Development (OECD), International Energy Agency (IEA), independent research organizations such as the World Resources Institute (WRI), or compiled data services and databases, e.g., Climate Action Tracker (CAT). The databases selected for each flow and the criteria for their selection are also documented in view of the need for updating data, which can be performed on the basis of identified data sources and the most convenient way of access.

3.2.2. Evaluation of Data Quality

The assessment of data quality for current flows is not a straightforward task. International as well as national organizations and statistical offices follow general procedures of quality assurance: the United Nations Fundamental Principles of Official Statistics prescribes guidelines and good practices to ensure the high quality of national statistical systems [24]. For environmental issues, the UN Framework for the Development of Environmental Statistics [25] and the System of Environmental-Economic Accounting [26] exist. However, these frameworks “give only general guidance and leave a lot open to different approaches and interpretations”, and databases rarely include explicit information on data quality in terms of uncertainty [27]. Factually, data quality is divergent for different environmental issues. The most rigorous efforts for data quality are encountered in the area of climate change [28]. In the case of CO₂ emissions, an estimation of data uncertainty can be found in Macknick [29], who identified variations in the data of global primary energy use and resulting CO₂ emissions from fossil fuel combustion of 9.2% and 2.7%, respectively, based on data in 2007. For the areas of air and water quality, no estimates on uncertainties are found, but several sources of problems as to the data quality of existing statistics are identified (e.g., United Statistics Division [30]). Notably, in the area of waste management, data quality is considered to be low due to the following reasons: for waste statistics, different classification schemes are applied, and the underlying principles and concepts are unclear and/or overlapping [27]. Problems of lacking or incomplete data are most severely encountered in low-income countries [31], where several important aspects of waste management (illegal waste collection, trade and dumping, informal waste

picking, private waste sector) are not reflected by official waste statistics. Consequently, absolute amounts of waste flows and the percentage of recycled waste may be significantly underestimated [27].

3.3. Step 2: Selection of Policy Targets for Critical Flow

3.3.1. Criteria for Selection of Policy Targets

For critical flows, quantitative environmental protection targets for environmental impacts or issues have to be identified. Frischknecht et al. [11] point out that “targets should ideally be adopted in legally binding form or at least defined as targets by competent authorities”. As the legislative process for legally binding targets is exclusively allocated to sovereign nations, legally binding targets can only be found on the national level (with one exception of the EU, where the member states have transferred part of their legislative sovereignty to the European level). However, legally binding political targets at the national level do not exist for many environmental issues and indicators. To complete the list of desired EF, it is necessary to also include other targets to derive critical flows. The significance of the resulting EF will vary depending on the character of the underlying target. A specification for different sets of EF was proposed by Muhl et al. [19] and for weighing factors for the EU by Castellani et al. [32]. However, here the grouping of targets followed the underlying homogeneous framework of European policy targets. In contrast, outside the EU, no overarching single policy framework exists. Thus, generally applicable definitions for the classification of the character of targets had to be developed, substantiated as far as possible by recognized definitions from political science. The following three sets were defined:

Set “National Legally Binding” (NLB)

The term “legally binding” is unambiguous as it is defined by the fact that the rule in question has successfully passed through the legislative process within a sovereign nation and has become the “law of the land”. The respective targets comprise the following: (1) Individual national legally binding targets; (2) International targets that are directly enforced at the national level based on respective international agreements (today, this applies only to the EU based on the primary law agreed in EU treaties); (3) International targets that have become legally binding at the national level either by the ratification of international treaties or by single governmental and parliamentary decisions.

Set “(National) Intended/International Consensus” (NIIC)

This set is based on what is known as “soft law” in international law and political science, i.e., nonbinding instruments and their related targets that, thus, cannot be legally enforced but still have legal and behavioral effects. At the national level, nonbinding targets may come from intended governmental programs or policies that have not (yet) gone through the legislative process but are already foreshadowing governmental action. At the international level, in view of the general lack of enforcement of international law, nonbinding targets are the main instrument of international policy. A well-known example is the UN Declaration of Human Rights of 1948 [33], which started as a soft law but is now universally recognized as absolutely binding. Similarly, in the field of environmental policy, “nonbinding instruments increasingly establish international procedures with direct implications for state administrators” [34].

In summary, respective targets from soft law notably comprise the following: (1) national intended targets formulated by the government or competent national authorities; (2) international targets set by permanent international intergovernmental organizations (UN, IEA, WEO (World Economic Outlook), IPCC (Intergovernmental Panel on Climate Change), etc.); (3) international targets from consensus-building processes steered by international organizations.

Set “Expert Recommendation” (ER)

This set may comprise any target-setting by experts and epistemic communities. Here, the selection of targets is arbitrary in the sense that it is not necessarily based on a consensus-building process; however, as an expert recommendation, it is derived from scientific evidence and expertise and is, thus, based on corresponding procedures of quality assurance in science.

3.3.2. Research and Data Sources of Policy Targets

The search of environmental protection targets covers the national level governmental information, laws, and regulations, as well as documents from national authorities or competent bodies. In addition, two databases of international research organizations that provide information on national legal targets or laws of nations were searched [35,36]. Information on international target-setting was sought notably from international institutions involved in intergovernmental negotiations in the field of international environmental law or environmental regimes, e.g., the United Nations Framework Convention on Climate Change (UNFCCC). Here, up-to-date information on the status of ratification and, thus, the legal enforcement of international agreements on the national level can be found. All identified data sources have also been documented in view of the need of the future updating of EF. If neither national nor international targets could be identified, individual procedures for the derivation of targets in the sense of “Expert recommendations” were determined.

A general problem is the different timelines of policy targets. For reasons of comparability, within one environmental issue, if possible, one target year for all countries was selected. If no common target year could be extracted for all countries, different target years were reported. Principally, a harmonization of targets to one timeline can be conceived; however this would have needed further assumptions or even calculation models. These, in turn, implicate a high uncertainty due to necessarily arbitrary decisions and thus were refrained from.

3.4. Step 3: Elaboration of the Specific Calculation Approach for Each EF

In cases where flow data were available in terms of mass per year, the direct calculation of EF according to Equation (2) was possible. In cases where no flow data existed, an adapted calculation procedure had to be elaborated, including additional data and information. As far as possible, the procedures proposed in Frischknecht et al. [11] and Ahbe et al. [16] were followed, also incorporating the application of characterization factors, which were used only in the case of climate change. In single cases, due to the selected terminology/definition of flows, specific calculation approaches were developed. These are documented in detail in the Supplementary Materials (SM).

3.5. Step 4: Assignment of the Calculated EF to Sets

After all EF had been calculated, they were grouped into sets based on the classification of the underlying policy goals. These classifications were performed by scrutinizing the procedure of formulating the target, and/or the character of the organization in charge of formulating this target. The rationale for allocating a target to a set is documented in the SM. The sets can be provided for each country individually and for the full list of EF.

4. Results and Discussion

4.1. Environmental Issues and Indicators

In total, 134 EF for six environmental issues were calculated. These EF and their assignment to sets are presented in Table 1.

Table 1. EF calculated for eight countries. Set NLB (national legally binding): green; Set NIIC ((national) intended/international consensus): blue; Set ER (expert recommendation): orange.

Environmental Issue	Eco-Factor (EF) for Indicator	Unit	Argentina	Brazil	China	India	Mexico	Rusia	South Africa	United States
Emissions to Air	SO _x ¹	EP/g	9.876	4.919	0.067	1.419	1.386	1.062	3.126	0.231
	NO _x ²	EP/g	6.976	0.616	0.068	0.676	0.706	0.784	2.248	0.157
	PM _{2.5} ³	EP/g	5.897	1.185	0.115	0.334	2.659	3.265	4.830	1.350
Climate Change	NMVOC ⁴	EP/g	2.074	0.567	0.057	0.180	0.087	0.464	0.772	0.109
	CO ₂ ⁵	EP/kg	1.887	1.170	0.067	0.092	1.135	0.446	3.424	0.490
	COD ⁶	EP/g		0.022	0.007	0.0009	0.031	0.000005	0.178	
Emissions to Surface Water	TN ⁷	EP/g	0.257	0.034	0.616	0.722	3.315	0.000093	6.345	0.264
	TP ⁸	EP/g	0.843	3.826	1.824	2.540	35.712	0.058021	0.107	2.058
Scarcity of Freshwater Resources	low	EP/m ³	1.658	0.836	0.105	0.096	0.730	1.025	4.032	0.149
	low to medium	EP/m ³	14.920	7.522	0.947	0.868	6.567	9.221	36.290	1.343
	medium to high	EP/m ³	59.682	30.088	3.787	3.472	26.267	36.885	145.161	5.374
Scarcity of Energy Resources	high	EP/m ³	238.727	120.353	15.146	13.889	105.067	147.541	580.645	21.495
	extremely high	EP/m ³	537.135	270.794	34.079	31.250	236.400	331.967	1306.452	48.364
Waste Generation	non-renewable energy	EP/MJ	0.148	0.055	0.007	0.008	0.147	0.036	0.184	0.019
	renewable energy resources	EP/MJ	0.142	0.040	0.006	0.007	0.130	0.036	0.162	0.016
Waste Generation	hazardous waste	EP/g	3.392	0.264	0.051	0.128	0.440	0.113	0.085	0.030
	non-hazardous waste	EP/g	0.162	0.006	0.001	0.019	0.023	0.003	0.023	0.004

¹ Sulphur oxide; ² Nitrogen oxide; ³ Particulate matter with a diameter below 2.5; ⁴ Non-methane volatile organic compounds; ⁵ Carbon dioxide; ⁶ Chemical oxygen demand; ⁷ Total Nitrogen; ⁸ Total Phosphorous.

Subsequently, for each environmental issue, a short summary of the calculation approach is given. The comprehensive documentation of all data sources, assumptions, and procedures for the calculation are found in the SM.

4.1.1. Emissions to Air

The pollutants sulphur oxide (SO_x), nitrogen oxide (NO_x), particulate matter with a diameter below 2.5 µm (PM_{2.5}), and non-methane volatile organic compounds (NMVOC) are major compounds contributing to environmental pollution, notably in urban areas. For current flows, data could be partly taken from national sources. Missing data were completed by the use of the Emissions Database for Global Atmospheric Research (EDGAR) [37]. Data for critical flows were drawn in most cases from the Gothenburg Protocol, which defines emission reduction targets for air pollutants [38].

4.1.2. Climate Change

The indicator “CO₂-equivalent” comprehends the six greenhouse gases (GHG) included in the Kyoto Protocol: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), fluorinated GHGs, perfluorinated hydrocarbons, and sulfur hexafluoride (SF₆). The characterization factors used are based on IPCC 2007 [39]. Data for current flows of GHG were drawn from the CAT, with 2014 as the reference year for all current flows [40]. For critical flows, in most cases, targets could be drawn from nationally determined contributions (NDC) submitted by countries for the Paris Agreement.

4.1.3. Emissions to Surface Water

The chemical oxygen demand (COD) is a general indicator of water quality. In cases where no data on COD is available, figures are derived from data on the biological oxygen demand (BOD). The indicators inorganic nitrogen (represented as total nitrogen, TN) and inorganic phosphorous (represented by total phosphorous, TP) were selected to stand for the most widespread water quality issue of nutrient enrichment.

For identification of current flows, national data sources could be used for Brazil, China, Russia, South Africa, and the US. In the cases of Argentina, India, and Mexico, an estimation approach for current flows based on wastewater and fertilizer input into surface water was determined. Critical flows were derived partly from national and international sources and partly from the scientific literature. For both current and critical flows, the conversion to flows was performed using the total renewable surface water resource in the respective countries, extracted from the Aquastat Database [41].

4.1.4. Scarcity of Freshwater Resources

The issue of water scarcity is represented by the indicator of water stress, following the definition by the OECD [42]. As water scarcity is highly dependent on regional environmental and socio-economic framework conditions, a country's average value of water stress does not represent regional scarcity adequately [11]. Consequently, EF for five water stress categories were calculated based on the WRI definition. The national total freshwater withdrawal given in the Aquastat Database was employed as normalization flow [41]. To derive the regional EF for a certain location within the country, the maps provided by the WRI in its Aqueduct Water Risk Atlas were used [43].

4.1.5. Scarcity of Energy Resources

As for indicators of the environmental issue of scarcity of energy resources, the flows of "non-renewable primary energy demand" and "renewable final energy consumption" represent the principle that primary energy consumption should be reduced, while the share of renewable energy consumption in primary energy consumption should be increased [16].

Data on current flows for both indicators can be drawn from the World Energy Outlook [44]. As for critical flows, the International Renewable Energy Agency provides an overview on existing sector-related targets [45]. However, no cross-sectoral targets exist for any of the countries investigated, both in terms of the total future primary energy demand and the consumption of non-renewable primary energy. Thus, an approach was derived based on the so-called 450 ppm scenario of the IEA 2015 World Energy Outlook [44].

4.1.6. Waste Generation

The environmental issue of waste generation is represented by the indicators "total amount of non-hazardous waste" and "total amount of hazardous waste". The current flows of hazardous and non-hazardous wastes could be identified for each country but based on the international terms, municipal and industrial wastes are used in most national classification schemes. As to critical flows, no target values for waste exist in any country. For this reason, the approach used in the case of Germany was adapted; this approach considers the current flow to be equal to the maximum tolerable waste amount, i.e., the critical flow values equal the respective current flows [16].

4.2. EF for Eight Countries: Analysis of Differences

For an in-depth discussion of the differences between the investigated countries, Figure 2 presents a compilation of the EF for all eight countries, structured along with the single indicators, and expressed as a ratio to German EF from Ahbe et al. [16]. For comparison, the EF for freshwater were calculated on national flows, not taking into account regional differences. More detailed information used for the discussion is provided in the SM, comprising the data for current, critical, and normalization flows as well as ratios of current to critical flows. For the interpretation of EF and the discussion of differences between countries, per capita values of current and critical flows have been calculated, which are also found in the SM. The use of per capita values notably helps to distinguish the influence of the population from other possible influences on the normalization flows, e.g., the economic structure of a country.

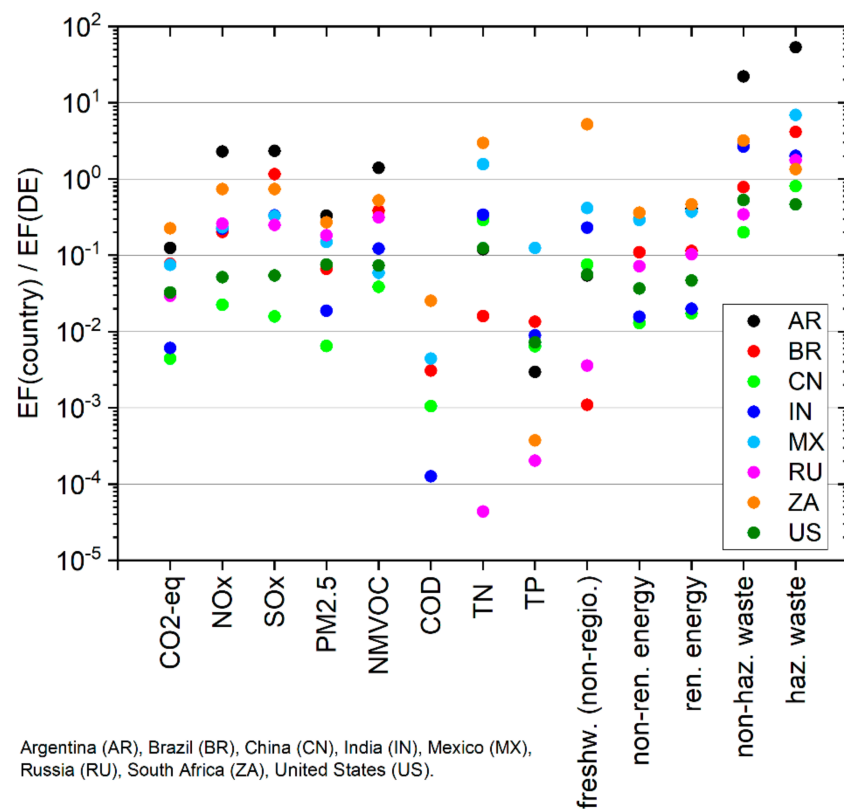


Figure 2. Compilation of the EF for all eight countries, structured along the single indicators and expressed as ratio to German EF from Ahbe et al. [16]. The EF for freshwater are based on national flows only.

The EF show substantial deviations between the eight countries, and from the EF derived for Germany [16]. From Equation (2), it can be concluded that two factors govern the resulting value of an EF: first, the ratio of current to critical flow, which encompasses the notion of ecological scarcity; second, the normalization flow, which is grossly influenced by the size of a country, also in addition to the factors mentioned above. The resulting EF mirrors the influences of both factors. Thus, a higher ecological scarcity may be partly compensated by a higher normalization flow and vice versa.

As a generic finding, the EF for the eight countries tend to be considerably lower compared to Germany. This can be explained by the fact that for Germany, the typically high values of ecological scarcity go along with rather low to medium values of normalization flows. The high values of ecological scarcity can be attributed to comparatively advanced political target-setting, substantiated by the finding that per-capita values of critical flows for Germany tend to be in the lower range of all the countries. At the same time, normalization flows in absolute numbers are in the low to medium range due to the fact that Germany, by area and population, can be rated as a low to medium-sized country. Higher values of EF compared with Germany are found notably for the environmental issues of waste and—in single countries—air and water emissions. In the case of waste, as all values of ecological scarcity have been set to one, differences can be attributed exclusively to the differences in the normalization flows. For other environmental issues, individual reasons accounting for differences will be discussed later.

Another generic finding is that the EF for China tend to be low. This can be attributed to the large values of normalization flows, expressing a high population. It is, however, also related to a comparably high degree of industrialization, which is supported by the finding that the per capita current flows for China are in general more than double that of India, which has a comparable number of inhabitants. In contrast, the EF for Argentina and South

Africa tend to be in the high range of countries, due mainly to the small normalization flow from a low population, as per capita flows lie in the medium range of the countries.

Within environmental issues, individual differences stand out for single countries. In the case of climate change, the EF for India and China are more than one magnitude lower compared to the other countries. In both cases, a rather low ecological scarcity coincides with rather large normalization flows. For India, the main reason is a low factor of ecological scarcity. Comparing this with the rating of climate goals according to CAT [40], India's NDC is rated to be in line with the 2-degree goal, while China's NDC is rated as highly insufficient. However, China has by far the highest normalization flow, which compensates for and shifts its EF in the same range as India's. In the cases of NO_x and SO_x, the EF of the US and China are in the lowest range, which corresponds to a medium ecological scarcity and a rather high normalization flow in both countries. In contrast, for PM_{2.5}, the low EF can be attributed to the large normalization flows for China and India. For COD, TN and TP, all results for Russia are outstandingly low due to an outstandingly low ecological scarcity based on a high value of critical flows (in absolute terms as well as per capita).

In the case of freshwater, the EF calculated from national flows reflect the order of national non-regionalized water stress [46].

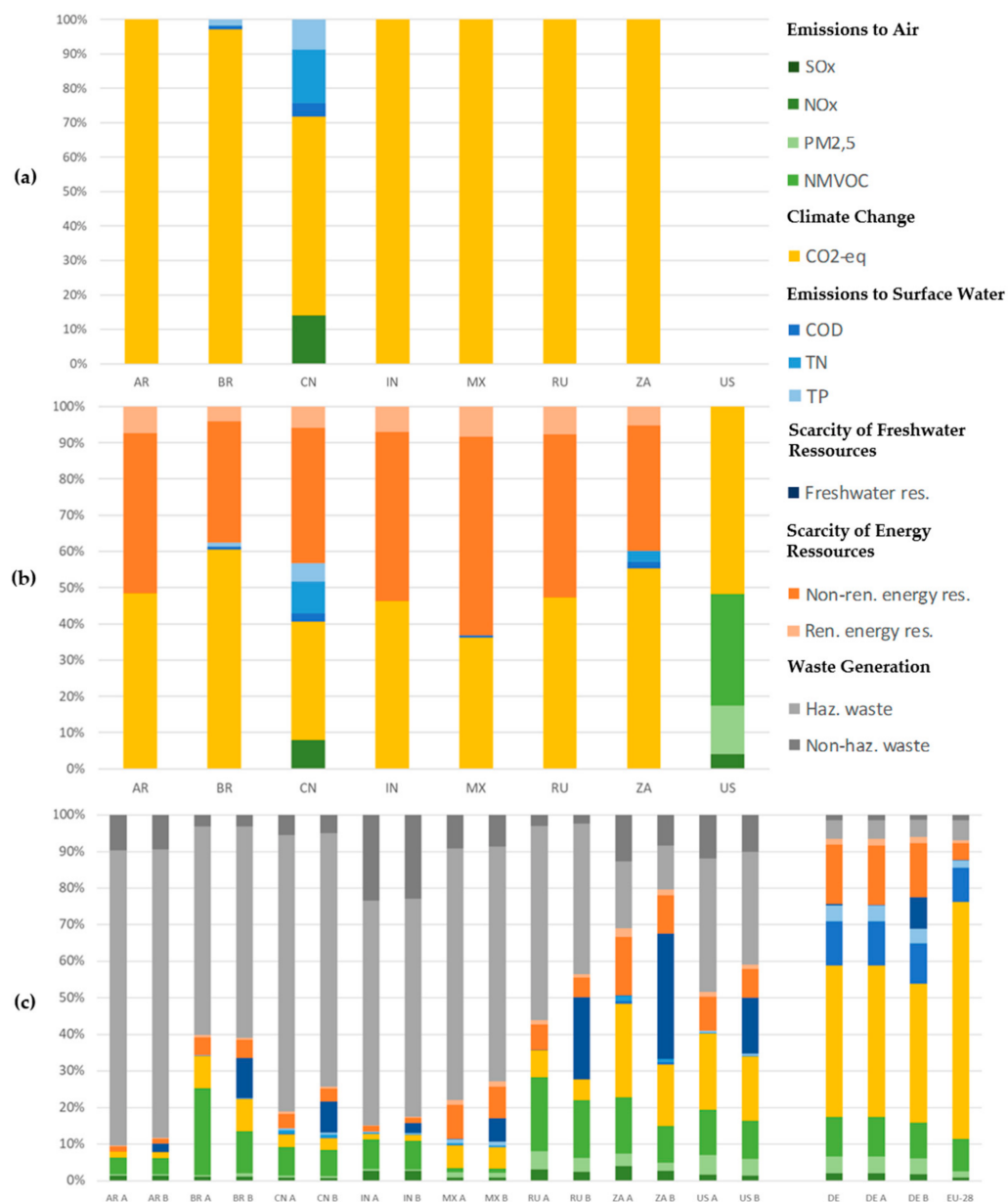
4.3. Case Study

For the application of the EF for eight countries, as a case study, the compilation of total emissions per produced vehicle was selected, which is published in the VW sustainability report 2018 [47]. This compilation, presented in Table 2, comprehends all flows from VW production sites but no upstream emissions (e.g., mining of raw materials and production of commodities such as steel).

Table 2. Data provided in the VW Sustainability Report for the year 2018 [47].

Environmental Issue	Indicator	Value	Unit	Comment
Emissions to air	SO _x	1	g/vehicle	
	NO _x	173	g/vehicle	
	PM _{2.5}	68	g/vehicle	Value for total particle emission, no value given for PM _{2.5}
	NMVOG	1.93	kg/vehicle	Value for VOC, no value given for NMVOG
Climate change	CO ₂ -eq	720	kg/vehicle	
Emissions to surface water	COD	449	g/vehicle	
	TN	21.3	g/vehicle	Internal approximation of the Volkswagen Group (average)
	TP	4	g/vehicle	Internal approximation of the Volkswagen Group (average)
Scarcity of freshwater resources	Freshwater	3.86	m ³ /vehicle	
Scarcity of energy resources	Non-renewable energy resources	1684	kWh/vehicle	Calculation includes primary energy factor according to EnEV
	Renewable energy resources	400	kWh/vehicle	Share of renewable energy resources as a mean of Volkswagen Group
Waste generation	Non-hazardous waste	52.37	kg/vehicle	Sum of waste amount for recycling (46.91 kg/vehicle) and waste amount for disposal (5.46 kg/vehicle)
	Hazardous waste	20.8	kg/vehicle	Sum of waste amount for recycling (14.06 kg/vehicle) and waste amount for disposal (6.74 kg/vehicle)

Based on the definition of the sets of EF in Section 3.3.1, three alternative cases were calculated: Case I: using only NLB; Case II: using sets NLB and NIIC; Case III: using all three sets. The results are presented in Figure 3, including results based on EF for Germany [16] and the EU [18] in case C for comparison. Here, in contrast to Figure 2, the results for water scarcity are calculated using exemplary EF for low (A) and extreme (B) water scarcity.



Argentina (AR), Brazil (BR), China (CN), India (IN), Mexico (MX), Russia (RU), South Africa (ZA), United States (US)

Figure 3. Shares of environmental impacts for VW production per vehicle, using different sets of EF. (a): Set “National legally binding” (NLB) only; (b): Sets “National legally binding” (NLB) and “(National) Intended/international consensus” (NIIC); (c): Set “National legally binding” (NLB), set “(National) Intended/international consensus” (NIIC), and set “Expert recommendation” (ER); Exemplarily, low (A), and extreme (B) water stress levels are shown. For comparison with Germany (DE) and the EU-28, the original data from Ahbe et al. [16] and Ahbe et al. [18] are included. For Germany, in addition, the EF for low (DE A) and extreme (DE B) water scarcity were calculated from the data of Ahbe et al. [16].

The shares of the single environmental impacts vary substantially between the countries, which underlines the importance to account for national framework conditions. Generally, it is noteworthy that within one country, the share of one environmental impact is always the result of the interaction of all EF, where a higher share of one impact may be the result of a higher weight of this impact or lower weights of the others, compared with a given reference, e.g., Germany.

The selection of different sets has a major impact on the results. In case I, set NLB (Figure 3a) restricts the results to one or only a few EF for each country. For the US, no EF exists in set NLB. This is due to the withdrawal of the US Trump administration from the

Paris agreement, which was conveyed to the UN Secretary-General on 4 November 2019 and took effect on 4 November 2020 [48]. The newly-elected US President Biden announced in April 2021 to rejoin the Paris agreement again and declared his ambitions that the new target aims at a 50–52% reduction of US greenhouse gases from 2005 levels before 2030 [49]. However, currently, this declaration is not yet legally in force, and thus the target was included in Set NIIC. For all other countries, EF for the environmental issue of climate change exist, which displays the current overarching importance of the climate regime in international policies. For Brazil and China, further EF exist for the environmental issues of emissions to air and emissions to surface water. These have minor contributions in the case of Brazil but account for more than 40% of the total impact in the case of China, which has set national legal targets for air pollutants.

The inclusion of set NIIC in case II (Figure 3b) provides a broader picture of the environmental issues. For the US, EF for climate change and air pollutants exist, the latter due to the acceptance of the Gothenburg Protocol. For the other countries, the EF for the issue of scarcity of energy resources notably contribute to the overall impacts. Together, the EF for climate change and scarcity of energy resources dominate in all countries, with the exception of China and the US.

The use of all EF in case III (Figure 3c) changes the picture again: The consideration of regionalized EF for water scarcity reveals major differences in the results, most significantly for Russia and South Africa [50]. Most notably, however, now waste generation is the overarching environmental issue in most countries, where in contrast, the share of waste generation is far lower for Germany [16] and the EU [18]. From the findings in Section 3.2, this can be explained by the higher values of the EF for waste generation in the eight investigated countries compared to Germany, displayed in Figure 2.

4.4. Discussion

Based on the development of a systematic procedure, EF have been worked out for eight countries and six environmental issues. Data gaps, as well as inconsistencies between data sources encountered in the process of data research, could be tackled in most instances by the specific approaches applied for the six environmental issues. Thus, a largely homogeneous compilation of EF for application in EMS could be elaborated. The comparison of the national EF to German EF and between the eight countries reveals the contributing factors to the calculation result for EF for the single environmental issues and emphasizes the relevance of national framework conditions.

As to the uncertainty of the calculated EF, Equation (2) shows that from the calculational perspective, contributions may come both from the critical flow and the current flow. However, the character of uncertainty between these flows is fundamentally different. In the case of critical flows, the uncertainty goes along with the formulation of the underlying political target, where a cloudy definition of target values or a weak connection to target years are possible reasons. In the case of current flows, uncertainty is related to the deviation of the values taken from statistics to reality. It has to be noted that this kind of uncertainty may also contribute to critical flows in the case of emissions to surface water, where targets are defined as concentration and have to be converted using data for surface water flows. For statistical data for current flows, the analysis of data quality evidenced large differences between environmental issues, with the issue of climate change as an area of high quality and the waste sector as the most crucial area. Notably, future improvement of data quality and method development is highly desirable. Here low data quality correlates to high uncertainty of the quantitative values of EF. Above this, it can be argued that the assumption of an ecological scarcity of 1 is arbitrary as well as far too optimistic, indicating a low environmental concern, which obviously is not the case for waste management in many countries. At the same time, the likely underestimation of waste quantities leads to a low normalization flow, in turn to a higher EF, which to some degree might compensate.

The assignment of EF to the sets developed in this study enhances the transparency for the user as to the underlying process of political decision-making. The application in a case study shows that the selection of sets of EF has a decisive influence on the outcome for EMS. The restriction of EF to national legally based targets (i.e., set NLB) is not feasible for application in EMS as it omits important environmental impacts, and the absence of EF for specific environmental issues strongly distorts the results between countries. Consequently, the inclusion of the sets NIIC and ER is recommended in EMS for multinational companies. The case study results also show how the three sets mirror the development of international policies. Today, international NLB targets are found predominantly in the area of climate policy. This area also dominates the NIIC set, complemented by targets for renewable energies. In addition, the areas of emissions to air and emissions to surface water contribute. In the case of air emissions, most targets can be traced back to an international agreement, while in the water sector, national targets dominate. No international conventions and national goals are encountered in the areas of water consumption and waste. As to the environmental issue of freshwater resources, our approach is based on the WRI definition of water scarcity and water stress, which is used in Frischknecht et al. [11], and is an internationally acknowledged expert approach. In contrast, as with waste generation, no similarly general acknowledged approach exists, again emphasizing the demand of method development for valuation of the environmental relevance of waste flows. Overall, the compilation of all three sets for application in EMS provides a comprehensive view regarding policy targets while at the same time disclosing the current relevance of each target and reflecting the status of different areas of environmental policy.

Based on this comprehensive picture, companies can address the requirement of international standards for EMS, notably 14001 und EMAS, for the site-specific evaluation of the relevance of their environmental aspects. The EF developed in this study cover major aspects; however, as has been pointed out, they omit flows where no targets exist. Above these, they necessarily also neglect environmental aspects mentioned in 14001 and EMAS that do not have the character of flows, such as operation and maintenance of facilities. These aspects are complemented in the case of VW by additional evaluation procedures specified in the SEBU system. Similar approaches will have to be set in other companies if applying the ESM in EMS. In the case of upstream and downstream aspects in the supply chain, and notably of impacts from the product, the evaluation has to draw on results from LCA studies.

In international companies, the use of country-specific EF fosters a shift from a rigid and general top-down management to a more regional and specific target setting process. From the site assessment using country-specific EF, the individual relevance of environmental impacts related to the regional framework becomes visible. The evaluation of the application of ESM at the Volkswagen production sites shows that this allows the local management to easily understand the environmental relevance of different environmental aspects and the connection to the internal processes, material flows, and outputs [50]. In contrast to the generic picture resulting from the case study in this publication, much more detailed real-world applications, also for the identification of single production lines or materials, targeted measures shall be conceived. Thus, the ESM allows a very detailed ranking of the most relevant measures of improvement. Due to the positive experiences, the application of ESM will be integrated into Volkswagen's global sustainability strategy "goTOzero" [51].

5. Conclusions

The ESM is particularly suitable for the assessment of environmental aspects in EMS due to its basic principle of distance-to-target, which integrates information on the current state of environmental issues and the policy targets for the respective environmental issues. As a novel approach, we developed a procedure for the joint derivation of national EF for a broad scope of countries. In former studies, the selection process of data and targets for EF has been based predominantly on the domestic viewpoint of one country, thus omitting the

possibility of a deeper understanding and the interpretation of specific national framework conditions from an outside view. Our procedure is based on an international perspective and includes clear reasoning for the selection of data sources and environmental targets. The documentation of all steps for the calculation of national EF fosters transparency and reproducibility and reveals the influence of national as well as international policies.

Some general methodological and practical problems were encountered, which should be tackled in further developments. First, policy targets are often set in different countries for diverging time frames, confining comparability of the level of ambition of those targets. Here, approaches for adapting time frames should be developed, which could be orientated on general timeframes of international policies and conventions, e.g., the Paris Agreement or the UN Sustainable Development Goals. Second, notably, in a highly dynamic field such as climate change, policy targets as well as current flows are evolving in short time frames, showing the need for the regular updating of EF. Based on the documentation of data sources within the specific approaches for each environmental field, a yearly updating of the EF seems feasible and necessary for the issue of climate change, whereas for other environmental issues, a five year update could be envisaged. The updating links the EF to the current policy development in the way that more ambitious targets, i.e., smaller values of critical flows, will result in a higher EF, giving the respective environmental impact more weight within an evaluation.

Above this, the transfer of the ESM to an international level sheds light on the inherent strengths and weaknesses of the method itself. As to strengths, the ESM provides a convenient way to implement a distance-to-target approach in priority setting for measures in EMS. Today, the inclusion of distance-to-target approaches in environmental assessment methods is of high interest, fostered on the one hand by the global 2- respectively 1.5-degree target in climate policy, on the other hand by the notion of planetary boundaries introduced in the political discourse by the publication of Rockström et al. [52]. Approaches have been proposed to deduce from the global level individual targets for countries, sectors or even single companies or products. These approaches, however, are quite diverse and for the allocation of emission budgets or environmental burdens necessarily include value choices, where up to now, there is no uniform and generally agreed upon procedure regarding how to implement these choices. In comparison, the ESM ideally builds on the process of legal decision making in democratic nations, where the inherent value choices have taken place on the level of democratically legitimized bodies and not by individual scientists or single groups of experts. In this ideal case, there is an unequivocal EF result, although it has to be noted that these provide no absolute target values for environmental flows but only weighing factors.

The focus on national policy targets, however, can be seen as an inherent weakness of ESM. First, EF necessarily are restricted to environmental flows where legal target values exist. Neglecting all other flows is clearly a bias, which makes it necessary to complement legally based targets by further targets, including expert approaches. Second, the case of the US, which in 2019 resigned from the Paris Agreement, illustrates the question of whether any target set by a nation can or should be followed by a company. Obviously, it is not manageable for companies to follow and accept the low-ambition policy of one government that is contradictory to those international consensus processes its own company policy is oriented on. This is not the aim of ESM, which states as a further requirement for the selection of targets that they should be “oriented to sustainability as much as possible” [11]. Thus, the consideration of national framework conditions is intended to account for the specific national relevance of environmental pressures, e.g., a higher water scarcity, or for more ambitious targets of a country, e.g., as to climate mitigation, and not to adapt to low-ambitious national goals conflicting with international or consensus-based policies. Consequently, the further development of ESM on an international level should aim for embedding national targets in a top-down perspective, i.e., in a common understanding from internationally recognized sustainability goals. Here, drawing targets from international soft law could be an interesting topic of further research for international EF.

Supplementary Materials: The following Supplementary Materials are available online at <https://www.mdpi.com/article/10.3390/su132413897/s1> (SM) at LINK, Table S1-1: Eco-factors worked out for Germany, Table S2-1: Current flows of air pollutants for the selected countries, Table S2-2: EU emission reduction targets according to Gothenburg Protocol for the year 2020, Table S2-3: Current flows of air pollutants for the base year 2005 for the derivation of critical flows, Table S2-4: Critical flows of air pollutants for the selected countries and assignment to set, Table S3-1: Current flows of CO₂-emissions for the year 2014 in the selected countries, Table S3-2: Overview of national CO₂-eq-emission targets of the selected countries, Table S3-3: Critical flows of CO₂-emissions resulting from the national emission targets given in Table S3-2, Table S3-4: Nationally determined contributions, Table S4-1: Total renewable surface water (annual surface runoff) according to the FAO Aquastat Database, Table S4-2: Current concentration of water pollutants, Table S4-3: Current flows of water pollutants for the selected countries. If no reference is mentioned, the values were calculated from current concentrations given in Table S4-2, Table S4-4: Critical concentration of water pollutants, Table S4-5: TN concentration limit values for rivers within the US, Table S4-6: TP concentration limit values for rivers within the US, Table S4-7: Critical flows of water pollutants for the selected countries and assignment to set, Table S4-8: Data used for the estimation of current TN and TP flows in Argentina, Table S4-9: Data used for the estimation of current TN and TP flows in India, Table S4-10: Data used for the estimation of current TN and TP flows in Mexico, Table S4-11: Critical TN and TP flows for Argentina, India and Mexico, Table S5-1: Baseline water stress categories according to World Resources Institute, Table S5-2: Calculation of the weighting factor for freshwater resources, Table S5-3: Normalization flows of freshwater for the selected countries, Table S6-1: Current flows for energy resources for the selected countries, Table S6-2: Energy flows from the WEO 2015 in the 450 ppm scenario for the year 2040 and critical flow for TPED-NRE, Table S6-3: Share of renewable energy consumption ($x_{RE,i}$) in the 450 ppm scenario for the year 2040, Table S7-1: Overview of the databases for waste within the selected countries, Table S7-2: Current flows of waste generation in the selected countries, Table S8-1: Data for current and critical flows of sulfur oxides per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-2: Data for current and critical flows of nitrogen oxides per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-3: Data for current and critical flows of PM_{2.5} per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-4: Data for current and critical flows of NMVOC per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-5: Data for current and critical flows of CO₂-eq. per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-6: Data for current and critical flows for COD per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-7: Data for current and critical flows of TP per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-8: Data for the current and critical flows of TN per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-9: Data for current and critical flows of non-hazardous waste per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-10: Data for current and critical flows of non-hazardous waste per capita for the selected countries as well as the resulting “ecological scarcity”, Table S8-11: Data for current and critical flows of hazardous waste per capita for the selected countries as well as the resulting “ecological scarcity”, Table S9-1: Data provided in the VW Sustainability Report for the year 2018, Figure S5-1: Water stress categories of Argentina, Figure S5-2: Water stress categories of Brazil, Figure S5-3: Water stress categories of China, Figure S5-4: Water stress categories of India, Figure S5-5: Water stress categories of Mexico, Figure S5-6: Water stress categories of Russia, Figure S5-7: Water stress categories of South Africa, Figure S5-8: Water stress categories of the US.

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