Quick-guide to Life Cycle Sustainability Assessment using the Social Footprint methodology 2021 with versatile options for contribution analyses

Bo P. Weidema
2.-0 LCA consultants, Aalborg, Denmark
March 2023

Contents

When citing this report, please use the following reference:
Weidema B P. (2023). Quick-guide to Life Cycle Sustainability Assessment using the Social Footprint methodology 2021 with versatile options for contribution analyses. Aalborg, Denmark: 2.-0 LCA consultants.

1 Measuring sustainable wellbeing

1.1 Quality-Adjusted person-Life-Years (QALY) as a measurement unit

Quality-Adjusted person-Life-Year (QALY) is suggested as a unit for 'Sustainable wellbeing' (Weidema 2006, 2018), in parallel to the Disability-Adjusted Life-Year (DALY) measure used in comparisons of health impacts (although QALY and DALY will have opposite signs, due to DALYs expressing a detriment, while QALYs express wellbeing benefits). QALYs thus also include the non-health aspects of wellbeing.

The Quality-Adjustment is a severity score between 0 (death) and 1 (full wellbeing) and is applied to all years of life until the average maximum value for life expectancy at birth (currently set to 94 years, based on the global averages for life expectancy at birth and Years of Life Lost from the IHME Global Burden of Disease Results Tool for year 2019).

1.2 The different contributions to a QALY

In Figure 1, the four fully drawn rectangles illustrates four types of contributions to the value of a QALY. Additionally, an unavoidable loss of wellbeing is added at the top, illustrating that it is never be possible to achieve full wellbeing for all people all the time, due to unavoidable life-events, such as natural disasters, deaths of close relatives and friends, and unavoidable diseases. The maximum achievable QALY/person-life-year at population level is here set to be 0.96.

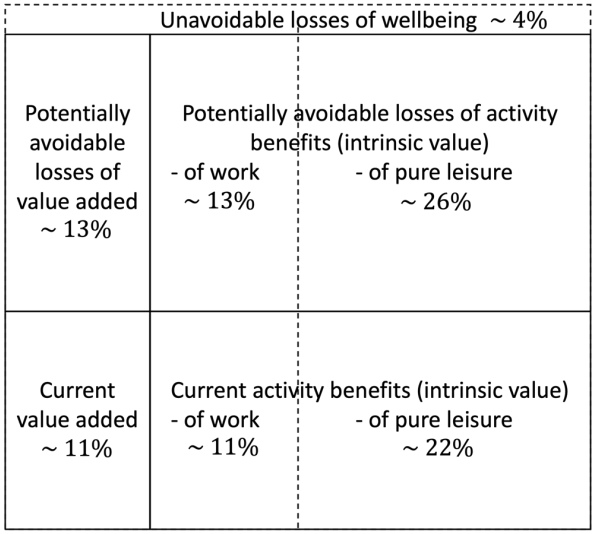

Figure 1. Contributions to the total value of a QALY.
Percentages represent estimated current global averages.

The lower rectangles in Figure 1 express the current level of wellbeing, which is estimated by Helliwell et al. (2021) to be 5.03 on a scale from 0-10, or 0.503 on the 0-1 QALY scale. When corrected for the value of lost life expectancy (YLL from the IHME Global Burden of Disease) at 0.3 QALY/YLL, this becomes 0.44 QALY/person-life-year.

The upper rectangles in Figure 1 express the potentially avoidable losses of wellbeing, i.e., the difference between the current level of 0.44 QALY/person-life-year and the potentially achievable level of 0.96 QALY/person-life-year.

The internal vertical lines in Figure 1 separate both current and potential wellbeing into value added (left rectangles of Figure 1), i.e., the value that work (productive activities) add to products, and the activity

benefits (right rectangles of Figure 1). i.e., the value of the positive emotions that people obtain from performing or taking part in specific activities (originally named 'process benefits' by Juster et al. (1981); also known as 'experienced' or 'hedonic' wellbeing). The dotted line separates the activity benefits experienced during work (i.e., beyond the value of the work outputs) from those experienced from leisure activities. The size of these different parts of wellbeing is estimated to be approximately 25% for the value added, 25% for the activity benefits from work, and 50% for the activity benefits from leisure. This distribution is estimated on the one hand from the trade-off between leisure and work, that implies that the benefits of a marginal hour of work equals the benefits of a marginal hour of pure leisure, and on the other hand from the finding of Helliwell et al. (2020) that income only explains approximately 25% of the difference in life satisfaction scores.

1.3 The conversion factor between value added and QALY

When summed over all productive activities, the value added is the same as the Gross World Product (the annual Gross Domestic Products summed over all countries), currently 88 trillion USD_{2019} or 11'409 USD_{2019}/person. The potentially achievable value added was calculated by Weidema (2018), applying the potential GDP/person of the United States of America (USA) as a realistically achievable potential also for the global GDP/person. The potential of USA was chosen, because it has a large and diverse economy while also having the largest current GDP/person when excluding banking and oil producing countries. Weidema & Schmidt (2018) justified the choice of USA on the basis of a sensitivity analysis with 11 other countries. The calculations of the potential GDP/person in Weidema (2018) and the update of Weidema & Schmidt (2018) were revised in a more detailed calculation by Weidema (2022b), showing the potentially achievable value added to be 8.5 times the current GDP/person or 97'000 USD_{2019}/person. The above suggestion that 25% of wellbeing is explained by value added then provides a conversion factor of 1 QALY = 4 * 97'000 = 388'000 USD_{2019}/person-year.

It should be noted that the contribution of value added to wellbeing is a logarithmic relationship, i.e., it is the log change in value added that contributes to a linear change in wellbeing. Therefore, the conversion factor of 388'000 USD_{2019}/person-year should be seen as an overall average, which also explains why the size of the left rectangles of Figure 1 are not linear proportional to their monetary values. The current value added of 11'409 USD_{2019}/person and the 85'600 USD_{2019}/person-year for potentially avoidable losses of value added should be multiplied with correction factors of 3.8 and 0.59, respectively, to correspond to the 0.11 and 0.13 QALY of the two corresponding rectangles, the much smaller factor for potentially avoidable losses reflecting the lower wellbeing value of an additional unit of value added when approaching the maximum achievable wellbeing, while the higher wellbeing value for current value added reflecting the relatively larger importance of fulfilling basic needs at lower incomes.

It should also be noted that the traditional measure of Gross Domestic Products applied here does not include the value added by unpaid work, which would add approximately 20% to the measured Gross World Product. However, as long as unpaid work is not more precisely valued, its inclusion in the conversion factor would just imply a shift in base units and not affect the relative size of the contributions to a QALY. Thus, to avoid adding an unnecessary source of confusion, unpaid work has not been included in the conversion factor. This does not imply that changes in the amount of unpaid work should not be included in cost-benefit assessments of specific products or activities.

2 Life Cycle Sustainability Assessment (LCSA)

2.1 The functional unit

The starting point for any Life Cycle Assessment (LCA) is the functional unit, i.e., the quantified amount of product (tangible good or intangible service) for which the impact is calculated. This relates to the purpose of the LCA, i.e., the decision that the LCA is going to support, typically a choice between product alternatives. Sometimes, you start with assessing only the impact of the existing product, to identify and focus improvements on the areas of largest impacts. More details on how to identify the functional unit of a study is described in Weidema (2017).

In this quick-guide, a simple example product is used for illustration: The functional unit is 400 Mg of glass on the French market. The functional unit can be expressed as a demand vector for the products of the EXIOBASE hybrid LCA database that we use in this example:

Country	**Product**	**Unit**	**Amount**	**Source**
FR	Glass and glass products	tonnes	400	Merciai (2021)

i.e.:
f = 400 [Mg]

2.2 Measurement and assessment of current value added (Life Cycle Costing)

The current value added of the functional unit is equal to the price of the functional unit, since the price is the sum of the value added over the life cycle (Moreau & Weidema 2015). This is equal to the currently internal(ised) costs and benefits (as opposed to external costs and benefits).

The price of 400 Mg glass on the French market is 321.3 $kEUR_{2011}$. This corresponds to the total life cycle cost (= value added over the life cycle), therefore likewise 321.3 $kEUR_{2011}$.

The payments of value added (labour expenditures, payments of entrepreneurs, and net tax expenditures) implies a benefit to those who receive the payments, while for those who pay for the value added (ultimately the consumers), the benefit (value) obtained from the product received is counterbalancing the cost. The value added is thus counted only once, either as a cost (to the consumer, when comparing products with the same functionality) or as a benefit (to the ultimate recipients of the payments of value added, when assessing contributions to wellbeing).

Note that when comparing two products with different life cycle costs, a monetary rebound effect is added to the product with the lowest costs, representing the increase in marginal consumption from the saved money, thereby including the full effects of shifting between the compared products. Since the life cycle costs thereby become the same for the compared products, it is unnecessary to include the life cycle costs in the LCSA, thus avoiding the additional uncertainty from the conversion from currency units to QALYs.

The benefit of a payment to the ultimate recipient depends on the prior level of wealth of the recipient, since an increase in income is relatively more valuable to a poor person than the same increase in income for a rich person. Equity-weighting is applied to account for this relative benefit of income. Lacking data on wealth levels of the recipients, the equity-weights are calculated from data on income levels per industry and skill level, using this formula:

$$DI_{i,g} * EW_{i,g} = DI_{i,g} * ((DI_c/WH_c)/(DI_{i,g}/WH_{i,g}))^{\delta}$$

where DI is direct income (compensation of employees + operating surplus)*, EW is equity-weight, WH is Work Hours, subscript *i* indicates industry, subscript *g* indicates income-group, and subscript *c* indicates country (set to 'global' when using the global average wage level as the reference), and δ is the elasticity of marginal utility of income (Lambert 2001). For the example calculations, a value for δ of 1.24 has been used, with a 95% confidence interval of 1.14-1.35, based on Layard et al. (2008, p. 1856), who calculate this value from 6 surveys that relate wellbeing to income. When equity-weighing is applied across different countries with different purchasing power of their nominal currencies, the income data have first to be Purchasing Power Parity (PPP) corrected.

The above-described calculation of direct income by industry and the equity-weighting of income by industry and skill level has been performed for the 2011 hybrid version of the EXIOBASE LCA database (Merciai 2021) in Weidema (2022a; Excel file 'Social footprint update 2022_QALY 2019 by skill level and industry using Exiobase 2011 as economy', sheet 'VA_act and social footprint', rows 38 and 61 labelled 'Sum direct income by industry' and 'Globally equity-weighted direct income by industry, PPP corrected', respectively, both in units of million EUR_{2011}).

This row can be added to the **B** matrix of elementary flows of EXIOBASE (Merciai 2021), so that it can be included in the normal LCA calculation:
$\mathbf{m} = \mathbf{BA}^{-1}\mathbf{f}$
where **m** is the resulting life cycle totals of each of the elementary flows per unit of output of each activity, and **A** is the activity matrix representing the transactions in the economy.

The equity-weighting implies a change in the value of the direct income by industry. An increase in the value implies that the monetary re-distribution implied by the product life cycle has a beneficial wellbeing effect, relative to an average product.

Applying the **f** vector for the French glass system in the normal LCA calculation, using the 2011 hybrid version of EXIOBASE (Merciai 2021) as database, with the added extensions of 'Sum direct income by industry' and 'Globally equity-weighted direct income by industry, PPP corrected', provides the life cycle result vectors per activity, of which the sum and contributions from the top 8 activities are shown in Table 1.

Table 1. Direct income and equity-weighted direct income for 400 Mg glass in France

Activity	Direct income [kEUR2011]	Equity-weighted direct income ... [kEUR2011]
Total	284.64	61.49
Manufacture of glass and glass products [FR]	96.25	8.66
Wholesale trade ... [FR]	47.08	3.75
Other business activities (74) [FR]	18.38	3.5
Supporting and auxiliary transport activities ... [FR]	9.24	0.3
Retail trade ... [FR]	9.19	11.55
Other land transport [FR]	6.46	0.81
Sale, maintenance, repair of motor vehicles ... [FR]	5.85	0.73
Computer and related activities (72) [FR]	3.79	0.69
All other activities	88.39	31.5

* In absence of detailed data re-distribution of taxes and operating surplus, taxes and subsidies on products and production are currently ignored, and operating surplus is distributed proportionally to the wages.

Comparing the sum of 'Sum direct income by industry' to the Life Cycle Cost, indicates the share of the excluded net taxes: (321.3-284.6)/321.3 = 11.4%. The result after equity-weighting shows a lower result than before equity-weighting, namely 284.64 – 61.49 = 223.15 $kEUR_{2011}$ or 78.4 % lower. This indicates a *loss* of utility caused by the monetary re-distribution related to the French glass. Recalling from section 1.3 that 1 QALY = 388'000 USD_{2019}/person-year and global average factor of 3.8 for the current value added, the loss of utility expressed in QALY has a value of 3.8 * 223'150 EUR_{2011} * 1.153 USD_{2019}/EUR_{2011} / 388'000 USD_{2019} = 2.520 QALY.

In addition to the payments of value added, specific foreground activities in the product system may make voluntary transfers (gifts), e.g., via charitable organisations. If these are not already recorded as intermediate flows, their monetary re-distribution effect may be estimated in the same way as for the direct income above, as the equity-weighted monetary value for the recipient minus the equity-weighted value for the spender.

2.3 Measurement and assessment of current activity benefits

The current activity benefits of pure leisure are unrelated to purchased products and shall therefore not be included in the Life Cycle Sustainability Assessment. Similarly, it can be argued that the current activity benefits of work are rather to the overall value added of society than to the output of a specific product, since the former is largely unaffected by changes in the latter, due to the mobility of labour.

Thus, all current activity benefits (of both work and pure leisure) are regarded as unrelated to purchased products and shall therefore not be included in the Life Cycle Sustainability Assessment.

2.4 Measurement of potentially avoidable non-organisation-specific impacts

For both value added and activity benefits, the potentially avoidable impacts (net losses or external cost and benefits) can be divided in three parts, as illustrated in Figure 2. Non-organisation-specific impacts (red hatched in Figure 2) makes up the largest part, approximately 78% of all potentially avoidable impacts, and covering nearly 90% of the avoidable losses of value added. For activity benefits, leisure is slightly more affected than work, due to health impacts and unwanted pregnancies mainly affecting leisure time.

The remaining impacts (i.e., outside the red hatched area in Figure 2 and elaborated in the following section) are organisation-specific impacts, which requires specific data from each industry and sometimes for each organisation. The latter situation is included in the blue hatched area, which has its largest presence in the area of activity benefits of work, since the work environment is an issue that often requires data specific to the individual organisation.

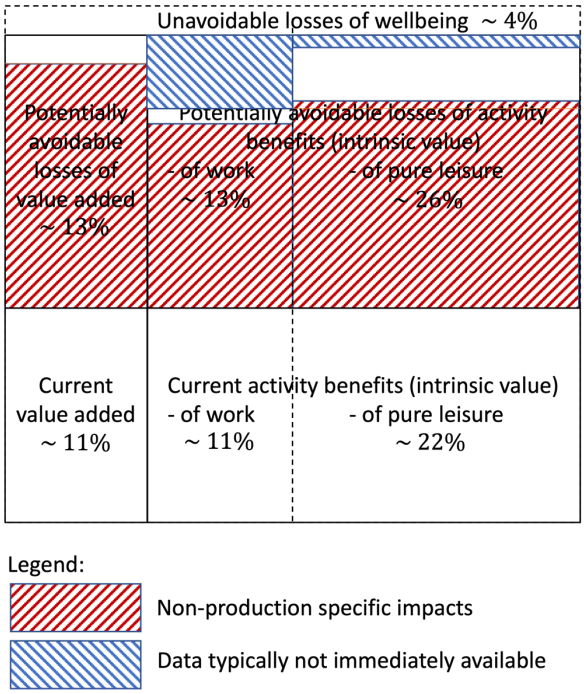

Figure 2. Contributions to the total value of a QALY (from Figure 1), with indication of the three measurement groups.

Non-organisation-specific impacts are those that are not dependent of the organisation-specific products, activities, or technology, but rather dependent on the quality of governance of the local society, and therefore quantifiable from national statistics without need to access detailed technology- or organisation-specific data (Weidema 2018). Thus, these impacts can also be called 'governance impacts' or more precisely 'impacts of missing governance'. While it is the direct responsibility of government institutions to maintain good governance and effective and efficient provision of necessary social services (such as education, health care, equitable rule of law, social security, employment, physical infrastructure, conservation of cultural heritage, and natural disaster damage prevention and mitigation), it is the role and responsibility of the productive sector to provide the funding for these activities, either directly, through payments of taxes, or through sufficient payments to the labour force so that they can pay for these services.

The non-organisation-specific impacts are measured at the country level (see current data in Weidema 2022a; Excel-file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheet '2019 QALY_live formulas', row 87), and distributed over the industries in proportion to their contribution to the country-wise equity-weighted direct income; see the formula in Section 2.2. Compared to a simple distribution relative to the value added of the industries, which would punish industries that actually do pay a fair wage, the equity-weighting includes the differences in wage levels between and within industries, with the intention to give more weight (responsibility) to those industries that have low-paid employees.

The above-described distribution of non-organisation-specific impacts over industries has been performed for the 2011[†] hybrid version of the EXIOBASE LCA database (Merciai 2021) in Weidema (2022a; Excel file 'Social footprint update 2022_QALY 2019 by skill level and industry using Exiobase 2011 as economy', sheet 'VA_act and social footprint', row 57 labelled 'Sum of non-organisation-specific lost wellbeing by industry' in units of QALY). This row can now be added to the B matrix of elementary flows of EXIOBASE, so that it can be included in the normal LCA calculation ($m = BA^{-1}f$).

[†] To align the 2019 data for non-production specific impacts to the economy matrix for 2011, the 2019 data per person per country have been applied to the 2011 populations of each country, before the distribution of the impacts.

Applying the **f** vector for the French glass system in the normal LCA calculation, using the 2011 hybrid version of EXIOBASE (Merciai 2021) as database, with the added extension of 'Sum of non-organisation-specific lost wellbeing by industry', provides the life cycle result vector per activity, of which the sum and contributions from the top 10 activities are shown in Table 2.

Table 2. Potentially avoidable non-organisation-specific impacts for 400 Mg glass in France

Activity	Potentially avoidable non-organisation-specific impacts [QALY]	Percentages
Total	3,924	
Retail trade ... [FR]	0,702	17,9
Manufacture of glass and glass products [FR]	0,526	13,4
Wholesale trade ... [FR]	0,228	5,8
Other business activities (74) [FR]	0,213	5,4
Cultivation of vegetables, fruit, nuts [WF]	0,072	1,8
Other land transport [WF]	0,059	1,5
Extraction of crude petroleum ... [WA]	0,059	1,5
Sale, maintenance, repair of motor vehicles ... [FR]	0,051	1,3
Other land transport [FR]	0,049	1,2
Supporting and auxiliary transport activities ... [WF]	0,046	1,2
All other activities	1,919	48,9

2.5 Measurement of potentially avoidable organisation-specific impacts

The organisation-specific impacts include those covered by data of traditional, biophysical LCA, which can therefore be reused here, by applying the additional conversion factors to QALY. The requirement is that the applied LCA database has complete global coverage, so that the global normalisation reference of the LCA database can be matched to the global QALY values in Weidema (2022a) for the corresponding impact category. For example, the global-warming-characterized emissions (expressed, e.g., in mass units of CO_2-equivalents) from the EXIOBASE 2011 inventory (Merciai 2021) can be expressed in QALY by multiplying by a factor obtained by multiplying the global QALY value in Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheet '2019 QALYimpact_per person', cell G90[‡]) by the 2011 global population and dividing by the global sum of global-warming-characterized emissions from EXIOBASE 2011 (Merciai 2021). From the global QALY value from Weidema (2022a) of 27.9 million QALY caused by an annual emission of 50 billion metric tonnes GWP100 CO_2-equivalents, we obtain a characterisation factor of 0.56 mQALY/metric tonne CO_2-equivalents. Multiplying by the 388'000 EUR_{2019}/QALY this corresponds to a monetary value of 216 EUR_{2019}/metric tonne CO_2-equivalents.

‡ If applying a global warming metric that allows to distinguish between impacts on marine, freshwater, and terrestrial ecosystems, property damage, and human health impacts, then the global QALY value from cell G90 should be replaced by the impact-specific QALY values in cells G7, G9, G13, G17, and G82, respectively.

For the French glass system, using the 2011 hybrid version of EXIOBASE (Merciai 2021) as database, the life cycle result vector for global warming per activity is obtained, of which the sum and contributions from the top 10 activities are shown in Table 3.

Table 3. Global warming impacts for 400 Mg glass in France

Activity	Global warming impact [QALY]	Percentages
Total	0,2292	
Manufacture of glass and glass products [FR]	0,1608	70,2
Extraction of natural gas ... [WM]	0,0054	2,4
Extraction of crude petroleum ... [WA]	0,0037	1,6
Production of electricity by gas [FR]	0,0033	1,4
Production of electricity by coal [FR]	0,0029	1,3
Extraction of crude petroleum ... [WM]	0,0028	1,2
Petroleum Refinery [FR]	0,0025	1,1
Wholesale trade ... [FR]	0,0017	0,7
Incineration of waste: Oil/Hazardous waste [FR]	0,0016	0,7
Extraction of crude petroleum ... [RU]	0,0012	0,5
All other activities	0,0433	18,9

For most other organisation-specific impacts, it may be relevant to apply location-specific characterisation factors. To calculate the conversion factors to QALY, the country-specific QALY values per impact category from Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)') can be applied.

Table 4 provides a list of organisation-specific impact categories, beyond global warming, for which data sources are reasonably available, sometimes even within LCA databases. Table 4 is sorted according to global importance. The data sources in Table 4 will in most cases allow the establishment of distribution keys that are better than a simple distribution of country-specific QALY values per impact category in proportion to the value added of each industry, as suggested for the impact categories listed in the next section (on estimating impacts for which data are not immediately available).

For the EXIOBASE (Merciai 2021), the addition of the distribution keys for the organisation-specific impact categories (beyond global warming) have not yet been done. For the French glass system, the impacts listed in Table 4 are therefore treated together with those of Table 5, as described in the next Section.

Table 4. Organisation-specific impacts, beyond global warming, for which data are reasonably available, sometimes already within LCA databases. Sorted by importance. For references, see Weidema (2021, 2022b). For country-specific QALY values, see Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)').

Impact category number	Impact category	Data sources for pressure indicators	World, total impact 2019 [million QALY]
H11	Health impacts, avoidable, harmful substance emissions	Emissions per substance, including indoor (occupational and household) emissions	137.50
H4 & H30	Undernutrition, impacts on health and cognitive skills, attributable to extreme underpay	See Chapter 5.5 of the data collection guideline for pressure indicators (Weidema 2021)	120.28
H16	Health impacts, avoidable, dietary risks	Nutrient density of qualifying and disqualifying nutrients in ingested or ingestible part of product and glycaemic index for carbohydrate content	64.52
H21	Health impacts, avoidable, unintentional injury	Incidences of injuries, and reductions from application of specific safety-enhancing technologies; Employee coverage of OSH management system and skills in injury prevention and first aid	50.47
N9	Terrestrial biomass and biodiversity, overexploitation	Area-time of land occupied; Emissions of ammonia, acid anhydrides, and particulates; Contraband seizure data for CITES listed species	29.86
H32	Impacts on cognitive skills, lead exposure	Emissions of lead, including indoor household	29.79
H2	Sub-clinical anxiety, threatening and traumatic traffic situations	Proxy indicator: Incidences of road injuries (GBD)	14.00
S13	Forced labour	Walk Free Foundation 2018	12.73
N5	Freshwater biomass and biodiversity, overexploitation	Live weight equivalent landings of aquatic wild fauna. Net reduction in volume of freshwater flow. Emissions of bioavailable phosphorous	7.65
N3	Marine biomass and biodiversity, overexploitation	Live weight equivalent landings of aquatic wild fauna. Dry mass of landings of aquatic wild flora. FAO Yearbook of Fishery and Aquaculture Statistics. Total N emissions to marine waters.	7.22
H14	Health impacts, avoidable, noise	Sound energy exposure; Incidences of peak sound pressure levels	4.51
H17	Health impacts, avoidable, inadequate physical exercise, occupational	Employee-specific weekly metabolic energy expenditure	3.05
S5	Distortionary subsidies, agriculture	OECD (2021)	2.71
N1	Sub-soil resource use	Extracted sub-soil resources. USGS Mineral Commodities Summaries.	2.53
S7	Distortionary subsidies, fossil fuels	FossilFuelSubsidyTracker.org	2.04
N7	Freshwater resources, untreated wastewater	UNESCO (2017)	0.35
M4	Property damage, air pollution	Emissions of acid anhydrides and particulates	0.30
N6	Freshwater resources, over-exploitation	Subsidies for irrigation and groundwater-extraction (default value: 0.05 USD/m3)	0.25
S8	Distortionary subsidies, renewables	Taylor (2020)	0.17
S6	Distortionary subsidies, fisheries	Sumaila et al. (2019)	0.15
S9	Distortionary subsidies, nuclear fuels	Taylor (2020)	0.10
S10	Distortionary subsidies, aluminium	OECD (2019) Table A A.2	0.07

Table 5. Organisation-specific impacts for which survey data are required. Sorted by importance. For references, see Weidema (2021, 2022b).

Impact category number	Impact category	Data sources for pressure indicators	World, total impact 2019 [million QALY]
S14	Inadequate working conditions	See Chapter 8.4 of the data collection guideline for pressure indicators (Weidema 2021)	**134.1**
H28	Insufficient development of skills, at work or at home	Working condition survey data on 'employee-years with self-reported inadequate conditions for workplace learning' and similar household survey data	**77.1**
H8	Health impacts, work-related psycho-socially caused	Working conditions surveys and monitoring, time use surveys, national legislation databases (e.g., World Bank Doing Business)	**56.7**
S16	Rent-seeking	Revenue of activities for which either there are no transparent documentation, reporting, and auditing procedures, an explicit anti-rent-seeking policy, a publicly announced fair wage policy and renouncement of net advantages obtained from differential treatment or distortionary taxes or subsidies; Revenue from products for which the producer holds more than a 50% market share; Revenue from access, occupation, extraction, or sale of natural assets or archaeological sites or artefacts, without documented approval from the affected indigenous population.	**28.6**
S3	Trade barriers	Value added of activities not covered by a publicly announced renouncement of net advantages obtained from differential treatment or distortionary taxes or subsidies. Tariff rates by product group and net positive Ad Valorem Equivalents of Non-Tariff Measures from Ghodsi et al. (2016).	**18.1**
H6	Health impacts, avoidable, clean water and sanitation, production-attributable	Skills in preventive practices with respect to infectious diseases; Deviations from hygienisation procedures at critical control points (HCCP)	**17.6**
H27	Inadequate access to social security	ILO (2017)	**11.0**
S11	Distortionary subsidies, transport	National estimates, when available. Global default value of 2.35% of GDP.	**9.0**
H20	Health impacts, avoidable, ergonomic risks, occupational	Work-time with self-reported work-related severe discomfort; Work-time involving ergonomic risk factors	**5.3**
I1	Tangible cultural heritage	Violation of indigenous people's rights; Inadequate procedural fairness in prioritisation of heritage conservation; Change in use of land or buildings without prior consultation of heritage conservation experts; Emissions of acid anhydrides and particulates; Tourism impact indicators	**4.9**
H15	Health impacts, avoidable, heat	Occupational heat stress; Changes to urban core area heat balance (albedo, evaporation, and heat emission)	**4.3**
M5	Property damage, amenity value	Hedonic pricing estimates of changes in real estate prices (Current default value: 0.18% of value added)	**3.5**
S1	Unfair commercial practices	Estimated value of transactional decisions made or foregone due to unfair commercial practices	**2.7**
S2	Tax avoidance	Value added of activities not covered by a publicly announced renouncement of net advantages obtained from differential treatment and from legal presence in countries having preferential corporate income tax rates. Default data from Table A2 of Cobham & Janský (2017).	**2.4**

2.6 Estimating impacts for which data are not immediately available

Table 5 lists impact categories that require survey data, typically at the organisational level, which implies that these data are typically not available in general databases. Table 5 is sorted according to global importance.

For unit processes where data are not available or for impact categories where characterisation factors are not immediately available or cannot be calculated within the limits of the budget of a specific LCA, default values can be applied, to avoid that the impact is set to zero. As default values, the country-specific QALY values per impact category from Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)') may be distributed over the industries in each country in proportion to their value added (for EXIOBASE proxied by 'Sum direct income by industry', row 38 in the above-referenced Excel file 'Social footprint update 2022_QALY 2019 by skill level and industry using Exiobase 2011 as economy', sheet 'VA_act and social footprint').

The poor data availability should not be seen as justifying an exclusion of these impact categories from further assessment, but rather as an incentive for specific data collection efforts in those countries and industries that from the available, poorly disaggregated data can be identified as hotspots.

For the French glass system, the above-described default values were applied for all organisation-specific impact categories, except global warming. The sums and contributions from the top 11 activities are shown in Table 6. This includes the top 9 activities for each of the two types of data availability from Table 4 and 5.

Table 6. Default distribution of contributions to organisation-specific impacts for 400 Mg glass in France

Activity	Organisation-specific impact categories for which data sources are reasonably available [QALY]	Depends on survey data [QALY]	Sum of organisation-specific impact categories, except global warming [QALY]
Sum	0,801	0,832	1,633
Manufacture of glass and glass products [FR]	0,098	0,178	0,276
Wholesale trade ... [FR]	0,048	0,087	0,135
Extraction of crude petroleum ... [WF]	0,046	0,023	0,069
Extraction of natural gas ... [WM]	0,032	0,027	0,059
Other business activities (74) [FR]	0,019	0,034	0,053
Extraction of crude petroleum ... [WA]	0,028	0,017	0,045
Extraction of crude petroleum ... [WM]	0,022	0,018	0,04
Supporting and auxiliary transport activities ... [FR]	0,009	0,017	0,026
Retail trade ... [FR]	0,009	0,017	0,026
Supporting and auxiliary transport activities ... [WF]	0,017	0,009	0,026
Other land transport [WF]	0,017	0,009	0,026
All other activities	0,456	0,396	0,852

Adding the sums from Table 2, 3 and 6 gives 3.924 + 0.229 + 1.633 = 5.786 QALYs of external costs. Adding the 2.520 QALY adverse effect of monetary re-distribution (see below Table 1) gives 8.306 QALY as the total QALY value for potentially avoidable losses for the functional unit.

Obtaining a total QALY value for the analysed functional unit is mainly relevant when comparing systems, to assess the more sustainable option, especially when also taking into account the uncertainty on the results, so that it will be possible to distinguish significant from insignificant differences. A systematic inclusion of uncertainty has not yet been possible for the current dataset.

3 Contribution analyses for LCA

Beyond comparing systems on their overall QALY score, it is often relevant to understand the contributions of specific impact pathways and their indicators. In this chapter, methods for contribution analysis are described.

3.1 Contributions per impact category

In Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheets '2019 QALYimpact', rows 6-80 and row 82), the total potentially avoidable loss of sustainable wellbeing, measured in QALY, are calculated from the contributions to 76 different impact categories. Thus, to see the contribution from each impact category, it is necessary to perform the procedures in Sections 2.4 – 2.6 for distributing the country-level impacts over the industries for each of the each of the 76 rows of both non-organisation-specific and organisation-specific impact categories, and to add each of the resulting vectors to the database **B** matrix before calculating the life cycle results. In the above-mentioned Excel file, columns E and F shows for each specific impact category whether it belongs to the group of non-organisation-specific impacts (column F; distribution procedure of Section 2.4) or to the group of organisation-specific impacts (column E, labelled 'attributable to specific activities'; distribution procedures of Sections 2.5 – 2.6).

For the French glass system, the sums for each impact category are calculated and the share of each impact category out of the overall QALY score for the French glass system are compared to the shares of each impact category out of the global average QALYs. The most important impact categories are shown in Table 7 together with the top contributing activity for each impact category.

Table 7. Contributions for the 15 most important impact categories for 400 Mg glass in France compared to global average normalised to the same value added. The delta value shows the relative better performance of 'Glass FR' compared to a global average product with the same value.

Impact category	Glass FR [QALY]	Global QALY	delta Glass FR [QALY]	Top contributing activity for Glass FR
S23 Participation restrictions	0,897	4,391	3,494	Retail trade ... [FR]
S24 Discrimination	0,66	3,229	2,569	Retail trade ... [FR]
H29 Insufficient development of skills, formal education system	0,529	2,337	1,808	Retail trade ... [FR]
S22 Inequality in wellbeing	0,462	2,261	1,799	Retail trade ... [FR]
S14 Inadequate working conditions	0,301	0,77	0,47	Manufacture of glass and glass products [FR]
I2 Underinvestment in intellectual infrastructure	0,211	1,035	0,824	Retail trade ... [FR]
H11 Health impacts, avoidable, harmful substance emissions	0,19	0,776	0,586	Manufacture of glass and glass products [FR]
S12 Labour market monopsony	0,18	0,188	0,008	Retail trade ... [FR]
H35 Health impacts, global warming ...	0,154	0,11	-0,044	Manufacture of glass and glass products [FR]
H28 Insufficient development of skills, at work or at home	0,136	0,438	0,302	Manufacture of glass and glass products [FR]
H34 Impacts on cognitive skills, child maltreatment	0,134	0,389	0,255	Retail trade ... [FR]
H8 Health impacts, work-related psycho-socially caused	0,127	0,326	0,198	Manufacture of glass and glass products [FR]
H4 ... avoidable, undernutrition, attributable to extreme underpay	0,125	0,451	0,326	Extraction of crude petroleum ... [WF]
H10 Health impacts, avoidable, drugs misuse and self-harm	0,119	0,322	0,203	Retail trade ... [FR]
H26 Restrictions on civil liberties	0,11	0,661	0,551	Retail trade ... [FR]
All other 61 impact categories	1,451	5,117	3,665	
Sum	5,786	22,801	17,014	

3.2 Contributions per asset type (Area of Protection) and safeguard subject

Using the exhaustive classification of the so-called capital models (Carney 1998, IIRC 2011), sustainable wellbeing can be attached to assets, that can be divided in natural, manufactured, human capabilities, social networks, and financial assets (see Table 7). Manufactured assets can further be divided in physical and intellectual.

In table 8, the value of each asset is furthermore connected to specific safeguard subjects, which can also be classified according to whether they represent an intrinsic or an instrumental value. Instrumental values

are means to an end and thus related to the concept of productive capital, i.e., they enable production of other valuable goods, as opposed to intrinsic values that are ends in themselves (hence intrinsic), i.e., they are related to the concepts of activity benefits, final consumption, or enjoyment.

Table 8. Classification of assets having intrinsic enjoyment value and/or instrumental capital value. From Weidema (2019).

Assets considered: Ends/means values:	**Natural**	**Manufactured** Physical	Intellectual	**Human capabilities**	**Social networks**	**Financial**
Ends: Intrinsic value (for enjoyment / final consumption)	Natural heritage (incl. biodiversity)	Physical consumption goods; Physical cultural heritage	Intellectual consumption goods; Intellectual heritage	Time; Autonomy; Health; Skills	Participation & influence; Safety & security; Intangible cultural heritage	-
Means: Instrumental value (for production)	Natural resources (incl. ecosystems)	Manufactured physical capital (biotic & abiotic)	Intellectual capital	Human capital	Social network capital	Financial capital

Each of the 76 impact categories impact a specific asset type (Areas of protection), which is reflected in its impact category number in Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheets '2019 QALYimpact', column A):

Areas of Protection / Asset type	**Impact category numbers**
Natural assets	N1 to N9
Manufactured physical assets	M1 to M6
Intellectual assets	I1 and I2
Human capabilities	H1 to H35
Social networks	S1 to S24

The total impact per asset type (Area of Protection) can therefore be obtained by summing the impacts for each of the above 5 groups of impact categories.

Note that financial capital measured at the global societal level is zero, since in any financial transaction, the change in debit of the capital users counterbalances the change in credit of capital owners, so that financial capital are not impacted as such by any impact category, while capital market failures caused by insufficient social network capital are particularly prominent as a causal factor for labour market monopsony (impact category S12) and in the underinvestment of education (impact category H29), physical infrastructure, research, innovation, technology development (impact categories M1 and I2), and disaster damage prevention (impact categories M2 and H9).

For the French glass system, the sum of impacts for each asset type are shown in Table 9 and compared to relative shares of each impact category in the global QALYs.

Table 9. Contributions to the five asset types for 400 Mg glass in France, and the relative shares compared to a global average product.

	Impacts 400 Mg Glass FR [QALY]	Glass FR impact shares	Global impact shares	Percentage difference to global
Natural assets	0,173	3,0%	1,4%	209%
Manufactured physical assets	0,033	0,6%	0,4%	158%
Intellectual assets	0,222	3,8%	4,7%	82%
Human capabilities	2,375	41,0%	39,1%	105%
Social networks	2,984	51,6%	54,5%	95%
Sum	5,786	100,0%	100,0%	

The distinction between value types (instrumental production values vs. intrinsic activity benefits) is summarised in Table 5 of Weidema (2022b). In this table, some impact categories are grouped, but the relative distribution between the two types of value is the same within each group of impact categories, with the exception of:

- 'Health impacts', which in Table 5 of Weidema (2022b) include the two impact categories H1 and H2 for 'Sub-clinical anxiety' belonging fully to intrinsic activity benefits, while the general distribution factor for 'Health impacts' is otherwise 14.3% to instrumental and 85.7% to intrinsic.
- 'Social network impacts, not elsewhere classified', which covers impact categories S21-S24 ('Unemployment, intrinsic value', 'Inequality in wellbeing', 'Participation restrictions' and 'Discrimination'), all 100% impacts on intrinsic values, and impact category I2 ('Underinvestment in intellectual infrastructure'), which is fully an impact on instrumental values.

With this information, it is possible to allocate each impact category between instrumental production values and intrinsic activity benefits, and thus to obtain a sum value for each of these value types, as well as splitting this on the impacts on each asset type.

For the French glass system, the described split between instrumental production values and intrinsic activity benefits has been performed for each impact category. The resulting sums are presented in Table 10.

Table 10. Contributions to the five asset types for 400 Mg glass in France, divided on intrinsic and instrumental safeguard subjects

	Natural assets	Manufactured physical assets	Intellectual assets	Human capabilities	Social networks	Sum
Intrinsic	0,152	0,023	0,01	1,465	2,444	4,094
Instrumental	0,021	0,01	0,211	0,91	0,54	1,692
Sum	0,173	0,033	0,221	2,375	2,984	5,786

For each asset type (Area of Protection) in Table 8, there is only one instrumental safeguard subject, while there is often more than one intrinsic safeguard subject:

- For manufactured physical assets, a distinction is made between the instrumental physical capital (with impact categories M1 to M4 of underinvestment and property damage) and the intrinsic safeguard subject 'Physical consumption goods' that can be affected by theft and burglary (impact category M6) or loss of amenity values (impact category M5). Physical (tangible) cultural heritage (historical buildings, artefacts, cultural landscapes, and archaeological sites and remains) also belongs to manufactured physical assets, although the impact category for 'Tangible cultural

heritage' has been labelled I1, indicating the close relationship to intellectual manufactured capital, for which there are no separate impact categories (i.e., no separate damage is foreseen on the safeguard subjects of intellectual consumption goods and intellectual heritage, which is that part of the intangible cultural heritage that is described and preserved in physical media, such as libraries, and thus can be preserved independently of the original social practices).

- For human capabilities, four intrinsic safeguard subjects are distinguished: (leisure) time, autonomy, health, and skills. While leisure time is of unquestionable value, no specific impact categories have been listed for loss of leisure time or quality of leisure time (this may indeed be an important omission that should be considered in future updates). Personal autonomy is the safeguard subject for the impact categories H23 and H24 ('no access to contraception', 'unwanted pregnancies') and H26 and H27 ('restrictions on civil liberties', 'inadequate access to social security'). Health is the safeguard subject for the impact categories H1-H22, H25, and H35, while Skills is the safeguard subject for impact categories H28-H34. Note that both health and skills also impact on the instrumental human capital.
- For social network assets, three intrinsic safeguard subjects are distinguished: 'Participation & influence', 'Safety & security', and 'Intangible cultural heritage'. Participation & influence is the safeguard subject for intrinsic value loss from impact categories S13-S16 ('forced labour', 'inadequate working conditions', and 'foregone benefits of migration', all of which also have impacts on the instrumental social network capital) and S20-S23 ('Incarceration', 'Unemployment, intrinsic value', 'Inequality in wellbeing', and 'Participation restrictions'). Safety & security is the safeguard subject for impact categories S17-S19 ('Current conflicts', 'Intimate partner violence', and 'Violence against children', all of which also have impacts on the instrumental social network capital). 'Intangible cultural heritage' is the safeguard subject for impact category S24 ('Discrimination').

3.3 Contributions per SDG topic

The 17 UN Sustainable Development Goals (SDGs) provide a comprehensive set of policy areas and indicators for sustainable development from a government perspective. However, the official set of 244 SDG indicators does not provide a consistent framework for assessing the contribution to sustainable development of specific activities or products. For this purpose, a restructuring of the indicators is required, to create an impact pathway framework without overlaps and gaps. In Weidema (2020) the impact pathways descriptions have been structured in 17 chapters, largely mirroring the 17 SDGs, as shown in Table 11. A detailed reasoning for the restructuring is provided in Box 1.

Table 11. Official SDGs and the restructured topics for consistent impact pathway descriptions. From Weidema (2020).

Official SDGs (short form)	SDG impact pathway topics (chapters)
No poverty	Poverty
Zero hunger	Undernutrition
Ensure healthy lives	Healthy lives
Quality education	Education and learning
Gender equality	Unequal opportunities
Clean water and sanitation	Clean water supply and sanitation
Affordable and clean energy	Human migration
Decent work and economic growth	Decent working conditions
Industry, innovation and infrastructure	Physical infrastructure
Reduced inequality	Income and assets inequality
Sustainable cities and communities	Cultural heritage
Responsible consumption and production	Sustainable consumption and production
Climate action	Global warming
Life below water	Marine ecosystems
Life on land	Terrestrial and freshwater ecosystems
Peace and strong institutions	Safety and security
Partnerships to achieve the goals	Social infrastructure and participation

Box 1. The restructured SDG impact pathway topics, with rationales for the renaming or restructuring From Weidema (2020).

1. **Poverty:** "End poverty in all its forms everywhere" says SDG 1. From an impact pathway perspective, the topic of poverty shares impact pathways with those of SDG 10 that measure inequality in general, and is then concerned with those levels of inequality that leads to absolute poverty when not counteracted by specific interventions to prevent and reduce poverty.
2. **Undernutrition:** "End hunger" is the short form of SDG 2. The full title of SDG 2 also includes "promote sustainable agriculture" that we treat with Topic 5 ("Unequal opportunities"), 10 ("Income and assets inequality") and 12 ("Sustainable consumption and production"). One of the targets of SDG 2 also addresses overnutrition that we treat with Topic 3 "Healthy lives".
3. **Healthy lives:** "Ensure healthy lives" says SDG 3. Avoidable health impacts are comprehensively quantified in the "Global Burden of Disease" studies. Some of these are separately covered under other SDGs and Topics, such as diseases related to undernutrition (Topic 2), clean water supply, sanitation, and infectious diseases (Topic 6), occupational health (Topic 8), and violence (Topic 16). The impact pathway descriptions in Chapter 3 therefore cover the avoidable diseases not covered elsewhere.
4. **Education and learning:** "Quality education" is the short form of SDG 4. Education is the production of skills through an intentional, organised, and structured human activity with defined learning objectives. Skills may also be acquired through informal or non-formal learning.
5. **Unequal opportunities:** SDG 5 is formulated as "Achieve gender equality and empower all women and girls". The targets address both discrimination and violence against women and girls. To distinguish between these two aspects, we treat violence more generally in Topic 16 on "Safety and security" and limit the impact pathway description here to non-violent forms of discrimination. We include all aspects of unequal opportunities, irrespective of whether the discrimination is based on gender or other personal characteristics.
6. **Clean water supply and sanitation:** SDG 6 is formulated as "Ensure availability and sustainable management of water and sanitation for all". We treat the topics addressed by the targets under two different Topics: Topic 6 covers universal and equitable provision of clean water supply and sanitation, as well as infectious diseases in general, while aspects of ambient water quality and efficient use of water are covered with Topic 15 on terrestrial and freshwater ecosystems.
7. **Human migration:** SDG 7 is dedicated to ensuring "access to affordable, reliable, sustainable and modern energy for all". However, energy supply is just one out of many product groups, all of which share fundamental issues related to contributing to health impacts (Topic 3), physical infrastructure (Topic 9), and impacts on global warming (Topic 13). None of the issues addressed by the SDG 7 targets are issues that are specific to energy, and a separate impact pathway for energy use would thus duplicate what is covered more generally for all products by the impact pathways of the other Topics. Instead, we re-use the number 7 for "Human migration" because this issue, which is covered by a few targets under SDG 10 ("Reduce inequality within and among countries"), merits a treatment separate from that of income and assets inequality.
8. **Decent working conditions:** The short form of SDG 8 is "Decent work and economic growth". To distinguish between these two aspects, we treat economic growth with Topic 4 (education) and inequality with Topics 5 and 10, and limit Topic 8 to cover the four strategic objectives of the ILO decent work agenda. Occupational health and safety issues are covered separately with Topic 3.
9. **Physical infrastructure:** SDG 9 is formulated as "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". Here, we focus on the first part, the physical infrastructure, while the remaining aspects are captured by Topic 5 ("inclusive") and Topics 10 and 13 ("sustainable industrialisation and foster innovation"). Conservation aspects of physical manufactured assets are dealt with by Topic 11 ("Heritage").
10. **Income and assets inequality:** "Reduce inequality" says SDG 10. The targets address a number of different topics: Income and assets inequality (which we treat here as Topic 10), aspects of equal opportunity (Topic 5), migration (Topic 7), and representation and voice of developing nations (covered by Topic 17).
11. **Cultural heritage:** SDG 11 is formulated as "Make cities and human settlements inclusive, safe, resilient and sustainable". The targets address a number of different topics: Cultural heritage (Topic 11), air quality (of which health impacts are covered by Topic 3), aspects of equal access (Topic 5), physical infrastructure and urbanisation (Topic 9), safety and security (Topic 16), and inclusive and participatory planning and management (covered by Topic 17).
12. **Sustainable consumption and production:** SDG 12 is formulated as "Ensure sustainable consumption and production patterns". SDG 12 provides an overarching perspective on the other SDG topics. The contributions to SDG 12 can be calculated on the basis of the indicators already included in the impact pathways of the other Topics. Thus, no new impact pathways are introduced with Topic 12 in addition to the ones of the other Topics.
13. **Global warming:** SDG 13 is formulated as "Take urgent action to combat climate change and its impacts" but the focus of the targets is on national policies, strategies, and planning, strengthening "resilience and adaptive capacity to climate-related hazards and natural disasters" (covered with Topic 16) and improving human and institutional capacity and support for developing countries (covered with Topic 10 on income and assets inequality). The impact pathways of Topic 13 instead covers the actual global temperature increase from human activities that either have or regulate greenhouse gas emissions or capture and store atmospheric carbon.
14. **Marine ecosystems:** SDG 14 is formulated as "Conserve and sustainably use the oceans, seas and marine resources for sustainable development". The targets address a number of different topics: Impacts on marine ecosystem (covered here as Topic 14), transfer of knowledge on and benefits from marine resources (covered with Topic 10), and equal market access for small-scale artisanal fishers (covered by Topics 5 and 8).
15. **Terrestrial and freshwater ecosystems:** Although the short form of SDG 15 is "Life on land", target 15.1 makes it clear that this goal includes also inland freshwater ecosystems. Besides the impacts on terrestrial and freshwater ecosystems, some targets also reference the Nagoya Protocol on genetic resources, and address poaching and trafficking of protected species, both issues we covered with Topic 5.
16. **Safety and security:** "Peace, justice and strong institutions" is the short form of SDG 16. We distinguish between "Peace" (or more precisely "Safety and security" as name of Topic 16), issues related to rent seeking, rule-of-law, and strong institutions (covered by Topic 5), and issues of participation (Topic 17).
17. **Social infrastructure and participation:** The short form of SDG 17 is "Partnerships for the goals" and covers a large number of targets and indicators related to capacity-building, sharing technology, financial resource mobilisation, and networking partnerships (covered with Topic 10), especially for developing countries and involving non-discriminatory trade and macroeconomic stability (covered with Topic 5), and respecting local policy spaces and leadership (covered by Topic 11). We re-use the number 17 for the closely related topic of "Social infrastructure and participation", which is an important policy area, not explicitly covered by any SDG, but nevertheless addressed in several SDG targets, such as 10.2, 11.3, and 16.7.

For each of the 76 impact categories, the relevant SDG impact pathway topic(s) are shown in Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheets '2019 QALYimpact', column C labelled 'Impact pathway chapters'). To avoid double-counting, note especially that SDG topics 1 and 12 should not be included in the calculation. A more detailed description of the linking is found in Chapter 5 of Weidema (2022b).

With this information, it is possible to group the results from the 76 impact categories according to the 17 SDG impact pathway Topics.

For the French glass system, the described grouping to SDG impact pathway Topics has been performed for each impact category. The resulting sums are presented in Table 12 and compared to the values for an average product.

Table 12. Contributions to the 17 SDG impact pathway Topics from 400 Mg glass in France, with comparison to global impact shares.

	Impacts 400 Mg Glass FR [QALY]	Glass FR impact shares	Global impact shares	Percentage difference to GLO average
SDG 2 Topic	0,207	3,58%	3,54%	101%
SDG 3 Topic	0,678	11,72%	11,10%	106%
SDG 4 Topic	0,665	11,50%	12,17%	94%
SDG 5 Topic	1,159	20,03%	23,03%	87%
SDG 6 Topic	0,053	0,92%	1,15%	80%
SDG 7 Topic	0,044	0,76%	0,18%	416%
SDG 8 Topic	0,667	11,53%	6,47%	178%
SDG 9 Topic	0,006	0,10%	0,21%	49%
SDG 10 Topic	0,673	11,63%	14,45%	81%
SDG 11 Topic	0,012	0,21%	0,13%	159%
SDG 13 Topic	0,229	3,96%	0,72%	551%
SDG 14 Topic	0,015	0,26%	0,18%	143%
SDG 15 Topic	0,094	1,62%	1,03%	158%
SDG 16 Topic	0,259	4,48%	4,85%	92%
SDG 17 Topic	1,024	17,70%	20,78%	85%
Sum	5,785	100,00%	100,00%	

3.4 Contributions per official SDG

The full links between the 17 impact pathway Topics and each of the official 244 SDG indicators is provided in Weidema (2022a; Excel file 'Life Cycle SDG Assessment_Links to SDG indicators.xlsx', sheet 'Links to SDG indicators'). In this Excel file, it is possible to filter for each impact pathway Topic (see columns G to L), and thus to see the official SDG indicators covered under each Topic, and vice versa, to filter for each official SDG or Target, to see which impact pathway Topic(s) contribute to each SDG or Target.

However, within each impact pathway Topic, there are a number of distinct impact pathways, each with its specific indicators and characterisation factors. Currently, not all impact pathways are fully described and individually quantified for each of 76 impact categories. The current state of the art for each impact pathway Topic is provided on the individual sheets (named 'Impact pathway chapter [No.]') of Weidema (2022a; Excel file 'Life Cycle SDG Assessment_Links to SDG indicators.xlsx').

Since each official SDG indicator will typically only be linked to specific impact pathways within each impact pathway Topic, the current incomplete state of the impact pathway descriptions implies that while the

QALY contributions to each of the 76 impact categories have been estimated (see Section 3.1) and each of the 76 impact categories have been related to a specific SDG impact pathway Topic (see Section 3.3), it is still not possible for all impact pathway Topics to provide an unambiguous link of the QALY contributions of each impact category to each specific impact pathway, and thus to unambiguously quantify the QALY contribution to each specific official SD indicator, target, or goal.

Nevertheless, for some SDG topics, the current impact pathway descriptions are already sufficient for a quantification of contributions to the official SD indicators, targets, or goals, which can be illustrated by a few examples:

- SDG 2: Targets 2.1 and 2.2 lie on the same impact pathway of 'Child and maternal undernutrition' for which the data sources for the contribution are already provided by impact categories H3-H5 and H30-H31 (see Weidema 2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)'). Yet, SDG indicator 2.2.2 also includes overweight, which is included in the impact category H16 (dietary risks) and can be distinguished from the same data source. However, the QALY contributions to the remaining official SDG 2 Targets cannot currently be quantified.
- SDG 4: Impact categories H28 and H29 can be fully ascribed to this SDG. However, the share of the QALY contributions for each Target cannot currently be quantified. In addition, SDG Targets 4.5 and 4.a have contributions from other impact categories that cannot currently be disaggregated per impact pathway.

3.5 Contributions per pressure category (triple bottom line)

The triple-bottom-line concept (Kraaijenbrink 2019) is a way to divide impacts according to three kinds of pressure indicators: economic, ecosystem, and social. The same division has been made in the data collection guideline for pressure indicators (Weidema 2021), where chapter 5 covers the economic pressure indicators, chapter 6 and 7 cover the ecosystem pressure indicators (resource and emissions indicators, respectively), and chapter 8 cover the social pressure categories (mainly related to occupational pressures). The additional pressure categories for specific types of organisations (Weidema 2021d, Chapter 9) can likewise be grouped as economic, ecosystem, or social.

The 76 impact categories can relatively easily be grouped according to the triple-bottom-line type of pressure indicator. All the non-organisation-specific impact categories are ultimately caused by insufficient funding (see Section 2.4), i.e., economic pressure indicators. As already mentioned in Section 3.1, the distinction between non-organisation-specific impact categories and organisation-specific impact categories (impacts attributable to specific activities) has already been made in Weidema (2022a; Excel file 'Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021)', sheets '2019 QALYimpact', columns E and F). It is thus straightforward to identify and obtain the sum results for the non-organisation-specific impact categories.

In addition, some of the organisation-specific impacts are also related to economic pressure indicators, see Table 13.

The remaining organisation-specific impacts can be related to either ecosystem or social pressure indicators, as detailed in Table 14.

Table 13. Organisation-specific impact categories related to economic pressure indicators.

H4	Health impacts, avoidable, undernutrition, attributable to extreme underpay (Section 5.5 of Weidema 2021)
H27	Inadequate access to social security (Section 5.5 of Weidema 2021)
H30part	Impacts on cognitive skills, undernutrition, attributable to extreme underpay (99.72%; rest is Social, see Table 15)
S1	Unfair commercial practices (Section 5.6 of Weidema 2021)
S2	Tax avoidance*
S3	Trade barriers*
S5	Distortionary subsidies, agriculture*
S6	Distortionary subsidies, fisheries*
S7	Distortionary subsidies, fossil fuels*
S8	Distortionary subsidies, renewables*
S9	Distortionary subsidies, nuclear fuels*
S10	Distortionary subsidies, aluminium*
S11	Distortionary subsidies, transport*
S16	Rent-seeking*

* (Section 5.7d of Weidema 2021)

Table 14. Organisation-specific impact categories according to either Ecosystem or Social pressure indicators.

N1	Sub-soil ressource use	Ecosystem
N2	Marine biomass and biodiversity, global warming	Ecosystem
N3	Marine biomass and biodiversity, overexploitation	Ecosystem
N4	Freshwater biomass and biodiversity, global warming	Ecosystem
N5	Freshwater biomass and biodiversity, overexploitation	Ecosystem
N6	Freshwater resources, overexploitation	Ecosystem
N7	Freshwater resources, untreated waste water	Ecosystem
N8	Terrestrial biomass and biodiversity, global warming	Ecosystem
N9	Terrestrial biomass and biodiversity, overexploitation	Ecosystem
M3	Property damage, due to global warming	Ecosystem
M4	Property damage, air pollution	Ecosystem
M5	Property damage, amenity value	Ecosystem
I1	Tangible cultural heritage	Ecosystem
H2	Sub-clinical anxiety, threthening and traumatic traffic situations	Social
H3	Health impacts, avoidable, undernutrition, attributable to working conditions	Social
H6	Health impacts, avoidable, clean water and sanitation, production-attributable	32.4% Ecosystem (HCCP); 67.6% Social (skills in preventive practice)
H8	Health impacts, work-related psycho-socially caused	Social
H11	Health impacts, avoidable, harmful substance emissions	Ecosystem
H12	Health impacts, avoidable, ultraviolet radiation exposure	Ecosystem
H13	Health impacts, avoidable, ionising radiation exposure	Ecosystem
H14	Health impacts, avoidable, noise	Ecosystem
H15	Health impacts, avoidable, heat	Ecosystem
H16	Health impacts, avoidable, dietary risks	Ecosystem
H17	Health impacts, avoidable, inadequate physical exercise, occupational	Social
H20	Health impacts, avoidable, ergonomic risks, occupational	Social
H21	Health impacts, avoidable, unintentional injury	Social
H28	Insufficient development of skills, at work or at home	Social
H30part	Impacts on cognitive skills, undernutrition, attributable to working conditions	Social (rest is economic, see Tbl.14)
H32	Impacts on cognitive skills, lead exposure	Ecosystem
S13	Forced labour	Social
S14	Inadequate working conditions	Social
H35	Health impacts, global warming (partly increases in future impacts)	Ecosystem

For the French glass system, the described grouping to triple-bottom-line type of pressure indicators has been performed for each impact category. The resulting sums are presented in Table 15 and compared to the values for an average product.

Table 15. Contributions from the triple bottom line pressure indicators from 400 Mg glass in France.

	Impacts 400 Mg Glass FR [QALY]	Glass FR impact shares	Global impact shares	Percentage difference to GLO
Economic	4,322	74,7%	82,6%	90%
Ecosystem	0,724	12,5%	8,3%	151%
Social	0,741	12,8%	9,1%	140%
Sum	5,787	100,0%	100,0%	

References

Carney D. (ed.) (1998). Sustainable Rural Livelihoods: What contribution can we make? London: Department for International Development.

Helliwell J F, Layard R, Sachs J D, De Neve J-E. (Eds.) (2020). World Happiness Report 2020. New York: Sustainable Development Solutions Network.

Helliwell J F, Layard R, Sachs J D, De Neve J-E., Aknin L B, Wang S. (Eds.) (2021). World Happiness Report 2021. New York: Sustainable Development Solutions Network. Data file: https://happiness-report.s3.amazonaws.com/2021/DataPanelWHR2021C2.xls

IIRC. (2011). Towards Integrated Reporting. Communicating Value in the 21st Century. London: International Integrated Reporting Council.

Juster F T, Courant P N, Dow G K. (1981). A theoretical framework for the measurement of well-being. Review of Income and Wealth 27(1):1-32.

Kraaijenbrink J. (2019). What the 3Ps of the triple bottom line really mean. Forbes. Accessible at https://www.forbes.com/sites/jeroenkraaijenbrink/2019/12/10/what-the-3ps-of-the-triple-bottom-line-really-mean/

Lambert P J. (2001). The distribution and redistribution of income. Manchester University Press.

Layard R, Nickell S, Mayraz G. (2008). The marginal utility of income. Journal of Public Economics 92:1846–1857.

Merciai S (2021). Practical guide to the EXIOBASE hybrid version. Aalborg: 2.-0 LCA consultants. Version 3_3_18. Accessible at https://zenodo.org/record/7244919#.Y9ZzCezntJU

Moreau V, Weidema B P. (2015). The computational structure of environmental life cycle costing. International Journal of Life Cycle Assessment 20(10):1359-1363.

Weidema B P. (2006). The integration of economic and social aspects in life cycle impact assessment. International Journal of Life Cycle Assessment 11(1):89-96. https://doi.org/10.1065/lca2006.04.016

Weidema B P. (2017). Short procedural guideline to identify the functional unit for a product environmental footprint and to delimit the scope of product categories. 2.-0 LCA consultants, report to the Nordic Council of Ministers. https://lca-net.com/p/2527

Weidema B P. (2018). The social footprint—a practical approach to comprehensive and consistent social LCA. International Journal of Life Cycle Assessment 23(3):700-709.

Weidema B P. (2019). Assessing socio-economic impacts of agriculture. Chapter 8 in Weidema B P (ed.): Assessing the environmental impact of agriculture. Burleigh Dodds Science Publishing, Cambridge, UK.

Weidema B P. (2020). An exhaustive quantitative indicator and impact pathway framework for sustainable development. Interim report for the 2.-0 SDG Club. Aalborg: 2.-0 LCA consultants.

Weidema B P. (2021). Data collection guideline for pressure indicators for LCSA. Aalborg: 2.-0 LCA consultants. https://lca-net.com/p/4635

Weidema B P. (2022a). Life Cycle SDG Assessment. Aalborg: 2.-0 LCA consultants. https://lca-net.com/p/4640

Weidema B P. (2022b). Relative importance of sustainability impact pathways – A first rough assessment. Aalborg: 2.-0 LCA consultants. https://lca-net.com/p/4638

Weidema B P, Schmidt J. (2018). The social footprint: Linking the global wellbeing and productivity gap to specific human production and consumption activities. Aalborg: 2.-0 LCA consultants.