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RESEARCH ARTICLE

Reflecting the importance of human needs fulfilment in absolute sustainability assessments

Development of a sharing principle

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Abstract

Absolute environmental sustainability assessments (AESAs) evaluate whether the environmental impact of a product system is within its share of a safe operating space as determined by biophysical sustainability limits such as the planetary boundaries (PBs). The choice of sharing principle has significant influence on the result of an AESA, and any studies call for further research on how to share the safe operating space in an operational way that relates to the product's contribution to the welfare of the user. In this study, we develop the "Fulfilment of Human Needs" (FHN) principle as a sharing principle that operationalizes sufficientarianism (making sure everyone gets enough). The FHN principle is tested on two case studies (a food item and a textile) against four of the PBs: climate change, land-system change, water use, and nitrogen cycling. The operationalization of the FHN principle is slightly different between the PBs; the starting point for climate change is the average consumption pattern in countries classified as "most sustainable," while for the other three PBs the status quo impact in the most sustainable countries is used. To operationalize the FHN principle on the product level, each consumption category is downscaled according to objective sources that determine the value delivered to the users. We demonstrate that, compared to other previously applied sharing principles, the FHN principle supports a stronger relation to the importance to the users of the delivered outcome.

KEYWORDS
absolute environmental sustainability assessment, AESA, industrial ecology, planetary boundaries, sharing principle, SoSOS

1 | INTRODUCTION

Humanity faces two intertwined challenges: delivering a decent standard of living for everyone while staying within environmental limits, as implicitly stated in the Brundtland Report (World Commission on Environment & Development, 1987). The environmental limits can be determined with different frameworks (Vea et al., 2020), one of the most used frameworks is the Planetary boundaries (PBs) as introduced in 2009 and revised in 2015 (Rockström et al., 2009; Steffen et al., 2015). The PBs are a set of boundaries for human impacts on nine key Earth System processes that are considered essential for maintaining the Earth in a Holocene-like state with a stable climate that allows humanity to develop and thrive. The PBs define a safe operating space for humanity that the sum of environmental pressures associated with all human activities should remain within (Steffen et al., 2015).

The historical consumption of natural resources and the use of fossil fuels to fulfil the needs and demands of the growing population, especially since the middle of the 20th century, have led to a transgression of several of the boundaries that define this safe operating space (Rockström et al., 2009), increasing the risk for the stability of Earth Systems. This may compromise the possibility for future generations to fulfil their needs. Despite the current overshoot of six of the nine PBs (Persson et al., 2022; Wang-Erlandsson et al., 2022) many people still fall short in fulfilling their basic needs; 8.9% of the global population is undernourished (United Nations, 2018), one third of the global population lack access to clean drinking water (United Nations, 2016), and 10% do not have access to electricity (The World Bank, 2021).

To address the constraints posed by a limited safe operating space in product design and development, the absolute perspective has been brought into decision making through absolute environmental sustainability assessments (AESAs) by operationalizing and downscaling the PBs (Ryberg et al., 2018a). The absolute perspective for life cycle engineering means shifting focus from doing better to doing what is needed to fulfil the needs of both present and future generations within the biophysical limits of the planet (Hauschild et al., 2020). Companies thus need a benchmark or reference level from absolute product sustainability while previously, companies have focused only on comparing environmental impacts for their competitive advantage. The purpose of AESAs is to help companies determine when their products are "good enough" and not just better than an alternative (Ryberg et al., 2018b).

It is a general challenge for AESA that it is difficult for a company to conclude whether a product is absolute sustainable since it depends on human behavior and the total consumption of a person. However, for companies to be able to judge what is needed for absolute sustainability from their product development it is necessary to scale down to product level despite the uncertainties that human behavior induces (Hauschild et al., 2020).

Environmental impacts are quantified in AESAs using life cycle assessment (LCA) and are then compared to the product's Share of the Safe Operation Space (SoSOS). The PBs are downscaled to product or industry level using sharing principles that are based upon distributive justice theories. AESA is an emerging field (Bjørn et al., 2020a) still with a rather limited number of practical case studies (Andersen et al., 2020; Ryberg et al., 2020b, 2018a).

Utilitarianism is the most used distributive justice theory in AESAs that considers industries and products, with its focus on maximizing the total welfare (Ryberg et al., 2020a). However, the utilitarian principle lacks an outcome-based currency that describes the obtained welfare of the user (Ryberg et al., 2020a). Final consumption expenditure (FCE) is often used as an approximation for the achieved utility or welfare, as exemplified in Andersen et al. (2020), Chandrakumar et al. (2019), and Ryberg et al. (2018a). However, the correlation between monetary spending and obtained welfare is not always proportional (Jebb et al., 2018; Land et al., 2017). The problems inherent in using FCE are exemplified by Engel's Law stating that an increase in income decreases food expenditure while increasing luxury consumption (Zimmerman, 1932). Using FCE as an allocation key for wealthy countries results in assigning a too small share for a fundamental need like food making it impossible to provide a healthy diet for all within the assigned SoSOS. In the Danish case, only 6% of the budget is currently spent on food in Denmark (see Supporting Information S1), while the EAT-Lancet Commission estimates that for the climate change PB, 9.6% is necessary in 2020 with the IPCC SSP1-1.9 scenario.

Other frequently used sharing principles are the gross value added, assigning shares proportional to the economic gross value added of the product, and Grandfathering that bases the SoSOS on the sector or product's share of the total environmental impacts in a given reference year (Bjørn et al., 2016, 2020a). These principles conflict with equity ideals because they pass historical or current inequalities and unsustainable consumption patterns on into the future (Bjørn et al., 2019a). Hjalsted et al. (2020) explored aspects of ethical sharing principles to accommodate this issue and proposed the distributive justice principle sufficientarianism; deciding what is "enough" (making sure that everyone has enough to fulfil their basic needs), as a more fair way of sharing. However, they conclude that sufficientarianism is complicated to operationalize and yet unfeasible as a sharing principle on a sector or product level.

Many AESA studies conclude that the choice of sharing principle has strong influence on the results (Bjørn et al., 2020b; Ryberg et al., 2016, 2018a; Sandin et al., 2015), and several studies call for further research on how to share the safe operating space in a practical and rational way to a product level (Clift et al., 2017; Häyhä et al., 2016; Ryberg et al., 2016).

In this paper we present a first attempt at developing a "Fulfilment of Human Needs" (FHN) sharing principle to determine the SoSOS assigned to a sector or product based on the importance of the need that the sector or product meets for the users. This sharing principle combines three distributive justice principles: egalitarianism, sufficientarianism, and utilitarianism, and it mixes currencies. Egalitarianism is represented by using equal per capita (EPC) as the first downscaling of the global safe operating space. Other principles, for example "historical debt" can substitute the EPC if desired. We illustrate the use of the FHN sharing principle in two different case studies (100 g of peanuts and a cotton t-shirt) meeting two fundamental needs (nutrition and keeping warm/protected) within the SoSOS for the PBs climate change, land-system change, freshwater use, and nitrogen cycling. For the latter three, we use the status quo (SQ) principle (belonging to the acquired rights distributive justice theory and similar to the Grandfathering principle but based on current emissions and not historical emissions) to apprehend the fact that sectors demand varying shares of the different PBs.

TABLE 1 The Share of the Safe Operation Space assigned to food production for four planetary boundaries from Willett et al. (2019); global amount of cropland use, water use, greenhouse-gas emissions, and nitrogen pollution. The global boundary shown for climate change for 2020 is in accordance with the IPCC SSP1-1.9 scenario in 2020 (Rogelj et al., 2018). Sources for the other global boundaries: Henry et al. (2018), Steffen et al. (2015).

PB	Control variable	SoSOS food	Global boundary	Share of total safe operating space in 2020 (%)
Climate change	GHG emissions [Gt CO_2-eq / year]	5	52.1	9.6
Nitrogen cycling	Nitrogen application [Tg nitrogen / year]	90	62	>100
Freshwater use	Consumptive water use [km^3 / year]	2500	4000	62.5
Land-system change	Cropland use [million km^2]	13	20.1	65

2 | METHODS

Section 2.1 presents the rationale behind a two-sided approach in the development of the FHN principle: one approach for climate change and another approach for the three other PBs. Section 2.2 presents the method for climate change adopting priorities in the EAT-Lancet Commission report (The Eat-Lancet Commission, 2019; Willett et al., 2019) that has been seminal in the discussion of absolute sustainability for diets and food products, and adopting consumption patterns in countries identified as "closest to sustainable" based on their performance against a set of social and environmental criteria. Section 2.3 presents the sustainable consumption (SC) principle on sector level using the data presented in Section 2.2. Finally, Section 2.4 operationalizes the developed sharing principle on product level for climate change and provide a stepwise guidance for how to do this for any product, while Section 2.5 introduces a variation of the SQ principle to determine an SoSOS for the three other PBs (land-system change, freshwater use, and nitrogen). Section 2.6 illustrates the SoSOS equations of the FHN principle for the two case studies.

2.1 | Different approach for different PBs

The development and application of SOS sharing based on the FHN principle differs between PBs. For climate change we developed a method (presented in Sections 2.2. and 2.3) which takes its starting point in sustainable consumption patterns. Energy accounts for 72% of the global green house gas (GHG) emissions (Center for Climate & Energy Solutions, 2017), and since all production processes use energy, CO_2-emissions and consumption are strongly correlated across most economic sectors. Economic expenditure is therefore a relevant basis of the allocation for the climate change PB. On the other hand there are large variations in the current impact across PBs from the different sectors. This is exemplified for food by the EAT-Lancet Commission in Table 1, where food is assigned 9.6% of the safe operating space for the climate change PB but 65% for the land-system change PB. Therefore, it is not purposeful to assign the same SoSOS for a product across PBs. To vary the shares across PBs for products we propose using the SQ principle as part of the sharing method in Section 2.5, since the SQ principle is the only sharing principle that differs the share across PBs.

2.2 | Prioritizing needs

The EAT-Lancet Commission report examines the essential human need, nutrition. The Commission evaluates which transition is needed to provide the global population with a healthy diet while staying within the safe operating space. Their study includes behavior (the most sustainable and healthy choice of diet and reducing food waste), and improvements in production methods and efficiency (Willett et al., 2019). They assign a share of the safe operating space to food based on two principles; sufficientarianism and ability to reduce of the sectors, considering both consumer choices and technology efficiency (Willett et al., 2019).

The SoSOS for the four PBs that are assigned to food by the Eat-Lancet Commission report are shown in Table 1. According to the Commission, these are the lowest shares we can assign to food production and still feed the global population with a healthy diet.

If similar work had been done for other sectors, ideally in coordination with the EAT-Lancet Commission work, we could use it for further development of the FHN sharing principle. This is not the case at present, and we therefore had to take an alternative approach to determine the share for other needs than food.

If an absolute sustainable country exists both in terms of the social and environmental sustainability dimension, the consumption pattern in that country could provide an allocation key reflecting the relative importance of different need fulfilments for a human population living within the biophysical limits of the planet. In order to identify potential candidate countries, we selected three broadly applied indicators for

TABLE 2 Countries that meet all sustainability criteria: Human Development Index > 0.7, ecological footprint < 3 gha/capita/year and impact on global warming < 5 ton CO_2-eq/capita/year.

Country	HDI	Ecological footprint gha/capita/year	Carbon footprint ton CO_2-eq/capita/year consumption based (2015)
Albania	0.79	2.1	3.7
Algeria	0.72	1.9	4.7
Armenia	0.73	1.9	3.2
Costa Rica	0.80	2.6	2.5
Dominican Republic	0.74	2.7	2.9
Fiji	0.71	2.6	1.2
Jordan	0.72	1.9	4.0
Philippines	0.72	1.3	1.2
Samoa	0.71	2.8	3.1
Sri Lanka	0.78	1.5	1.8
Tunisia	0.72	2.2	3.5

approximations of national social and environmental sustainability levels; the Human Development Index (HDI), which on a scale between 0 and 1 had to be above 0.8 (UNDP, 2020), the ecological footprint, which had to be below 1.6 global ha/capita/year (Jeffrey et al., 2016; O'Neill et al., 2018), and the consumption-based GHG emissions which had to be below 985 CO_2-eq/capita/year (Bjørn & Hauschild, 2015).

No country meets all three criteria but some come close. Therefore, we relaxed the criteria slightly to identify the most sustainable countries according to these indicator thresholds: HDI > 0.7, ecological footprint < 3 global ha/capita/year, and consumption-based GHG emissions of less than 5 ton CO_2-eq/capita/year.

The carbon footprint constitutes a part of the ecological footprint, but being based on GHG emission inventories, the uncertainty in global warming potential is in general lower than in other impact categories including the ecological footprint. Thus we desired to include the consumption-based GHG as a criteria on its own. One third of the counties were eliminated due to this additional criteria and thus we found it relevant to include the GHG emissions regardless of it already being part of the ecological footprint.

Despite the fact that HDI is widely applied to represent human welfare, it is not comprehensive. Therefore, we also considered other social perspectives (Gini index representing equality within the population; Bellù & Liberati, 2006, corruption perceptions index; Transparency International, 2021, human freedom index; Porcňik & Vásquez, 2015, and child mortality; Ruger & Kim, 2006) to ensure that the chosen countries had no major issues with, for example, inequality, corruption, or other social issues not well covered by the HDI. A full overview of the data and indicators used in evaluating the countries is provided in Supporting Information S1. For the countries that met the criteria set, we collected household and government spending data. Twenty-three countries met all relaxed sustainability criteria, but it was only possible to find consumption expenditure data for the 11 countries shown in Table 2. Household consumption cannot stand alone since many needs are predominantly taken care of by the government, for example, education and healthcare. The sources for consumption data including references and a list of all 23 countries can be found in SI1.

2.3 | The sustainable consumption principle on sector level

We used the average of 19 different consumption categories from the household and government spending in the countries in Table 2 as an approximation for helping prioritizing human needs. The SoSOS assigned to food by the EAT-Lancet Commission (9.6%) in 2020 is smaller than the average consumption of the 11 countries (22.5%), and we therefore distributed the remaining safe operating space for climate change evenly among the other sectors, resulting in the sector shares shown in the last column of Table 3.

In the rest of the paper, we will refer to the set of adjusted average shares for each sector in Table 3 as basis for operationalization of the sustainable consumption (SC) principle.

2.4 | Operationalizing the FHN principle at product or service level for climate change

To operationalize the sharing principle for climate change at product or service level, an additional methodological step is needed to divide the average shares for the 19 consumption categories from Table 3 further down. For this step, we need to determine the utility to individuals. Some of the 19 consumption categories address a single need (e.g., "Transport" and "Food and non-alcoholic beverages") and the products or services can be

TABLE 3 Average government and household spending in 11 countries that meet the sustainability criterion of Human Development Index > 0.7, ecological footprint < 3 gha/capita/year, and ton CO_2-eq/capita/year < 5. The parentheses indicate the range in each consumption category for the 11 countries. The adjusted share for food is from the EAT-Lancet Commission report. The adjusted average consumption pattern in the last column is the basis of the operationalization of the SC principle.

	Consumption categories (sectors)	Average consumption (%)	Adjustment of consumption with EAT-Lancet's share assigned to food (%). SC_{sector}
Government	General public services	6.9 (2.5–12)	8.0
	Defence	2.4 (0–10)	2.8
	Public order and safety	2.5 (0.5–5)	2.9
	Economic affairs	5.8 (2–11)	6.8
	Environmental protection	0.4 (0–2)	0.4
	Housing and community amenities	1.8 (0.1–6)	2.1
	Health	6.1 (3–14)	7.1
	Recreation, culture, and religion	3.4 (0.2–12)	4.0
	Education	6.9 (2–14)	8.1
	Social protection	4.1 (1–8)	4.7
Household	Food and non-alcoholic beverages	22.5 (14–38)	9.6
	Alcoholic beverages, tobacco, and narcotics	1.8 (0.4–5)	2.1
	Clothing and footwear	2.2 (0.6–5)	2.6
	Housing, water, electricity, gas, and other fuels	8.8 (3–12)	10.2
	Furnishings, household equipment and routine maintenance of the house	3.0 (0.9–6)	3.5
	Transport	8.1 (4–10)	9.5
	Communication	2.0 (0.04–4)	2.3
	Restaurants and hotels	2.9 (0.5–9)	3.4
	Miscellaneous goods and services	8.4 (0.01–19)	9.8

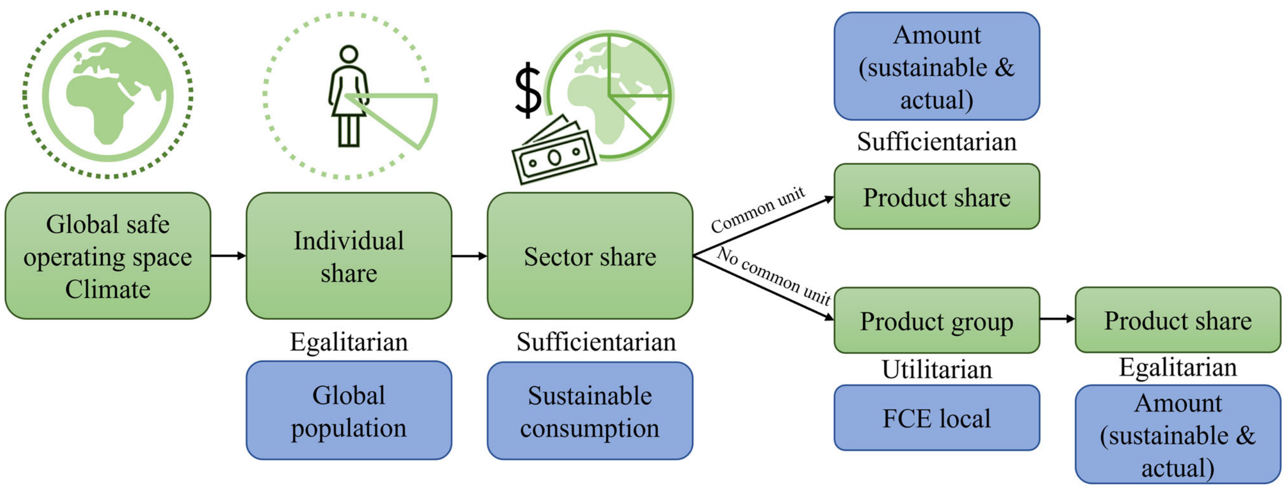

FIGURE 1 Flow chart of the Fulfilment of Human Needs principle with ethical norms as applied for climate change.

expressed in a common unit (e.g., distance or nutritional value), however, most of the consumption categories address several needs and services, which demands an additional differentiation between needs. This is done with the utilitarian ethical norm through local expenditure, and lastly the egalitarian norm is used however only for the qualified people or materials. This will be exemplified in case study 2. An overview of the steps in the sharing principle can be seen in Figure 1.

For the consumption categories that have a common unit we recommend using a function-based approach, for example, determine the current total average transport distance per person per year, or estimating the minimum transport distance an average person needs per year as done by

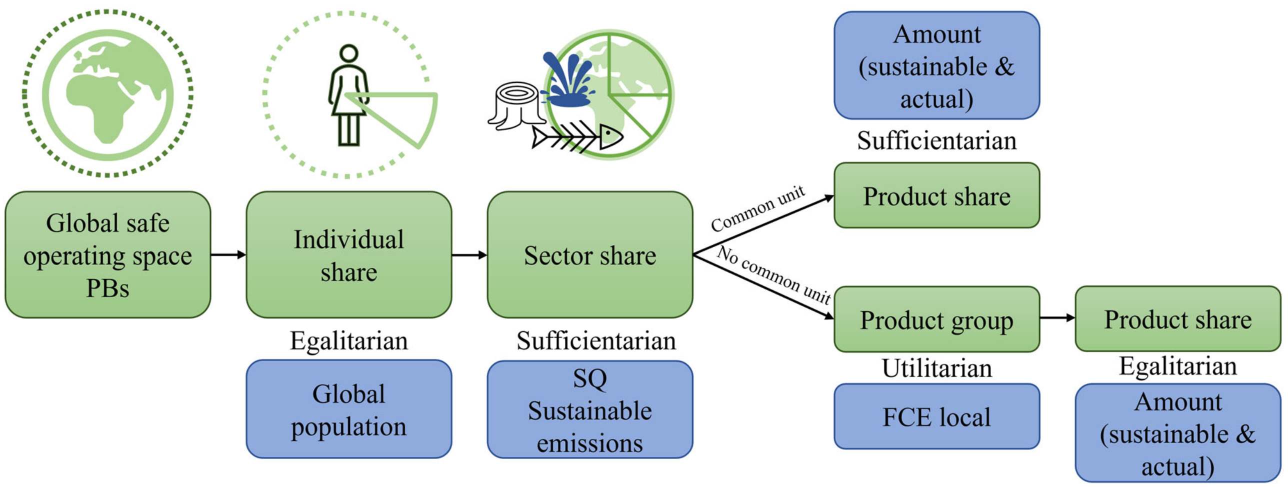

FIGURE 2 Flow chart for the steps in the Fulfilment of Human Needs principle as applied for the other planetary boundaries (land-system change, freshwater use, and nitrogen cycling).

Millward-Hopkins et al. (2022). For the consumption category "Food and non-alcoholic beverages" we use the reference intake (RI) as proposed by the Danish Veterinary and Food Administration (Fødevarestyrelsen, 2016), to determine the human requirement for essential types of nutrients. The essential nutrients are based on Matthiessen et al. (2021). We illustrate the FHN principle for food in case study 1 and details can be found in Supporting Information S2.

The minimum levels should be used if it is desired to include sustainable consumption behavior by the users, and national statistics should be used if current consumption levels are desired in the model. Both measures are included in case study 2 for comparison.

For consumption categories where a common unit does not exist, for example, "Health" (which covers all types of healthcare and construction of hospitals), we recommend using FCE within that consumption category of the country of interest to divide the share among subgroups. Subsequently the number of people receiving the services or the capacity is used to determine the total share for larger product systems (e.g., number of residents in a dwelling or patient days in a hospital). For smaller product systems, for example, a t-shirt, the FCE in the country of interest should also be used to separate the consumption category into subgroups, in this case to separate clothing and footwear. At this point a common unit is reached and the method described above to estimate the current consumption, or the total amount needed can be used. This is exemplified in case study 2.

2.5 | Operationalizing the FHN principle at product or service level for land-system change, freshwater use, and nitrogen cycling

We selected the SQ principle because it varies the shares between the PBs as justified in Section 2.1. There are only few studies that investigate the ability of different sectors ability to reduce their impact (Evrard et al., 2016; Krabbe et al., 2015; Pineda et al., 2015; Willett et al., 2019), and they are limited to considering impact on climate change. The Best Available Techniques (BAT) concept has been designed to compare a project to a reference project but not to compare reduction potential across sectors (Evrard et al., 2016). It has therefore not been possible to include ability to reduce for sectors in the FHN principle for the PBs land-system change, freshwater use, and nitrogen cycling. The reduction potential from behavior change is included through the study of Millward-Hopkins et al. (2022). The results can be seen in Section 3.2. Figure 2 is a flow chart illustrating the approach taken for the other thee PBs considered in this study.

For the SQ calculations we used environmentally extended input/output modeling (EE-IO) and the EXIOBASE (Stadler et al., 2018) to calculate the current impact from different sectors in the most sustainable countries. Among the 23 identified countries, only Indonesia, (which is not among the 11 countries in Table 2 due to data limitations for consumption) had the data available in the EXIOBASE, so we were limited to this country for determining the current level of impact per capita. Therefore, this study mainly serves as a demonstration and proof of the method and we recommend further research in this area.

We used EXIOBASE v3.3.1.6b2 as part of SimaPro released by 2.–0 LCA consultants in 2020. The I/O tables are from 2011. The model used marginal electricity mix and it included capital goods and indirect land use change (iLUC). We used the International Life Cycle system Data (ILCD) method to get the impact categories in units that match the carrying capacity-based normalization references from Bjørn and Hauschild (2015) and Sala et al. (2016). The global boundaries used in this study are shown in Table 4. The consumption-based impact in Indonesia can be found in Supporting Information S3.

TABLE 4 Global safe operating spaces from Bjørn and Hauschild (2015) and Sala et al. (2016). The individual Share of the Safe Operation Space is calculated using the global population in 2020 of 7762 million people (The World Bank, 2020) and egalitarianism (EPC).

PB	Unit (compatible with ILCD)	Global safe operating space	SoSOS per person per year in 2020
Nitrogen cycling	kg N-eq	2.00E + 11	2.58E + 01
Freshwater use	m^3 water eq	6.85E + 11	8.83E + 01
Land-system change	kg C deficit	1.37E + 14	1.77E + 04

TABLE 5 The annual Share of the Safe Operation Space per capita for climate in 2020, 2030, 2040, and 2050 based on IPCCs SSP1-1.9 scenario (IPCC, 2018) and projections for the global population (United Nations, 2019 for projections and The World Bank, 2020 for population in 2020).

	2020	2030	2040	2050
$SOS_{climate}(t)$ [Mt CO_2-eq/year]	52,069	30,876	17488	8327
$Pop_{world}(t)$ [million]	7761.6	8548.5	9198.8	9735
$SOS_{climate}(t)/Pop_{world}(t)$ [t CO_2-eq/cap/yr]	6.68	3.61	1.90	0.86

The downscaling of the SoSOS for each of the 163 sectors in EXIOBASE to product level is demonstrated for both case studies in Sections 2.6.1 and 2.6.2.

2.6 | Cases

2.6.1 | Case study 1 “Peanuts”

We tested the FHN principle on the food case study of 100 g of peanuts. Peanuts is as a particularly interesting food according to the EAT-lancet report that states in the conclusion that in order to reach a sustainable diet globally, the intake of nuts should increase in all continents compared to current diets. The consumption category “Food and non-alcoholic beverages” got 9.6% of the safe operating space for climate change in 2020 (Table 3). To determine the share for the product, we evaluated the contribution of 100 g of peanuts to a daily RI for one person, assuming that macro- and micronutrients (minerals and vitamins) are of equal importance. See S2 for further details.

The absolute environmental sustainability reference (AESR) for 100 g of peanuts in 2020 is calculated with Equation (1):

$$SoSOS_{climate_{peanuts}} = \frac{SOS_{climate}(t)}{Pop_{world}(t)} \cdot SC_{food} \cdot \frac{1}{365} \cdot \frac{1}{|S|} \sum_{i \in S} A_c^{(i)} \quad (1)$$

where,

$A_c{}^{(i)}$ is the average daily coverage, the RI, of macronutrients and micronutrients (vitamins, minerals),

$S = \{M, V, m\}$, the number of nutrients groups (macronutrients, vitamins, and minerals),

SC_{food} is the percentage assigned to food based on the sustainable consumption in Table 3.

We determined the $SOS_{climate}(t)$ for 2020, 2030, 2040, and 2050 based on IPCC SSP1-1.9 scenario, and the medium variant global population projections by United nations (2019), which can be seen in Table 5.

The individual operating space for climate change has been determined by Bjørn and Hauschild (2015) with a non-dynamic approach, assuming that humanity emits a sustainable level of emissions every year and thus never has to reach negative emissions. They determine the share for climate to 985 CO_2-eq/capita/year as a steady state emission flow that allows us to respect the planetary boundary.

To calculate the SoSOS for the other PBs we exchanged the part of Equation (1) which relates to the SC principle with a part that introduces the SQ principle based on the approximation for sustainable emissions from Indonesia. The result is Equation (2), which we used to determine the share for each of the other three PBs.

We merged the impact on land-system change, freshwater, and nitrogen cycling for all sectors related to food production in our result for Indonesia (see SI 3) due to the cultural influence on more specific choices of diet.

$$SoSOS_{PB_{peanuts}} = \frac{SOS_{PB}(t)}{Pop_{world}(t)} \cdot \frac{SQ_{PBfood}}{SQ_{PB}} \cdot \frac{1}{365} \cdot \frac{1}{|S|} \sum_{i \in S} A_c^{(i)} \quad (2)$$

where,

SQ_{PBfood} is the current impact on the PB from food in Indonesia as representative for the most sustainable countries,

SQ_{PB} is the total impact on the PB in Indonesia.

2.6.2 | Case study 2 “A t-shirt”

In our second case study we determined the SoSOS for a t-shirt used in Denmark. The SoSOS for the t-shirt is calculated according to Equation (3), which first defines the SoSOS for individuals and goes on to scale it to the relevant sector using the SC principle, which assigns 2.6% of the individual SoSOS for clothing and footwear based on current consumption patterns (FCE). To only consider clothes, we divided the Danish average household spending on clothes with the total Danish average spending on clothing and footwear. See SI 3 for more details.

The total amount of new clothing needed on a yearly basis is estimated by Millward-Hopkins et al. (2022) to 4 kg, and the Danish consumption level is 10.9 kg (Miljøstyrelsen, 2018). Both values were used to compare the difference between sustainable consumption levels and the current Danish level.

$$SoSOS_{climate_{t-shirt}} = \frac{SOS_{climate}(t)}{Pop_{world}(t)} \cdot SC_{Clothing\&footwear} \cdot \frac{FCE_{ClothingDK}}{FCE_{Clothing\&footwearDK}} \cdot \frac{mass_{shirt}}{Total_{clothing}} \quad (3)$$

where,

$SoSOS_{climate\_-shirt}$ is the sustainability reference for the t-shirt,

$SOS_{climate}(t)$ is the global safe operating space for climate change at time t,

$SC_{Clothing\&footwearH}$ is the share allocated to “Clothing and footwear” based on the sustainable consumption principle for household in Table 3

$FCE_{ClothingDK}$ is the household economic spending on clothing in Denmark,

$FCE_{Clothing\&footwearDK}$ is the total household economic spending in the consumption category “Clothing and footwear” in Denmark,

$mass_{t\text{-}shirt}$ is the mass of the t-shirt, $Total_{clothing}$ is the total mass of new clothing needed per year

An LCA of the cotton t-shirt was performed according to ISO 14040 with the method ILCD 2011 Midpoint+ V1.11, using the Ecoinvent database. The $SoSOS_{climate}(t)$ of climate change was calculated based on the IPCC SSP1-1.9 scenario as introduced in Table 5 for 2020.

To calculate the t-shirt’s SoSOS for the other PBs, the same approach was used as for the food case, changing the part of Equation (3), which relates to the SC principle with a part that introduces the SQ principle as an approximation for sustainable emissions based on the impact distribution in the most sustainable countries (represented by Indonesia only). Equation (4) was used to determine the SoSOS for the t-shirt.

$$SoSOS_{PB_{t-shirt}} = \frac{SOS_{PB}(t)}{Pop_{world}(t)} \cdot \frac{SQ_{PB\ Textiles}}{SQ_{PB}} \cdot \frac{mass_{shirt}}{Total_{clothing}} \quad (4)$$

where,

$SOS_{PB}(t)$ is the global safe operating space for the PB at time t,

$SQ_{PBTextiles}$ is the current impact from textiles manufacturing on the PB of interest in Indonesia (representing the most sustainable countries),

SQ_{PB} is the total impact on the PB of interest in Indonesia (representing the most sustainable countries).

3 | RESULTS

3.1 | Case study 1 “Peanuts”

Using Equation (1) results in an SoSOS of 0.42 kg CO_2-eq/100 g peanuts in 2020. For comparison, the FCE sharing principle assigns 0.075 kg CO_2-eq/100 g peanuts in 2020. See the calculation for the FCE principle in SI 2.

According to Stylianou et al. (2021) peanuts in general emit around 0.23 kg CO_2-eq/100 g. Peanuts are on track for the IPCC reduction pathway with the FHN sharing principle, since the sustainability ratio (the actual impact divided with the assigned share) is smaller than 1 in 2020. If the global boundary by Bjørn and Hauschild (2015) is used with the sustainable consumption (14–38%) the sustainability ratio is 1.07–2.91 (see SI 3). In this case the climate impact from peanuts should be more than halved to reach an absolutely sustainable level. The results for the remaining three impact categories using Equation (2) are shown in Table 6. In ILCD the impact categories are called: water resource depletion, land use, and marine eutrophication, and the units are the same as the boundaries defined by Sala et al. (2016), thus we used the impact categories from ILCD as measures for the planetary boundaries. With the applied sharing approaches (approximation for the sustainable consumption for climate change,

TABLE 6 The share assigned to peanuts ($SoSOS_{Peanuts}$) for climate change and the other three planetary boundaries (PBs) from Equations (1) and (2). All results and calculations can be seen in SI 3. The actual impacts are from Stylianou et al. (2021). A product can be considered absolute sustainable if the sustainability ratios are smaller than 1. The brackets show the result for climate change when using the consumption interval for food and beverages (14%–38%) presented in Table 1. There are only intervals for climate change since we only have one nation in the dataset for the SQ impact for the other PBs.

PB	Unit	$SoSOS_{peanuts}$ 100 g	Actual impact 100 g peanuts	Sustainability ratio
Climate change	Kg CO_2-eq	0.42 (0.61-1.67))	0.23	0.56 (0.14–0.38)
Marine eutrophication	kg N-eq	1.08E-02	7.07E-05	0.0065
Water resource depletion	m^3 water eq	3.88E-02	1.75E-02	0.45
Land use	kg C deficit	5.58	2.71	0.49

TABLE 7 Life cycle assessment result and the Share of the Safe Operation Space for the t-shirt determined with the Fulfilment of Human Needs principle. The sustainability ratio indicates that the actual impacts exceed the assigned share for all planetary boundaries (PBs). The brackets shows the result for climate change when using the consumption interval for clothing and footwear (0.6%–5%) presented in Table 1. There are only intervals for climate change since we only have one nation in the dataset for the SQ impact for the other PBs.

PB	Unit	SoSOS_t-shirt sustainable consumption	Actual impact t-shirt	Sustainability ratio
Climate change	kg CO_2-eq	7.5 (1.7–14.5)	5.43	0.7 (0.4–3.1)
Marine eutrophication	kg N-eq	1.4E-03	0.06	41.5
Water resource depletion	m^3 water eq	6.2E-03	2.24	361.8
Land use	kg C deficit	1.56	26.64	17.0

and approximations for sustainable emissions for the other PBs), peanuts are absolutely sustainable for all PBs included in this study because the actual impact of peanuts are smaller than the assigned SoSOS.

3.2 | Case 2 “A t-shirt”

The LCA results for the cotton t-shirt and the SoSOS assigned to the t-shirt with the FHN principle can be seen in Table 7. See details about the LCA and assigned SoSOS in SI 3. The sustainability ratio of 0.7 for climate change indicates that the t-shirt is absolute sustainable here, whereas it is very far from being absolute sustainable in the other PBs.

We investigated the influence of using the estimate of total new clothing needed per year by Millward-Hopkins et al. (2022) of 4 kg compared to using the current consumption of clothes in Denmark, which is 10.9 kg (Miljøstyrelsen, 2018). When changing the $Total_{clothing}$ from Equations (3) and (4) to the Danish consumption level of clothing the sustainability ratios increase by a factor of 2.7. When accounting a larger consumption than the suggested sustainable level, a smaller share is available for each piece of clothing, which is reflected in the increased sustainability ratio. This indicates that a sustainable consumption level is almost sufficient to bring the t-shirt within absolute sustainable levels for climate change for clothing. On the other hand, the environmental footprint of the t-shirt must be reduced significantly for the other PBs to make it absolutely sustainable.

The Danish SQ shares of the impact on marine eutrophication, water resource depletion and land use caused by textiles are larger than the SQ shares in Indonesia. Therefore, we calculated the influence of our assumptions about using the SQ impact in Indonesia instead of the Danish SQ impact and included Danish consumption level of clothing, which is the usual approach in AESAs. This increased the SoSOS significantly (with 30%—60%) for the three PBs, but the t-shirt is still far from being absolutely sustainable. We also tested the FCE principle for the t-shirt and found that for t-shirts that cost less than 100 Euro the FCE principle assigns a smaller SoSOS to the t-shirt than the FHN principle. More details about the analysis of the different assumptions in the SoSOS allocation for clothing can be found in Supporting Information S3.

4 | DISCUSSION

In the discussion we first look into methodological contributions and challenges and then we discuss the implications for the industry.

4.1 | Methodological contributions and limitations

The FHN sharing principle for AESAs was developed to reflect the importance of the necessities delivered to users. This principle is a first attempt to operationalize the distributive justice theory sufficientarianism for AESA. The FHN principle highlights the sectors and products that should reduce their environmental footprint most, based upon how essential the need delivered to the users is. This motivates companies to focus on producing the "right things" since non-essential products would receive an insufficient share. This is the largest strength and contribution of the FHN sharing principle.

The EAT-Lancet Commission report assigns a share to food production that makes sure everyone gets enough, while also taking the sectors' ability to reduce and sustainable behavior into consideration. This is also the ambition with the FHN principle. Unfortunately, it has not been possible to include ability to reduce beyond GHG emissions from the food sector.

The average consumption patterns in "the most sustainable" countries (where the average lifestyle approaches a sustainable lifestyle) was used as an estimate of the importance of the needs in the FHN principle. Other calculation methods to identify an optimal share for sectors regarding importance of necessities delivered, for example, depending on climate zone and ability to reduce impact could be explored, for example, statistical optimization with least squares optimization across the consumption categories.

In the identification of "the most sustainable" countries, we applied the HDI as an approximation for the level of welfare to represent social sustainability. HDI is, however, criticized for being biased by the GDP and for excluding parameters such as inequality. Other social indicators should be explored for identification of the most sustainable countries.

The operationalization of the FHN principle differs among PBs. Climate change is strongly correlated with energy use and hence economic flows. Therefore, FCE was identified as a potential allocation key for the safe operating space. This is not the case in the other PBs, hence we used the SQ principle on the identified most sustainable countries, to determine the shares for the other three PBs included here. The SQ principle is often highlighted as problematic in sustainability contexts, due to the risk of continuing and favoring current unsustainable practices. We limited the risk of including unsustainable behavior by using the current impact from the shortlisted countries with an impact profile that is close to sustainable, compared to, for example, using the SQ in Scandinavian or Western countries.

The method is tested on a very limited data foundation and the outcome should be seen as a demonstration and proof of the method and not a conclusive result. We recommend further research to improve and develop this method and in particular the data foundation.

According to Caney (2012) and Hjalsted et al. (2020) it is likely that assigning "enough" to everyone on Earth would be impossible within the safe operating space for several of the PB's. This is indeed true for climate change if we fail in capturing carbon. As shown in Table 5 the total safe operating space in 2050 for climate change is 855 Mt CO_2-eq/year and with 5000 Mt CO_2-eq assigned to food production, it is not possible to feed the global population beyond 2040 and stay within the PB without a negative contribution from carbon capture in the energy sector and carbon uptake in organic materials (Rogeli et al., 2018).

4.2 | Implications for companies

We limited the study to consider global boundary setting, however, land-system change, freshwater use, and nitrogen cycling should rather be assessed on a regional scale (Bjørn et al., 2020b). To further improve the sharing principle and increase the relevance for companies, we recommend exploring the possibilities of integrating regional perspectives for boundary setting for land-system change, freshwater use, and nitrogen. Despite recent work in this area (Bjørn et al., 2019b, 2020b, 2020c) the methods are very young and only tested on one simple case study. Regional analyses are extensive even for simple product systems, and due to the data requirement for the origin of all materials in the product system, the method needs refinement to be applicable for more complex product systems with many components and multiple materials along with being attractive and accurate for companies.

Case study 1 demonstrated the applicability of the FHN principle to any food product, however it also revealed challenges related to special food products. It does not accommodate food types that contain essential micronutrients which are only present in a few food types but are rather low in nutritional content across nutrients. It could be argued that certain micronutrients, which only appear in a few food products should get a larger share. Furthermore, while looking into complete diets would make better sense on the individual level, the perspective of single food products is needed for target setting for food producing companies. It could be argued that a company's portfolio of products is what should stay within its assigned share. This allows the companies to reduce the footprint even more than the SoSOS for some products while reducing less for other products as long as the total SoSOS for the portfolio of products does not exceed their share. Food products mainly consumed for pleasure constitute another issue. An example is coffee, which provides limited amount of nutrition, but might still be prioritized by consumers over other goods. This prioritization could move coffee into the consumption category "Miscellaneous goods and services" instead of "Food and non-alcoholic beverages." Drinking water is part of "Housing, water, gas and other fuels," however, this constitutes another issue, since the quality of tap water differs from country to country. If the water is not clean enough for drinking purposes, water will be part of the budget spent on "Food and non-alcoholic beverages," but bottled water does not contain many nutrients. For these countries a share assigned to drinking water from the "Housing, water, gas and other fuels" sector should be moved to "Food and non-alcoholic beverages."

The proposed FHN principle differs from other sharing principles reported in the literature by focusing on the needs fulfilment of the product or service (in LCA terms; on the functional unit). The use of the FHN principle assigned a much larger share to the peanuts than the FCE principle, which reflects current consumption behavior. This indicates that other food types and sectors contribute less to needs fulfilment and therefore should receive a smaller share of the safe operating space. The equation prevents that more than 100% can be assigned to food products, thus the total share cannot be exceeded (with the exception if the total consumption is larger than the RI in average per person (e.g., eating too much and food waste).

A challenge with the FHN principle is, however, that it is not straight forward to apply for all types of products and services. The downscaling from the sector shares (in Table 3) has to be developed or adapted to the specific product. In order to make this downscaling more practical and consistent, guiding principles were introduced in Section 2.4. Business to business products are problematic when assigning a SoSOS with the FHN principle. More research is needed here to develop the method to embrace these products. Another challenge with the FHN principle is determining when an individual has enough of something to reach a sufficient level of well-being. Other sharing principles do not have similar challenges when determining the total amount, since they ignore that unsustainable behavior currently is reflected in national statistics (for economic spending or emissions). The FHN principle differs from other principles by including change in human behavior. However, if the consumption pattern does not change, it will allow some product too large a share, as we illustrated in case study 2. Millward-Hopkins et al. (2022) suggest a minimum level of services to reach a decent living standard, which might offer a reference for comparison with the current consumption levels. We recommend that companies use both current consumption patterns and the sustainable consumption levels to determine the share for their products. The national culture, climate zone, landscape character, and typologies might influence the need for some services and the way in which needs can be fulfilled. Millward-Hopkins et al. (2022) included this to some degree in their study, but it should be explored further to reach a fair sharing principle.

Case study 2 also demonstrated the extent of the importance of sustainable consumption levels and human behavior. Changing the textile consumption in Denmark from 10.9 kg of new clothes per year to 4 kg results in the t-shirt being absolute sustainable for climate change. This means that the textile industry does not needs to reduce their impact on climate change per clothing item if the global consumption and production levels were reduced to the minimum level needed. Such change in behavior is, however, insufficient for the other PBs in this case. Considering the large water and nutrient use for cotton production a mixture of other textiles might help textile companies reach an absolute sustainable level within all PBs.

Concluding that a product is absolute sustainable should always be done be with great care due to the strong dependence on the assumptions and choice of sharing principle and uncertainties in the LCA. Thus, for companies to claim that a product is absolute sustainable the LCA result should be smaller than the SoSOS determined with several sharing principles. We recommend to always indicate the result showing the uncertainty, for example, by providing the result as an interval and with the underlying assumptions for transparency.

5 | CONCLUSION

In this study we developed a new sharing principle for AESAs that operationalize the distributive justice theory, sufficientarianism, and the ability to reduce. We determined the importance of needs, based on the EAT-Lancet Commission report and the consumption patterns in a shortlist of countries with an impact profile that is close to sustainable. We tested the FHN sharing principle on two case studies: (1) 100 g of peanuts and (2) a cotton t-shirt. We compared the SoSOS for climate change of the peanuts determined with the FHN principle with the share assigned with FCE principle, which is currently the most applied principle. The FHN principle assigned a much larger share to the peanuts than the FCE. The FHN introduces a major change in the perspectives of sharing principles since the emphasis is directly on or closely linked to the functional unit of the product or service and the importance of the need that they fulfil (e.g., the contribution of a food product to one person's daily RI) compared to other principles, which consider contribution to economic growth, size, or cost.

In this study we illustrated the importance of consumption levels in relation to reaching absolute sustainability. If the consumption levels decrease to a sufficient level for a decent standard of living, the pressure for reducing emissions for companies is significantly reduced.

The FHN principle can be used to assign a share of the safe operating space that reflects the importance of different needs, and also incorporates the first steps toward including a sector's "ability to reduce" by assigning a share of GHG emissions to food production, derived from EAT-Lancet Commission report. A further development and integration of ability to reduce for each sector in this principle is desired for future research.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supporting information of this article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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