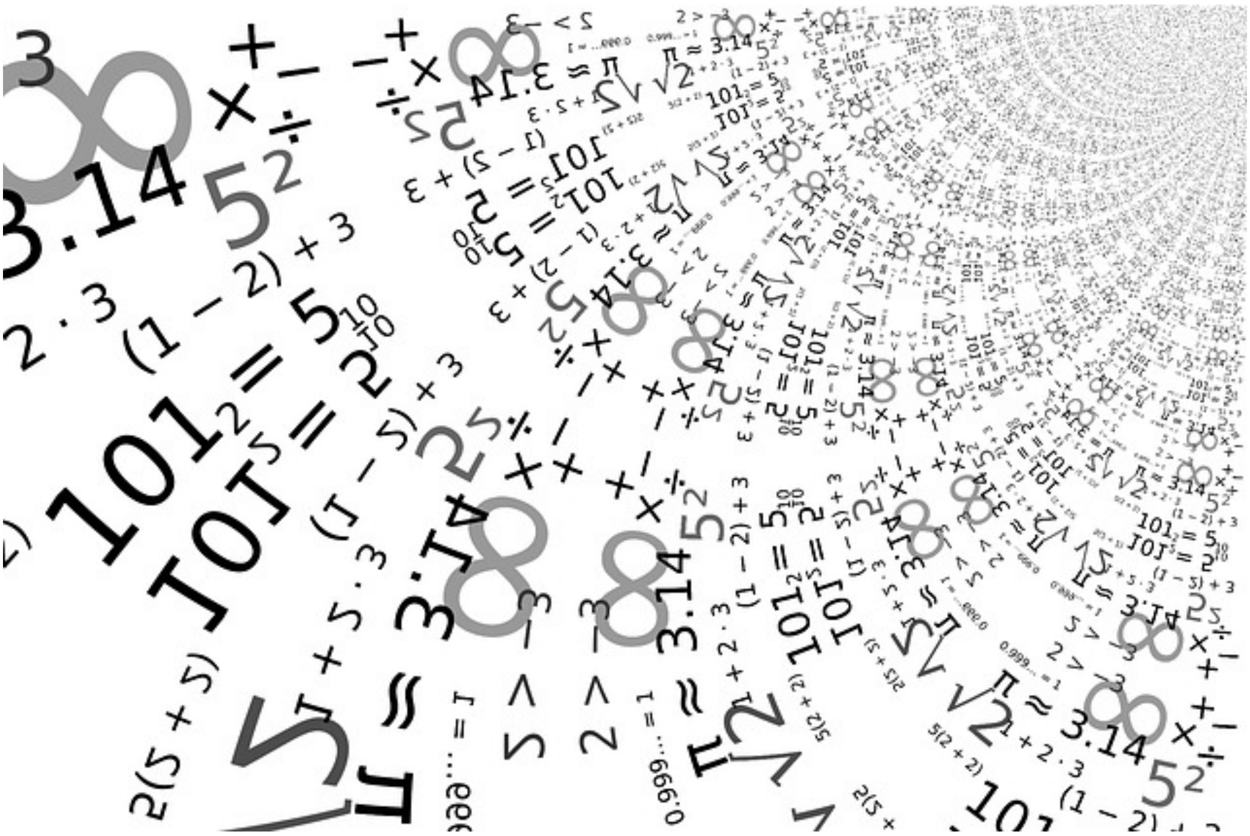

Relative importance of sustainability impact pathways
– *A first rough assessment*

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Preface

This report is one out of three that provide guidance on how to perform Life Cycle based Sustainability Assessment (LCSA) including all indicators of the UN Sustainable Development Goals (SDG) framework. The three reports are prepared by Bo P. Weidema for the 2.-0 SDG Club and the UNEP Life Cycle Initiative as part of the project “Linking the UN Sustainable Development Goals to life cycle impact pathway frameworks”.

The three reports are:

- **“An exhaustive quantitative indicator and impact pathway framework for sustainable development”** that contains an introduction and 17 chapters, each of which describe the impact pathways from changes in human activities via one or more of the 17 UN SDGs, further to a single endpoint measure of sustainable wellbeing (“Utility”) expressed in Quality-Adjusted person-Life-Years (and potentially in monetary units to be integrated with internal and supply-chain costing data). Each SDG target and indicator is placed within the quantitative framework, showing its role in the overall impact pathway framework. [At the current state of the project, this report exist only as a data file (‘Life Cycle SDG Assessment_Links to SDG indicators.xlsx’) that summarises the current state of the framework, and as an unpublished draft manuscript, still missing many of the midpoint indicators, characterisation factors, and detailed pressure indicators for chapters 7, 9, 12, 13, 14, 16, and 17.]
- **“Data collection guideline for pressure indicators for Life Cycle based Sustainability Assessment”** that covers the specific issues of each pressure category indicator (in LCA parlance called inventory indicators) in the above framework. The pressure category indicators are organised in groups, covering the triple bottom line of economic, ecosystem (resources and emissions), and social (mainly occupational) indicators that are relevant for data collection in the foreground system, i.e., the activities that are under direct control of a decision maker.
- **“Relative importance of sustainability impact pathways – A first rough assessment”** (the report at hand) provides guidance to focus the data collection and the development of further precision and accuracy of indicators and characterisation factors (linking the quantified impacts to their quantified causes) on the impact pathways that are of particularly high relative importance. This top-down assessment of importance is done by using Quality-Adjusted person-Life-Year (QALY) as a unit for sustainable wellbeing, informed by the annual UN measures of subjective wellbeing, and using the exhaustive classification of the so-called capital models as ‘Safeguard subjects’ to provide a structured and exhaustive account of the current impacts (estimated for year 2019) on each of the ‘Areas of Protection’, covering both instrumental values (productivity, value added, or income) and the intrinsic values of natural and manufactured assets, human capabilities, and social networks.

By this combination, the Life Cycle based Sustainability Assessment takes advantage of integrating the triple bottom line approach (for pressure indicators at the organisational level), the capital approaches (as ‘Areas of protection’ for an exhaustive account of impacts), and the 17 SDGs (as an exhaustive policy framework), to provide a fully quantitative impact pathway framework with a single endpoint measure of sustainable wellbeing.

Additionally, a datafile **‘Life Cycle SDG Assessment impact data for 2019 (Social footprint methodology 2021).xlsx’** is available with impact data expressed in QALY for 76 impact categories for 163 countries and 1 residual Rest-of-World as well as a document with ‘**Instructions for software implementation**’ for use in LCA.

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Contents

1 Why do we need estimates of the relative importance of impact pathways?

For a specific sustainability assessment, not all indicators, impact pathways, or characterisation factors will be of equal relevance, and it will therefore be justified to reduce the assessment effort to those that can be expected to be of importance. However, to provide a credible justification for exclusion of specific indicators, impact pathways, or characterisation factors in a specific context, it is useful to be able to refer to a quantitative estimate the relative importance of the different impact pathways. Although such estimates should ideally consider the specific context of the assessment, the aggregate or average importance provides a reasonable starting point for more specific estimates.

While the tentative description of the impact pathways for sustainable development and their quantitative indicators in Weidema (2020) has made it plausible that all such impact pathways can be quantified, the detailed quantification is still an outstanding task. To focus the collection of data and the development of further precision and accuracy of indicators and characterisation factors (linking the quantified impacts to their quantified causes), estimates of the relative importance of these impact pathways are needed.

2 Estimating the overall sustainability gap

Since the single-score endpoint for all sustainable development impact pathways is the impact category 'Sustainable wellbeing', representing equity-weighted utility (wellbeing) loss integrated over time, this endpoint appears a logical place to initiate an assessment of importance. If the overall loss of sustainable wellbeing could be estimated, the amount to be distributed over the different causal pathways would also be known. Quality-Adjusted person-Life-Year (QALY) has been suggested as a unit for 'Sustainable wellbeing' 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), while the latter would then also include the non-health aspects of wellbeing (Weidema 2003).

While 'Sustainable wellbeing' can be expressed in the single common unit of QALYs, it is still made up of many different aspects that each have specific intrinsic value. Using the exhaustive classification of the so-called capital models (Carney 1998, IIRC 2011), these intrinsic values are attached to assets that can be divided in natural, manufactured, human capabilities, social networks, and financial assets (see Table 1).

Table 1. Classification of assets having intrinsic enjoyment value and/or instrumental capital value. From Weidema (2019).

Objects considered: / Ends/means values:	**Natural**	**Manufactured** Physical	**Manufactured** 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

'Sustainable wellbeing' can thus be described in terms of the objects that have intrinsic value for enjoyment or final consumption; see the green middle row Table 1. However, these objects of intrinsic value are to some extent dependent on the existence of sufficient amounts of resources or capital that serve to produce or maintain the objects of intrinsic value. These resources or capitals are therefore said to have instrumental value; see the blue bottom row in Table 1. In the context of Life Cycle Assessment, the different asset classes in Table 1 are called 'Safeguard subjects' and each specific asset type constitutes an 'Area of Protection' (Jolliet et al. 2003).

The instrumental values have the advantage of being largely tradable on markets and therefore providing clear expressions of their relative values. In some cases, the market values are influenced by externalities and therefore have to be corrected before they can be used to express the social value of the resources. Social network capital is different from the other forms of resources in that it cannot be privately owned, bought, or sold, and like a public good it does not diminish when consumed. However, since a social network asset can still be built and maintained, consumed, degraded, and depleted, its value can be determined in parallel to that of the other capitals, as its ability to increase productivity and reduce transaction costs. Finally, financial capital plays the role of facilitator, allowing the other capitals to be lent from the capital owners to those capital users who currently can put the capitals to their most productive uses. Since the debit and credit of financial capital counterbalances, the amount of financial capital at the global societal level is zero. However, its distribution over different actors at different points in time is nevertheless essential for understanding developments in economic activity and inequality.

Some objects with intrinsic value are also sold on markets, especially consumption goods, but the majority of objects with intrinsic value are not. To estimate the relative value of such non-traded objects, it is necessary to resort to choice experiments, in which representative samples of the affected population respond to hypothetical trade-offs between different objects of intrinsic and/or instrumental value. The trade-offs can be arranged with inclusion of objects with monetary value or as time trade-offs, where amounts of labour or leisure time can be traded for increases in the otherwise non-tradable objects. Knowing the total monetary assets or income or the total time available to the respondents allows to express the value of the non-tradable objects in relation to these absolute totals per person, and thus to be aggregated across individuals.

Chapter 3 provides estimates of current annual impacts on wellbeing related to the different asset types. While the overall impacts on 'Sustainable wellbeing' and intrinsic values can be directly expressed in the unit of QALY, impacts on instrumental values are most naturally expressed as the loss of productivity or income, measured in monetary units. Thus, in Sections 3.1 to 3.6, the different impacts on instrumental values are estimated relative to the current GDP and expressed in USD_{2019}. In Sections 3.7 to 3.11, the different impacts on intrinsic values are estimated and expressed mainly in QALY. Chapter 4 summarises the impacts on both instrumental and intrinsic values in QALYs, which requires a conversion rate between USD_{2019} and QALY, based on an understanding of how instrumental values affect wellbeing. Here, the findings from the subjective wellbeing research have provided several clues.

The measurement of subjective wellbeing has advanced significantly over the last decades, with the annual 'World Happiness Reports' (Helliwell et al. 2020a) as a prominent example. Subjective wellbeing can be measured both as more general cognitive self-evaluation of life satisfaction and as self-evaluations of positive and negative moment-to-moment affect in relation to current activities (also known as 'experienced' or 'hedonic' wellbeing). For recent reviews of the scientific field, see Diener et al. (2013, 2018) and OECD (2013).

While measures of positive affect appear to be well correlated to the more general life satisfaction, negative affect does not appear to have as lasting an influence (Helliwell et al. 2020b).

A well-proven measure of cognitive self-evaluation of life satisfaction on a scale from 0 to 10 is provided by the answers to the Cantril (1965) ladder question: “Please imagine a ladder with steps numbered from 0 at the bottom to 10 at the top. The top of the ladder represents the best possible life for you and the bottom of the ladder represents the worst possible life for you. On which step of the ladder would you say you personally feel you stand at this time?” Cantril points seen as averages over a year can thus be converted to QALY by dividing by 10, and vice versa.

The annual survey results from the application of the Cantril ladder question in the Gallup World Poll are presented in the World Happiness Report (Helliwell et al. 2020a) that also seeks to explain the variation of these measures across countries by six explanatory variables: Income (the natural logarithm of GNI), Healthy Life Expectancy at birth (years), Social support (boolean), Freedom to make choices (boolean), Generosity (donation to charity during past month; boolean), and Perceptions of corruption (0 to 1). The lowest national average score for each variable provides a benchmark (called “Dystopia” by Helliwell et al. 2020a) at a Cantril ladder score of 1.97, against which the contributions of the six explanatory variables can be measured. For the difference in life satisfaction scores between the top 10 countries and the bottom 10 countries, Helliwell et al. (2020a, Statistical Annex, Table 21) find that the six variables explain 71%. Applied to the full range from Finland on top with a Cantril score of 7.809 to Afghanistan at the bottom with a Cantril score of 2.567, income explains 23% (1.19 Cantril point), social support 19% (1.00 point), health 15% (0.78 point), freedom of choice 7% (0.34 point), perceptions of corruption 6% (0.32 point), and generosity 2% (0.11 point) of the difference in life satisfaction scores, leaving 1.5 Cantril points (29%) unexplained.

The finding of Helliwell et al. (2020a) that log income explains 23% of the difference in average wellbeing, could be used a basis for converting the contribution of income in monetary units to units of wellbeing. Juster et al. (1981) suggest that SWB can be expressed as the sum of the instrumental value of income (equal to the value added generated from work) and the intrinsic activity benefit, i.e., the positive affect from performing or taking part in specific activities (named ‘process benefits’ by Juster et al.). In the illustration in Fig. 1, the four fully drawn rectangles illustrates four types of contributions to the value of a QALY. Additionally, an unavoidable

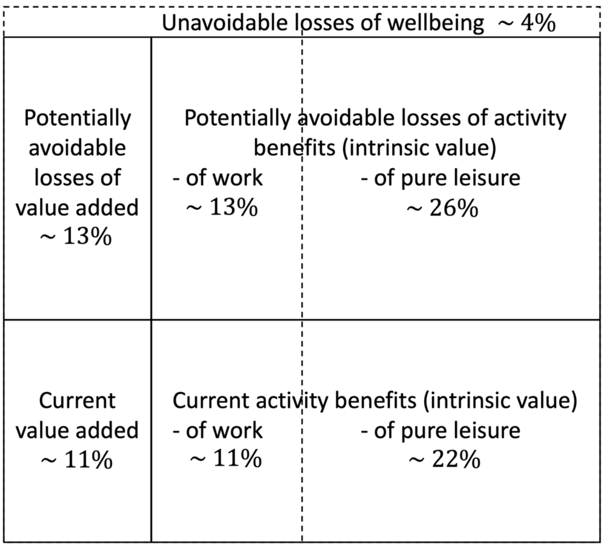

Figure 1. Contributions to the total value of a QALY. Percentages represent estimated current global averages.

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

The internal vertical lines in Fig. 1 separate both current and potential wellbeing into value added (left rectangles of Fig. 1), i.e., the value that work (productive activities) add to products, and the activity benefits (right rectangles of Fig. 1). i.e., the value of the positive emotions that people obtain from performing or taking part in specific activities. 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.

The implication is that total subjective wellbeing (Q) has a value approximately four times the total value added (VA) of production:

$Q = 4 * V_A$ (Equation 1)

thus providing a basis for expressing marginal subjective wellbeing (QALYs) in monetary units, and vice versa.

The approximate relationships in Fig. 1 can also be confirmed from the episodic (moment-to-moment) affect data collected by Krueger (2007) and Gershuny (2013). A useful insight from these data is that positive affect experienced from pure leisure exceeds the positive affect from work activities with a value around 0.25 on a 0-1 scale (after conversion from Krueger's 0-6 scale and the 0-10 scale used by Gershuny).

The above findings from subjective wellbeing research provide an important correction to Weidema (2009), where wellbeing was seen as exclusively related to consumption activities and as inseparably linked to production through the budget constraint, implying that the value of wellbeing was limited to be a mirror of the value of production, actually only describing the consumption and production aspects of instrumental benefits (value added), respectively. Furthermore, the focus on the budget constraint led to the counter-intuitive result that the same percentage-wise change in instrumental productivity benefits and intrinsic activity benefits would provide the same change in utility (wellbeing). This would mean that, e.g., a 10% reduction in wellbeing could be compensated by a 10% increase in income. In Weidema (2018), it was suggested to solve this problem by applying a different basis for calculation of equity-weights for changes in wellbeing versus changes in productivity and consumption only (i.e., without any concurrent change in wellbeing), resulting in a ratio of a QALY to value added of $Q = 2.36 * V_A$ (compare to Equation 1). However, this solution is blemished by the fact that the ratio is dependent on the number of income steps used in its determination (the value 2.36 reflects a normative choice of three income steps between zero and the current income level), and also maintains the fixed relationship – although no longer 1:1 – between intrinsic activity benefits and instrumental productivity benefits, i.e., it implies an assumption that a change in intrinsic activity benefits will always be accompanied by a change in productivity (Weidema 2009). More fundamentally, it implies an unfortunate dependency between the valuation of intrinsic activity benefits and the valuation of inequality. All of these points of critique do not apply to the more comprehensive expression for the value of a QALY, which uses the finding of Helliwell et al. (2020a) that income only explains approximately 25% of the difference in life satisfaction scores.

Note that the value of a QALY is quite sensitive to changes in the explanatory variable of preference for income (ratio of value added to total wellbeing). A change from 0.25 to 0.23 increases the conversion factor from 1/0.25 = 4.00 to 1/0.23 = 4.35 times the value added of production. Previous studies have provided both even lower values for the explanatory variable, giving implausibly high values for non-income effects (Fujiwara & Campbell 2011), and much higher values (e.g., Fritjers et al. 2004, Sacks et al. 2010), which are similarly implausible because they would imply a larger difference in activity benefit between leisure and work activities than what is empirically observed from positive affect studies (Krueger 2007, Gershuny 2013). So, while the preferences for income, work benefits, and pure leisure benefits may change independently over time and between persons, the interdependence of the relationships expressed in Fig. 1 provides reason to expect that, at the population level, average changes in relative preferences will be moderate.

3 Specific asset losses as contributions to the overall sustainability gap

In the following sub-chapter sections, estimates are provided for the relative values of the current impacts related to the different asset types, cf. Table 1. As already mentioned, the impacts on instrumental values are estimated in Sections 3.1 to 3.6, while impacts on intrinsic values are estimated in Sections 3.7 to 3.11, before summarising the total impact in Chapter 4, and linking this to the individual impact pathways in Chapter 5.

3.1 Impacts related to natural resources

Natural resources are composed of unimproved land and sub-soil assets, freshwater, wild fauna and flora, electromagnetic spectrum, and geospatial orbit. The value of natural resources can be determined from market prices when these resources are traded or from the rent paid for the right to extract a natural resource.

Several types of impacts can be discerned: Dissipating a non-renewable resource stock at a rate that exceeds the socially optimal, extracting a renewable resource at a rate that exceeds the sustainable yield, and affecting the sustainable yield (e.g., by pollution or physical changes).

Huppertz et al. (2019) provide a worst-case estimate of the social cost of **sub-soil resource use** of 2.42 times the net market value of the extracted virgin resources, implying an externality of 1.42 times the net market value. Estimating the net value of resource rents as the global mining industries´ payments of resource taxes at 153 billion USD and above-average net operating surpluses at 205 billion USD (both calculated from Exiobase for year 2011), the social loss from sub-soil resource use can be estimated to 1.42 * (153 + 205) = **508 billion USD_{2011}**. As pointed out by Huppertz et al. (2019), the applied multiplier provides a maximum or worst-case estimate. On the other hand, the above estimate of resource rents excludes the share of resource rents appropriated by the workers, potentially measurable as excess wages in the mining industries.

The World Bank (2017) estimated current over-extraction of **marine biomass resources** to cause an annual social loss of **83 billion USD_{2012}** globally (with a 90% confidence interval of 57-103 billion USD, representing a situation where the biomass level, fishing effort, and extraction was 37%, 179%, and 89% of sustainable global levels of 580 million metric tonnes live weight, 54 billion USD, and 90 million metric tonnes live weight, respectively). Diaz & Rosenberg (2008) estimate that marine eutrophication reduces fishery potential by 0.34-0.73 million metric tonnes over an affected area of 245’000 km^2, with a lost value of **0.5-1.2 billion USD_{2012}** using the landing price of 1.6 USD/kg from World Bank (2017). Using ensemble modelling, Lotze et al. (2019) find that global warming will reduce marine biomass by 5% for every degree of warming, implying a 0.4% reduction in marine biomass for current annual emissions of 50 billion metric tonnes of CO_2-equivalents. A similar percentage reduction in the available sustainable harvest would be 0.36 million metric tonnes live weight annually, with a value of **0.6 billion USD_{2012}** using the same landing price as above.

Global catch of **freshwater fish** has been estimated to 17 million metric tonnes live weight (Fluet-Chouinard et al. 2018), but this is not related as closely to the net primary productivity as in marine ecosystems but rather to river discharge, i.e., the volume of water flow (McIntyre et al. 2016), which is mainly influenced by climatic factors, and for about 25% of the watersheds also by artificial water withdrawal (Shi et al. 2019). The data from McIntyre et al. (2016) indicate that in about half of the watersheds, fish resources are overexploited. A rough estimate of this could amount to a loss of 3 million metric tonnes live weight annually, with a value of **5 billion USD_{2012}**.

The social cost over-extraction and pollution of the **freshwater resource** can best be estimated by, on the one hand, the current perverse subsidies for irrigation and groundwater-extraction, and on the other hand, the implicit, hidden subsidies for water pollution. The highly localized nature of both administration and over-extraction of freshwater resources makes it difficult to estimate global values. In the worst case, 100% of the extraction costs are covered by subsidies, while in a few countries full cost recovery has been obtained (Toan 2016). With a marginal extraction cost estimated at 0.1 USD/m^3, subsidies at 0.05 USD/m^3, and a global groundwater use of 1’000 billion m^3 annually, the subsidies could be as high as **50 billion USD_{2011}** annually. Emission of polluted water to surface freshwaters reduces the quality of the freshwater resource, and beside the biomass resource implications described above, the amenity impacts described in Section 3.8, and the health impacts described in Sections 3.3 and 3.8, this reduction turns into an added resource cost when the polluted freshwater is abstracted and then requires cleaning before use – a cleaning that should have been done before the emission or at least should be paid for by the polluter. When these cleaning costs are instead paid by the water consumer, this amounts to an indirect, distortionary subsidy to the polluter. The size of this subsidy can be estimated from the 80% of global industrial and municipal wastewater that goes untreated (UNESCO 2017), multiplied by the average treatment costs for these wastewaters, which at source can be estimated at 12 USD/capita/year (Haller et al. 2007, Dodane et al. 2012), giving a total perverse subsidy of **70 billion USD_{2011}** annually.

Haberl et al. (2007) estimates the annual global potential **terrestrial net primary production of biomass** at 65.5 Pg of carbon and the share harvested for human use at 12.5% (8.2 Pg). In addition, occupation by human infrastructure causes a reduction in net primary production of 0.5 Pg (0.8% of the annual global potential), while other land use changes, pollution, human induced wildfires, water abstraction, land degradation, and inefficient agricultural production cause a reduction of 6.9 Pg (10.5% of the annual global potential). This latter reduction can be seen as an over-extraction that is largely unnecessary, since ecosystems under modern agricultural and forestry practices can maintain production at the level of the potential net primary production. Current human appropriation of net primary production could thus be reduced by 10.5%/(12.5%+10.5%) =

45.7% without a reduction in harvest. Assuming that this efficiency improvement would involve a proportional reduction in extraction costs, the current net benefits of global use of forests, agricultural croplands, and rangelands of 1'882 billion USD would increase by 45.7%*1'882 billion USD = **860 billion USD_{2011}**. Not included in this number are impacts that do not necessarily reduce net primary productivity but rather damage (or replace) crops that are more valuable than average, such as the impact from global warming and invasive species. However, global warming is expected to imply a shift in the location of agricultural production rather than a change in overall output, while plausible estimates of the global total cost of invasive species are absent (the most recent risk estimate for the impact of invasive species on agricultural crops by Paini et al. (2016) amounts to 540 billion USD annually, which is a very large share of the value of the entire annual global harvest of agricultural crops). Note that the corresponding impacts from global warming and invasive species on natural heritage (biodiversity) are indeed covered in section 3.8.

Biodiversity and its foundational genetic diversity are currently being lost at rates that exceed the natural background rates. This can be seen as a loss of option values for future use. Although it has been argued that the cost of conservation of biodiversity is lower than any sensible lower-bound estimates of option values (Drucker & Caracciolo 2012), option values are notoriously difficult to estimate for resources that are not sold on markets and they are difficult to separate from expressions of non-use values, i.e., the willingness to pay for conservation of biodiversity simply to know that it exists and will be existing for future generations to enjoy. The option values of genetic resources can therefore be regarded as covered by the willingness to pay measure for biodiversity recorded in Section 3.8.

Ecosystem services beyond the above-described provisioning services (providing materials and energy carriers) fall under the headings of 'Regulation & Maintenance' and 'Cultural' in the CICES classification (Haines-Young & Potschin 2018). These include outputs from both natural and manufactured ecosystems, but in both cases rely heavily on the same underlying solar-energy driven biophysical processes of transport, transformation, and deposition of materials, which maintain conditions favourable for biomass production and enjoyment of the environment, while reducing the impact of pollution and extreme events. In the recent decades, large efforts have been spent to estimate the value of specific changes in these ecosystem services (Nijkamp et al. 2008, Bagstad et al. 2013). However, taking the examples included in InVEST and ARIES, the most widely accessible tools to estimate ecosystem services, these services are either:

- Not scarce, i.e. not fully utilised, which implies that they have zero marginal value, i.e. the value of an additional amount of the service is zero: For example, the ecosystem service of carbon sequestration is linked to net primary production, and part of this could be committed to long-term storage, e.g. as biochar in soils, thus counterbalancing current excess emissions of carbon dioxide from combustion of fossil fuels. However, in practice, out of the 8.2 Pg of carbon annually used by humans, very little is currently committed to long-term storage, so this ecosystem service is currently largely unused and thus freely available in excess amount. The same is true for solar-derived energy and the derived potential energy in gravitational and lateral flows of water, wind and wind waves, which are available in amounts that by far outstrips the current human consumption of energy of all forms. Another example is the ecosystem services of urban air purification and cooling by evapotranspiration that are linked to the net primary production of urban vegetation, which is only limited by the space that humans may decide to use for this purpose.
- Closely linked to the water flows related to the already accounted value of maintaining terrestrial net primary production, so should not be accounted for as additional to this, but rather as a separate specification as a (free, surplus) by-product: The ecosystem services of water purification and control of erosion, flooding, and sedimentation are by-products of maintaining intact vegetation and the related

decrease in lateral surface flows and increase in infiltration and storage of water. The regulation of the allocation of benefits between upstream and downstream water users is rather an issue of social network capital.

- Closely linked to the biodiversity and heritage values recorded in Section 3.8 (Mace et al. 2012), so should not be accounted for separately here to avoid double-counting: For example, the provision of the ecosystem service of pollination by wild pollinators has its basis in the conservation of the biodiversity of pollinators and the ecosystem they depend on. Other examples are unaffected enjoyment of scenic views and other aspects of ecosystem heritage that may be obscured or disturbed by artificial constructions, lights, litter, odour, or sound.

3.2 Impacts related to manufactured capital

Manufactured capital can be divided in physical capital and intellectual capital. Physical manufactured capital can be further divided in biotic (managed ecosystems and animals in human care) and abiotic (buildings, machinery, tools, and other abiotic production factors with a lifetime of more than one year). Intellectual capital is the intangible knowledge, procedures, and commercial rights that are owned by or embedded in an organisation, independently of its employees (as opposed to human capital that resides with the employees, and social network capital that cannot be owned but depends on relationships and shared norms). The value of manufactured capital can be determined from market prices when capital goods or commercial rights are traded, or from the rent paid for the right to use the capital, e.g. rents for use of patent rights or rents for use of improved land above the rent for use of unimproved land.

Three types of impacts can be discerned: 1) Underinvestment in physical infrastructure, research, and innovation and technology; 2) Damage to physical manufactured capital from theft and vandalism, preventable accidents, physical changes, and pollution; 3) Impacts on wellbeing of animals in human care.

Capital market failures are common for investments in infrastructure due to their merit, non-excludable, or non-rivalrous nature. The resulting **underinvestment in physical infrastructure** can be corrected by adequate fiscal policies, creating a favourable investment climate for the building of infrastructure for electricity, transport, telecommunications, and disaster prevention and mitigation, which could close the current global poverty gap to the level of 5.5 $USD_{2011,PPP}$ per person per day, thus avoiding an annual social loss of productivity of **1’990 billion USD_{2019}** (calculated from PovcalNet for 2017, latest year for which a global value was available, converting from 2950 billion $USD_{2011,PPP}$ to nominal USD_{2019} by a factor 0.675). **Underinvestment in intellectual infrastructure** (research, innovation, and technology development) is included in the residual calculated in Section 3.4 on social network capital.

Insurance claims provide a measure of the loss of manufactured capital due to sporadic events such as accidents and extreme weather events. While the insurance payment is simply a transfer of the damage to a wider group of people, the payments are an indication of the losses that occur. The global non-life insurance premiums amounted to 3’376 billion USD in 2019 (Swiss Re 2020), out of which 440 billion USD_{2019} was related to extreme weather events, fire and other disasters. Out of such property damage, only 31.2% of the damage is estimated as avoidable (calculated by multiplying the 2010-2020 data in the International Disaster Database (https://public.emdat.be/) by the corresponding country ratio of avoidable damage calculated as the difference between the World Risk Report (Bündnis Entwicklung Hilft 2020) risk scores and the risk scores calculated with the vulnerability of the country with the lowest vulnerability score). This results in an estimated **avoidable property damage from disasters** of 440 billion USD_{2019} * 31.2% = **137 billion USD_{2019}**. It should be noted that the values for property damage in the mentioned International Disaster Database are only 35-44% of the above total premiums for property damage, and the corresponding data from UNstat for the SDG indicator 1.5.2 (Direct economic loss attributed to disasters VC_DSR_GDPLS) is a further 64-79% of the values of the International Disaster Database. However, considering that a significant part of property damage is likely to be uninsured, the relatively high estimate based on insurance premiums can be justified.

Impacts on manufactured capital is estimated to increase as a result of global warming. Assuming that new constructions will be adapted to accommodate the increased risks, the increased impacts can be limited to the 30 years average remaining lifetime of already built buildings and infrastructure. The risk of property damage is expected to quadruple by 2050 (Woetzel et al. 2020), i.e., an increase of three times the current level in 30 years. Assuming a linear relation, this means an average annual additional cost of **property damage due to global warming** of 3 * 440 billion USD_{2019} / 30 = **44 billion USD_{2019}** per current annual emissions of 50 billion metric tonnes of CO_2-equivalents.

Avoidable property damage from air pollution to manufactured building surfaces can be estimated at **68 billion USD_{2018}** annually, from an additional maintenance cost of 34% (average from Spezzano et al. 2019) of the market for façade maintenance (200 billion USD annually according to www.expertmarketresearch.com). Damage from pollution on agricultural crops is already included in the estimate for impacts on natural resources (terrestrial net primary production of biomass).

Impacts on **wellbeing of animals in human care** have not been included in the current assessment due to the high heterogeneity and low strength of evidence in willingness to pay studies for animal welfare (Clark et al. 2017).

3.3 Impacts related to human capital

Human capital is the productive ability of humans as individuals, as opposed to the social network capital that enhances the productive ability of groups of individuals through the beneficial relationships and shared norms of the group. The size of human capital is determined by the time that humans are able and willing to spend on productive activities (labour), as opposed to leisure, as well as their level of skills. The value of human capital can be determined from the production output per workhour.

Several types of impacts can be discerned: The impacts of morbidity and pre-mature mortality, potential impacts on the work-leisure preference, and impacts on the development of skills.

The global morbidity and pre-mature mortality are reported by the Global Burden of Disease Collaborative Network (IHME 2020). Of these reported **health impacts, the avoidable part** was calculated by Weidema & Fantke (2018) for year 2016. Adjusting this calculation to the latest 2019 data from IHME gives 1.776 billion avoidable Disability-Adjusted Life-years (DALY). With an average global productivity (GDP) per person-year of 11’409 $USD_{2019,PPP}$ in 2019, the productivity loss related to the avoidable DALYs is 1.776 * 11’409 = **20’260 billion $USD_{2019,PPP}$**.

The additional (future) **health impacts from global warming** have been estimated in several LCIA methods, and while there are large uncertainties these estimates (Dong et al. 2019) and several options for improving them, the central estimate of the ReCiPe method at 1.08 DALY per 1000 metric tonnes CO_2-equivalents is sufficient for this initial rough assessment. This amounts to 54 million DALY for the current annual global emission of 50 billion metric tonnes CO_2-equivalents, and with the same productivity loss per person as above, this gives an annual 54 million * 11’409 = **616 billion $USD_{2019,PPP}$** in productivity loss related to health impacts from current greenhouse gas emissions.

Beyond the obvious limitation that the above health impacts have on the number of workhours, there is also a limit to the number of workhours that healthy individuals wish to provide. This ‘maximum capacity utilisation potential’ of human capital is a reflection of the work-leisure preference, i.e., how manufactured assets are valued relative to the value of the leisure time needed to enjoy both manufactured and non-manufactured assets. It has often been suggested that labour-saving efficiency improvements over time would lead to less work and more leisure time. However, while the work-leisure preference may vary between persons and also for the same person over time, it has been found to be surprisingly stable at the aggregate level, when also considering the working time spent in household production (Ramey & Francis 2009). Likewise, it has often been suggested that distortionary taxes should influence the work-leisure preference, but in reality, what is affected is rather the ratio of market-based formal work to non-market informal work (Blanchard 2006), and thus the effect is rather on distribution than on overall productivity. It is thus questionable whether the work-leisure preference to any significant extent is amenable to external distortions reducing real wellbeing. Also, it should be noted that should the work-leisure preference change autonomously, i.e., in a situation of constant production efficiency and constant after-tax wage levels, this would not imply any change in overall real wellbeing, but rather a change in the distribution of the overall wellbeing over its sources, i.e. between the outputs of work and leisure (implying that a correction would be required between nominal and real wellbeing, when nominal wellbeing is expressed relative to the production output). In conclusion, no specific impacts from changes in work-leisure preference have been considered for the current assessment.

The productivity loss from **insufficient development of skills** was estimated in Weidema (2018) based on the work for the OECD by Psacharopoulos (1994). One of the more solid of recent studies is Tamborini et al. (2015). However, a review of the recent literature on marginal contributions to productivity from marginal increases in skill level has not provided any generally applicable relationships that improve the original model estimates of Psacharopoulos (1994) yielding a 10% increase in income per year of additional schooling until the 12th year, and a 6.8% increase per year of additional schooling between the 12 and 18 years, after which there is no further productivity effect on average, giving the GDP multiplier = (1.1)^(12-A)*(1.068)^(18-B), where A is MIN[years of schooling,12] and B is MIN[MAX(years of schooling,12),18] (Note that in Weidema (2018) there is a misprint in the formula for the GDP-multiplier, indicating a “+” instead of a “*” in the central position). Inserting the global average for year 2019 of 8.5 years of schooling (UNDP 2020) in the two parameters, a multiplier of 2.07 is obtained for the global GDP, i.e., a lost potential of 1.07 times the current GDP or 1.07 * 87’800 billion USD_{2019} = **94’000 billion USD_{2019}** compared to a situation where everyone had 18 years of schooling. While the best data source for years of schooling is UNDP, the World Bank EdStats (Education Statistics) include data on enrolment rates divided on primary, lower and upper secondary and tertiary education, including mobile tertiary, out-of-school children (should in principle be complementary to enrolment rate), illiterate numbers divided on youth (age 15-24) and age 25-64, as well as more recent data series on the quality of education (measured as achievement test scores). Since obtained skills should theoretically be more relevant for productivity than formal educational achievements, the data from the Programme for the International Assessment of Adult Competencies (PIAAC 2019) may over time become a better basis for estimating lost potentials of skill development. However, the coverage of countries in PIAAC is currently rather incomplete and when using the currently available data for OECD countries, practically the same GDP multiplier is obtained from using the PIAAC data on numerical skills (see Figure 5.2 in PIAAC 2019) as when using years of schooling. The above calculation is not the expected future impact of the current insufficient skills development, although for an individual with insufficient schooling, the calculated earning loss would occur for every remaining year of working life. This is justified by the potential for subsequent upgrading of the skill level, which again means that obtained skills of the current population would be a better measure than the past years of schooling. Rather, the above calculation is for the current global annual income loss for 1 year, under a steady-state situation with the current (insufficient) level of skills development. Correspondingly, the calculated value does not reflect the current impact from the levels of insufficient skills development in the past years (which would have resulted in a larger value for the loss).

Specific reductions in skills can be caused by exposure to undernutrition, infectious diseases, toxic substances, and violence. Undernutrition-induced reduction in cognitive skills can be calculated to be 215 million person-IQ points annually from a reduction of 6.6 person-IQ points/incidence of stunting, based on Sudfeld et al. (2015), and the current prevalence of stunting of 23.3% (2015 data from WHO Global Database on Child Growth and Malnutrition) in the annual global cohort of 140 million children. Several reviews and studies have shown an effect of breastfeeding on cognitive skills (Anderson et al. 1999, Horta et al. 2007, PROBIT 2008, Lee et al. 2016, Jedrychowski et al. 2012), but these findings have also been challenged (e.g., by Der et al. 2006). Here, no effect of breastfeeding in cognitive skills have been included. Likewise, while noting that the aggravating role of infectious diseases on undernutrition is well recognized, no separate effects of infectious diseases or subclinical enteropathy have been included here, since it is still being debated whether infectious diseases and subclinical enteropathy play independent roles in reducing cognitive skills (Humphrey 2009, Eppig et al. 2010, Hassall & Sherratt 2011, Bowen et al. 2012, MacIntyre et al. 2014, Orgill-Meyer & Pattanayak 2020) or whether this effect is exclusively indirect through the influence on undernutrition (Fischer Walker et al. 2012). Many substances have neurotoxic effects (Grandjean & Landrigan 2006, Liu & Lewis 2014) but dose-response relationships have only been established for few, notably lead and alcohol. For lead, a global annual loss of 140 million person-IQ points can be calculated by applying the model of Budtz-Jørgensen et al. (2013), showing a reduction of 3 and 5 IQ points for serum lead levels above 5 and 10 microgram/dL, to the global incidences of these levels in the annual cohort (1/20 of the 815 million and 175 million children below 20 years with serum concentrations above 5 and 10 microgram/dL, respectively, according to the IHME data in the annex of Rees & Fuller 2020). For alcohol use disorders, an annual loss of 8 million person-IQ points can be calculated by applying the loss of 4.8 person-IQ points over 42 years of drinking from Grønkjær et al. (2019) to the 70 million annual incidences of substance use disorders (IHME 2020). For violence, the influence on educational outcomes has been reviewed by Fry et al. (2018). Early childhood exposure has been suggested to reduce IQ by 7.5 points (Enlow et al. 2012), while mothers' exposure to intimate partner violence has been suggested to reduce the offspring's IQ by 3.8 points (Abel et al. 2019). Applying these values to the prevalences of child maltreatment of 31 million annually (based on the US estimate of 0.6 million children classified as maltreated by the US Child protective services in 2010 (Fang et al. 2012), extrapolated to the global level using a country index of five equally-weighted normalised indicators of five forms of violence against children reported by Stalker (2017)) and 11% of the 140 million children born annually whose mothers are exposed to intimate partner violence (see Section 3.4 for the sources of these prevalences), gives a total of 35 * 7.5 + 11% * 140 * 3.8 = 321 million person-IQ points lost annually. Summing these specific reductions in cognitive skills gives an annual global loss of 215 + 140 + 8 + 321 = 684 million person-IQ points, or 684/140 = 4.9 person-IQ point per child in the current annual cohort. With an earnings loss of 6.5% per person-IQ point (Jones & Schneider 2010), this gives a global annual loss of 3.9 * 6.5% * 87'800 billion USD_{2019} = **28'000 billion USD_{2019}** for the current level of these largely irreversible **impacts on cognitive skills**.

3.4 Impacts related to social network capital

Social network capital is the beneficial relationships and shared norms of a group of individuals that enhances their collective productive ability. Shared norms can be informal but are often embedded in an institutionalised power structure. Ultimately, all externalities, including those treated in the previous sections of this chapter, are caused by missing beneficial norms (non-participation in their creation and maintenance), beneficial norms that are not followed (non-compliance), or inability to change detrimental norms (collective action problem). For example, norms reduce the probability of rent-seeking (and thus the need for precaution); norms reduce the probability of interpersonal violence (and thus the need for precaution); norms reduce inefficiencies, e.g., by increasing predictability.

The value of social network capital can be estimated from the current social losses from the externalities in different social environments with different levels of norm-support, norm-compliance, and ability to participate in norm-setting. One of the most commonly used measures of social network capital is *trust*, most often specified as 'institutional trust' and 'generalised trust', where the former is seen as an important precursor the latter (Sønderskov & Dinesen 2014). Gunningham & Sinclair (2017) show how trust is associated with aspects of participation and procedural justice in a management context. In the widely used Copenhagen Psychosocial Questionnaire for social work environment assessments (COPSOQ 2019, Llorens et al. 2019), several survey-questions under the group headings of 'influence', 'sense of community', 'trust' and 'organisational justice' are relevant as indicators for social network capital. When available, and in absence of more specific indicators and surveys, these measures may be applied as proxies.

Impacts related to social network capital that are not already treated in the previous sub-chapter sections are: Unfair commercial practices, Tax avoidance, Trade barriers, Excess profits and distortions from taxation, Distortionary subsidies, Labour market monopsony, Inadequate working conditions, Foregone benefits of migration, Rent-seeking, Violence, Underinvestment in intellectual infrastructure (research, innovation, and technology development), and Inefficiencies from lacking participation and influence.

The impact from **unfair commercial practices** was estimated in Europe to account for 0.2%-0.7% of the traded value of the consumer goods market (Civic Consulting 2017). A review by OECD (2020b) lists studies with values up to 1.5% of GDP, all from developed countries. A global value for the impact from unfair commercial practices of 0.7% of GDP would imply 0.7% * 87'800 billion USD_{2019} = **615 billion USD_{2019}**. The global social loss from **tax avoidance** has been calculated by Cobham & Janský (2017) to **494 billion USD_{2013}**. The social cost of **trade barriers** has been conservatively estimated by the World Economic Forum (2013) to 4.7% of the gross world product = **4'127 billion USD_{2019}**.

In a competitive economy, i.e., with a low level of regulatory protection, corruption, entry barriers, and unregulated monopolies, markups (the ratio of sales prices to variable costs) will be close to 1 and marginal profits therefore close to zero, as was the case in most of the developed economies before 1980. However, since then, as illustrated in Figure 6 of Diez at al. (2018), the markups in developed economies have increased to between 1.23 and 1.5 (interquartile range), which is at the same level as in developing economies. Companies that exploit their product market pricing power, i.e., keep their prices above the marginal costs, cause a deadweight loss, expressed in the form of **excess profits**. With a 24% gross fixed capital formation, a conservative estimate of the global average level of markups of 1.23 corresponds to excess profits of (1-1/1.23)*(1-0.24) = 14.3% of GDP or a global deadweight loss of 14.3% * 87'800 billion USD_{2019} = **12'555 billion USD_{2019}**. In this calculation, using the full World Product, the public production is included, where the deadweight loss is not from excess profits, but instead caused by **distortions from taxation**, which are thus here assumed to be of at least the same relative magnitude, an assumption that is supported by mainstream economic models (Sørensen 2014). The value reported here also includes the untaxed part of sub-soil resource rents, estimated in Section 3.1 to 205 billion USD_{2011}.

The social cost of **distortionary subsidies** may to some extent be included already in the above values on trade barriers and excess profits, but since a large part of such subsidies are likely to be capitalised as resource rents, they are nevertheless included as additional here. The large variety of explicit and hidden subsidies, changing over time in different jurisdictions, makes it a rather daunting task to make a complete assessment. International organisations have so far monitored such annual distortionary subsidies only **for agriculture (619 billion USD_{2019})** (OECD 2020a), **fisheries (35 billion USD_{2019})** (Sumaila et al. 2019, Martini & Innes 2018), **fossil, biofuels, and nuclear fuels (447, 38, and 21 billion USD_{2017}, respectively)** (Taylor 2020), and **aluminium (14 billion USD_{2015})** (OECD 2019a). For transport subsidies, the EEA (2007) estimated approximately 280 billion EUR_{2005} for the EU-25 countries, or 2.35% of GDP, not including foregone congestion taxes (see Proost 2018) net of revenues from current taxation of road transport. Using the European GDP percentage at the global level gives an estimated global annual subsidy **for transport** of 2.35% * 87’800 = **2’063 billion USD_{2019}**.

Labour markets are subject to the monopsony power of employers, especially for workers in precarious situations where they have insufficient access to other production factors than labour and where the alternative to employment therefore is unemployment (rather than self-employment). The deadweight loss of **labour market monopsony** has been conservatively estimated by Naidu et al. (2018) to 8.3% of GDP, not including the related loss of distortionary labour taxation that would increase the overall deadweight loss to 13% (see Tables 2 and 4 in the online appendix of Naidu et al. 2018). Using the 8.3% of GDP as a global value gives a deadweight loss for labour market monopsony of 8.3% * 87’800 billion USD_{2019} = **7’287 billion USD_{2019}**. It should be noted that this value includes the cost of the resulting unemployment. Illegal **forced labour** adds another **150 billion USD_{2012}** according to de Cock & Woode (2014).

The influence of **inadequate working conditions** on productivity – beyond the impacts from health absenteeism covered in Section 3.3 – has been the topic of research on presenteeism (presence at work while ill). In a relatively recent study on the production loss from workplace stress, Brunner et al. (2019) find a loss of 3.2% of income (23.8% of the observed health-related production loss). Other previous studies find similar reductions due to presenteeism, although based on less robust methods (VISES 2014, Lohaus & Habermann 2019). Table 2 in VISES (2014) shows that productivity-losses from absenteeism and presenteeism exceed the disability-weights with an average of 50% over 13 non-communicable diseases and a factor 5 in the case of tension-type headache. Applying the 23.8% of the production loss from Brunner et al. (2019) to the global IHME (2020) value for Years-of-Life-lived-with-Disability (0.11 YLD/person), the estimated social loss is 2.6% of the gross world product of 87’800 billion USD_{2019} or **2’300 billion USD_{2019}**.

In general, the direction of human migration is from economies with low production options to economies with relatively higher production options. The long-term impact of voluntary, planned, and well-organised migration will therefore increase the productivity of the migrants, reduce the pressure on the limited production options in the communities of emigration, and increase the production in the communities of immigration. The short-term costs of migration can therefore be seen as an investment in the later increase in global production, as a part of the general reallocation of labour to match the demand and optimise production. In contrast, involuntary migration, occurring as a result of violent conflict and to a lesser extent natural disaster, will typically have larger costs and smaller benefits, mainly due to its unplanned and typically less well-organised nature, resulting in misallocation of the involuntary migrants (refugees) to places where they have less options to contribute efficiently to the local production. Inefficiencies may also occur in the organisation of voluntary migration, resulting in failed integration of the migrants and corresponding lower long-term benefits. In both cases, impacts on migration can therefore be measured as the **foregone benefits of migration** due to insufficient planning and organisation. UNHCR online statistics (www.unhcr.org/refugee-statistics/download/ ?url=bJt1) provides data on the number of involuntary migrants, divided on countries of origin and host countries. For the roughly 82 million involuntary migrant-years in 2019, the foregone benefits can be estimated as the difference between their current contribution to the gross world product (540 billion USD_{2019}, calculated as the number of migrants in each host country multiplied by the host country's per-person GDP) and the contribution that they could have with a uniform global distribution proportionally to each country's GDP corrected for purchasing-power (namely 1'951 billion USD_{2019}, similarly calculated), yielding a lost income of 1'951 – 540 = 1'411 billion USD_{2019} due to the non-uniform distribution of (responsibility for) involuntary migrants. For migrants in general, the loss of income due to excess periods of forced underemployment in the host country can be estimated reliably from national employment statistics (ILOSTAT MST_TUNE_SEX_AGE _CBR_RT_A_EN and MST_TEAP_SEX_AGE_CBR_NB_A_EN indicators for unemployment rate and labour force specified by foreign/native born). Taking the latest available data for each host country on the size of the foreign-born labour force, multiplied by the difference in employment rate between foreign-born and native-born, and multiplied by the per-person GDP of the host country, gives a net global loss of 43 billion USD_{2019} due to forced underemployment of foreign-born immigrants. Adding the two global numbers, gives a total estimate of 1'411 + 43 = **1'454 billion USD_{2019}** as the foregone benefits of migration due to insufficient planning and organisation. It could also be considered to add the excess costs of irregular migration, but the available data (de Cock & Woode 2014) does not indicate that this would change the estimate significantly.

Many of the detrimental impacts described so far are the result of active **rent-seeking**, i.e., seeking to obtain or maintain benefits from redistribution of already existing assets rather than from producing additional assets. Besides the described detrimental impacts of successful rent-seeking, the rent-seeking itself causes direct productivity losses when efforts that could have been used productively are instead used for seeking to obtain benefits from redistribution of already produced and fairly distributed assets. del Rosal (2011) provides a good overview of the rent-seeking literature. Due to the illegitimate nature of these efforts, the extent of rent-seeking activities is difficult to measure directly. One of the few empirical observations has been made by Hazlett & Michaels (1993) based on a natural experiment, observing an average spending of effort (rent dissipation) equal to 31.2% of the contestable rent. It is important to note that rent-seeking costs only occur when the rent is contested, i.e., when there is unclarity about the outcome. This may only be the case for a minor part of the impacts described so far, notably many included in this section and in Section 3.1. Direct theft, which is the crudest form of rent-seeking, is already covered in Section 3.2. Out of the impacts in Table 2, those marked in *italics* are estimated to be contestable, and the 31.2% rent dissipation from Hazlett & Michaels (1993) is applied to the sum of these impacts, resulting in an estimate of the social loss of rent-seeking at **10'446 billion USD_{2019}**.

The impacts from **violence** go well beyond that of the medical costs and lost productivity related to injuries and subsequent disease risks that are included under health impacts in Section 3.3 (approximately 0.6% of the gross world product, with conflicts and terrorism responsible for 6.8 million DALY at 11'409 USD_{2019} = 78 billion USD_{2019}, out of which 32 billion USD_{2019} relate to non-fatal impacts, and interpersonal violence responsible for 41 million DALY at 11'409 USD_{2019} = 470 billion USD_{2019}, out of which 10 billion USD_{2019} relate to non-fatal impacts). Mueller (2013) provides a model estimate of direct reduction in GDP of 5.7% in countries affected by armed conflict, plus 1.6% of GDP scaled by the natural log of the conflict intensity given in victims per 1000 inhabitants, followed by a linear recovery over 20 years. Applying this model to the countries currently affected by conflicts with intensities above 0.031 fatalities/1000 persons, using 2019 data from the UCDP Georeferenced Event Dataset Global version 21.1 from the Uppsala Conflict Data Program (Sundberg et al.

2013, Högblad 2021), the accumulated global impact of **current conflicts** can be calculated to **311 billion USD$_{2019}$**. For interpersonal violence, the ratio of total incidences to incidences involving injuries requiring medical attention to is 11:1 (Vara Horna 2013, Sinha 2013). A number of detailed country studies (Vyas 2013, Peterson et al. 2018, Duvvury et al. 2019) have assessed the lost work hours and/or income for the victims of intimate partner violence. Duvvury et al. (2012) and Vara Horna (2013, 2015) include also the lost work hours for perpetrators and witnesses of intimate partner violence and find a total of 80 - 85 lost workdays per victim, corresponding to approximately 28% of a work-year. Combined with the 245 million women violated during the last 12 months (WHO 2021), this translates into a loss of 28% * 11’409 USD$_{2019}$ * 245 million = **783 billion USD$_{2019}$** due to **intimate partner violence**. Fang et al. (2012) calculate a low estimate of the cost of **violence against children** corresponding to 0.8% of the US GDP based on the 0.6 million children (1% of all) classified as maltreated by the US child protective services in 2010. Stalker (2017) provides global prevalence data on five indicators of violence against children (corporal punishment at home, bullying, physical fights in schools, physical violence against adolescent girls, and sexual violence against adolescent girls). Since these indicators have very different levels of severity and extent, we apply an equally-weighted index of the five normalised indicator values to extrapolate the estimate of Fang et al. (2012) to the global level, providing a value of 31 million children (1.6% of all) classified as maltreated and 1.3% of the gross world product of 87’800 billion USD$_{2019}$ = **1’140 billion USD$_{2019}$**. Together, these three estimates of the cost of violence amount to 3% of the gross world product. Since all these estimates are rather conservative, they should be seen as additional to the 0.6% of the gross world product due to the violence-induced health impacts mentioned above.

There are a few impacts for which it has not been possible to identify a sufficient credible data source, namely for underinvestment in intellectual infrastructure (research, innovation, and technology development), and inefficiencies from lacking participation and influence. There is a large theoretical literature that agree on the existence and causes of underinvestment in R&D (Jones & Williams 1998, Jones & Williams 2000, Tassey 2004, Hall & Lerner 2010, Kokko et al. 2015), but most estimates, especially at the cross-country level, have little solid foundation (Hall et al. 2010). Similarly, lack of employee participation and influence has generally been found to be detrimental for the levels of productivity and innovation, and workplace culture typically reflects the broader social level of democratic participation and influence. Nevertheless, there is limited quantitative estimates available of the size of this effect, especially at cross-industry and cross-country levels (Jones & Williams 2000, Jones 2016, Tassey 2004). From a pure productivity perspective, these two groups of impacts can be seen as intertwined, since both can be seen as a reflection of governance and capital market failures that maintain the innovative capacity below its social optimum. It is thus not so farfetched to group the two impact categories as a residual lack of social network capital.

The residual at the global level is calculated with the approach of 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 a few banking and oil producing countries. Weidema & Schmidt (2018) justified the choice of USA on the basis of a sensitivity analysis with 11 other countries. However, the calculations of the potential GDP/person in Weidema (2018) and the update of Weidema & Schmidt (2018) were limited to four impacts (underinvestment in education, health impacts, trade barriers, and unemployment), while the above-described more detailed data sources for a large number of impacts now makes it possible to provide an improved estimate, as shown in the first three columns of Table 2.

The product of the multipliers on the GDP for the USA in Column 2 of Table 2 is 2.3, giving a potential GDP of 2.3 * 13’873 billion USD$_{2019,PPP}$ = 31’907 billion USD$_{2019,PPP}$ or 96’964 USD$_{2019,PPP}$ per person (see Table 3). With the assumption that this GDP is potentially achievable for the global population (7.713 billion in 2019), this gives a potential global GDP of 7.713 * 96’964 = 747’928 billion USD_{2019} (last number in last row of Table 2), corresponding to the multiplier of 8.519 on the current gross world product in Column 5 of Table 2. In the light green shaded cell of this column, the GDP multiplier for the residual is then determined as 8.519/5.793 = 1.471, where the 5.793 is the product of the GDP multipliers for all the preceding impacts. The corresponding value for the **residual** in column 4 is thus 0.471 times the current GDP or **41’313 billion USD_{2019}**, a value that should cover the total global loss of GDP from **underinvestment in intellectual infrastructure** (R&D), incl. inefficiencies from lacking participation and influence. It is worth noting that the described calculation only affects the size of the residual, not the relative importance of the remaining impacts.

3.5 Impacts related to financial capital

As mentioned in the introduction to this chapter, the amount of financial capital at the global societal level is zero, because in any financial transaction, the change in debit of the capital users counterbalances the change in credit of capital owners. Therefore, it does not make sense to talk of depletion of financial capital. Nevertheless, the efficiency of production that comes from the division of labour crucially depends on the availability of financial capital, i.e., the willingness of capital owners to extend credit to those capital users who currently can put all capitals (factors of production) to their most productive uses. The failure of financial capital markets can therefore have severe implications for the efficiency of use of all the other ‘real’ capitals. Capital market failures are particularly prominent as a causal factor for labour market monopsony and in the underinvestment of education, physical infrastructure, research, innovation, technology development, and disaster damage prevention; all impacts that have been treated in the preceding sections.

Governments play a crucial role in regulating capital markets, especially with respect to ensuring an appropriate amount of liquidity to counterbalance the inherent tendency of cycles of optimism and pessimism in business investments, known as ‘business cycles’, where underinvestment invariably occurs at the socially most inconvenient times. Capital market failures are therefore generally linked to government failures (Greenwald & Stiglitz 2013) and can be seen as captured by the residual calculated under social network capital in Section 3.4.

3.6 Summary of the impacts on instrumental values (impacts on income)

Table 2 summarises the findings of the previous sections, before continuing to the impacts on intrinsic values. Columns 4 to 6 of Table 2 repeats the estimated values of the impacts as recorded in Sections 3.1 to 3.5; here corrected for inflation, so that all estimates are expressed in billion USD_{2019}. Most of the impacts have a multiplier effect on the GDP, rather than just being additive. This multiplier effect is shown in column 5, and the last number in column 5 is the product of these multipliers, i.e., the total multiplier (8.5). The bottom value of column 6 shows the resulting gross world product with all the impacts internalised, i.e., a value 8.5 times the current gross world product, and the individual entries in column 6 show the result of distributing the contributions to this potential GDP proportionally to the contribution of each impact in column 4, including the contribution that is already internalised in the current GDP. It should be noted that the size of the total multiplier effect is affected by how many of the impacts are independent multipliers on the GDP.

Table 2. Summary of all impacts on instrumental values for the USA and the World. See notes on the following page.

	Values estimated for USA 2019 (***)			Global values estimated for 2019			
	Value of impact [billion USD 2019]	Expressed as a multiplier on current GDP	Contribution to GDP including multiplier effect [billion USD 2019]	Value of impact [billion USD 2019]	Expressed as a multiplier on current global GDP	Contribution to GDP including multiplier effect [billion USD 2019]	Year of original estimates
Purchasing power correction factor applied →	0.647		0.647	1.000		1.000	
Sub-soil resource use	*16*	1.001	*23*	*577*	1.007	*1 630*	2011
Marine biomass	*3*	< 1.001	*4*	*94*	1.001	*266*	2012
Freshwater biomass	*0*	< 1.001	*0*	*6*	< 1.001	*16*	2012
Freshwater resources, overexploitation	*2*	< 1.001	*2*	*57*	1.001	*161*	2011
Freshwater resources, untreated wastewater	*2*	< 1.001	*3*	*80*	1.001	*225*	2011
Terrestrial biomass	*27*	1.002	*40*	*977*	1.011	*2 765*	2011
Underinvestment in physical infrastructure	3	< 1.001	5	1 990	1.023	5 625	2017
Property damage, from disaster, avoidable	24	1.002	35	137	1.002	387	2019
Property damage, due to global warming *)	5	<1.001	7	44	1.001	124	2019
Property damage, air pollution	11	1.001	16	69	1.001	196	2018
Health impacts, avoidable	1 997	1.144	2 940	20 260	1.230	57 255	2019
Health impacts, global warming *)	34	1.002	50	616	1.007	1 741	2019
Insufficient development of skills *)	3 162	1.228	4 657	94 000	2.068	265 644	2010
Impacts on cognitive skills *)	714	1.051	1 052	28 000	1.318	79 128	2019
Unfair commercial practices	2	< 1.001	4	615	1.007	1 740	2019
Tax avoidance	*134*	1.010	*198*	*542*	1.006	*1 531*	2013
Trade barriers	*271*	1.020	*399*	*4 127*	1.047	*11 663*	2019
Excess profits and distortions from taxation	*1 645*	1.119	*2 422*	*12 555*	1.143	*35 482*	2019
Distortionary subsidies for agriculture	*65*	1.005	*95*	*619*	1.007	*1 749*	2019
Distortionary subsidies for fisheries	*2*	< 1.001	*3*	*35*	< 1.001	*99*	2019
Distortionary subsidies for energy carriers	*22*	1.002	*32*	*527*	1.006	*1 493*	2017
Distortionary subsidies for aluminium	*0*	< 1.001	*0*	*15*	< 1.001	*43*	2015
Distortionary subsidies for transport	*325*	1.023	*480*	*2 063*	1.023	*5 830*	2019
Labour market monopsony	*1 115*	1.083	*1 696*	*7 304*	1.083	*20 641*	2019
Forced labour	*8*	1.001	*12*	*167*	1.002	*472*	2012
Inadequate working conditions	*518*	1.037	*762*	*2 300*	1.026	*6 500*	2019
Foregone benefits of migration	*428*	1.031	*631*	*1 454*	1.017	*4 109*	2019
Rent-seeking	1 441	1.104	2 122	10 452	1.119	29 536	2019
Current conflicts, except health impacts *)	0	1	0	311	1.004	880	2019
Intimate partner violence, except health impacts	123	1.009	181	783	1.009	2 213	2019
Violence against children, except health impacts *)	111	1.008	163	1 140	1.013	3 222	2019
Underinvestment in intellectual infrastructure (residual)	0	1	0	41 584	1.473	117 515	2019
Product of all multipliers on GDP		2.300			8.500		
Sum of all impacts on instrumental values **)	12 246		18 032	233 500		660 000	
Current GDP **)	13 870		13 873	88 000		88 000	
GDP after internalisation **)			31 905			748 000	

Notes to Table 2:

Impacts marked in *italics* are considered to be objects for rent-seeking (see text in Section 3.4).

All estimates based on earlier years are corrected for inflation by dividing by the following factors: 2010: 0.853; 2011: 0.88; 2012: 0.899; 2013: 0.912; 2015: 0.928; 2017: 0.959; 2018: 0.982

*) Impacts extend into the future. The value is for one year under a steady-state assumption (see text for details).

**) The values do not include the value of or impacts on household production (see text).

***) The values for USA are calculated with the same data sources as for the global values described in Sections 3.1 to 3.5 and summarized in columns 4 to 6, and the following additional procedures and data: Since natural resources are assets of the global community, the global impacts have been distributed in proportion to population; Excess profits have been calculated with the very conservative pre-1990 value of average markups of 1.175, considering its large uncertainty and the large sensitivity of the results to this value; For property damage due to air pollution, trade barriers, distortionary subsidies for transport, and labour market monopsony, the source data have been distributed in proportion to GDP; For forced labour, the source data for developed economies have been distributed by population; For distortionary subsidies for energy carriers in the USA, fossil fuels and biofuels account for 8 and 9 billion USD_{PPP}, respectively, while nuclear subsidies are calculated at 0.005 USD_{PPP}/kWh * 809 billion kWh; Foregone benefits of migration for the USA are composed of 437 billion USD_{PPP} from the current deficit in refugees, minus 9 billion USD_{PPP} excess contribution of current refugees; For intimate partner violence, a victimization rate of 6% of women have been used for the USA (WHO 2021).

However, the total multiplier effect is mainly affected by the few large impacts that are indeed clearly independent, rather than the many small ones for which the independence may be more questionable. Therefore, the calculation is performed under the reasonable assumption that all the listed impacts have an independent multiplier effect on GDP.

Table 3. GDP per person before and after internalisation of all impacts on instrumental values for the USA and the World.

	Values estimated for USA 2019			Global values estimated for 2019		
	Current	Value of impacts	With internalisation	Current	Value of impacts	With internalisation
Real GDP per person, PPP [USD_{2019}]	42 157	54 799	96 956	11 409	85 548	96 956

Two caveats apply:

- Some impacts extend over several years. In general, the application of discounting to future impacts has been avoided (with an exception for 'Violence against children', where the original value from Fang et al. (2012) already included a discounting of future losses with a constant 3% discount rate). Instead, a steady-state assumption is applied, which implies that the impacts that will occur over the coming years as a result of the human activities in the current year are assumed to be equal to the impacts that occur in the current year as a result of the human activities in previous years. For the current comparison, which involves many different impacts and models, this is a more transparent approach than discounting, although it implies an overestimation of impacts that decline over time and an underestimation of impacts that increase over time. In Table 2, the impacts that have significant temporal delays have been marked with a single asterisk (*).
- The GDP values do not include the value of unpaid work (household production). Unpaid work adds on average 20% to the GDP (range 10 - 37%). Including the value of unpaid work in the GDP values in Table 2 would increase the total values in the last three rows of columns 3 and 6 of Table 2 with a factor 1.2, while this would only be a weighted average of the factors that would be applicable for the individual impacts.

Figure 2 illustrates the valuation of the current income (GDP) and impacts. The area under the blue line represents the ordinary GDP and the grey line shows how purchasing-power-correction reduces the value of the GDP of the rich countries to the left in the graph, while similarly increasing the value for the poorer countries to the right in the graph. The areas under the blue line and the grey line have the same size; it is only the distribution that is different. Note that this is a feature of purchasing-power-correcting to the average GDP, as opposed to adjusting to the purchasing power of the USD, as done with International Dollar PPP.

The red line in Figure 2 represents the 'target value' for the GDP/person, i.e., the potential productivity when all impacts on instrumental values have been internalised. The area below this red line corresponds conceptually to the value in the last row and column of Table 2. The area between the red and the grey lines represent the total current impacts.

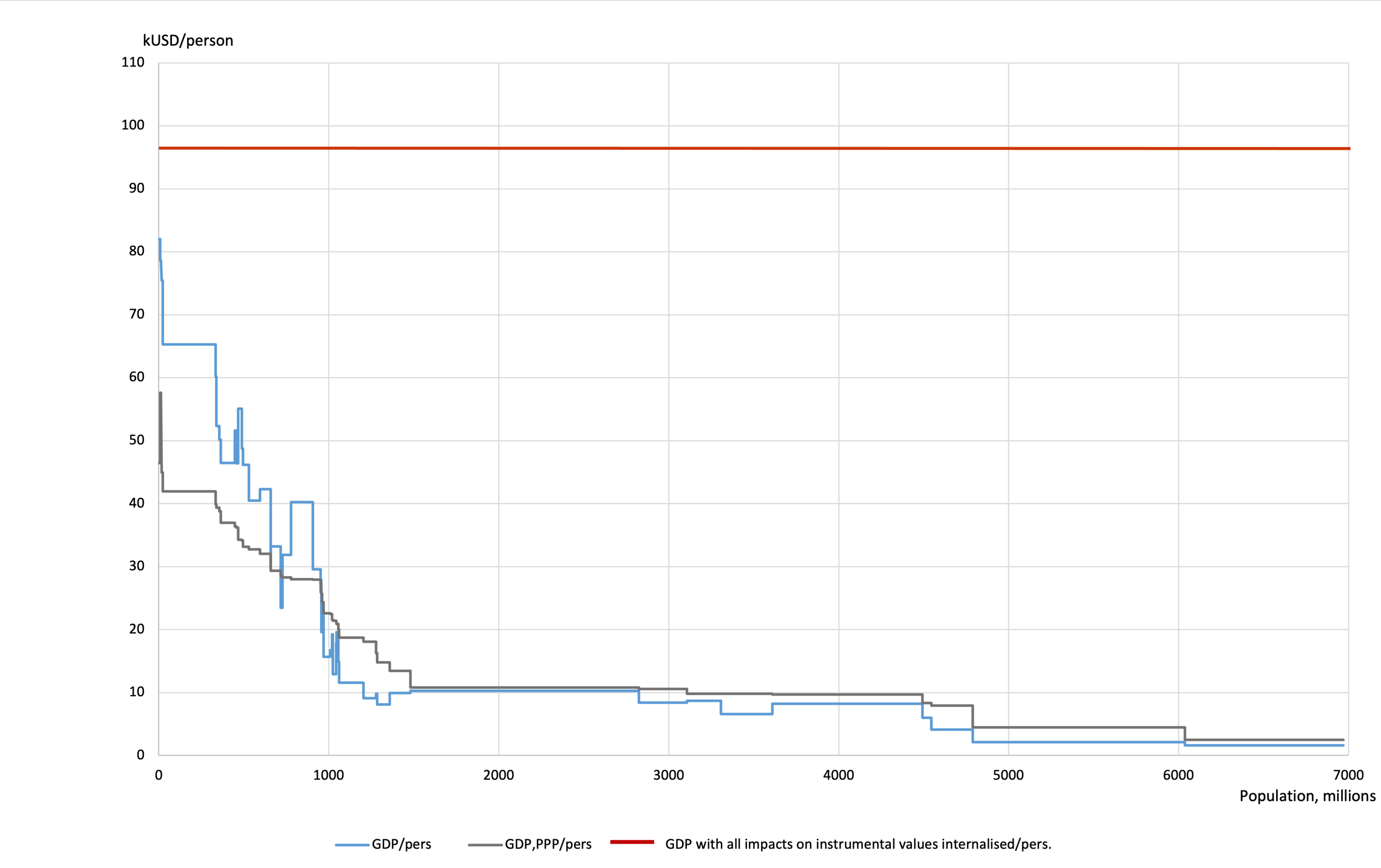

Figure 2. Instrumental value (GDP) of annual global human production in 2019, without (blue line) and with purchasing power correction (grey line), and with all detrimental impacts on instrumental values internalised (red line). Each step on the curves represents a country or region, sorted from left to right by size of values on the grey line. For example, the long horizontal line at around 2 billion people is for China.

3.7 Introduction to the impacts on intrinsic values

In parallel to the way instrumental values were quantified in the previous sections in terms of the value obtained from production, intrinsic values can be quantified in terms of the value obtained from the time spent on production and consumption, i.e., the activity benefits of Figure 1.

Accepting the ratio of instrumental to intrinsic values from Figure 1, the potential world product can be seen as contributing 25% of the value of a QALY, while the activity benefits would contribute 75%. With the potential world product per person of 96'956 USD_{2019} from Table 3, an approximate value of a QALY of 97'000/0.25 = 388'000 USD_{2019} is obtained.

In the following sections the specific impacts on the intrinsic activity benefits are quantified, primarily measured or expressed in QALY, to avoid the possible confusion of current and potential GDP values. When it is relevant to express impacts in monetary values, this is done in relation to a potential gross world product of 748'000 billion USD_{2019}, a potential global value of wellbeing of 748'000/0.25 = 2'992'000 billion USD_{2019}, and with a conversion factor of 388'000 USD_{2019}/QALY.

3.8 Impacts related natural, cultural and intellectual heritage

Heritage are assets that have been passed from previous generations to the current generation and which are identified by current social groups as valuable for conservation for enjoyment by current and future generations. Natural heritage is heritage residing in nature, more specifically in the form of biodiversity, unique landscapes, and sub-soil assets. Cultural heritage is heritage that reflects the evolving knowledge, beliefs and traditions of a society or group. Cultural heritage can be divided in intangible and tangible. The intangible cultural heritage is human languages, social practices, local knowledge, and specialised skills, while the tangible (physical) cultural heritage is buildings, artefacts, cultural landscapes, and archaeological sites and remains. Finally, intellectual heritage 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 impacts on natural heritage, the main issue of concern is biodiversity. Biodiversity is a complex concept covering both compositional, structural, and functional aspects at many different levels, from genes to landscapes (Noss 1990). A large number of different indicators have been proposed, including composite indicators, which results in empirically intractable frameworks (Lean & Maclaurin 2016). Also, some of the proposed indicators are more relevant than others as a general measure of current biodiversity impacts. For example, some suggested proxy measures, such as soil organic carbon, are in fact not very well correlated to other measures of biodiversity, while being reasonable indicators for productivity. Measures of diversity at the species level have the inherent problem of weighting all species equally, a limitation that is overcome by combining with a phylogenetic diversity measure that also serves as a reasonable predictor of structural and functional diversity (Faith 2016). Chaudhary et al. (2018) combine countryside species–area relationships and species-specific evolutionary distinctiveness to obtain a robust measure of phylogenetic diversity loss that can be related to specific human drivers and to other more traditional LCA biodiversity measures expressed in potential regional and global species loss (Chaudhary & Brooks 2018). The IPBES (2019) report provides, in its Chapter 2.2, a list of the many different indicators, of which most agree on the trends and size of change when considered at the same level. At the global level, the indicators of within-population genetic diversity, overall functional intactness, and overall terrestrial habitat extent, as well as the indexes of species habitat, mean species abundance, and biodiversity intactness, although conceptually very diverse and based on very different underlying data, all indicate a decadal decrease of approximately 1%, i.e., 0.1% annually. The IPBES (2019) report identifies, in its Chapter 2.2.6, change in area use as the most important anthropogenic driver of biodiversity loss with a relative impact of 30%, followed by direct exploitation (23%), climate change (14%), pollution (14%), invasive alien species (11%), and others, such as fire, human disturbance, recreational activities, and tourism (9%). From a phylogenetic perspective, global warming and pollution gain importance (+4% and +10%) at the expense of change in area use change and direct exploitation. For terrestrial ecosystems, invasive species are also relatively more important (+4%), while direct exploitation is more important for freshwater and marine ecosystems. Murakami et al. (2018) perform a choice modelling study giving a ratio of 478'300 DALY (here understood to be equivalent to QALY) per global species lost, with a current global annual species loss set to 102 species. This gives a global value of willingness-to-pay of 48.8 million QALY annually for avoiding the current global annual species loss. Although approximately 80% of species are found in terrestrial ecosystem, and only 5% and 15% in freshwater and marine, respectively (Grosberg et al. 2012), 39% of taxonomic phyla are exclusive to the latter only

(Costello & Chaudhary 2017), reflecting the longer evolutionary history of life in the oceans. Furthermore, there is an over-proportional share of the threatened phylogenetic heritage in freshwater and marine ecosystems. Based on the data presented by May-Collado & Agnarsson (2011), a split of 64%, 19% and 17%, or **31.2, 9.3 and 8.3 million QALY** for **biodiversity in terrestrial, freshwater, and marine ecosystems, respectively**, is applied here.

Murakami et al. (2018) list as a topic for further research, whether a larger value would be obtained if valuing damages that occur 'closer to home', i.e., local species extirpations with higher amenity value. In general, amenity value can best be measured through the induced variations in property prices. Out of total property value, the share that can be regarded as resulting from amenities is relatively small. For example, Dumm et al. (2016) found waterfront in the Tampa Bay to be the most important parameter influencing house prices, with 17% of all properties representing 22.5% of property value having an average waterfront amenity premium of 7.2%, implying that the total waterfront amenity value was only a minor share (22.5%*7.2% = 1.6%) of all residential property value. If the lost value due to decrease in **amenity value**, including scenic views obscured or disturbed by artificial constructions, lights, litter, odour, or sound, is set at 2% of the global housing expenditures (actual and imputed rents at an average 9% of potential GDP), this adds up to 2%* 9% * 748'000 = 1'346 billion USD_{2019} = **3.47 million QALY**.

For impacts on **tangible cultural heritage** (buildings, artefacts, cultural landscapes, and archaeological sites), a global value estimate is not available. The only choice modelling study known to us is for Australia (Allen Consulting 2005), suggesting a value of 0.2% of GDP, which is in line with previous survey results showing an order of magnitude smaller willingness-to-pay values than for protection of biodiversity. Thus, here a value of 1/10 of the above value for biodiversity is used, namely **4.88 million QALY** = 1'893 billion USD_{2019}. Historical buildings are estimated to have a heritage value at 15% of the property value (estimated from Table 4.1 in Nijkamp 2012). Assuming that 162 billion m^2 building area (5% of the global building area) is at risk of loss of heritage value, the annual global risk of loss of tangible cultural building heritage value of 15% * 9% * 5% * 748'000 = 505 billion USD_{2019}, or 3.1 USD_{2019}/m^2-year at risk. The value of protecting cultural landscapes and potential archaeological sites from changes in land use would then amount to the residual of the above estimated 1'893 billion USD_{2019}, i.e., 1'893 - 505 = 1´388 billion USD_{2019}. Assuming that such risks occur on 10% of the global urban and arable farming area (10% = 1'400 billion m^2), this would imply an average potential willingness-to-pay of 1'388/1'400 = 0.99 USD_{2019}/m^2-year or 9'900 USD_{2019}/ha-year of protection. Note that the monetary values here are expressed relative to the potential gross income, not to the current income level.

For intellectual heritage, no additional damage to consumption is expected, beyond the potential distortions in supply due to underinvestment, covered as part of the impacts on production (Section 3.4).

Impacts on intangible cultural heritage, such disturbance, discrimination, or active suppression of languages or unharmful social practices, are closely linked to participation restrictions, and therefore treated in Section 3.11.

3.9 Impacts related to consumption goods

Consumption goods are generally traded on markets and their intrinsic enjoyment value is already measured by their price and thus equal to their marginal production cost, noting that the value of consumption increases with the internalisation of the production externalities described in Sections 3.1 to 3.4. External damage to consumption goods can be estimated from insurance payments (or ideally from insurance claims). In addition to the avoidable property damage from disasters already quantified from insurance payments as an impact on instrumental values in Section 3.2 and Table 2, another 24% and 14% of the global non-life insurance premiums (3’376 billion USD in 2019 according to Swiss Re 2020) are for motor vehicle insurance and other property damage, respectively, according to OECD (2019b). **Motor vehicle** t**heft and physical damage** are 37% of motor vehicle insurance claims (based on US data from NAIC 2020), so the resulting annual loss can be estimated to 3’376 * 24% * 37% = 300 billion USD_{2019} = **0.773 million QALY**. Out of other property damage, **theft and vandalism** account for 7% of the insurance claims (based on US data from III 2018), thus estimated at 3’376 * 14% * 7% = 33 billion USD_{2019} = **0.085 million QALY**. Note that an additional 0.4 million QALY is added as burglary-induced anxiety in Section 3.10, Table 4.

3.10 Impacts related to enjoyment of health, autonomy, safety, security, and skills

The global avoidable health impact is reported in Section 3.3 at 1.776 billion Disability-Adjusted Life-years (DALY) and an additional 54 million DALY health impacts from global warming. Following the finding of Helliwell et al. (2020a), health impacts on intrinsic values should only make up approximately 15% of the total impacts on subjective wellbeing (i.e., 15% of the 4’084 billion QALY in Table 5). This requires the introduction of a conversion factor of 0.3 QALY/DALY, so that the **avoidable health impact** gives 1.776 billion * 0.3 = **533 million QALY** plus another 54 * 0.3 = **16 million QALY for health impacts from global warming**.

Global impacts on autonomy and sources of sub-clinical anxiety were estimated by Weidema (2006) using health state equivalents following the N3 tariff of Dolan et al. (1995) and the assumption that 1 DALY = 1 QALY. These first estimates have been updated in Table 4 with more recent incidence data and with the new reduced value of 0.3 QALY/DALY for the damage/incidence estimates, in parallel to what was done for the other values based on DALYs (aggregated under ‘Health impacts, avoidable’). The impacts now amount to **373 million QALY for autonomy infringements** and **169 million QALY for sub-clinical anxiety**, or a total of 542 million QALY annually.

The impact on wellbeing from skills development (proxied by years of education; see Section 3.3) is mainly mediated through income, social relationships, and health, rather than having a separate direct impact, although a small effect in the range of 0.1 Cantril points is acknowledged (Layard et al. 2012), corresponding to 0.01 QALY or **77 million QALY** for the **insufficient development of skills** of the global population. The debate on this issue is nevertheless still ongoing (see Jongbloed 2018). The losses of intrinsic value from impacts on **cognitive skills** are estimated to have the same proportion to the losses of intrinsic value from insufficient development of skills as the proportion that the two impact categories have in terms of losses of instrumental values, in Tables 2 and 5 (0.3/1), giving a value of 77 million * 0.3 = **23 million QALY** for the reduction in intrinsic values.

Notes to Table 4 (next page):

(a) Damage in QALY applies the QALY/person factors from Weidema (2006) multiplied by 0.3 like the other values based on DALYs (aggregated under ‘Health impacts, avoidable’). The damages are for impacts on intrinsic values, additional to the impacts on instrumental values summarised in Table 2.

*) In table 5, aggregated under 'Forced labour'

**) In table 5, aggregated under 'Inadequate working conditions'

§) In table 5, aggregated under 'Current conflicts'

§§) In table 5, placed under 'Violence against children'

§§§) In table 5, placed under 'Foregone benefits of migration'

^) In table 5, renamed to 'Restrictions on civil liberties'

^^) In table 5, aggregated under 'Health impacts, avoidable'

Table 4. Estimates of the global burden of autonomy infringements (13 first rows) and sources of sub-clinical anxiety (6 last rows). Original estimates from Weidema (2006) updated with new sources for the numbers of persons affected and damage. See notes on the previous page.

Terms used in Weidema (2006); See notes for classification used in this document.	Original estimates of affected population [million persons]	Updated estimates of affected population [million persons]	Updated estimates of damage [million QALY] (a)	Source of updated estimate of affected population
Bonded labour*	20	24.9	5.7	Walk Free Foundation (2018)
Child labour (worst forms)**	180	72.5	28	ILO (2017a)
Trafficking*	3.7	4.5	6.3	de Cock and Woode (2014)
Incarceration	9	10.8	2.6	Fair & Walmsley (2021)
Excessive work**	1 000	1 083	65	Messenger (2018)
Torture§	0.1	0.57	0.9	https://irct.org//our-impact
Genital mutilations§§	15	15	5.6	Same as in Weidema (2006)
Interpersonal violence	26	276	50	See Section 3.4
No access to contraceptives	200	219	6.6	Sully et al. (2020)
Unwanted pregnancies	60	104	78	Sully et al. (2020) relative to unavoidable baseline from Bradley et al. (2019)
Refugees or internally displaced§	37	82	7.4	www.unhcr.org/refugee-statistics/download/?url=bJt1
Warehoused refugees§§§	8	1.07	0.7	Calculated from unemployment rates; see Section 3.4
Infringement of freedom of expression^	2 400	3 855	116	'Civil Liberties' indicator from Freedom House (2020)
Inadequate access to health care^^	1 600	2 776	75	'Universal Health Coverage' indicator (WHO&World Bank 2017)
Inadequate access to social security	680	409	11	SDG 1.3.1 indicator from ILO (2017b)
Threats of violence / contact crimes	130	1 380	37	As in Weidema (2006): 5 times incidences of violence
Burglary or attempted burglary	220	15	0.4	https://dataunodc.un.org/data/crime/burglary
Threatening/traumatic traffic situations^^	140	516	14	As in Weidema (2006): 5 times incidences of road injuries
Stressful working conditions**	600	1161	31	35.5% of the 3.271 billion employed (Brunner et al. 2019)
Sum			542	

3.11 Impacts related to participation, influence and inequality

If the split of 25/75 for instrumental/intrinsic values as suggested by Figure 1 is to be maintained, there is still a sizeable residual impact on intrinsic values of 1’737 million QALY to be explained by discrimination, inequality and participation restrictions. The comparable estimate from Weidema (2006) was less than 1/3 of this, namely 540 million QALYs, using severity factors of 0.09 QALY/person-year for both ‘unequal opportunities’ and ‘political rights’. These severity factors can now be improved on the basis of data from the European Social Survey and the Gallup World Poll, as analysed by Helliwell et al. (2020b), finding that:

- **Unemployment** has a negative impact on subjective wellbeing of 0.39-0.75 Cantril points (averaging to 0.057 QALY/person-year).
- **Inequality** of wellbeing has a separate impact on wellbeing. Inequality of wellbeing between countries can explain a difference of 0.35 Cantril scores (0.035 QALY/person-year) in wellbeing.

- **Discrimination** has a negative impact on subjective wellbeing of 0.5 Cantril points (0.05 QALY/person-year) which can be fully off-set by institutional trust (Table 2.3 of Helliwell et al. 2020b). This is also assumed to capture impacts on intangible cultural heritage, such as disturbance or active suppression of languages or unharmful social practices.
- **Participation restrictions** (lack of social connections and trust) has a negative impact on subjective wellbeing of 0.23-0.68 Cantril points (averaging to 0.046 QALY/person-year), largest for those with lower overall wellbeing.

Of the above four impact categories, only for **unemployment** an obvious incidence measure exists, namely the global number of unemployed in 2019 of 186.6 million, the wellbeing impact thus amounting to 0.057*186.6 = **10.6 million QALY**. For the remaining three categories (inequality, discrimination, and participation restrictions), the number of people affected cannot currently be determined with any reasonable precision, so it may be assumed that all three types of impacts affect approximately the same number of people, thus distributing the remaining residual proportionally to the high end of the Cantril point ranges, arriving at **395 billion QALY for inequality, 564 billion QALY for discrimination, and 767 billion QALY for participation restrictions**. In Table 5, these impacts are subsumed under 'Social network impacts, not elsewhere classified'.

From the analysis reported in the accompanying data file, where the impacts specified in the current report are distributed over 163 countries (covering more than 99% of the global GDP and population), it can be seen that the residual is clearly largest in countries with high levels of conflict or inequality (more than 0.2 QALY/person in Afghanistan, Botswana, India, Jordan, Lebanon, Rwanda, Sri Lanka, Tanzania, Tunisia, Zambia, and Zimbabwe, compared to less than 0.01 QALY/person in Luxembourg and Switzerland), which supports the distribution of the residual over the mentioned topics of discrimination, inequality, and participation restrictions.

4 Summary of the sustainability gap

Table 5, column 2, summarises the impacts on intrinsic activity benefits, as far as possible placed in parallel to the similar impacts on instrumental values in column 1 (taken from Table 2, converted to QALYs; see the note to Table 5 for details). Column 3 of Table 5 sums the impacts on instrumental and intrinsic values. The last line, entitled 'Potential wellbeing', shows the theoretical potential. The next-last line is based on the 2019 global average subjective wellbeing of 5.03 Cantril points, calculated from the country data of Helliwell et al. (2021), divided by 10 to convert to the 0-1 QALY scale, and adjusted for the value of the current Years of Life Lost (YLL = DALY, thus 0.3 QALY/YLL), using the current life expectancy at birth (LE_{actual} = 73.5 years) relative to the maximum (LE_{max} = 94 years), i.e., 5.03/10 - 0.3*(94 - 73.5)/94 = 0.438 shown in Table 6, and finally multiplying by the world population (7.713 billion for 2019) and using the split of 25/75 for instrumental/intrinsic values as suggested by Figure 1. Table 6 reproduces the last three rows of Table 5, but expressed per person (i.e., divided by the world population).

Note to Table 5 (next page):

§) The values of foregone instrumental value in column 1 are calculated from column 6 of Table 2, dividing by 388'000 USD_{2019}/QALY and multiplying by 0.6, the latter factor to take into account that the wellbeing value of changes in income follow a logarithmic curve, so that the larger the current income, the lower the value of additional income. Applying the factor 0.6 results in instrumental values contributing 25% of the 7'386 million QALY potential wellbeing, in line with the finding of Helliwell et al. (2020a) and Figure 1. Example: The value for Sub-soil resource use in column 6 of Table 2 is 1'634 billion USD. Multiplying by 0.6 and dividing by 388'000 USD_{2019}/QALY gives 1´634*0.6/388 = 2.5 million QALY.

Table 5. Summary of all impacts on instrumental (column 1) and intrinsic (column 2) values. See note on the previous page.

	Impacts on instrumental values§ [million QALY]	Impacts on intrinsic values [million QALY]	Impacts on sustainable wellbeing [million QALY]
Sub-soil resource use	2.5		2.5
Marine biomass and biodiversity	0.41	8.3	8.7
Freshwater biomass and biodiversity	0.02	9.3	9.3
Freshwater resources, overexploitation	0.2		0.2
Freshwater resources, untreated wastewater	0.3		0.3
Terrestrial biomass and biodiversity	4.3	31.2	35.5
Underinvestment in physical infrastructure	8.7		8.7
Property damage, from disaster, avoidable	0.6		0.6
Property damage, due to global warming	0.2		0.2
Property damage, air pollution	0.3		0.3
Property damage, amenity value		3.5	3.5
Tangible cultural heritage		4.9	4.9
Property damage, theft, burglary, and related anxiety		1.3	1.3
Health impacts, avoidable	88.6	621.8	710.4
Health impacts, global warming	2.7	16.2	18.9
No access to contraceptives		6.6	6.6
Unwanted pregnancies		78.0	78.0
Restrictions on civil liberties		116.0	116.0
Inadequate access to social security		11.0	11.0
Insufficient development of skills	411.5	77.1	488.6
Impacts on cognitive skills	122.6	23.0	145.6
Unfair commercial practices	2.7		2.7
Tax avoidance	2.4		2.4
Trade barriers	18.1		18.1
Excess profits and distortions from taxation	55.0		55.0
Distortionary subsidies	14.3		14.3
Labour market monopsony	31.9		31.9
Forced labour	0.7	12	12.7
Inadequate working conditions	10.1	124.0	134.1
Foregone benefits of migration	6.4	0.7	7.1
Rent-seeking	45.7		45.7
Current conflicts, except health impacts	1.4	8.3	9.7
Intimate partner violence, except health impacts	3.4	77.5	80.9
Violence against children, except health impacts	5.0	15.4	20.4
Incarceration		2.6	2.6
Social network impacts, not elsewhere classified	180.9	1737.4	1918.3
Sum value for all impacts	1 021	2 986	4 007
Current wellbeing	845	2 534	3 379
Potential wellbeing	1866	5 520	7 386

Table 6. Global average level of subjective wellbeing (impacts, current, and potential) in QALY/person-life-year

	Instrumental values	Intrinsic activity benefits	Sum of instrumental and intrinsic values	Comments
Sum value for all impacts	0.132	0.387	0.520	Values from sum row of Table 5 divided by the global population (7.713 billion for 2019)
Current wellbeing	0.110	0.329	0.438	Cantril scores from Helliwell (2020a) divided by 10 and adjusted for the QALY value of current years of life lost over the maximum expected lifetime; distributed 0.25/0.75 over instrumental and intrinsic values as in Figure 1
Potential wellbeing	0.242	0.716	0.958	Sum of the above rows

For an entire population it will obviously never be possible to reach an average level of 10 on the Cantril ladder or 1 QALY per person-life-year, due to unavoidable life-events, such as natural disasters, deaths of close relatives and friends, or unavoidable diseases. Nevertheless, the theoretical limit of 1 QALY per person-life-year provides a strong constraint on the sum value for all impacts, reflected in the application of the factor 0.6 to the QALYs for instrumental values (see note to Table 5; this factor gives a stronger reduction than what would be obtained by applying the natural logarithm to the income difference), and the factor 0.3 QALY/DALY to health impacts. The average potential wellbeing of 0.958 QALY/person-life-year, suggested by Table 6, may still appear unrealistically high, and may warrant reductions in some of the more uncertain assumptions or estimates of prevalence, incidence, or QALY/incidence; uncertainties that have not been explicitly quantified in this first rough assessment.

Such reductions would also be required to make room for inclusion of any impacts that may accidentally have been overlooked in this assessment. It is likely that the reader of Table 5 or 7 (or some of the previous tables) will at some point think that some important impact or relationship has been left out. Nevertheless, the reader to whom such a notion occurs is encouraged to think first of two other likely explanations, namely that:

- The impact is in fact included, but under a different name or heading, or with a different impact pathway, than what the reader may have in mind; see for example the explanation in Section 3.1 on why ecosystem services are not explicitly included as such, but instead covered under other headings.
- The impact is insignificant in the context (insignificant can in this global context be rather large; for example, an impact (property damage) of 12 billion USD_{2019} from the use of de-icing salt was left out, because in the grand context, this would amount to 0.0004% of all impacts).

5 From sustainability gap to specific impact pathways

While some of the causal factors for the asset losses have already been mentioned in Chapter 3, the losses still need to be more systematically related to the specific impact pathways described in Weidema (2020). This is done in Table 7.

Table 7. Distribution of global annual impacts expressed in million QALY over the impact pathways chapters in Weidema (2020).

	Impact pathway chapters in Weidema (2020); see chapter topics in notes on next page																
Impacts from Table 5:	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Sub-soil resource use					2.5												
Marine biomass and biodiversity													1.5	7.2			
Freshwater biomass and biodiversity													1.7		7.6		
Freshwater resources, overexploitation					0.2												
Freshwater resources, untreated wastewater					0.3												
Terrestrial biomass and biodiversity													5.6		30		
Underinvestment in physical infrastructure	→								8.7								
Property damage, from disaster, avoidable																0.6	
Property damage, due to global warming													0.2				
Property damage, air pollution											0.3						
Property damage, amenity value															3.5		
Tangible cultural heritage											4.9						
Property theft, burglary & related anxiety																1.3	
Health impacts, avoidable		103	416		16	49		57								15	55
Health impacts, global warming													19				
No access to contraceptives					6.6												
Unwanted pregnancies					78												
Restrictions on civil liberties					116												
Inadequate access to social security								11									
Insufficient development of skills				489													
Impacts on cognitive skills		46	30													68	1.7
Unfair commercial practices	→				2.7												
Tax avoidance					2.4												
Trade barriers					18												
Excess profits and distortions from taxation	→				55												
Distortionary subsidies					14												
Labour market monopsony	→							32									
Forced labour								12.7									
Inadequate working conditions								134									
Foregone benefits of migration							7.1										
Rent-seeking	→				46												
Current conflicts, except health impacts																9.7	
Intimate partner violence, excl. health impacts																81	
Violence against children, excl. health impacts																20	
Incarceration																	2.6
Social network impacts, not elsewhere classified	→				564			10.6		576							767
Sum for each column (sums to 4'007 mio. QALY)	→	*149*	*446*	*489*	*922*	*49*	*7.1*	*257*	*8.7*	*576*	*5.2*	**	*28*	*7.2*	*41*	*196*	*826*

Notes to Table 7:

*) See text at the top of next page for explanation on Chapter 1.

The column headers refer to the topics of the chapters in Weidema (2020):

Ch. 1: Poverty
Ch. 2: Undernutrition
Ch. 3: Healthy lives
Ch. 4: Education and learning
Ch. 5: Unequal opportunities
Ch. 6: Clean water supply and sanitation
Ch. 7: Human migration
Ch. 8: Decent working conditions
Ch. 9: Physical infrastructure
Ch. 10: Income and assets inequality
Ch. 11: Cultural heritage
Ch. 12: Sustainable consumption and production
Ch. 13: Global warming
Ch. 14: Marine ecosystems
Ch. 15: Terrestrial and freshwater ecosystems
Ch. 16: Safety and security
Ch. 17: Social infrastructure and participation

**) See text in second paragraph on next page for an explanation of the empty column for Chapter 12.

Chapter 1 of Weidema (2020), covering the topic of poverty, is the only chapter to which it has not currently been possible to assign a quantitative part of the impact categories from Table 5. It is clear that poverty is an extreme form of inequality and that inadequate access to labour and credit markets and physical infrastructure play important roles, as described in Chapters 5, 8, 10, and 11 of Weidema (2020). The difficulty consists in determining which parts of the relevant impact categories (Underinvestment in physical infrastructure, Unfair commercial practices, Excess profits, Labour market monopsony, Rent-seeking, and lacking Participation and influence, the latter listed in Table 5 and 7 under 'Social network impacts, not elsewhere classified') are specific to the creation and persistence of poverty. The column for Ch. 1 in Table 7 is therefore limited to point to the other columns that refer to the relevant general impact pathway descriptions.

The empty column for Chapter 12 of Weidema (2020) may appear conspicuous. The reason for the empty column is that this chapter, which deals with indicators for sustainable consumption and production, does not introduce any new impact pathways in addition to the ones of the other chapters, but rather provides an overarching, supplementary perspective on the other SDG topics and describes how the contributions to the SDG Targets 12.1 to SDG 12.5 can be calculated from the indicators described in the other chapters.

As can be seen from Table 7, most of the impact categories from Table 5 can be assigned to a single impact pathway chapter of Weidema (2020), and there are even some of these chapters that exclusively treat one impact category, for example chapter 4 that exclusively covers the impact category 'Insufficient development of skills' (as indicated by the otherwise empty column for Ch. 4).

For the few impact categories that are distributed over more than one impact pathway chapter of Weidema (2020), the distributions are explained in this way:

1. For the three 'biomass and biodiversity' categories, 18% of the intrinsic biodiversity impact is covered in Ch. 13 on Global Warming.
2. For 'Health impacts, avoidable', diseases related to undernutrition (295 million DALY = 103 million QALY) are covered in Ch. 2, diseases related to unwanted pregnancies (45.5 million DALY = 15.6 million QALY) covered in Ch. 5, diseases related to unsafe water, unsafe sanitation, lack of hygiene and emergency preparedness for infectious diseases (140 million DALY = 49 million QALY) are covered in Ch. 6, work-related psycho-socially caused diseases (18.8% of YLD = 162 million DALY = 57 million QALY) are covered in Ch. 8, diseases from avoidable violence and disasters (42 million DALY = 15 million QALY) are covered in Ch. 16, and diseases from drugs misuse and self-harm (158 million DALY = 55 million QALY) are covered in Ch. 17. The rest (416 million QALY) is covered in Ch. 3, including 89 million QALY from Table 4.
3. For 'Impacts on cognitive skills', those related to undernutrition are covered in Ch.2, those related to lead in Ch. 3, those related to violence in Ch. 16, and those related to alcohol misuse in Ch. 17.
4. For 'Social network impacts, not elsewhere classified', the impacts on intrinsic values (1737 million QALY) are split with the 564 million QALY from discrimination covered in Ch. 5, the 10.6 million QALY from unemployment in Ch. 8, the 395 million QALY from inequality (together with the 181 million QALY residual impacts on instrumental values assigned to underinvestment in intellectual infrastructure) in Ch. 10, and Ch. 17 covers the 767 million QALY from participation restrictions.

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References

Abel K M, Heuvelman H, Rai D, Timpson N J, Sarginson J, Shallcross R, Mitchell H, Hope H, Emsley R. (2019). Intelligence in offspring born to women exposed to intimate partner violence: A population-based cohort study. Wellcome Open Research 4:107 (15 pages).

Ahmad N, Koh S-H. (2011). Incorporating Estimates of Household Production of Non-Market Services into International Comparisons of Material Well-Being. STD/2011/07. Paris: OECD.

Allen Consulting (2005). Valuing the Priceless: The Value of Heritage Protection in Australia. Sydney: Heritage Chairs and Officials of Australia and New Zealand.

Bagstad K J, Semmens D J, Waage S, Winthrop R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services 5: 27-39.

Blanchard O. (2006). The Many Dimensions of Work, Leisure, and Employment. Comments on the papers presented at the Rodolfo DeBenedetti Conference, Portovenere, June 2006. https://economics.mit.edu/files/690

Bowen A, Agboatwalla M, Luby S, Tobery T, Ayers T, Hoekstra R M. (2012). Association between intensive handwashing promotion and child development in Karachi, Pakistan: a cluster randomized controlled trial. Archives of Pediatrics and Adolescent Medicine 166(11):1037-44.

Bradley S E K, Polis C B, Bankole A, Croft T. (2019). Global Contraceptive Failure Rates: Who Is Most at Risk? Studies in family planning 50(1):3–24.

Brunner B, Igic I, Keller A C, Wieser S. (2019). Who gains the most from improving working conditions? Health-related absenteeism and presenteeism due to stress at work. European Journal of Health Economics 20(8):1165–1180.

Budtz-Jørgensen E, Bellinger D, Lanphear B, Grandjean P, International Pooled Lead Study Investigators. (2013). An international pooled analysis for obtaining a benchmark dose for environmental lead exposure in children. Risk Analysis 33(3):450-61.

Bündnis Entwicklung Hilft. (2020). World Risk Report Results 2020. https://weltrisikobericht.de/download/1386/

Cantril H. (1965). The pattern of human concerns. New Brunswick: Rutgers University Press.

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

Chaudhary A, Brooks T M. (2018). Land Use Intensity-Specific Global Characterization Factors to Assess Product Biodiversity Footprints. Environmental Science & Technology 52(9):5094-5104.

Chaudhary A, Pourfaraj V, Mooers A O. (2018). Projecting global land use-driven evolutionary history loss. Diversity and Distributions 24(2):158– 167.

Civic Consulting (2017). Study on measuring consumer detriment in the European Union. Final report Part 1 - Main report. Luxembourg: Publications Office of the European Union.

Clark B, Stewart G B, Panzone L A, Kyriazakis I, Frewer L J. (2017). Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. Food Policy 68:112-127.

Cobham A, Janský P. (2017). Global distribution of revenue loss from tax avoidance. Re-estimation and country results. Helsinki: United Nations University World Institute for Development Economics Research (WIDER Working Paper 2017/55).

de Cock M, Woode M. (2014). Profits and poverty: The economics of forced labour. Geneva: International Labour Office.

Costello M J, Chaudhary C. (2017). Marine Biodiversity, Biogeography, Deep-Sea Gradients, and Conservation. Current Biology 27(11):R511–R527.

COPSOQ. (2019). The Third Version of the Copenhagen Psychosocial Questionnaire. Safety and Health at Work 10(4):482-503.

Diaz R, Rosenberg R. (2008). Spreading Dead Zones and Consequences for Marine Ecosystems. Science 321: 926-929

Diener E, Inglehart R, Tay L. (2013). Theory and Validity of Life Satisfaction Scales. Social Indicators Research 112(3):497–527.

Diener E, Lucas R E, Oishi S. (2018). Advances and Open Questions in the Science of Subjective Well-Being. Collabra Psychology 4(1):15. (49 pages)

Diez F J, Leigh D, Tambunlertchai S. (2018). Global Market Power and its Macroeconomic Implications. Washington DC: International Monetary Fund. IMF Working paper 18/137.

Dodane P-H, Mbéguéré M, Sow O, Strande L. (2012). Capital and Operating Costs of Full-Scale Fecal Sludge Management and Wastewater Treatment Systems in Dakar, Senegal. Environmental Science & Technology 46(7):3705-3711.

Dolan P, Gudex C, Kind P, Williams A. (1995). A social tariff for EuroQoL: Results from a UK general population survey. University of York, Centre for Health Economics. (Discussion paper 138)

Dong Y, Hauschild M, Sørup H, Rousselet R, Fantke P. (2019). Evaluating the monetary values of greenhouse gases emissions in life cycle impact assessment. Journal of Cleaner Production 209:538-549.

Drucker A, Caracciolo F. (2012). The Economic Value of Plant Genetic Resources for Food and Agriculture. Pp. 11-38 in Moeller N I & Stannard C (eds.) (2013): Identifying Benefit Flows Studies on the Potential Monetary and Nonmonetary Benefits Arising from the International Treaty on Plant Genetic Resources for Food and Agriculture. Rome: Food and Agriculture Organization of the United Nations.

Dumm R E, Sirmans C S, Smersh G T. (2016). Price Variation in Waterfront Properties Over the Economic Cycle. Journal of Real Estate Research 38:1-26.

Duvvury N, Minh N H, Carney P. (2012). Estimating the costs of domestic violence against women in Viet Nam. Hanoi: UN Women Viet Nam.

Duvvury N, Asante F, Fenny A, Dzudzor M, Chadha M, Scriver S Ballantine C, Raghavendra S, Sabir M, Alvarado G, O'Brien-Milne L, Mueller J, Grant-Vest S, Kennedy J, Mensah W. (2019). Economic and Social Costs of Violence Against Women in Ghana: Summary Report. Galway: National University of Ireland.

EEA (2007). Size, structure and distribution of transport subsidies in Europe. Copenhagen: European Environmental Agency. EEA Technical Report No. 3/2007

Enlow M B, Egeland B, Blood E A, Wright R O, Wright R J. (2012). Interpersonal trauma exposure and cognitive development in children to age 8 years: A longitudinal study. Journal of Epidemiology and Community Health 66(11):1005-1010.

Eppig C, Fincher C L, Thornhill R. (2010). Parasite prevalence and the worldwide distribution of cognitive ability. Proceedings of the Royal Society B 277:3801-3808.

Fair H, Walmsley R. (2021). World Prison population List. 13th Edition. London: Institute for Criminal Policy Research.

Faith D P. (2016). The PD Phylogenetic Diversity Framework: Linking Evolutionary History to Feature Diversity for Biodiversity Conservation. Pp. 39-56 in Pellens R, Grandcolas P. (Eds).: Biodiversity Conservation and Phylogenetic Systematics. Cham: Springer. (Topics in Biodiversity and Conservation vol. 14)

Fang X, Brown D S, Florence C S, Mercy J A. (2012). The economic burden of child maltreatment in the United States and implications for prevention. Child Abuse & Neglect 36(2):156-165.

Fischer Walker C L, Lamberti L, Adair L, Guerrant R L, Lescano A G, Martorell R, Pinkerton R C, Black R E. (2012). Does childhood diarrhea influence cognition beyond the diarrhea-stunting pathway? PLoS One 7(10):e47908 (6 pages).

Fluet-Chouinard E, Funge-Smith S, McIntyre P B. (2018). Global hidden harvest of freshwater fish revealed by household surveys. Proceedings of the National Academy of Sciences 115(29):7623-7628.

Freedom House. (2020). All Data. FIW 2013-2020. https://freedomhouse.org/sites/default/files/2020-02/2020_All_Data_FIW_2013-2020.xlsx

Frijters P, Haisken-DeNew J, Shields M. (2004). Money Does Matter! Evidence from Increasing Real Income and Life Satisfaction in East Germany Following Reunification. The American Economic Review 94(3):730-740.

Fry D, Fang X, Elliott S, Casey T, Zheng X, Li J, Florian L, McCluskey G. (2018). The relationships between violence in childhood and educational outcomes: A global systematic review and meta-analysis. Child Abuse & Neglect 75:6–28.

Fujiwara D, Campbell R. (2011). Valuation techniques for social cost-benefit analysis. The valuation of non-market impacts – stated preference, revealed preference and subjective well-being approaches. London: HM Treasury.

Gershuny J. (2013). National Utility: Measuring the Enjoyment of Activities. European Sociological Review 29(5):996-1009.

Gunningham N, Sinclair D. (2017). 40 Trust, culture and the limits of management-based regulation: Lessons from the mining industry. Pp. 711-724 in Drahos P. (Ed.): Regulatory Theory: Foundations and applications. Canberra: Australian National University Press.

Grandjean P, Landrigan P J. (2006). Developmental neurotoxicity of industrial chemicals. Lancet 368:2167–78.

Greenwald B, Stiglitz J E. (2013). Industrial Policies, the Creation of a Learning Society, and Economic Development. Pp. 43-71 in Stiglitz J E & Jin J Y: The industrial revolution I. The role of government beyond ideology. Houndmills/New York: Palgrave Macmillan.

Grønkjær M, Flensborg-Madsen T, Osler M, Sørensen H J, Becker U, Mortensen E L. (2019). Intelligence Test Scores Before and After Alcohol-Related Disorders - A Longitudinal Study of Danish Male Conscripts. Alcoholism, Clinical and Experimental Research 43(10):2187–2195.

Grosberg R K, Vermeij G J, Wainwright P C. (2012). Biodiversity in water and on land. Current Biology 22(21):R900-R903.

Haines-Young R, Potschin M B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. Nottingham: Fabis Consulting.

Haberl H, Erb K H, Krausmann F, Gaube V, Bondeau A, Plutzar C, Gingrich S, Lucht W, Fisher-Kowalski M. (2007). Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences 104(31):12942–12947.

Hall B H, Lerner J. (2010). The Financing of R&D and Innovation. Pp. 609–639 in Hall B H, Rosenberg N (Eds.): Handbook of the economics of innovation, Vol. 1. Amsterdam, Boston: Elsevier.

Hall B H, Mairesse J, Mohnen P. (2010). Measuring the Returns to R&D. Pp. 1033–1082 in Hall B H, Rosenberg N (Eds.): Handbook of the economics of innovation, Vol. 2. Amsterdam, Boston: Elsevier.

Haller L, Hutton G, Bartram J. (2007). Estimating the costs and health benefits of water and sanitation improvements at global level. Journal of Water and Health 5(4):467-80.

Hassall C, Sherratt T N. (2011). Statistical inference and spatial patterns in correlates of IQ. Intelligence 39(5):303-310.

Hazlett T W, Michaels R J. (1993). The cost of rent-seeking: evidence from cellular telephone license lotteries. Southern Economic Journal 59:425–435.

Helliwell J F, Huang H, Grover S, Wang S. (2018). Empirical linkages between good governance and national well-being. Journal of Comparative Economics 46(4):1332-1346.

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

Helliwell J F, Huang H, Wang S, Norton M. (2020b). Social Environments for World Happiness. Chapter 2 in Helliwell et al. (2020a) (see below).

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

Hillis S, Mercy J, Amobi A, Kress H. (2016). Global Prevalence of Past-year Violence Against Children: A Systematic Review and Minimum Estimates. Pediatrics 137(3):e20154079.

Humphrey J H. (2009). Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet 374:1032-35.

Huppertz T, Weidema B P, Standaert S, De Caevel B, van Overbeke E (2019). The social cost of sub-soil resource use. Resources 8(1):2-17.

IHME. (2020). Global Burden of Disease Study. Burden by Risk 1990-2019. Seattle: Institute for Health Metrics and Evaluation, Global Burden of Disease Collaborative Network. <http://ghdx.healthdata.org/gbd-results-tool>

III. (2018). Data from the Insurance Information Institute website https://www.iii.org/fact-statistic/facts-statistics-homeowners-and-renters-insurance (Accessed 2020-11-30)

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

ILO. (2017a). Global estimates of child labour: Results and trends 2012-2016. Geneva: International Labour Organization.

ILO. (2017b). World Social Protection Report 2017–19. Geneva: International Labour Organization.

MacIntyre J, McTaggart J, Guerrant R L, Goldfarb D M. (2014). Early childhood diarrhoeal diseases and cognition: Are we missing the rest of the iceberg? Paediatrics and International Child Health 34(4):295-307.

McIntyre P B, Reidy Liermann C A, Revenga C. (2016). River fisheries, food security, and biodiversity. Proceedings of the National Academy of Sciences 113(45):12880-12885.

IPBES. (2019). Global assessment report on biodiversity and ecosystem services. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Jongbloed J. (2018). Higher education for happiness? Investigating the impact of education on the hedonic and eudaimonic wellbeing of Europeans. European Educational Research Journal 17(5) 733-754.

Jolliet O, Brent A, Goedkoop M, Itsubo N, Mueller-Wenk R, Peña C, Schenk R, Stewart M, Weidema B P. (2003). Final report of the LCIA Definition study. Life Cycle Impact Assessment Programme of The UNEP/SETAC Life Cycle Initiative. Paris: United Nations Environmental Programme. Available from https://lca-net.com/p/1100

Jones C I. (2016). The Facts of Economic Growth. Pp. 3–69 in Taylor J B (Ed.): Handbook of macroeconomics, Vol. 2. Amsterdam: Elsevier. (Handbooks in economics, Vol. 15).

Jones C I, Williams J C. (1998). Measuring the Social Return to R&D. The Quarterly Journal of Economics 113(4):1119–1135.

Jones C I, Williams J C. (2000). Too Much of a Good Thing? The Economics of Investment in R&D. Journal of Economic Growth 5(1):65–85.

Jones G, Schneider W J. (2010). IQ in the Production Function: Evidence from Immigrant Earnings. Economic Inquiry 48(3):743-755.

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.

Kelting D L, Laxson C L. (2010). Review of Effects and Costs of Road De-icing with Recommendations for Winter Road Management in the Adirondack Park. Saranac Lake: AdkAction. http://www.protectadks.org/wp-content/uploads/2010/12/RoadDeicing-1.pdf

Kokko A, Gustavsson Tingvall P, Videnord J. (2015). The Growth Effects of R&D Spending in the EU: A Meta-Analysis. Economics E-Journal. DOI: 10.5018/economics-ejournal.ja.2015-40.

Krueger A B. (2007). Are We Having More Fun Yet? Categorizing and Evaluating Changes in Time Allocation. Brookings Papers on Economic Activity 2007(2):193-215.

Layard R, Clark A, Senik C. (2012). The causes of happiness and misery. Pp. 58-89 in Helliwell J, Layard R, Sachs J. (Eds.): World Happiness Report 2012. New York: UN Sustainable Development Solutions Network.

Lean C, Maclaurin J. (2016). The Value of Phylogenetic Diversity. Pp. 19-37 in: Pellens R, Grandcolas P. (Eds).: Biodiversity Conservation and Phylogenetic Systematics. Cham: Springer. (Topics in Biodiversity and Conservation vol. 14)

Liu J, Lewis G. (2014). Environmental toxicity and poor cognitive outcomes in children and adults. Journal of Environmental Health 76(6):130–138.

Llorens C, Pérez-Franco J, Oudyk J, Berthelsen H, Dupret E, Nübling M, Burr H, Moncada S. (2019). COPSOQ III. Guidelines and questionnaire. Freiburg im Breisgau: COPSOQ International Network.

Lohaus D, Habermann W. (2019). Presenteeism: A review and research directions. Human Resource Management Review 29(1):43-58.

Lotze H K, Tittensor D P, Bryndum-Buchholz A, Eddy T D, Cheung W W L, Galbraith E D, Barange M, Barrier N, Bianch Di, Blanchard J L, Bopp L, Büchner M, Bulman C M, Carozza D A, Christensen V, Coll M , Dunne J P, Fulton E A, Jennings S, Jones M C, Mackinson S, Maury O, Niiranen S, Oliveros-Ramos R, Roy T, Fernandes J A, Schewe J, Shin Y-J, Silva T A M, Steenbeek J, Stock C A, Verley P, Volkholz J, Walker N D, Worm B. (2019). Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. Proceedings of the National Academy of Sciences 116(26):12907–12912.

Mace G M, Norris K, Fitter A H. (2012). Biodiversity and ecosystem services: A multilayered relationship. Trends in Ecology & Evolution 27(1):19-26.

Martini R, Innes J. (2018). Relative Effects of Fisheries Support Policies. Paris: OECD Publishing. OECD Food, Agriculture and Fisheries Papers No. 115.

May-Collado L J, Agnarsson I. (2011). Phylogenetic Analysis of Conservation Priorities for Aquatic Mammals and Their Terrestrial Relatives, with a Comparison of Methods. PLoS ONE 6(7):e22562 (10 pages).

Messenger J. (2018). Working time and the future of work. Geneva: International Labour Organization.

Mueller H. (2013). The economic costs of conflict. London School of Economic and Political Science: International Growth Centre.

Murakami K, Itsubo N, Kuriyama K, Yoshida K, Tokimatsu K. (2018). Development of weighting factors for G20 countries Part 2: Estimation of willingness to pay and annual global damage cost. The International Journal of Life Cycle Assessment 23(12):2349-2364.

NAIC (2020). Data from National Association of Insurance Commissioners cited from the Insurance Information Institute website https://www.iii.org/fact-statistic/facts-statistics-auto-insurance (accessed 2020-11-30)

Naidu S, Posner E, Weyl G. (2018). Antitrust Remedies for Labor Market Power. Harvard Law Review 132:537-601.

Nijkamp P. (2012). Economic valuation of cultural heritage. Pp. 75-106 in Licciardi G, Amirtahmasebi R (Eds.): The Economics of Uniqueness: Historic Cities and Cultural Heritage Assets as Public Goods. Washington DC: World Bank.

Nijkamp P, Vindigni G, Nunes P A L D. (2008). Economic valuation of biodiversity: A comparative study. Ecological Economics 67(2):217-231.

Noss R F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4(4):355-364.

Novta N, Pugacheva E. (2020). The Macroeconomic Costs of Conflict. Washington DC: International Monetary Fund. IMF Working paper No. 20/110.

OECD. (2013). OECD Guidelines on Measuring Subjective Well-Being. Paris: OECD Publishing.

OECD (2019a). Measuring distortions in international markets: the aluminium value chain. Paris: OECD Publishing. OECD Trade Policy Papers No. 218

OECD (2019b). OECD.stat dataset: Insurance business written in the reporting country: Premiums written by classes of non-life insurance. https://stats.oecd.org/Index.aspx?DataSetCode=PT5

OECD (2020a). Agricultural Policy Monitoring and Evaluation. Paris: OECD Publishing.

OECD (2020b). Measuring consumer detriment and the impact of consumer policy: Feasibility study. Paris: OECD Publishing. OECD Digital Economy Papers No. 293

Orgill-Meyer J, Pattanayak S K. (2020). Improved sanitation increases long-term cognitive test scores. World Development 132:104975 (20 pages).

Paini D R, Sheppard A W, Cook D C, De Barro P J, Worner S P, Thomas M B. (2016). Global threat to agriculture from invasive species. Proceedings of the National Academy of Sciences 113(27):7575-7579.

Peterson C, Kearns M C, McIntosh W L, Estefan L F, Nicolaidis C, McCollister K E, Gordon A, Florence C. (2018). Lifetime Economic Burden of Intimate Partner Violence Among U.S. Adults. American Journal of Preventiver Medicine 55(4):433-444.

PIAAC (2019). Skills Matter: Additional Results from the Survey of Adult Skills. OECD Skills Studies. Paris: OECD Publishing. https://doi.org/10.1787/1f029d8f-en

Proost S. (2018). Reforming Private and Public Urban Transport Pricing. Paris: OECD Publishing. International Transport Forum Roundtable Discussion Paper 170.

Psacharopoulos G. (1994). Returns to Investment in Education: A Global Update. World Development 22(9):1325-1343.

Ramey A V, Francis N. (2009). A Century of work and leisure. American Economic Journal: Macroeconomics 1(2):189–224.

Rees N, Fuller R. (2020). The Toxic Truth: Children’s Exposure to Lead Pollution Undermines a Generation of Future Potential. New York: UNICET and Pure Earth.

del Rosal I. (2011). The empirical measurement of rent-seeking costs. Journal of Economic Surveys 25(2):298-325.

Sacks D W, Stevenson B, Wolfers J. (2010). Subjective Well-Being, Income, Economic Development and Growth. Cambridge, MA: National Bureau of Economic Research. (NBER Working Papers 16441)

Shi X, Qin T, Nie H, Weng B, He S. (2019). Changes in Major Global River Discharges Directed into the Ocean. International Journal of Environmental Research and Public Health 16(8):1469 (19 pages).

Singh S, Sedgh G, Hussain R. (2010). Unintended pregnancy: Worldwide levels, trends, and outcomes. Studies in Family Planning 41(4):241-250.

Sinha M. (2013). Measuring violence against women: Statistical trends. Juristat. Component of Statistics Canada catalogue No. 85-002-X. Ottawa: Statistics Canada.

Sønderskov K M, Dinesen P T. (2014). Danish Exceptionalism: Explaining the Unique Increase in Social Trust Over the Past 30 Years. European Sociological Review 30(6):782-795.

Sørensen P B. (2014). Measuring the deadweight loss from taxation in a small open economy. A general method with an application to Sweden. Journal of Public Economics 117:115-124.

Spezzano P, Tidblad J, Bojić M, Brüggerhoff S, Faller M, Grøntoft T, Verney-Carron A, La Torretta T, Nordänger S, Andersson J. (2019). Inventory and condition of stock of materials at UNESCO world cultural heritage sites. Part III – Economic evaluation. Rome: ENEA. ICP Materials Report no. 86.

Stalker P. (Ed.) (2017). Ending Violence in Childhood. Global Report 2017. New Delhi: Know Violence in Childhood.

Sudfeld C R, McCoy D C, Danaei G, Fink G, Ezzati M, Andrews K G, Fawzi W W. (2015). Linear Growth and Child Development in Low- and Middle-Income Countries: A Meta-Analysis. Pediatrics 135(5):e1266-e1275.

Sully E A, Biddlecom A, Darroch J E, Riley T, Ashford L S, Lince-Deroche N, Firestein L, Murro R. (2020). Adding It Up: Investing in Sexual and Reproductive Health 2019. New York: Guttmacher Institute.

Sumaila U R, Ebrahim N, Schuhbauer A, Skerritt D, Li Y, Kim H S, Mallory T G, Lam V W L, Pauly D. (2019). Updated estimates and analysis of global fisheries subsidies. Marine Policy 109:103695 (11 pages).

Swiss Re. (2020). World insurance: Riding out the 2020 pandemic storm. Sigma no. 4/2020.

Tamborini C R, Kim C H, Sakamoto A. (2015). Education and Lifetime Earnings in the United States. Demography 52(4):1383–1407.

Tassey G. (2004). Underinvestment in Public Good Technologies. The Journal of Technology Transfer 30(1-2):89–113.

Taylor M. (2020). Energy subsidies: Evolution in the global energy transformation to 2050. Abu Dhabi: International Renewable Energy Agency.

Toan T D. (2016). Water Pricing Policy and Subsidies to Irrigation: a Review. Environmental Processes 3(4):1081–1098.

UNDP. (2020). Human Development Index and its components. New York: United Nations Development Programme. http://hdr.undp.org/sites/default/files/2020_statistical_annex_table_1.xlsx

UNESCO (2017). The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris: United Nations Educational, Scientific and Cultural Organization.

Vara Horna A A. (2013). Los Costos Empresariales de la Violencia contra las Mujeres en el Perú. Lima: Universidad de San Martín de Porres.

Vara Horna A A. (2015). Los costos empresariales de la violencia contra las mujeres en Bolivia. La Paz: Cámara de Comercio e Industria Boliviano-Alemana.

Vyas S. (2013). Estimating the association between women's earnings and partner violence: Evidence from the 2008-2009 Tanzania National Panel Survey. Washington DC: World Bank. Women's Voice, Agency, & Participation Research Series 2013 No.2.

VISES. (2014). The Impact of Health on Worker Attendance and Productivity in the APEC Region. Melbourne: Victoria Institute of Strategic Economic Studies.

Walk Free Foundation. (2018). The Global Slavery Index 2018. Perth: Walk Free Foundation. Dataset from https://www.globalslaveryindex.org/resources/downloads/

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.

Weidema B P. (2009). Using the budget constraint to monetarise impact assessment results. Ecological Economics 68(6):1591-1598.

Weidema B P. (2018). The social footprint – A practical approach to comprehensive and consistent social LCA. The 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. Cambridge, UK: Burleigh Dodds Science Publishing.

Weidema B P. (2020). An exhaustive quantitative indicator and impact pathway framework for sustainable development. Draft manuscript 2020-08-10. Aalborg: 2.-0 LCA consultants.

Weidema B P, Fantke P. (2018). Relating the Global Burden of Disease to life cycles. Procedia CIRP 69:417–422.

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.

WHO, World Bank. (2017). Tracking universal health coverage: 2017 global monitoring report. Geneva: World Health Organization.

WHO. (2021). Violence against women prevalence estimates, 2018. Geneva: World Health Organization. Annex 6. https://apps.who.int/iris/handle/10665/341337

Woetzel J, Pinner D, Samandari H, Engel H, Krishnan M, Boland B, Powis C. (2020). Climate risk and response. Physical Hazards and socioeconomic impacts. McKinsey Global Institute. www.mckinsey.com/mgi/

World Bank. (2017). The Sunken Billions Revisited: Progress and Challenges in Global Marine Fisheries. Washington DC: World Bank.

World Economic Forum. (2013). Enabling Trade. Valuing Growth Opportunities. Geneva: World Economic Forum.