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SOCIETAL LCA

Towards a method for quantifying health benefits from economic value in social life cycle assessment

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Abstract

Purpose The economic value generated in processes along product life cycles can satisfy the needs and pleasures of the earners. In this study, we investigate whether that economic value can lead to positive health benefits for workers and other people through subsequent economic exchanges, and whether such benefits can be quantified in the context of social life cycle assessment (SLCA).

Methods A brief literature review on the connection between the generation of economic value and health is provided. This review identifies two main impact pathways: the materialistic pathway and the psychosocial pathway. Of these, this paper focusses on developing characterization factors for the materialistic pathway. They are derived by multiplying a country-level income health factor (IHF) with a process-level value added (VA). The IHF was derived from a regression analysis of country-level life expectancy and income data. The VA can be calculated for each individual process based on differences in constituent and output prices.

Results and discussion IHFs are highest for low-income countries, such as Somalia, and lowest for high-income countries, such as Luxembourg. The characterization factors can be multiplied by flows related to the functional unit, yielding results in disability-adjusted life years (DALY). The approach is illustrated with a simple unit process representing artisanal cobalt mining, showing that the magnitude of positive health impacts from economic value can be considerable, which suggests it is important to consider these in SLCA.

Conclusions This work takes further steps towards developing a method that relates the generation of economic value to positive health impacts, with explicitly calculated characterization factors and fewer constraints compared to previous attempts at assessing health benefits from economic value in SLCA. Limitations include the need for continuous updates of the characterization factors.

Keywords Disability-adjusted life years · Social life cycle assessment · Preston curve · Gross domestic product · Characterization factor

1 Introduction

In most processes along product life cycles, such as resource extraction and manufacturing, economic value is generated. The value generated can be used to satisfy the needs and pleasures of the earners. In this study, we investigate whether the economic value generated along life cycles can lead to health benefits for the workers involved, as well as other people through subsequent economic exchanges, and whether such benefits can be quantified. Positive health impacts have been quantified in several previous social life cycle assessment (SLCA) studies, including Dutch electricity (Norris 2006), airbags (Baumann et al. 2013), catalytic converters (Arvidsson et al. 2018), and tire studs (Furberg

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et al. 2018). In these cases, the positive health impacts were related to the utility (or function) of the studied product, but it has been argued that considering positive impacts beyond product utility is important (Di Cesare et al. 2018). Only two previous SLCA studies have been found that quantify positive health impacts related to economic exchanges rather than the utility of the product.

The first study is Feschet et al. (2013), who developed a social life cycle impact assessment (SLCIA) method capturing how changes in life expectancy at birth (LEX) link to changes in gross domestic product (GDP) per person in a country, called the Preston pathway. The study provided four criteria to be fulfilled for the method to be used: (i) the GDP per person of the country must be < 10,000 USD, (ii) the assessed activity must account for a significant share of the country's GDP (about 1% or more), (iii) the duration of the activity must be long enough (minimum 4 years), and (iv) the added value of the activity must be distributed equally within the country.

The second study is Bocoum et al. (2015), who developed an SLCIA method for how infant mortality changes with varying income distributions due to changes in a life cycle, called the Wilkinson pathway. The Gini coefficient, a measure for how equal or unequal income is distributed in a population, was used for the quantification of income distribution. Due to the use of country-level data, this method is constrained in terms of when it can be used, as the economic activity assessed must be large at a national scale.

These two studies thus constitute important foundations for further development of methods relating income to health. However, none of the studies provide characterization factors (CFs), which is important for enabling practical use of the method. In addition, the criteria outlined limit the situations in which the methods are applicable.

In this context, a third study can also be mentioned. Hutchins and Sutherland (2008) discussed several options for social indicators across supply chains, eventually proposing and testing a weighted index involving companies' health care expenses. These were aggregated with measures of labour equity, safety and philanthropy, and then multiplied with the value of the product produced. Although this approach does not consider actual impacts on health, it does relate a proxy of health impacts (healthcare expenses) to economic value.

Building on this previous research, the aim of this paper is to take further steps towards developing an SLCIA method that relates the generation of economic value to positive health impacts, with explicitly calculated CFs and reduced constraints. Within SLCA, a difference is made between SLCIA methods based on relative reference scales reflecting company performance (type I) and social impact pathways (type II) (UNEP 2020). Since this work concerns a pathway of causal relationships between economic value and health, it falls within the type II impact assessment classification. Before the proposed method is presented, a brief literature review on the connection between the generation of economic value and health is provided. After the method description, a simple application of the proposed method is provided for a unit process representing artisanal cobalt mining in the Democratic Republic of the Congo (DRC). Finally, the proposed method is contrasted to previous work and suggestions for future research are provided.

2 Literature review

On the most fundamental level, as stated by the constitution of the World Health Organization, health is a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity (WHO 1946). The state of health can be altered negatively and positively in many different ways. Records of the most important direct causes of death globally is available, topped by diseases such as heart attacks, strokes, and cancer, but also include accidents, suicides, and homicides (Roser 2021). In this study, we are interested in the socioeconomic mechanisms *behind* these direct causes. Differences in health and longevity due to socioeconomic status and social relationships have been addressed in many studies — some from as far back as the 1800s — and in general, these studies have found that individuals with high socioeconomic status who are more socially integrated experience lower rates of morbidity and mortality (Goldman 2001). Such health status and social integration can be measured in different ways, such as by income, education level, wealth, occupation and income inequality (Robert and House 2000).

As noted by Feschet et al. (2013), a foundational work related to income and health is that by Preston (1975), who showed that there is a positive monotonic relationship between LEX and national average income per person when a wide range of countries was considered. However, at a certain level of income, the curve flattens, obtaining a much lower albeit still rising slope. This suggests a positive relationship between health and income, which is particularly strong in low-income countries and weaker in high-income countries. Although the relative importance of the mechanisms underpinning this relationship is subject for discussion, the relationship itself is still considered valid (Bloom and Canning 2007). Specifically, the causality has been shown to mainly go from income to health, rather than the other way around (Goldman 2001; Robert and House 2000), although there might be elements of a reinforcing two-way relationship (Gupta and Mitra 2004; Khullar and Chokshi 2018). In other words, 'the causal direction is from wealth to health' (Rajan et al. 2013).

This positive relationship between income and health, i.e. that 'wealthier is healthier', has also been confirmed by more local studies, e.g. in Latin America (Biggs et al. 2010), India (Rajan et al. 2013), the United States (Ashiabi and O'Neal 2007; Chetty et al. 2016; Fiscella and Franks 1997), Canada (Gupta et al. 2007), Ireland (Madden 2011) and Australia (Kendall et al. 2019). There are several factors that prevent poor people from attaining good health, such as lack of health care, lack of sanitation and malnutrition from low spending on food (Banerjee and Duflo 2007).

Another important finding, which forms the basis for the Wilkinson pathway proposed by Bocoum et al. (2015), is that reduced economic inequality also leads to improved health. This was first observed by Wilkinson (1992) and has also been shown in several settings, e.g. in Latin America (Biggs et al. 2010).

The two perspectives on socioeconomic causes of health can be combined into a joint conceptual model with two distinct pathways as shown in Fig. 1 (Rajan et al. 2013). The first pathway can be referred to as the *materialistic pathway*, which forms the basis for the Preston curve and the Preston pathway. Increased income leads to improved health, partly at the individual (micro) level due to the possibility to purchase more food and medicine, but also at the societal (macro) level due to health-improving investments in, for example, health care and sanitation. Another potential mechanism through which income can lead to improved health is that higher income yields a higher feeling of economic security, which has a positive influence on mental health (Kendall et al. 2019). The second pathway can be referred to as the *psychosocial pathway* since it acts through the minds of people. At the individual level, inequality leads to feelings of disadvantage that generate stress, depression and similar mental problems. This leads to unhealthy behaviours such as drinking and smoking. At the societal level, these feelings manifest themselves in terms of reduced civic participation and social trust, which affect the health of others negatively (also those with higher incomes). Therefore, because of reduced unhealthy behaviour at the individual level and improved trust at the societal level, reduced inequality improves health. It has been noted that the materialistic pathway is more significant in low-income countries, whereas the psychosocial pathway is more significant in high-income countries (Rajan et al. 2013). The flipsides of these two pathways can be referred to as 'poor material conditions', obstructing the materialistic pathway, and 'lack of social participation', obstructing the psychosocial pathway (Marmot 2002).

Several factors can influence these pathways, that is, modify their strength. For example, corruption reduces the efficiency by which income is taxed and used for investments in infrastructure, as well as reduces trust in society (Achim et al. 2020). Profit shifting to other countries by multinational companies also reduces the income that is taxed and can be used for health-improving investments (O'Hare 2018).

3 SLCIA method development

Given the state-of-play regarding socioeconomic causes of health status presented in the previous Sect. 2, the attention is now set on how this can be applied in SLCA. Foundational to any LCA is the assessment of impacts of products (Finnveden et al. 2009; ISO 2006). Of the two pathways outlined in Fig. 1, the materialistic pathway is more clearly related to products and their life cycles. Extracting raw materials, producing goods and recycling scrap into new and valued products — as well as using products to provide sellable services — can generate economic value, which in turn can be linked to improved health as per the materialistic pathway. Inequality, on the other hand, is largely an emergent

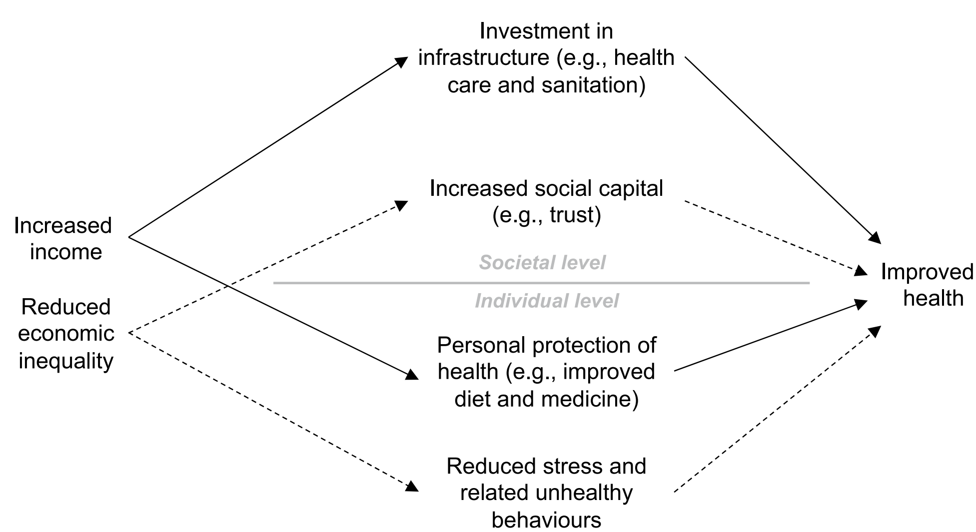

Fig. 1 Graphical illustration of the materialist pathway (full arrows) and the psychosocial pathway (dashed arrows). Modified from Rajan et al. (2013)

phenomenon that arises from differences in economic value across a region. It is challenging to attribute such differences to a single product, as income distributions typically involve economic value generated from a plurality of products.

Thus, this paper focusses on the implementation of the materialistic pathway in SLCA while acknowledging that the psychosocial pathway is also important (Marmot 2002; Robert and House 2000). Below, we propose an approach to deriving CFs for this pathway by combining parameters related to the country (Sect. 3.1) and the process (Sect. 3.2) where the product is produced, used or disposed. Regarding stakeholders, the pathway covers health impacts on effectively all people within the countries where the processes occur, including workers, consumers, children, the local community and society. Possibly, highly isolated communities not influenced by, e.g. public investments in health care and sanitation, would not be affected by the pathway.

3.1 Country-level health factor

CFs that quantify how economic value influences health need to relate an 'amount of economic value' to an 'amount of health'. In search of starting point for a mathematical formulation, and considering the previous use of the disability-adjusted life years (DALY) indicator in both SLCA (Arvidsson et al. 2022, 2018; Norris 2006) and environmental LCA (Goedkoop and Spriensma 1999; Huijbregts et al. 2017), operationalizing 'health impact' as DALY seems convenient. Additionally, the most established quantitative relationship between economic value and health is the above-mentioned Preston curve. Like Feschet et al. (2013), we thus find it reasonable to base an SLCIA method linking economic value to health impacts on that curve, since it relates the LEX (unit: life-years/person, similar to the life-years of DALY) to income generated (unit: USD/person). For the given year 2020, using all country-level data provided by Gapminder (www.gapminder.org), we plotted the LEX against the annual GDP per person (purchasing power parity inflation adjusted), resulting in Fig. 2. The GDP per person is used as a proxy for income and the purchasing power parity means that the GDP values are unaffected by, e.g., sudden changes in currency exchange rates. United States dollars (USD) is used as measure of economic value in this paper, but of course, other currencies can also be used.

We then performed a regression analysis, in which a relationship is estimated between two variables (LEX and annual GDP per person in this case). The regression was performed in MS Excel, using the least square method. A logarithmic trendline was found to fit the data best. This was determined by the coefficient of determination (R^2), which tells the proportion of the dependent variable (LEX in this case) that is predictable from the independent variable (annual GDP per person in this case). Values close to 1 represent a good fit, whereas values close to 0 represent a poor fit. The logarithmic curve much resembles the monotonic curvilinear line seen in Preston's (1975) original work (Fig. 2). The equation describing the curve is as follows:

$$\mathrm{LEX}_i = 4.73 \times \ln\left(\mathrm{GDP}_i\right) + 28.7 \tag{1}$$

where GDP_i is the purchasing power parity inflation adjusted GDP per person for country i and LEX_i is the life expectancy at birth in country i. The R^2 value is about 0.68, which is deemed acceptable considering the notable spread in data according to Fig. 2. The total degrees of freedom in the regression, i.e. the number of countries with LEX and GDP data minus one, are $186 - 1 = 185$. The p value, which tells the likelihood that the observed data could occur by chance, is < 0.00001, suggesting that the relationship is significant.

While Eq. 1 tells how the LEX varies due to GDP, it does not reveal how a certain amount of value generated influences health. We are here interested in how LEX changes due to changes in GDP, measured in the unit 'amount of health impact per amount of economic value'. This can be obtained by taking the derivative of Eq. 1, which tells how the output parameter (LEX) changes due to changes in input parameter (annual GDP per person). In other words, the derivative is the slope of a curve, such as the one in Fig. 2. The derivative of Eq. 1 with regard to GDP is thus calculated, resulting in:

$$\frac{\partial \mathrm{LEX}_i}{\partial \mathrm{GDP}_i} = \frac{4.73}{\mathrm{GDP}_i} \tag{2}$$

Equation 2 thus represents the marginal change in LEX from a change in GDP in country i (unit: life-years/USD).

The change in LEX corresponds to an equal change in DALY, specifically in the years of life lost (YLL) component of the DALY indicator (the other component being years of life disabled, YLD) (Murray 1994). However, in this case, contributions to the GDP will lead to years *gained* rather than *lost*, i.e. to negative DALY. Consequently, we here define a negative parameter that represents the country-level income effect on DALY in country i, which we name the income health factor (IHF, unit: life-years/USD):

$$\mathrm{IHF}_i = -\frac{4.73}{\mathrm{GDP}_i} \tag{3}$$

This equation is plotted in Fig. 3 for the reference year 2020. The IHFs represent the slopes (rates of change) at different points on the Preston curve, giving large health improvements (negative DALY) for low-income countries on the left side of the curve (below 20,000 USD/person), such as Somalia, Burundi and the Central African

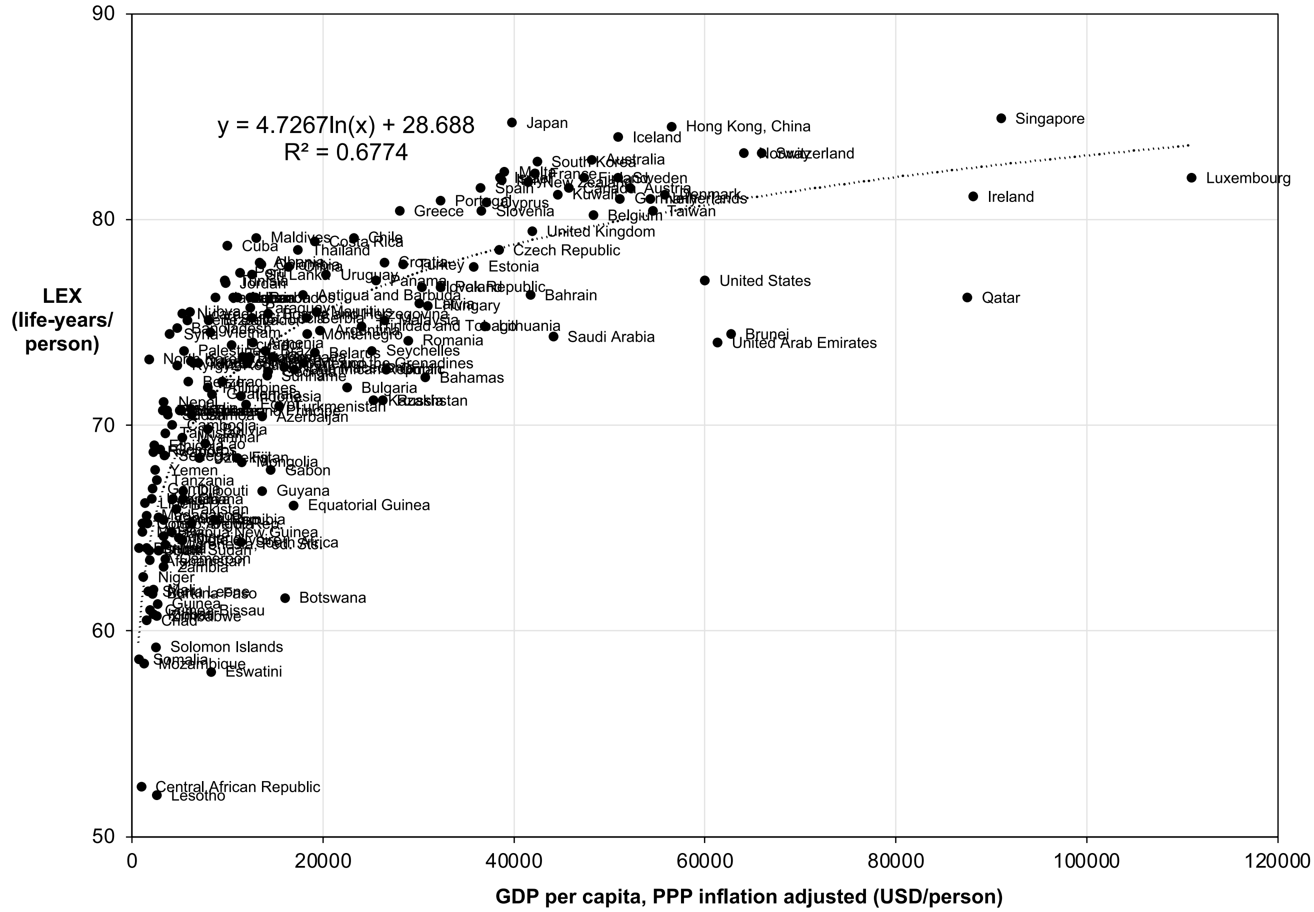

Fig. 2 The Preston curve redrawn for the year 2020 using data from Gapminder (www.gapminder.org), provided in Table S1 in the Supplementary Material. Dotted line shows logarithmic regression. In the regression line equation, the parameter *y* corresponds to LEX and the parameter *x* corresponds to annual GDP per person (PPP inflation adjusted). LEX, life expectancy at birth; GDP, annual gross domestic product per person; PPP, purchasing power parity; USD, United States dollar

Republic. Contrary, for high-income countries on the right side of the curve (above 20 000 USD/person), such as Luxemburg, Singapore and Qatar, the health improvements are lower. A list of IHFs for all countries and data used for the calculations are provided in Table S1 in the Supplementary Material (SM). In addition, average IHFs are also provided for 'low-income countries', 'high-income countries' and 'all countries'. These can be applied as proxies in cases when the exact country of origin is unknown.

3.2 Process-level value added

The country-level IHFs tell how many life-years are generated from a certain generation of economic value in the unit life-years/USD. These factors need to be matched with a measure of how much a certain amount of reference flow contributes to the GDP of a country, in USD/output, in order to tell how many life-years that output generates. Such a factor corresponds to the value added by the output from a process *j*. This value is calculated as the market value of all outputs from a process minus the market value of all inputs. In each process, value is added, which can be summed to the final value of a product. The value generated by all products and services can, in turn, be summed to the GDP of the country where the activities occur. In reality, the value generation might not always benefit the population of the specific country — for example, a share of this value might be sent to owners abroad. Still, the Preston curve shows a correlation between the total value added by all economic activities in a country (i.e. the GDP) and the LEX. This value addition can then be interpreted such that processes that add much value per output also contribute much to improvements in health.

A note can be made here that there are two ways to calculate GDP. The 'income approach' sums all net incomes, which is why GDP per person is a good measure of income in the Preston curve. The 'value-added approach' instead sums the value added by all processes in the economy.

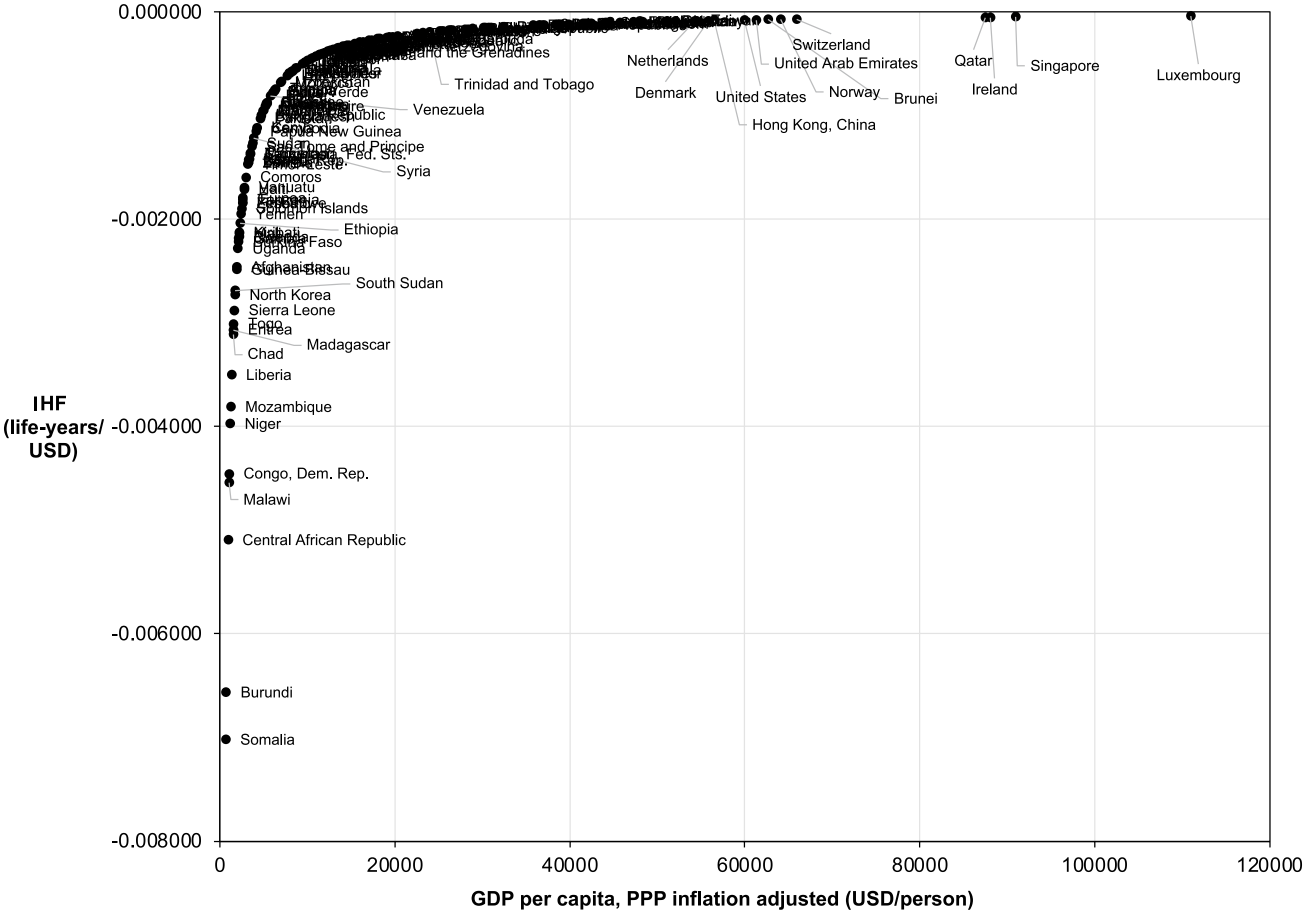

Fig. 3 Country-level income health factors (IHFs) plotted against the annual GDP per person (purchasing power parity (PPP) inflation adjusted), according to Eq. 3. The data underpinning the figure can be found in Table S1 in the Supplementary Material

This is why the value added can be used here, even though income is used in the Preston curve — they both add up to the GDP.

3.3 Combined characterization factor

Combined CFs for the materialistic pathway can be derived by multiplying the country-level IHF with the value added (VA) in the process[1]:

$$CF_{ij} = IHF_i \times VA_j \tag{4}$$

Considering that the unit of the IHF is life-years/USD and the unit of the VA is USD/output, the unit of the CF becomes life-years/output. The CF can be multiplied by an inventory flow with the unit output/functional unit (e.g., kg of lithium brine required per person-km of an electric car) to obtain a final impact score (DALY) with the unit life-years/functional unit. Consequently, the inventory flow data needed for this SLCIA method is the same as in environmental LCA — physical flows of energy and materials in activities that generate economic value. However, for the calculation of the CF, economic data is also needed to calculate the VA. In Sect. 5, we illustrate with a limited example how this proposed SLCIA method can be applied in practice.

4 Illustration of the developed method

Artisanal cobalt mining in the DRC constitutes an interesting case for social assessments, since it has been associated with various social impacts, such as hard working conditions and child labor (Sovacool 2019; Tsurukawa et al.

[1] Note that this CF construction by multiplying several factors is mathematically similar to the USEtox impact assessment method for (eco)toxicity, where the CF is derived by multiplying the fate factor (FF), exposure factor (XF), and effect factor (EF): $CF = FF \times XF \times EF$ (Rosenbaum et al. 2008). An alternative option could have been to place the VA as part of the inventory, since it is an economic flow. However, we here instead choose to adhere to the notion of inventory flows common in (environmental) LCA.

2011). Previous studies have performed qualitative SLCA of responsible sourcing initiatives for cobalt (Mancini et al. 2021), assessed the total wellbeing of cobalt mining (Orola et al. 2022), begun gathering inventory data for future SLCA of artisanal cobalt mining (Bamana et al. 2021) and assessed negative health impacts from emissions and occupational accidents during artisanal and industrial cobalt mining (Arvidsson et al. 2022), but no study has so far quantitatively assessed the possibility of positive health impacts of artisanal cobalt mining.

As illustration, we apply the proposed SLCIA method for positive health impacts to a simple unit process representing artisanal cobalt mining in the DRC with 1-kg cobalt content (i.e. pure cobalt) as reference flow. Such mining is typically done with basic low-tech tools, such as hatches, shovels and buckets (Sovacool 2019). The market value of inputs per kg of cobalt extracted can thus be assumed negligible. As described by Gaedicke et al. (2020), prices at depots where artisanal cobalt is sold vary considerably depending on grade and over time. However, over time (2000–2020), the cobalt ore price has varied roughly between 10 and 40 USD/lb cobalt content (Gulley 2023) or approximately 20–90 USD/kg. Assuming this range roughly reflects the market value of the outputs, the value added to the economy by this activity can be approximated as 20–90 USD/kg cobalt content. Multiplying this value by the IHF for the DRC (-0.0045 years/USD) according to Eq. 4 gives the range -0.09 to -0.4 years/kg cobalt content.

This range can be compared to the negative health impacts from fatal accidents in artisanal cobalt mining in the DRC. In a previous study (Arvidsson et al. 2022), we estimated these at 0.0028 years/kg cobalt content. This value is based on estimated 2000 annual fatalities in artisanal cobalt mining in the DRC (MacDonald and Pokharel 2020). These fatalities were converted to DALY by multiplying with the difference between the average LEX in the DRC (61 in 2021) and the median age of artisanal cobalt miners in the DRC (25 years according to Elenge et al. 2013), that is, the number of years lost given a fatal accident for a miner. These health impacts were then distributed over the annual output of cobalt content from artisanal mining in the DRC (average over 2009–2015 according to Al Barazi et al. 2017) to obtain the number of DALY per cobalt content output.

Importantly, the positive and negative health impacts from artisanal cobalt mining in the DRC presented here are calculated in different ways. Both calculations involve uncertainties, and the impacts affect different stakeholders. The negative ones are obtained from estimated fatality data and affect workers directly. The positive ones are calculated based on the more macroeconomic materialistic pathway and affect a wide range of stakeholders. Still, the range of positive health impacts is 30–140 times higher than the negative health impacts from the fatal accidents. This indicates that the magnitude of positive health impacts from economic value can be considerable, which suggests it is important to consider these in SLCA studies that include health impacts. However, since different stakeholders are impacted, the results should not be seen as an argument against reducing negative health impacts related to accidents in artisanal cobalt mining in the DRC. As Sovacool (2019) writes, it is important to reduce negative health impacts on artisanal cobalt miners in the DRC by enforcing better occupational standards.

5 Discussion

As mentioned in Sect. 1, Feschet et al. (2013) provide four conditions for their Preston pathway SLCIA method to be justified for use. Feschet et al. (2013) also eliminated all countries with high HIV prevalence in their data. Below, we discuss the present work in relation to these conditions.

Regarding (i) that the gross domestic product (GDP) of the country must be $< 10{,}000$ USD, such a requirement is not included in the proposed SLCIA method because income-related health differences are present also between high-income countries, albeit to a lower extent. For example, even high-income countries such as Belgium can increase their income per person and thus also the LEX to, for example, that of Switzerland. However, as can be seen in Fig. 3, high-income countries have comparatively low CFs in the proposed SLCIA method, so a higher value must be added to achieve the same health improvement as in a low-income country.

Regarding (ii) that the assessed activity must account for a significant share of the country's GDP, no such requirement was included in the proposed SLCIA method either. The subdivision of activities in LCA is arbitrary — an activity can be aggregated into a large activity (which can be referred to as an aggregated process or system process; Zhang et al. 2021) or disaggregated into small unit processes, sometimes reflecting data availability or the willingness to disclose modelling details. Feschet et al. (2013) studied the banana industry in Cameroon, but this activity can be disaggregated (e.g. into different steps or banana production in different Cameroonian regions) or aggregated (e.g. to the Cameroonian fruit industry or Central African banana industry). The higher the aggregation, the more likely is the activity to contribute notably to a country's GDP.[2]

[2] In fact, having multiple smaller economic activities that contribute to a country's prosperity (i.e. economic diversification), rather than a few bigger ones, is generally considered beneficial for economic development (Fruman 2017).

Regarding (iii) that the duration of the activity must be long enough, it is probably correct that an activity needs to have a long-enough duration to have an influence on the LEX. A brief 'pulse value added' to an economy would likely not influence the LEX. However, a continuous duration is conventionally assumed in life cycle inventory (LCI) modelling, as described by Ciroth et al. (2021): 'LCI is indeed implemented by assuming an 'infinite' flow of products, from one process to the next one in a given life cycle, in consecutive periods of time […] and by assuming that all the involved technologies were to remain the same […].' Sudden production halts or bankruptcies are rarely considered. This condition is thus in line with conventional LCI modelling.

Regarding (iv) that the value added of the activity must be distributed equally within the country, it is correct that value added in a country without sufficient distribution contributes less to health improvements. This is partly captured in the regression analysis by considering 'net LEX' data, which is already influenced by various unfavourable factors, such as corruption, income inequality, HIV prevalence and companies sending profit overseas. However, the outcome of the regression analysis considers the average effect of such factors across countries. This means that for specific countries where such factors are particularly prominent, the health impacts derived from this SLCIA method might be overestimated (countries below the graph in Fig. 2) or underestimated (countries above the graph in Fig. 2). An example of the former is Botswana and Eswatini, both with HIV prevalence > 20%. An example of the latter is Cuba, with its high income distribution and economic equality. In the illustration of the developed method in Sect. 4, the positive health impact is likely overestimated because cobalt mining companies in the DRC tend to be Chinese owned, and part of the value added is transferred to China or benefits Chinese citizens living in the DRC (Kara 2023). This constitutes a limitation of the developed method that can lead to over- and underestimations, but does not render the method invalid.

It can also be noted that there is a correlation between condition (i) and condition (iv): Poorer countries tend to have higher corruption (Ambraseys and Bilham 2011). Restricting an SLCIA method to low-income countries with low corruption would thus leave a relatively small number of countries left, which would limit the usefulness of the SLCIA method. Imposing these two conditions, particularly at the same time, should thus preferably be avoided.

Importantly, the developed SLCIA method is based on country-level income and LEX data for the IHF, thus representing a macroeconomic perspective. In microeconomic contexts, there might be regional or sectorial factors that influence the accuracy of the method, especially in countries with large variations across regions and industry sectors. For example, the Chinese influence on the cobalt mining in eastern DRC mentioned above can lead to less value added going to health improvements than for some average value added generated in the DRC. Conversely, the microeconomic situation can theoretically have a more positive influence on health. An example could be that a company invests some of its revenues into health-improving infrastructure, thereby directing a larger share of the value added towards improving health. The possibility to differentiate between value added in such different microeconomic contexts in the CFs constitutes an area of possible future improvement of the proposed SLCIA method. Until such improvements have been implemented, the proposed SLCIA method should be considered assessing *potential* rather than *actual* health impacts, in line with impact assessment in environmental LCA (Finnveden et al. 2009).

From a practical perspective, to avoid the need for frequent updates, it is a merit of any LCIA method to not be time sensitive (Arvidsson et al. 2020). However, the social system arguably changes more rapidly than does the natural system often considered in environmental LCIA. Therefore, a higher time-sensitivity should be expected in SLCIA. The shape of the Preston curve has remained the same since the 1970s, but the income levels and LEX are increasing over time. Since the proposed SLCIA method considers the relative change in LEX given a change in income (∂DALY/∂GDP), the IHFs derived will likely not change as rapidly as the underlying data. However, there is still a need to update the proposed method regularly to ensure the values remain accurate, for example, every 10th year. Updated IHFs can be calculated using the provided method, also in the future.

The VA is even more time-sensitive than the IHF and might need to be derived anew recurringly, e.g. each year considering the quick changes in prices for many unit processes. For example, as discussed in Sect. 4, prices on cobalt have varied by approximately a factor of four during 2000–2020 (Gulley 2023). Prices of many other metals, such as lithium, have also been volatile over the last decade. A wide time range (2000–2020) for prices has been considered in this study, which could be recommended in sensitivity analyses in future applications of the proposed SLCIA method.

6 Conclusions

This study presents an SLCIA method that assesses positive health impacts from economic value through the materialistic pathway, building on previous work on the Preston pathway (Feschet et al. 2013). IHFs for effectively all countries in the world are provided, along with average IHFs for low- and high-income countries. Combining these with case study–specific data for the VA generated in each process, corresponding CFs can be calculated. Limitations include the use of average data across countries and the need for continuous updates of the IHFs as the input parameters (incomes and life expectancies) change over time. The SLCIA method was tested on the case of artisanal cobalt mining in the DRC, but additional testing would be valuable to verify the feasibility of the method and identify further room for improvement. The incorporation of microeconomic considerations into the CFs would constitute an important methodological improvement. Furthermore, as this study focuses on the materialistic pathway, further development of SLCIA methods based on the psychosocial pathway is recommended, building on previous work by Bocoum et al. (2015). Finally, health is but one of many important social impacts. So far, only some social impacts have been described in terms of impact pathways in the SLCA field (Sureau et al. 2020; Ugaya et al. 2023). When more impact pathways have been developed, the question of how and if these impacts can be aggregated to facilitate interpretation can be addressed.

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Author contribution Rickard Arvidsson: conceptualization, methodology, formal analysis, investigation, data curation, writing (original draft), visualization, project administration, funding acquisition.

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Declarations

Conflict of interest The authors declare no competing interests.

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