A new consistent framework for assignment of safe operating space to B2C and B2B industries for use in Absolute Environmental Sustainability Assessments

Hendrik Christiaan Oosterhoff[1,2,*], Laura Golsteijn[1], Alexis Laurent[2], Morten Walbech Ryberg[2]

[1]PRé Sustainability bv, Stationplein 121, 3818 LE Amersfoort, The Netherlands

[2]Section for Quantitative Sustainability Assessment, Department of Environmental and Resource Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

[*] Corresponding author: Oosterhoff@pre-sustainability.com

Abstract

The planetary boundaries define a safe operating space for humanity to act within without potentially destabilizing the planet. The safe operating space is often used a sustainability reference in Absolute Environmental Sustainability Assessments (AESAs) where a share of the safe operating space (SoSOS) is assigned to the assessed activity. An identified challenge, is that current methods are suited for business-to-consumer (B2C) industries and companies, but ill-suited for assessments of business-to-business (B2B) as the sharing is often based on the direct value to humans. Thus, this study presents a systematic framework for assigning a SoSOS to both B2C and B2B industries and companies. The framework uses multi-region input-output models to link industries and estimate the direct and indirect value to humans for both B2B and B2C industries. The framework was tested in a case study for a B2B company to show its application and to evaluate the sensitivity of the framework towards different modelling choices. The results of the case study and sensitivity analysis was used to provide recommendations for further improvement of the framework. While there is still need for improvement and refinement, the framework shows large potential. Mainly because it directly facilitate AESA of B2B industries and companies to help gauging their environmental performance relative to absolute boundaries and, thus, provide better basis supporting strategic sustainability related activities.

Keywords Absolute sustainability; Sharing principles; Distributive justice; Safe operating space; Downscaling; Organizational life-cycle assessment

1. Introduction

Sustainability goes by many definitions. Ever since it was defined in the “Brundtland report” Our common future by the World Commission on Environment and Development in 1987, various understandings of sustainability have been proposed. Nevertheless, the three decade old definition of sustainable development – one that “…meets the needs of the current generations, without compromising the ability of future generations to meet their needs” – is still considered as one of the most widely used definitions (Vos, 2007; WCED, 1987). An important acknowledgement in the Brundtland report is that limitations to development are imposed by environmental limits, such as the availability of resources and capacity of the biosphere to accommodate anthropogenic impacts (WCED, 1987). Rockström et al. (2009) combined the identified environmental limits into the Planetary Boundary (PB) framework, which describes nine limiting biophysical Earth system processes and quantifies a safe operating space for humanity to act within. The boundaries are defined to prevent a drift from the Holocene to a new Earth system state that is less stable than the Holocene state (Crutzen, 2002; Rockström et al., 2009; Steffen et al., 2015, 2018). Increase environmental instability would put the ability of both current and future generations to meet their needs at risk (Crutzen, 2002).

Thus, it is important that the sum of human activities should remain within the Planetary Boundaries. While the boundaries are global, the actions for reducing e.g. greenhouse gas (GHG) emissions to within the boundaries require decisions and actions at non-global scale. For instance at the scale of countries, industry sectors, companies, or individuals (Ryberg et al., 2018a). Here, Absolute Environmental Sustainability Assessments (AESAs) can be used for quantifying and evaluating the environmental impacts of the actors at non-global scale and relate these impacts to an assigned share of the safe operating space in order to evaluate to which extent the activity acts within its assigned Share of the Safe Operating Space (SoSOS). In case the activity exceeds its assigned SoSOS, AESA can be used for deriving science-based reduction targets for the activity that can be used as part of strategic planning in order for the activity to be considered sustainable in an absolute sense (Bjørn et al., 2020).

AESA consists of two parts: determining the SoSOS that is occupied by the assessed activity and the assignment of a SoSOS to the assessed activity. The second part is especially important. This downscaling is delicate and demands caution, due to its normative nature. Sharing principles, based on ethical considerations, e.g. based on egalitarian or utilitarian distributional theories, can provide guidance for the procedure (Ryberg et al., 2020a). Several studies showed that the uncertainty due to the choice of sharing principle exceeds uncertainties present in the data or the quantification of the PBs (Ryberg et al., 2018b). To effectively use AESA in decision-making contexts, the uncertainty due to the selection of the sharing principle should be decreased. The development of a standard or consensus for downscaling the PBs could decrease this uncertainty and improve comparability across AESA studies (Ryberg et al., 2020a). A common approach for assigning the SoSOS to companies or industries has been to first downscale to the level of the individual human being, and subsequently upscale to the assessed company or industry based on the value that the company or industry provides to the final consumers (Hjalsted et al., 2020; Wolff et al., 2017). As an example of this final value, so far the assigned SoSOS has primarily been based on Final

Consumption Expenditure (FCE) in sector and company level AESAs (Brejnrod et al., 2017; Hjalsted et al., 2020; Ryberg et al., 2018a; Ryberg et al., 2020b). The FCE describes how individuals spend their money on goods and services, used to meet their individual needs (Eurostat, 2016). Consequently, FCE is a useful metric for getting a rough estimate about the value consumers place on different products or services. Yet, FCE can only be used to describe consumers' value that can be expressed in monetary terms. Monetary value represent only a portion of the total value created (Adler and Treich, 2015).

Not all products and services are sold to consumers as Business-to-Consumer (B2C). Generally, three main relationships between businesses and their clients (B2X) can be distinguished: companies delivering products or services only to end consumers (B2C), companies delivering products or services only to other companies (B2B), and companies delivering products or services to both companies and end consumers (business-to-many; B2M). Here, final consumption by e.g. consumers and government, only addresses companies in the B2C by definition. The approach is, therefore, not applicable for B2B. Application of the FCE directly for B2B and B2M would result in zero or a largely underestimated assigned SoSOS, since the companies are only credited for the value delivered directly to final users (i.e. B2C) and not credited for the value that is indirectly delivered to individuals, through B2B. Nevertheless, sectors operating higher up the supply chain are likely to produce resources for other sectors lower in the supply chain as well as for those that supply directly to individuals. The mining sector is an example of a sector with an underestimated assigned SoSOS if based purely on FCE because hardly any final consumption is done between the final consumer and the mining sector. Yet, products from the mining industry are present in almost every product purchased by individuals.

Thus, there is a need for developing methods that can reflect the indirect value of B2B and B2M companies and sectors to final consumers that can be used for assigning a SoSOS to the companies, as none currently exist. This study intends to tackle this challenge and aims to (i) provide an operational framework for assigning a SoSOS to B2X companies regardless of the relationship with their clients; and (ii) test and show use of the framework in a proof-of-concept real-life case study.

2. Methods

2.1 Assigning share of safe operating space to B2X

The proposed framework includes a step-by-step overview of the procedure for assigning a share of an environmental safe operating space to an industry *i* (Section 2.2) and further to a company that is part of industry *i* (Section 2.3). The framework covers a method for taking into account the direct value of industries and companies to humans (i.e. B2C) as well as the indirect value through the industries linkage and contribution to value creation for B2C industries. Figure 1 provides and illustrative overview of the framework and the steps involved in assigning a share of the safe operating space to B2X industries and companies.

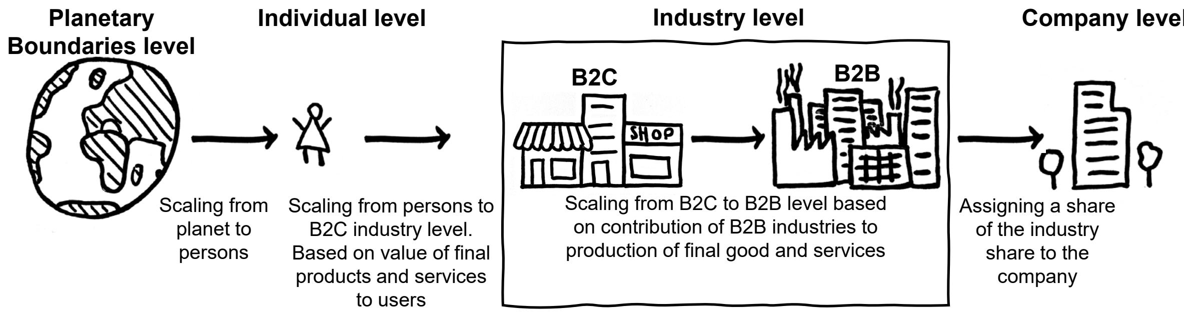

Figure 1 **Conceptual illustration of the framework and approach used for assigning a share of the safe operating space to B2X companies**

To take into account the indirect value of B2B companies to final consumers, methods for linking the inputs and outputs of industries across nations in relation to final consumption are needed. For this, multi-regional input-output (MRIO) models, such as Exiobase (Stadler et al., 2018) or world input output data (WIOD; (Timmer et al., 2015)) are used. MRIO models consist of a set of matrices and vectors that can be combined to provide an overview of the global economy and its interlinkages.

For assigning a share of the safe operating space to B2X, we rely on the coefficient matrix $\boldsymbol{A}$ and the final demand matrix $\boldsymbol{Y}$ from the MRIO model. The coefficient matrix $\boldsymbol{A}$ expresses the interconnections of industries via trade. $\boldsymbol{A}$ provide information on inputs (expressed in monetary terms) from industry *i* per unit of output from industry *j*. $\boldsymbol{Y}$ is the final demand matrix that includes monetary information on e.g. final demand of consumers, governments and non-profit organizations serving households for each region *r* and each industry *j* covered by the MRIO model. In this study, to demonstrate the operability of our approach, we rely on the Exiobase version 3.8.1 MRIO model using the Industry by industry methodology (Stadler et al., 2018). Other MRIO models may also be applied.

2.2 Assigning a share of safe operating space at industry sector level

In Exiobase, the coefficient matrix $\boldsymbol{A}$ is a symmetric matrix (7987×7987), while the final demand matrix $\boldsymbol{Y}$ contains 7987 rows with different final demand groups organised into columns for each region (49 regions). Information on the final demand of consumers, governments and non-profit organizations serving households was extracted and summed per region *r* to construct the total final demand matrix $\boldsymbol{F_{j,r}}$ for each industry *j* in region *r*. The sum of $\boldsymbol{F_{j,r}}$ per region *r* gives the total final demand ($\boldsymbol{F_{tot,r}}$) within each region *r*. The final demand share matrix ($\boldsymbol{FR}_{j,r}$) for each industry j in region r was estimated as in Eq. 1:

$$\boldsymbol{FR}_{j,r} = \frac{\boldsymbol{F}_{j,r}}{\boldsymbol{F}_{tot,r}} \qquad \text{Eq. 1}$$

Next, the total direct and indirect gross output of all industry i was estimated as a result of the final demand in industry j. The gross output for all industries i per 1 unit additional final demand for industry j can be expressed as shown in Eq. 2, where $\boldsymbol{I}$ is the identity matrix.

$$\boldsymbol{L_{i,j}} = (\boldsymbol{I} - \boldsymbol{A})^{-\boldsymbol{1}}{}_{\boldsymbol{i,j}} \qquad \text{Eq. 2}$$

$\boldsymbol{L_{i,j}}$ is commonly known as the Leontief matrix, where rows indicate the output from industry i as inputs to final demand in industry j, which is given in the columns. $\boldsymbol{L_{i,j}}$ is used as basis for estimating the direct (equivalent to Scope 1 in corporate GHG accounting; WRI and WBCSD, 2004) and indirect (equivalent to Scope 2 and Scope 3) output for each industry as a result of B2C or B2B trade. The diagonal cells in matrix $\boldsymbol{L_{i,j}}$, i.e. $i = j$, indicate the industry subject to its direct final demand consumption. Here the direct and indirect gross outputs across input industries *i* per unit output from industry *j* were estimated as in Eq. 3 to give the so-called scaling matrix **S**. Here, estimation of the diagonal matrix entries for **S**, denoted as $\widehat{\boldsymbol{S}}_{i,j}$, is given from Eq. 3 where *e* denotes a column vector with all entries being one.

$$\widehat{\boldsymbol{S}}_{i,j} = \left(\boldsymbol{L}_{i,j}^{T} e\right) \circ \boldsymbol{I} \qquad \text{Eq. 3}$$

A number of additional steps are required to estimate the direct and indirect gross output for the non-diagonal cells (i.e. the industry indirectly affected by direct final demand for industry *j*). As in Eq. 3, the direct output from industry *i* as a result of final demand for industry *j* is expressed by $\boldsymbol{L_{i,j}}$. However, to take into account the indirect outputs as a result of the direct output from industry *i*, the indirect output was added to the direct output as shown in Eq. 4 to give $\tilde{\boldsymbol{S}}_{i,j}$, where the tilde denotes the off-diagonal entries in $\boldsymbol{S}$.

$$\tilde{\boldsymbol{S}}_{i,j} = \boldsymbol{L_{i,j}} + \left(\boldsymbol{L_{i,j}} \circ \left(f_{i,j} e^{T}\right)\right) \qquad \text{Eq. 4}$$

Where $f_{i,j}$ is a column vector that provides information on output related to Scope 2 and Scope 3 relative to the direct Scope 1 output from industry *i* as a result of final demand for industry *j*. This is used as input for Eq. 4, to estimate the full economic output (i.e. for Scope 1, Scope 2 and Scope 3) for industries that do not have direct final demand. $f_{i,j}$ is calculated as shown in Eq. 5.

$$f_{i,j} = \frac{\left(\boldsymbol{L_{i,j}} - (\boldsymbol{L_{i,j}} \circ \boldsymbol{I})\right)^{T} e}{(\boldsymbol{L_{i,j}} \circ \boldsymbol{I}) e} \qquad \text{Eq. 5}$$

Hereby, the direct and indirect gross output for each industry i contributing to industry *j* can be expressed as in Eq. 6.

$$\boldsymbol{S}_{i,j} = \widehat{\boldsymbol{S}}_{i,j} + \tilde{\boldsymbol{S}}_{i,j} \qquad \text{Eq. 6}$$

The subsequent share of safe operating space assigned to industry *i* contributing to industry *j*, in region *r* ($\boldsymbol{aSoSOS_{i,j,r}}$) was calculated as in Eq. 7.

$$\boldsymbol{aSoSOS_{i,j,r}} = \boldsymbol{FR}_{j,r} \times \frac{\boldsymbol{S}_{i,j}}{\widehat{\boldsymbol{S}}_{i,j}} \qquad \text{Eq. 7}$$

The results of Eq. 7 indicate the total life-cycle value provided by industry *i* as a result of the final demand from all industries *j* in region *r*. Here, industry *i* can be a fully intermediate B2B industry a fully final consumer industry (i.e. full B2C) or a combination (i.e. B2M). The value takes into account the direct value from industry *i* and the value from upstream industries in the supply chain of industry *i*.

Because a life-cycle approach is applied, the sum of fractions in Eq. 7 will exceed 1 due to the interlinkage of industries across supply chains. This can be explained in a simplified example. In the example there are only 3 industries in the world. Industry A is a B2C industry; Industry B is a B2B industry and supplies to Industry A; Industry C is a B2B industry and supplies to Industry A and Industry B. As Industry A is the only B2C industry, all final consumption is for Industry A, thus 100% of the safe operating space is assigned to Industry A. The life-cycle value of Industry B is 50% of the life-cycle value provided by Industry A. Thus the share assigned to Industry B is 100% × 50% = 50%. Now the life-cycle value of Industry C is 10% of the life-cycle value provided by Industry A and 50% of the life-cycle value provided by Industry B. Thus, the share assigned to Industry C is 100% × 10% + 100% × 50% × 50% = 35%. Thereby, the sum of fractions is 1.85 as the supply chains overlap and the assigned share include both the direct value provided by the industries as well as the indirect value provided by industries upstream in the supply chain. Thus, the method can be used to estimate the assigned share of safe operating space for a specific industry, taking into account the full life-cycle value by including the industry's supply chain and taking into account the interlinkage of industries.

The total share assigned to industry *i* based on the overall final demand for industry *j* in region *r* can hereafter be expressed as in Eq. 8.

$$\boldsymbol{aSoSOS_{i,r}} = \sum_j \boldsymbol{aSoSOS_{i,j,r}} \qquad \text{Eq. 8}$$

The total share assigned to industry *i* considering all regions *r* was estimated as follows.

$$aSoSOS_i = \sum_r \left(\boldsymbol{aSoSOS_{i,r}} \times \frac{P_r}{P_W} \right) \qquad \text{Eq. 9}$$

where P_r is the population in region *r* and P_W is the global population. In doing so, the safe operating space is equally distributed among all persons and the share assigned to each industry becomes a function of the final demand within each region under the assumption that this best approximates the needs within each region r.

2.3 Assigning share of safe operating space to company level

The share of $aSoSOS_i$ assigned to company *x* ($aSoSOS_x$) that is part of industry *i* is based on subsequent partitioning of the sector share (Eq. 10). For this, a scaling factor β_x is used as shown Eq. 10.

$$aSoSOS_x = aSoSOS_i \times \beta_x \qquad \text{Eq. 10}$$

The apportioning among companies within the same industry sector can be done using various indictors. Essentially the objective is to be able to identify the magnitude of the company relative to others. Ideally, we want to base this on the value that the company provides to individuals. Here, we use turnover (*TO*) as the indicator, assuming that a company's turnover compared to other companies within the same sector is a decent indicator for peoples' preferences for said company and, thus, a decent indicator for the wellbeing provided. The company's turnover ($TO_{\text{company x}}$) is divided by the total turnover of industry *i* (TO_i), as extracted from the global MRIO database to give the share of the sector assigned to the company (see Eq. 11).

$$\beta_{\mathrm{x}} = \frac{TO_{\text{company x}}}{TO_{\mathrm{i}}} \qquad \text{Eq. 11}$$

2.4 Case study

The proposed B2X framework was applied to a real-life case-study to show its application. The reporting organization was a major global construction manufacturer company. The company has a B2B relationship with its customers. The goal of the case study was not to identify whether the company is absolute sustainable (i.e. the environmental sustainability ratio (ESR) ≤ 1), but rather to use it as a proof-of-concept for the framework to demonstrate its operability.

First, the occupied share of the company was determined using an organizational life cycle assessment (LCA). Second, the assigned share of the company was determined using the proposed framework. Ultimately, both were compared to determine the ESR for the company, see Figure 2.

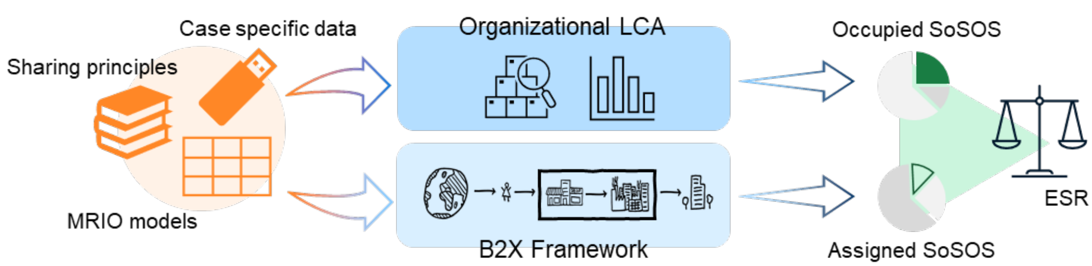

Figure 2 Overview of an AESA procedure using the proposed B2X framework. Case specific data, distributive justice theories and MRIO models serve as input for the organizational LCA and the B2X framework, which give the occupied and assigned SoSOS, respectively. The occupied and assigned SoSOS are compared to determine the ESR.

2.4.1 System scope and life cycle inventory

The life cycle inventory (LCI) of the resource uses and substance emissions (collectively termed "elementary flows") to the environment as a result of the company's activities were determined by conducting an organizational LCA, following the Guidance on Organizational Life Cycle Assessment of the United Nations Environment Programme (UNEP) using SimaPro 9.0 software (Pré Consultants, n.d.; UNEP, 2015). For the detailed documentation of the case study, see Supplementary Material (SM) Section S1.

The reporting flow was the annual production by the company. The operational control consolidation approach, in which operational control equals responsibility, was used. The reference period was 2019. Scope 1 and 2 environmental impacts, as identified in the Greenhouse Gas Protocol (WRI and WBCSD, 2004), were fully included. Due to limited data availability, only a selection of the Scope 3 categories were included, see Table 1 (WRI and WBCSD, 2004). Primary data from the company was used for the amounts supplied by other companies and for the direct emissions. For the conversion of energy carriers (natural gas and diesel) and for the production of steam, secondary data was used from the "ecoinvent 3.5, allocation, cut-off by classification – system" database (Weidema et al., 2013).

Table 1 Overview of categories included and excluded from the scope. Exclusion is based on unavailability of data. "N/A" indicates exclusion based on irrelevance within companies' activities. Scopes are based on the Greenhouse Gas Protocol (WRI and WBCSD, 2004).

Scope	Category	Included	Excluded
1	Direct emissions	X	
2	Energy related indirect emissions	X	
3.1	Purchased goods and services	X	
3.2	Capital goods		X
3.3	Fuel- and- energy related activities		X
3.4	Upstream transportation and distribution	X	
3.5	Waste generated in operations	X	
3.6	Business travel		X
3.7	Employee commuting		X
3.8	Upstream leased assets	N/A	
3.9	Downstream transportation and distribution		X
3.10	Processing of sold products	N/A	
3.11	Use of sold products		X
3.12	End-of-Life of sold products		X
3.13	Downstream leased assets	N/A	
3.14	Franchises	N/A	

2.4.2 Determining the company's occupied share

The elementary flows in the LCI were characterized as potential impacts on the environment using the Planetary Boundaries based Life-cycle impact assessment (PB-LCIA) methodology (Ryberg et al., 2018b). The PB-LCIA includes characterization factors for seven of the nine planetary boundaries and includes 15 impact categories to cover both global and regional planetary boundaries. The goal of the study was to demonstrate via a proof-of-concept the application of the method for assigning a share of safe operating space to B2X companies. Therefore, only the impact category “Climate change - Energy imbalance at top-of-atmosphere” was evaluated in this case study. The full set of characterized results for all impact categories covered in the PB-LCIA are however documented in SM Table S2; all these impact categories should be considered when performing full-fledged assessments.

2.4.3 Determining the company’s assigned share

Step 1: Downscaling to the individual level

To determine the occupied SoSOS for the company, the characterized results were divided by the remaining SOS available for human activities. The remaining SOS for Climate Change - Energy Imbalance is 1 Wm^{-2} (Ryberg et al., 2020b). The remaining SOS was first shared equal-per-capita across all individuals on Earth. Since the reference year for the occupied share is 2019, the 2019 global population was used (UN, 2019).

Step 2: Upscaling to the industry level

For the translation of household consumption patterns throughout the global economies, Exiobase 3.8.1 was used. 2011 was used as reference year as this is where the original Exiobase 3 data series ends (Stadler et al., 2018). Exiobase consists of the technical coefficient matrix (***A***), final consumption vectors for households, non-profit organizations and governments (***Y***), and output/emissions matrices. ***A*** covers 163 sectors in 49 regions giving a total of 7987 sector-region combinations.

Capital assets were included in the MRIO-model, as input to production (Miller et al., 2019), via capital endogenization as described in Södersten et al. (2018), using 2015 as reference year. In most national accounts and, thus, MRIO models, capital assets are aggregated into product or industry totals and does not provide information about the specific industries’ spending on capital assets. Hence, it is not possible to partition the impact of e.g. construction industry (for which the majority of the final demand is capital assets) to the relevant industries that are responsible for the construction work. Thereby, the emissions associated with their production are not allocated to the industries using them. Endogenization allows for partitioning the capital asset final demand among the relevant industries to ensure that the spending on capita assets is partitioned to the industries using them (Södersten et al., 2018).

The case study company sells their products to 72 countries, covered by 43 of the Exiobase countries and regions. The company was found to be part of the industry sector “Manufacture of rubber and plastic products” in the Netherlands. The methodology described in Section 2.2 was applied to assign a share of the safe operating space to the specific sector.

Step 3: Downscaling to the company level

For the downscaling step from the assigned SoSOS on sector levels to the company level, the utilitarian approach was used. The downscaling factor β_x (see Eq. 11) was determined using the 2019 revenue of the company which was related to the total economic output of the “Manufacture of rubber and plastic products” sector in the Netherlands.

2.4.4 Sensitivity analysis

To gain additional information about the performance of the developed framework, multiple scenarios were investigated to evaluate the sensitivity of different choices pertaining to using the framework (see Table 2). Each of the scenarios were evaluated on their effect on the assigned and occupied SoSOS and ultimately the conclusion of the AESA through the effect on the ESR. The sensitivity analysis scenarios were defined based on uncertainty in company input data (Scenario 1 and 2), variability of input data in the MRIO and major methodological decisions (Scenario 3 to 6).

Table 2 Summary of scenarios applied during the case study and their intended focus. Scenario 0 being the default scenario. Scenario 1 evaluating the sensitivity case specific data quality. Scenario 2 to 4 evaluating non-case specific methodological choices in the framework.

Scenario no.	Description	Focus of analysis
0	Default scenario as described in section 04.	Performance of the framework.
1	Base the scope 1 assigned SoSOS on an alternative company sector: “Manufacturing of bricks, tiles and construction products, in baked clay”.	Sensitivity of the assigned SoSOS towards input data and the relevance of its uncertainty.
2	Base assigned SoSOS on an increased (x2) revenue for the company.	Sensitivity of assigned SoSOS towards input data and the relevance of its uncertainty.
3	Base the economic output vector on only Household final demand vector instead of Total final demand vector including consumption vectors for households, non-profit organizations and governments	Assigned SoSOS, by applying other methodological choices.
4	Include capital assets as part of the final demand vector instead of capita endogenization	
5	Base the economic output vector on a Technical coefficient vector of an alternative base year: 2016 instead of 2011. Due to lack of data, the reference year for endogenization of capital assets is kept as 2015.	Assigned SoSOS, by applying other reference year.
6	Base the assigned SoSOS on an alternative MRIO database, i.e. WIOD instead of Exiobase. Due to lack of capital data for the WIOD model. Capital endogenization could not be performed. Instead Capital assets are included as part of the final demand category: gross fixed capital formation	Assigned SoSOS by applying other methodological choices.

3. Results

3.1 Results of case study default scenario

The occupied and assigned SoSOS for the utilitarian approach can be found in Figure 3. A total impact of 4.3×10^{-5} W/m^2 was characterized for the company (Figure 2). The majority of the company's impact was caused by their Scope 3 emissions (77%). The Scope 2 impacts were responsible for the remaining impact (22%) and the impact for Scope 1 was negligible (<1%). The purchase of electricity (Scope 2; 22%) and three main ingredients, namely activated carbon (Scope 3; 18%), kraft paper (Scope 3; 17%) and phenol (Scope 3; 15%) were responsible for the majority of the environmental impact. The remaining purchased materials and services together were responsible for 28% of the impact – none of them more than 10%. Almost all impact came from the emission of carbon dioxide (95%). It was found that the occupied SoSOS of the Scope 1 emissions were negligible compared to the remaining impact. The assigned SoSOS was found to be 9.9×10^{-6}. Thus, the ESR was 4.4, indicating that the company is acting beyond its assigned share of the safe operating space for climate change – energy imbalance. 21% of the assigned SoSOS related to direct final consumption (i.e. B2C) with the remaining relating to indirect demand as B2B.

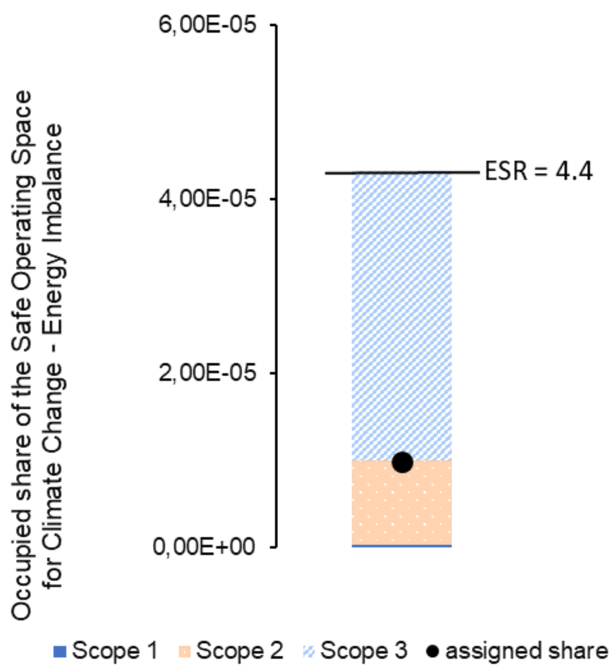

Figure 3 Occupied and assigned shares with the corresponding ESR values (4.4) for the company for the Climate Change – Energy Imbalance impact category. The occupied share for the Scope 1 (not visible in figure, ca. 1% of total), Scope 2 (orange, 22%) and Scope 3 (blue, 77%) are represented by the bar chart. The black dot represents the level of the assigned share, i.e. the occupied share exceeds the assigned share significantly. Data underlying the figure are provide in SM Table S3

3.2 Sensitivity analysis

The results of the sensitivity analyses can be found in Figure 4. Figure 4 shows the occupied and assigned SoSOS for the five alternative scenarios (described in Table 2) and the default scenario. We see that the assigned SoSOS for the company vary between a factor 0.94 and 8.9 across the scenarios compared to the default situation. The case study showed that the company's occupied share exceeds the assigned share, i.e. the ESRs are above 1, for all scenarios, except scenario 6 (see Figure 3) for climate change, indicating that the company cannot be considered sustainable in an absolute sense for these scenarios. The choice of a different MRIO model (i.e. WIOD) resulted in the largest change, with a factor 8.9 for Scenario 6. A switch from Exiobase to the MRIO model WIOD changed results to make the system perform within the assigned SoSOS. Thus, a change in MRIO model can lead to alternative conclusions on the sustainability of the assessed system. A change in industry sector to which the company belongs induced a change in assigned SoSOS of a factor 4.3. A doubling in company revenue led to a doubling in assigned SoSOS. The scenarios with an alternative definition of the demand vector (Scenario 3) and a different base year (Scenario 5) resulted in minor changes.

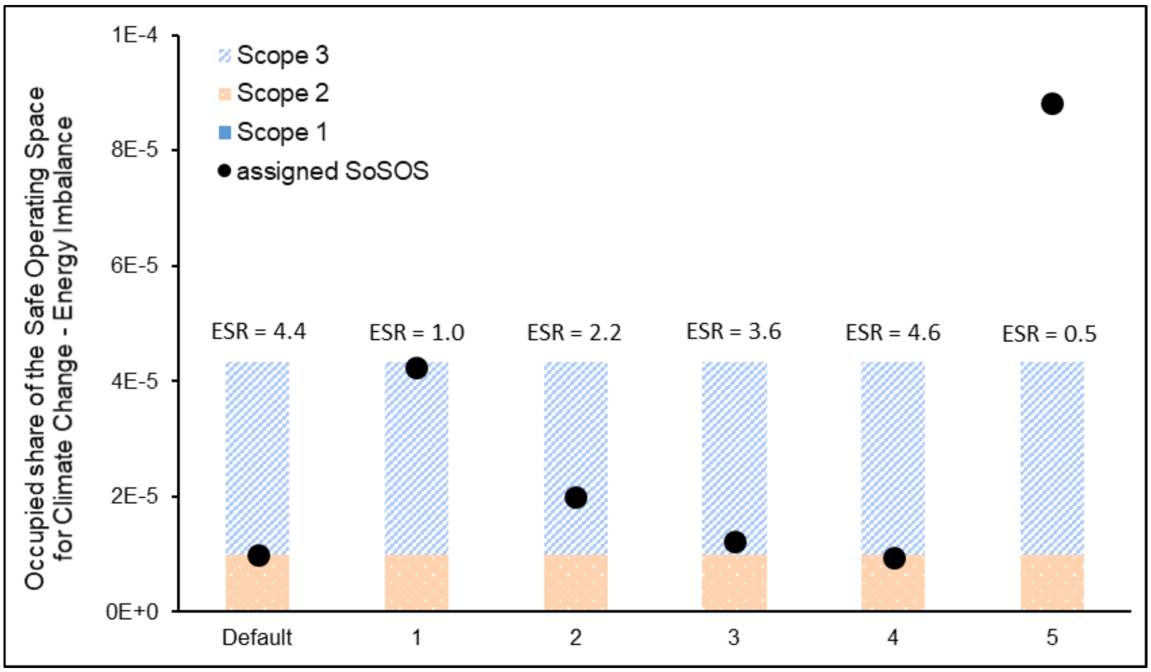

Figure 4 Occupied and assigned SoSOS for Climate Change – Energy Imbalance for the company, for the default and 6 alternative scenarios. The orange bar indicates the occupied SoSOS for Scope 2 and the blue bar for Scope 3. The impact of Scope 1 is not visible in the figure, ca 1% of total. Data underlying the figure are provide in SM Table S3

4. Discussion

4.1 Operability of the framework

The framework presented and demonstrated in the case study shows a novel approach for assigning a SoSOS that addresses the existing gap for AESA of B2B and B2M companies. This facilitates assigning a SoSOS to sectors and companies located early in the supply chain based on their relative contribution to the B2C sectors and companies. Thus, better reflecting their actual value to people. This is important to include as it allows for making more relevant AESAs to the B2B (or B2M) companies because the size of the assigned SoSOS better reflects the value of the company. Indeed, only 21% of the assigned SoSOS was related to B2C trade in the case study. This shows the importance of including the indirect contribution for companies that are fully or primarily B2B. It is possible that the share related to the B2B trade could prove decisive for conclusions about the absolute sustainability of a sector or company. While the method covers a known gap in AESAs, there are still a number of limitations and uncertainties to consider in the use of the framework and interpretation of the results it gives.

The case study showed the results to be sensitive towards several of the evaluated choices, thereby questioning the robustness of the results. Especially the classification of the company's sector (sensitivity scenario 1) and the choice of MRIO model (sensitivity scenario 6) decrease the robustness of the results and increase the uncertainty to the results of the AESA when applying the framework. The scenario analyses should therefore be considered as an integral part of the current version of the framework. Indeed, standard sensitivity analyses for data quality are suggested in LCA (ISO, 2006) and evaluation of the AESA results' sensitivity to different modelling or assessment choices is recommended. Thus, to increase robustness of the conclusions it is suggested to ultimately evaluate different scenarios to test the following three aspects when assigning shares of the safe operating space to the studied system: (I) different sharing principles, (II) different MRIO models and (III) different sectors the company is part of. The types of sharing principles and their importance as already been described in details in e.g. Ryberg et al. (2020a). The other two aspects specifically relate to the use of the framework proposed in this study.

Choice of MRIO models. Apart from the practical reasons to select one MRIO model over another, the effect of a particular MRIO model on the results should be evaluated as well. The case study showed that the change of MRIO model can change the results by a factor 3. This is related to the underlying data and method used for constructing the MRIO model. Indeed, when WIOD was used instead of Exiobase, a larger assigned SoSOS was found. The larger assigned SoSOS is due to the industry resolution of the MRIO models and the data used in the different MRIO models. Thus, the choice of MRIO model is a source of uncertainty to the results and overall conclusions. It is therefore suggested to pick a default MRIO model that fits the case best in terms of resolution and coverage, but also evaluate the results using an alternative MRIO model to evaluate the robustness of the results and conclusions. Section 4.2 provides additional discussion on the current and prospective capabilities of MRIO models.

Classification of a company within its sector. Ultimately, the effect of the sector of the company should be evaluated. As the case study showed, even though the effect on the results can be significant, it is not always obvious to what sector a company belongs to in terms of the MRIO models. Two perspectives can be applied: either the most fitting sector in terms of (I) activities done by the company, or in terms of (II) function that the company's products deliver to customers. Due to their global coverage, every business is in some extent included in the MRIO models. The MRIO models use classification systems to define sectors and thus the companies within them. To secure optimal alignment between the study and the MRIO model it is suggested to use the activity-perspective in the default scenario, following the classification system of the used MRIO model. For Exiobase and the WIOD, these classification systems are NACE rev.1 and ISIC (European Commission, 2008; Stadler et al., 2018; Timmer et al., 2015; United Nations, 2008). The functionality-perspective can then be applied in the scenario analysis to improve the certainty of the results.

4.2 The use of MRIO databases: coverage and resolution

Several MRIO models provide a complete description of the World's economies and thus a complete coverage of sectors and regions. Every organization should be able to find its associated industry sector in the MRIO data, meaning that the framework is not limited in terms of sector coverage. However, sector resolution is the main limiting factor of current MRIO models and the level of sector resolution varies greatly among different MRIO databases (Malik et al., 2019). The resolution of the MRIO database limits the resolution of the framework. The latest release of the MRIO models used in this study, Exiobase and WIOD, have a resolution of 163 sectors and 56 sectors, respectively (Stadler et al., 2018; Timmer et al., 2015). The aggregation can be problematic for heterogeneous sectors where the value of the evaluated company or industry might not be well represented in the MRIO industry-sector as a result of aggregation with other (larger) companies and industries.

The case study demonstrated that the resolution of sectors might be a limiting factor, where "Manufacture of rubber and plastic products" was considered the best fit in both Exiobase and WIOD. Although the company's products are technically plastic materials, their application might be more similar to the "Manufacture of bricks, tiles and construction products, in baked clay" sector. The change in industry sector was investigated in sensitivity scenario 1 and the results showed that the effect on the results of choosing the sector to which the reporting organization belongs, can be important. For consistent use, we generally recommended to identify the main sector the company belongs to. This can for instance, be found using corporate databases that provide general company information. Then, to test the robustness of conclusions, other potentially relevant sectors can be tested to evaluate if the change in sector leads to a change in conclusions.

Similar to the industry sectors, the regions have a complete global coverage, but the resolution of regions limit the framework. For instance, Exiobase divide the world in 49 regions, covering EU28 countries, 16 major economy countries outside Europe and 5 complementary regions within Africa, Asia, America, Europe and Middle East (Stadler et al., 2018). Other MRIO models have a different geographical resolution, but they all have some level of aggregation. Again, this means that the most aggregated regions are more uncertain and the actual representativeness of the region towards a specific company is reduced. Developments towards increasing the resolution and have more data a country level is ongoing. For instance, a new version of Exiobase, Exiobase3rx has been put forward, which include 214 regions (Bjelle et al., 2020).

4.3 Sharing safe operating space among industries along supply chains

The starting point for the proposed framework is that all human beings are assigned an equal share of the safe operating space. On the basis of this, B2C industries are assigned a share of the persons' safe operating space based on the welfare (or utility) the industries provide to the humans. This is considered a utilitarian approach as the SoSOS assigned to each industry is proportional to the utility it provides to humans.

In this study, we use final demand as a proxy for utility. Thus, the share of total spending spend on an industry express its relative contribution to total utility. This approximation is only valid up to a certain degree. Mainly because wealth increases, in developed countries in particular, has freed a large fraction of the economic budget. This means that after spending a portion of the budget on the products and services that we need (and which brings us most utility), a large fraction of the budget is available for spending on products and services that brings less additional welfare (or utility). Thus, current consumption patterns in wealthy high income countries does not represent well the consumption patterns that leads to a maximized utility. This is an important limitation for the method (Ryberg et al., 2020a) that must be addressed. Options for reducing this is to stop using final demand data and rely on different data that better reflect the value of product and services to people. This could be data expressing an optimized consumption of good and services based on marginal utility estimates or it could be based on national consumption data in countries with relative smaller economic budget where the consumption pattern is better expressing the welfare provided by consumption of product and services. Such work is ongoing and the developed framework allows for using this data as input, once it becomes available. When this data becomes available, then it can simply be implemented by creating an alternative final demand vector based on this data instead of current final expenditure data as is currently used.

After assigning a SoSOS to the B2C industries, the subsequent partitioning to B2B companies is performed. Currently, the sharing across the supply chain is based on gross economic output. That is, a B2B industry with a large gross economic output relative to the total economic output of the B2C industry where it is part of the supply chain, will be assigned a relative large share of the safe operating space for the B2C industry. There is no strong ethical rational for basing the assignment of this. It can be considered an acquired right, where industries with large economic output are entitled to a larger share. Another approach could be to base it on e.g. impacts to the environment. For instance, basing it on GHG emissions (e.g. as kg CO_2-eq) when evaluating climate change, where industries in the supply chain with high GHG emissions are assigned a larger share of the SoSOS assigned to the B2C industry. Thereby, industries with large direct and indirect GHG emissions are assigned a relative large share of the safe operating space assigned to the B2C industry. This might be more relevant than economic value because industries with relatively large GHG emissions might have a need for this compared to industries in the supply chain with a relatively low emissions. Essentially, the choice about partitioning the safe operating space to B2B industries contributing to B2C industries is only concerning sharing among industries, which is a value based choice. The sharing among people and sharing among industries contributing to peoples' welfare is not affected by this. In lieu of a single principle on which to base this sharing, we recommend applying different sharing principles, using different indicators on which to base the acquired rights, e.g. GHG emissions, economic output, etc. This allows for evaluating the variability in assigned share of safe operating space as a result of different acquired rights indicators and, thus, the overall robustness of the results and conclusions. Overall, the framework is developed to be flexible towards use of other sharing principles. This relates to the sharing among people, the sharing among B2C industries and the sharing for B2B industries that are part of the B2C industries' supply chains. The most critical issue is the data on which to base other sharing principles. The framework is developed in a manner that allows for easy implementation and application of other sharing principles, once this become available.

5. Conclusion

The study provided an operational framework for the B2X company level AESAs and guidance on its application. The framework is the first structured, methodological approach that allows company level AESAs regardless of the customer relationships of a company (B2B and B2M). An AESA case-study, using the framework, was done to test the applicability and provide recommendations based on the outcomes.

The ESRs of a B2B construction materials company were determined for seven scenarios in the case study to evaluate the importance of different choices pertaining to application of the B2X framework. In five scenarios, the company exceeded its assigned safe operating space by up to a factor 4.6. The main drivers for the impact were four processes, i.e. use of electricity, activated carbon, kraft paper, and phenol. The framework has shown to be flexible in the selection of its input parameters, not to rely on difficult data collection and to have a complete global coverage. However, the robustness of results and the inclusion of more sharing principles could be improved and should be further investigated.

Although, the proposed framework is operational and can provide the first solution to the existing gap for B2B and B2M company level assessments, further improvement is necessary in terms of its robustness and flexibility. The study showed that the framework is still sensitive towards several choices that are taken during the AESA, which decreases the robustness of the results. A quantitative assessment of the uncertainty was out of scope for the current study. Therefore, the first step for improvement could be a systematic quantification of the uncertainty. The second step could be towards standardization of the framework to reduce the uncertainty due to value based choices. Once the uncertainty is found to be sufficiently small, the framework can create additional value. Namely, by giving (I) the direction and magnitude of absolute sustainable decision making; (II) well-substantiated reduction targets that take into account the Earth's carrying capacity; and (III) based on these reduction targets, it paves the way for more precise and aligned reduction measures.

Overall, while there is still need for improvement and refinement, this developed B2X framework for systematically assigning a share of the safe operating space to industries and companies shows great potential. It directly facilitate AESA of B2B and B2M companies to help these gauge their environmental performance relative to absolute boundaries to provide an informed basis for setting environmental reduction targets and steer their sustainability related activities.

Supplementary Material

Supplementary Material contains details on the life-cycle inventory modelling for the case study organizational LCA. The Supplementary Material also includes details for the results, such as the full list of characterized results for the case study as well as the raw data underlying the results figures

Acknowledgments

We would like to acknowledge Daniël Kan for his support with input-output databases. We would like to acknowledge the global construction manufacturer company and our company contact person for providing inventory data for our case study.

6. References

Adler, M.D., Treich, N., 2015. Prioritarianism and Climate Change. Environ. Resour. Econ. 62, 279–308. https://doi.org/10.1007/s10640-015-9960-7

Bjelle, E.L., Többen, J., Stadler, K., Kastner, T., Theurl, M.C., Erb, K.-H., Olsen, K.-S., Wiebe, K.S., Wood, R., 2020. Adding country resolution to EXIOBASE: impacts on land use embodied in trade. J. Econ. Struct. 9, 14. https://doi.org/10.1186/s40008-020-0182-y

Bjørn, A., Chandrakumar, C., Boulay, A.-M., Doka, G., Fang, K., Gondran, N., Hauschild, M.Z., Kerkhof, A., King, H., Margni, M., McLaren, S., Mueller, C., Owsianiak, M., Peters, G., Roos, S., Sala, S., Sandin, G., Sim, S., Vargas-Gonzalez, M., Ryberg, M., 2020. Review of life-cycle based methods for absolute environmental sustainability assessment and their applications. Environ. Res. Lett. 15. https://doi.org/10.1088/1748-9326/ab89d7

Brejnrod, K.N., Kalbar, P., Petersen, S., Birkved, M., 2017. The absolute environmental performance of buildings. Build. Environ. 119, 87–98. https://doi.org/10.1016/j.buildenv.2017.04.003

Crutzen, P.J., 2002. Geology of mankind. Nature 415, 23. https://doi.org/10.1038/415023a

European Commission, 2008. NACE Rev. 2 – Statistical classification of economic activites in the European Community, Office for Official Publications of the European Communities. Office for Official Publications of the European Communities, Luxembourg.

Eurostat, 2016. Final consumption expenditure [WWW Document].

Hjalsted, A.W., Laurent, A., Andersen, M.M., Olsen, K.H., Ryberg, M., Hauschild, M., 2020. Sharing the safe operating space: Exploring ethical allocation principles to operationalize the planetary boundaries and assess absolute sustainability at individual and industrial sector levels. J. Ind. Ecol. jiec.13050. https://doi.org/10.1111/jiec.13050

ISO, 2006. Environmental management — Life cycle assessment — Requirements and guidelines (ISO Standard No. 14044:2016).

Malik, A., McBain, D., Wiedmann, T.O., Lenzen, M., Murray, J., 2019. Advancements in Input-Output Models and Indicators for Consumption-Based Accounting. J. Ind. Ecol. 23, 300–312. https://doi.org/10.1111/jiec.12771

Miller, T.R., Berrill, P., Wolfram, P., Wang, R., Kim, Y., Zheng, X., Hertwich, E.G., 2019. Method for endogenizing capital in the United States Environmentally-Extended Input-Output model. J. Ind. Ecol. 23, 1410–1424. https://doi.org/10.1111/jiec.12931

Pré Consultants, n.d. SimaPro 9.0.

Rockström, J., Steffen, Will, Noone, K., Persson, A., Stuart III Chapin, F., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., Steffen, W., K. Noone, Å. Persson, F. S. Chapin, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, J. A. Foley, 2009. A safe operating space for humanity. Nature 461, 472–5. https://doi.org/10.1038/461472a

Ryberg, M.W., Andersen, M.M., Owsianiak, M., Hauschild, M.Z., 2020a. Downscaling the planetary boundaries in absolute environmental sustainability assessments – A review. J. Clean. Prod. 276, 123287. https://doi.org/10.1016/j.jclepro.2020.123287

Ryberg, M.W., Bjerre, T.K., Nielsen, P.H., Hauschild, M., 2020b. Absolute environmental sustainability assessment of a Danish utility company relative to the Planetary Boundaries. J. Ind. Ecol. https://doi.org/10.1111/jiec.13075

Ryberg, M.W., Owsianiak, M., Clavreul, J., Mueller, C., Sim, S., King, H., Hauschild, M.Z., 2018a. How to bring absolute sustainability into decision-making: An industry case study using a Planetary Boundary-based methodology. Sci. Total Environ. 634, 1406–1416. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.04.075

Ryberg, M.W., Owsianiak, M., Richardson, K., Hauschild, M.Z., 2018b. Development of a life-cycle impact assessment methodology linked to the Planetary Boundaries framework. Ecol. Indic. 88, 250–262. https://doi.org/10.1016/j.ecolind.2017.12.065

Södersten, C.J.H., Wood, R., Hertwich, E.G., 2018. Endogenizing Capital in MRIO Models: The Implications for Consumption-Based Accounting. Environ. Sci. Technol. 52, 13250–13259. https://doi.org/10.1021/acs.est.8b02791

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J.H., Theurl, M.C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.H., de Koning, A., Tukker, A., 2018. EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. J. Ind. Ecol. 00. https://doi.org/10.1111/jiec.12715

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S., 2015. Planetary boundaries: Guiding human development on a changing planet. Science (80-.). 347, 736. https://doi.org/10.1126/science.1259855

Steffen, W., Rockström, J., Richardson, K., Lenton, T.M., Folke, C., Liverman, D., Summerhayes, C.P., Barnosky, A.D., Cornell, S.E., Crucifix, M., Donges, J.F., Fetzer, I., Lade, S.J., Scheffer, M., Winkelmann, R., Schellnhuber, H.J., 2018. Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. 115, 8252–8259. https://doi.org/10.1073/pnas.1810141115

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R., de Vries, G.J., 2015. An Illustrated User Guide to the World Input-Output Database: The Case of Global Automotive Production. Rev. Int. Econ. 23, 575–605. https://doi.org/10.1111/roie.12178

UN, 2019. World Population Prospects 2019: Data Booklet, Department of Economic and Social Affairs Population Division.

UNEP, 2015. Guidance on Organizational Life Cycle Assessment. UNEP-SETAC Life Cycle Initiative, Paris.

United Nations, 2008. International Standard Industrial Classification of All Economic Activities (ISIC), 4th ed. UNITED NATIONS PUBLICATION, New York.

Vos, R.O., 2007. Perspective Defining sustainability: a conceptual orientation. J. Chem. Technol. Biotechnol. 82, 334–339. https://doi.org/10.1002/jctb

WCED, 1987. Our Common Future. World Commission on Environment and Development. Oxford Univ. Press, Oxford.

Weidema, B.P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C.O., Wernet, G., 2013. Overview and methodology, Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3). St. Gallen.

Wolff, A., Gondran, N., Brodhag, C., 2017. Detecting unsustainable pressures exerted on biodiversity by a company. Application to the food portfolio of a retailer. J. Clean. Prod. 166, 784–797. https://doi.org/10.1016/j.jclepro.2017.08.057

WRI and WBCSD, 2004. Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard, Greenhouse Gas Protocol. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), Washington, DC.