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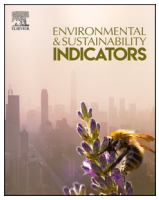

In search for ground rules for product-oriented full cost accounting methods: Ensuring construct validity

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ABSTRACT

Product value chains cause environmental and social impacts, of which many are currently unaccounted for in the price of products. Several methods exist to calculate the pressures of such impacts, as well as their monetization. In the context of life cycle assessment (LCA), expressing environmental and social impacts in monetary terms allows for aggregation and easier communication. Many methods for monetization exist, with fundamental differences in their underlying monetization approach, accuracy, availability and application. Scientific and private sector initiatives have introduced full cost accounting methods that also use different monetization approaches. We reflect on the differences between such existing methods. First, we review the foundations of monetization and introduce a new categorization to align terminologies. We summarize the connections between monetization and life-cycle assessment methods, since both categories of methods can be seen as the building blocks of existing full cost accounting methods. We then sketch the monetization landscape and its challenges. Next, we inventory current product-oriented full cost accounting methods and, through interviews with their developers, provide insights into their underlying monetization philosophy, data sources and quality, scoping, aggregation, and transparency. From this review, we propose four *provisional* ground rules for product-oriented full cost accounting methods in the discussion section, addressing theoretical framing, the time dimension, the integration of positive impacts and the methods' transparency.

1. Introduction

The increasing consumption of goods and products is a key cause of increasing sustainability challenges along their value chain (Bocken and Short, 2016). Value chain impacts from resource extraction, manufacturing, the product's use and disposal have led to an exceedance of the earth's biophysical carrying capacity limits, while complex social issues such as poverty persist (O'Neill et al., 2018). Many of such value chain impacts are currently unaccounted for in the price of products, in which case they are called externalities (Pizzol et al., 2015). Such externalities affect the welfare of people in places that are often distant from where the products are purchased and consumed and the potential for welfare of future generations (Bithas, 2011).

Transitioning towards a more sustainable and equitable society demands eliminating harmful impacts throughout the value chain of products. The United Nation's Sustainable Development Goals (SDGs) define the end goal of sustainable development as "eradicating poverty in all its forms and dimensions, combating inequality within and among countries, preserving the planet, creating sustained, inclusive and sustainable economic growth and fostering social inclusion, which are linked to each other and are interdependent" (United Nations General Assembly, 2015). To achieve this end goal, the ultimate solution to eliminating harmful impacts, or externalities, would be to correctly price them, or in other words: 'internalize the costs of preventing these impacts': the value of welfare loss is then paid by the agent causing the externality as an amount equal to the prevention or damage cost (Weidema et al., 2013).

The concept of Sustainable Development can be framed along three axes: the issues dimension (people, planet, prosperity; or PPP), time dimension (past, now and then) and place dimension (I, here and there) (Vermeulen, 2018). With respect to the 'issues' dimension, the academic fields of environmental and social impact assessment have developed methods for businesses to calculate the pressures on the people, planet and prosperity domains, to be able to quantify and manage them. Such measurement can have at least four purposes: as a source for decision making and management, as a tool in advocacy, as input for

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participation and consensus building, and as tool for research and analysis (Parris and Kates, 2003). Among such methods, one of the most widely used is life cycle assessment (LCA), which consists of the compilation and evaluation of the inputs, outputs and a wide range of potential environmental impacts of a product system throughout its life cycle (ISO, 2006). For a product's social impacts, Social Life Cycle Assessment (S-LCA) is available with a guidance framework (Benoît Norris et al., 2020).

One benefit – and complication - of such life cycle thinking methods is that they enable expressing potential impacts on a wide range of impact categories, using multiple indicators. When using the commonly used ReCiPe method for environmental LCA, for example, 18 midpoint impact categories are included (Huijbregts et al., 2017). A key challenge of LCA, S-LCA and various other methods is to communicate this complex web of product-level impacts in a convincing and understandable manner, allowing both businesses as well as policy makers and consumers to understand, engage and intervene (Galindro et al., 2019). Having multiple impact indicators requires an expert audience for interpretation and correct attribution. Meanwhile the trade-offs between different impact categories complicate decision-making and communication, as interactions between the various SDG's need to also be carefully considered (Hellweg and Canals, 2014).

To enable easier communication, aggregation and interpretation of results for each of the different impact categories, can be applied by means of various valuation and weighting methods (Ahlroth, 2014). One potential weighting approach is the monetary valuation of environmental (or, in the case of S-LCA, social) impacts. Generally, this means that the impacts on the different environmental impact categories are assigned a monetary value, allowing for their aggregation. A variety of such approaches exists, each having (sometimes subtle) differences in their underlying monetization approach, accuracy, availability and application (Amadei et al., 2021). A shared trait of those monetary valuation methods is that they are closely related to the concept of externalities. Currently, products are often 'too cheap', with considerable costs of damage to the environment and people (externalities) not being included in the transaction price (Croes, 2021). Monetary valuation methods often seek to quantify such externalities. These approaches enable revealing – and adjusting – such hidden costs to the planet and our society. This can serve as a tool in the creation of shared value along the value chain as prompted by (Porter and Kramer, 2011).

Not all sustainability scientists welcome monetization approaches for measuring impacts (e.g. Barter, 2016). Pizzol et al. argue that ethical objections to monetary valuation stem from a position commonly found in strong sustainability approaches, stating that some values are non-tradable, and from the misunderstanding that monetary valuation can attach a monetary value to e.g. human life or biodiversity in absolute terms (Pizzol et al., 2015). Others argue that there are good reasons for identifying the order of magnitude of environmental impacts by converting them into monetary terms, as this places them in relation to the real economy, and hereby facilitates decision making (Amadei et al., 2021).

Several scholars and initiatives have proposed more structured approaches to disclose the hidden cost of products, combining knowledge from different monetary valuation methods. Often, these are framed as 'total', 'true', or 'full' cost methods to calculate the 'total economic value': the sum of its use and non-use values (Turner et al., 1994). These methods use a combination of different monetary valuation approaches and methods. A few examples are KPMGs True Value method, the True Price method and the Oiconomy Pricing method. Thus far, an overview of methods specifically in the food sector has been published (see de Adelhart-Toorop, 2021), but a more zoomed-out methodological reflection on such methods is still lacking. Observing the urgency to provide such a reflection to fill this gap, this article aims to stimulate the scientific debate on such '*full cost accounting*' (FCA) methods and work towards increased construct validity on the topic. Given both the proliferation of the use of - and need for - FCA methods, this article inventories those that focus on the product level, and address both the environmental as well as social domain. From this inventory and subsequent categorizing, we provide an exploration of innovative ground rules for full cost accounting in the final section. Building on the knowledge created in the development of those methods, we aim to propose a guiding theoretical perspective that can inform future applications and methodological development.

The structure of this article is as follows:

- In section 2 we present the method that we applied to review the current state of FCA methods, both from a theoretical as well as from a practical perspective.
- In section 3 we provide the results of our review of the basic fundamental concepts related to monetary valuation and present a structured categorization of current understandings of FCA methods, monetary valuation approaches and methods, and monetary valuation coefficients (MVCs) or sets. Then we briefly put forward a literature synthesis of the connections between monetization and life-cycle methods. We argue that both categories of methods can be seen as the building blocks of existing FCA methods.
- In section 4 we present the inventory of current full cost accounting methods and describe them according to five review categories: monetization philosophy, data sources and quality (monetary valuation methods), scoping, aggregation, and transparency.
- In section 5, building on the results we sketch the FCA landscape and its challenges, and propose four provisional ground rules for FCA methods, aiming to initiate a discourse on this.
- In section 6, we present the limitations and conclusions of the study, and indicate potential ways forward.

2. Review method

To establish the provisional ground rules for FCA methods, we used a combination of a literature review and a mixed-methods approach. First, we conduct a review of literature relevant to FCA methods, focusing on their basic components: monetary valuation methods. This review aims to establish clarity on terminology and provide a structured categorization of monetary valuation methods. Next, we explore the connections between monetary valuation and LCA through a synthesis of relevant literature. After that, we present a broader theoretical perspective, in which we utilize a literature review to arrive at a brief description of the need for applying logical models and system thinking in monetary valuation.

The practical part of the research follows, in which we use a mixed-methods approach to inventory and categorize available FCA methods. First, a snowballing literature search is used to identify existing methods in academic and grey literature (Wohlin, 2014). As a starting point or 'start set', we use the overview article by de Adelhart Toorop et al. (2021). Since our goal is to provide a reflection specifically for product-level monetization methods that capture a broader range of sustainability impacts, we use the following three primary criteria to select the methods previously identified by these researchers: (A) the method uses a (combination of) monetization methods to express impacts in monetary terms, (B) the method is developed to be used on the product level; (C) the method is designed to include a broad spectrum of sustainability indicators, capturing the environmental, social and well as prosperity aspects (see Section 1).

After capturing the methods that fulfil these three criteria, an in-depth review of the methods' approach is conducted, using available online documentation (i.e. grey literature) and scientific articles where possible. Our review is based on extensive desk-research, in combination with interviews with the developers of such methods to validate our methodological understanding of the methods. From this, the methods are categorized according to four characteristics, based on our observations in Section 3 (see Table 1).

Table 1
Characteristics of full cost accounting methods to be reviewed.

Characteristic	Description
Monetization philosophy and monetary valuation approach(es) used	The underlying rationale for the method's use of monetization and the choice for its underlying monetary valuation approach (es).
Scoping	Selection of impact categories included in the method. These can be 'materiality based' (i.e. determined together with the product owner or client and its stakeholders) or 'fixed' (pre-determined or stipulated by the method and theory).
Aggregation	Summing of negative and positive impacts. This can occur per impact category, or overall: presenting a 'net' monetary score.
Data sources and transparency	Description of primary data sources and whether the datasets used are publicly available or held by the owner/developer of the method.

[11] This info here is based on TruCost's valuation methodology, from 2015 – before acquisition by S&P.

3. Results 1: Review of and reflection on current literature on full cost accounting

3.1. The basis of full cost accounting methods: monetary valuation methods

Monetary valuation methods are methods to express environmental and social impacts in monetary terms. These impacts can also be referred to as impacts on non-market goods, such as human well-being and biodiversity (Pizzol et al., 2015). The roots of those methods lie in Cost Benefit Analysis (CBA) of the impacts of public and private projects, which has been applied by governments already since 1936 (Persky, 2001; Weidema, Brandão and Pizzol, 2013). In CBA, economic benefits can be weighed against the cost of the environmental and social impacts of proposed projects. As part of a CBA, externalities can be taken into account: these are "costs or benefits on others, which are not reflected in the prices charged for the goods and services being provided by the value chain" (Benoît Norris and Mazijn, 2009). The quantification of such externalities is done through the application of monetary valuation methods, making them comparable to monetary costs and benefits (Alroth, 2014).

Monetary valuation methods use different perspectives, and, sometimes, different terms are applied for similar techniques. This leads to a need for additional theory-based structuring. Monetary valuation methods are connected to different monetary valuation approaches, which can be damage-based or solution-based in practice. FCA methods often use multiple of such monetary valuation approaches, and therefore monetary valuation methods, simultaneously. Without the space to explain all available methods, which has been done carefully by other authors, we present a categorization mainly based on the ones proposed by Pizzol et al. (2015), Arendt et al. (2020) and Amadei et al. (2021) in Fig. 1.

The key takeaway of this figure is that full cost accounting methods are often using a combination of monetary valuation approaches. These approaches can be seen as a larger category, containing several valuation methods. Finally, databases and sets of monetary evaluation coefficients are used in such methods to produce numbers that can then be applied to different cases.

3.1.1. Damage-based monetization methods

The bulk of monetary valuation methods focuses on monetizing environmental impacts from the perspective of damages. This holds both for those provided in the ISO 14008:2019 standard for monetary valuation of environmental impacts and related environmental aspects (International Organization for Standarization (ISO), 2019), and for the recently updated CE Delft's Environmental Prices Handbook (de Bruyn et al., 2023). As categorized in Pizzol et al. (2015), impacts or damages can be monetized using four primary monetary valuation approaches, with different degrees of 'directness': observed preferences (market price), revealed preferences (averting behaviour method, hedonic pricing method, travel cost method), stated preferences (contingent valuation, conjoint analysis) and the budget constraint approach. These approaches have in common that they view the impacts from the perspective of the affected human population, and their preferences and perspectives (ISO, 2019).

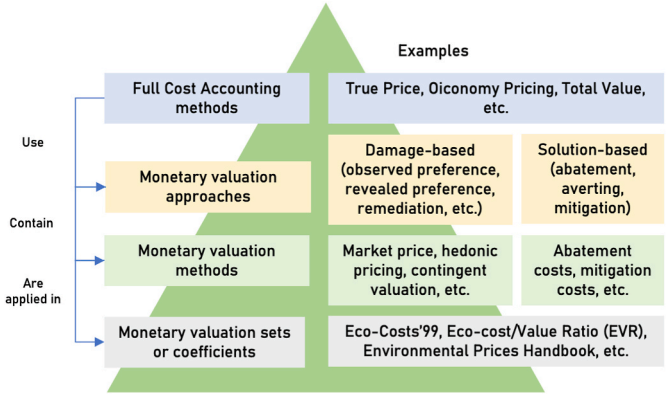

Fig. 1. Hierarchy and examples of full cost accounting methods, monetary valuation approaches, monetary valuation methods and monetary valuation coefficient sets.

Another way to estimate the costs of environmental and social damages is to view them from the perspective of remediation[1], including elements such as restoration and compensation (True Price Foundation, 2021a). While this is listed under 'abatement' by Pizzol et al. (2015), one could argue that this is a different perspective, focused on restoring a damaged situation to its original state, or compensating those affected people for economic and/or non-economic damage caused by the social and environmental impacts. Remediation in the form of restoration of compensation thus takes place *after* the damage has already been done, while abatement (or prevention) aims to prevent it altogether *before* damage occurs.

3.1.2. Prevention-based monetization methods

Another category, mentioned only briefly in Pizzol et al. (2015), is provided in the background documentation of the TruCost method (TruCost, 2015) and that of Oiconomy Pricing (Croes, 2021). Here, prevention or "abatement costs" are listed: the cost of preventing a negative by-product for example, by avoiding or reducing impacts *before* or while products are being produced (TruCost, 2015). Definitions of abatement differ slightly. In a review by (Pizzol et al., 2015), assessing the applicability of various existing methods for establishing cost factors, abatement costs are defined as an "estimation method where the change in availability of a non-market good is assessed in terms of the potential costs of the marginal counter-balancing change (replacement) that prevents the change". This terminology may not be easy to grasp by non-economists but refers to the costs of the measure to avoid impacts to a certain level of abatement aspired[2]. This marginal cost choice is more common in this field (see for example Vogtländer and Bijma 2000; Vogtländer et al., 2002).

[2] Pizzol et al. (2015) explicitly distinguish between potential and actual costs: "Methods using mitigation, avoidance, reduction, control, restoration, or replacement costs instead of abatement cost are conceptually analogous since the same potential cost approach is applied. This is in contrast to the Averting cost method, where it is the actual preventive or offsetting expenses that are measured."

Different sources use different categorizations of this type of method: in True Price's background documentation, 'prevention of re-occurrence costs' falls under 'remediation', while in the ISO 14008:2019, it is part of the revealed preference methods. Ahlroth (2014) groups avoidance/-prevention costs and restoration costs together. However, we argue here that prevention-based monetization methods can be seen as a different category entirely, since it is the only category that aims to prevent the impact altogether.

In different sources, varieties of prevention are mentioned, using the concept of prevention[3] loosely. For instance, the so-called 'averting cost method' comprises the actual preventive or offsetting[4] expenses that are measured, i.e., those that have been spent before or after a commitment to spending has been made (ISO, 2019). An example given is clean-up costs for contaminated sites, which is not directly compatible with the prevention of damages: the damages have already occurred. Another frequently mentioned method is 'mitigation'[5], which is associated with the expenditures to lower an impact, while not entirely preventing it. In practice, this can be a common method, since often no 100% abatement of impacts can be achieved (Croes, 2021). Relevant to the prevention or abatement[6] category is also Vogtländer's Environmental-Costs/Value-Ratio (hereafter EVR), which expresses the amount of environmental burden of a product based on prevention of that burden (Vogtländer et al., 2002).

3.2. Connections with LCA

In practice, monetary valuation has often been used as a weighting method to aggregate the results of LCA, making results from different studies comparable and provide a certain transparency (Ahlroth, 2014). The advantages and disadvantages of using the various available monetization methods as a weighting tool in LCA have been explored by several authors.

Ahlroth (2014) identifies different valuation and weighting techniques and highlights those methods that are suitable to use in LCA. To assist LCA practitioners, weighting sets are available, which are a set of monetary weights derived with the same method for all the environmental impacts involved. Examples of such sets that assign monetary values to environmental impact categories provided in Ahlroth (2014) are Eco-Costs'99, Ecotax 2002 - Ecovalue08 - EPS2000d (all Swedish), ExternE/NEEDS/EcoSense Web (EU), LIME (Japan), PUMAs Environmental Profit and Loss Account (uses averages), and Stepwise2006 (EU). Most of them use different underlying monetary valuation methods, such as prevention costs, willingness-to-pay, or stated preference methods. Ahlroth highlights that there is large room for improvement regarding the application of monetary valuation in LCA, and shows that using different valuation methods can influence the results when using weighting to interpret the outcome of an LCA. The author urges to be aware of the properties of the method(s) used when discussing the results of studies that use such weighting set.

Pizzol et al. (2015) study different monetary valuation approaches in the context of LCA and provide guidelines for their application. Using the method categorization as presented previously, their work shows that there are large differences in compatibility and relevance for LCA across methods. They conclude that not one method is generally recommendable for LCA, but rather a careful combination of methods is required. However, they identify recommended valuation methods for each separate LCA impact category, and state that this context and topic specific tailoring has serious drawbacks. Results of the impact oriented cost assessments vary strongly depending on the method chosen, but remain within the common preference within the LCA field for addressing damages rather than abatement or prevention costs (Pizzol et al., 2015, p. 177). The review recommends increasing efforts in increasing consistency in the monetary valuation of biophysical and social impacts, underlining the importance of construct validity of monetary valuation.

Arendt et al. (2020) compare the results of different monetization methods specifically designed to be used in LCA modelling (Ecovalue12, Stepwise2006, LIME3, Ecotax, Eco-costs Value Ratio (EVR), Environmental Priority Strategies (EPS), the Environmental Prices Handbook, Trucost and the MMG-Method[7]). Using several axes of analyses, they find that most methods use the damage costs as their cost perspective, whereas the EVR uses abatement costs and Ecotax uses societies' willingness-to-pay (WTP). The authors describe how the discrepancies between the monetary valuation approaches warrant careful attention from practitioners and method developers. The methods' resulting monetary values obtained when applying them in LCA studies, can vary significantly according to the choice of approach. The review also observes a lack of consensus on how to categorize the various impacts and where to limit the scope in the impact pathway.

Amadei et al. (2021) build on these articles and study practical challenges related to the application of monetary valuation in LCA. They find great variability in the availability of monetary valuation coefficients across impact categories, with some (e.g., climate change, ozone depletion, acidification) commonly analysed, compared to others (e.g., terrestrial eutrophication) for which very little information is available to date. Additionally, the authors note that exhaustive and complete information detailing the underpinning methodology applied for deriving the monetization coefficients is not always available.

To highlight the large differences in results between various monetization methods, both the Arendt et al. (2020) and the Amadei et al. (2021) review contains a relevant quantitative analysis, applying the various approaches reviewed comparatively to assess the size of various 'hidden costs'. Arendt et al. (2020, p. 15) apply this to the annual consumption of the average EU citizen, showing that the result varies between more than €244 and €7000 for a long list of environmental impacts. Amadei et al. (2021, p. 9) use a case study on the environmental impacts of the consumption of an average European citizen (of around € 16.000) to reflect on a comparative variation of results between 'monetary valuation coefficients' from different sources (mostly being damage-based). Their results show a variability of additional costs for the average EU28 household expenditure between 15% and 41%, with these variations relating to the monetarization approach applied.

Another recent review of approaches for the integration of the three

[1] True Price uses 'remediation' as defined in the UN Guiding Principles on Business and Human Rights, and refer to the definition offered there: *'Remedy may include apologies, restitution, rehabilitation, financial or non-financial compensation and punitive sanctions (whether criminal or administrative, such as fines), as well as the prevention of harm through, for example, injunctions or guarantees of non-repetition'*. Based on that they state: *'the following four types of costs that, when appropriately combined, form the remediation cost for an impact: 1) Restoration costs, 2) Compensation costs, 3) Prevention of re-occurrence costs and 4) Retribution costs'*. (True Price Foundation, 2021b, p. 9). In other documents they use the concept of remediation very widely, even talking about 'remediation markets' (True Price, 2019). Note that in the general dictionary *remediation* has a more reactive meaning: In Oxford Advanced Learner's Dictionary: *'the process of improving something or correcting something that is wrong, especially changing or stopping damage to the environment'*. In Cambridge Dictionary: *'the process of improving or correcting a situation'*.

[3] In Cambridge Dictionary: *'the act of stopping something from happening or of stopping someone from doing something'*. Averting is a synonym: *'to prevent something bad from happening'*. These refer to activities ***before*** something happens.

[4] In Cambridge Dictionary: in financial context: *'to balance one influence against an opposing influence, so that there is no great difference as a result'*, while in environment: *'to pay for things that will reduce carbon dioxide in order to reduce the damage caused by carbon dioxide that you produce'*.

[5] In Cambridge Dictionary: *'to make something less harmful, unpleasant, or bad'*.

[6] In Cambridge Dictionary: *'a reduction in the amount or degree of something'*.

[7] MMG stands for Environmental materials performance of elements of buildings (Milieugerelateerde Materiaalprestatie van gebouwelementen (De Nocker and Debacker, 2017).

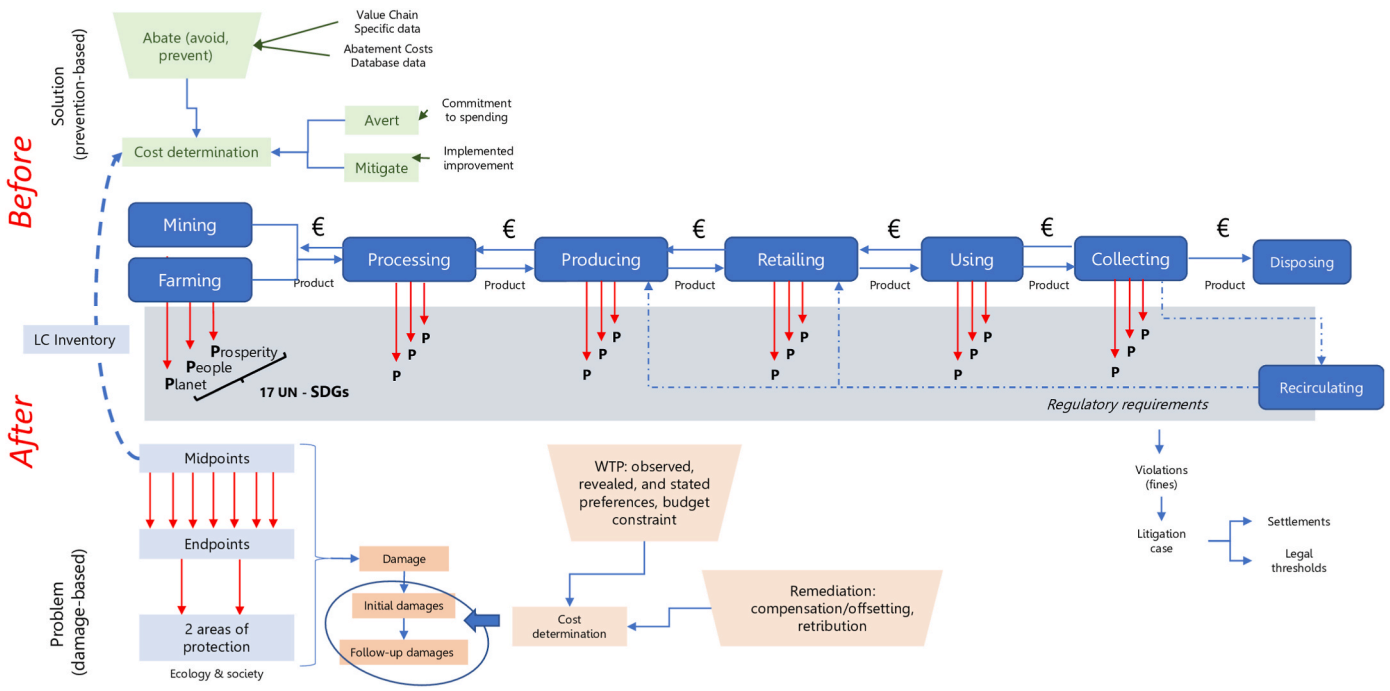

Fig. 2. Mapping of structured categorization of monetary valuation methods to a value chain and time perspective (explanation in text).

sustainability domains (environmental, economic and social) also includes some monetization approaches, with the 'True Value Methodology' of KPMG as example (Huysveld et al., 2021). This review especially focusses on integration within the three sustainability domains and across these domains, as well as effective forms of communicating aggregated results. It discusses various challenges of monetization, but mainly from the perspective of using this as a weighting approach in environmental LCA and LCSA. It does not include an assessment of prevention or abatement cost approaches. In their view the monetization approach is one of the less useful approaches. This review is interesting in its attention for the aggregation of negative and positive impacts and its reflections on the differences between strong and weak sustainability, which is not addressed in the above reviews.

A final useful review was published by Timmermans and Achten (2018), who investigated how LCA-based calculations of (cost of) externalities could be used in favour of a shift from value-added tax (VAT) or sales tax to a 'damage and value-added tax' (DaVAT), reviewing various monetization examples. They observe various obstacles, including inconsistency in the choice of the functional unit and in the characterization, normalization and weighting methods, weak transparency of information about the environmental score of the product, and challenges in associated costs of the calculations itself, risks of fraud, and price changes (Timmermans and Achten, 2018).

3.3. Mapping full cost accounting in the product value chain

Throughout the above sections we are stressing the definitions of the various categories mentioned in the literature, as discussed in the notes of this article, also referring to the common language use of these words. In the reviewed literature these concepts are regularly interpreted from varying perspectives, and we observe a *need for harmonization of language* used in relation to monetary valuation. This directly relates to the timing and nature of actions by responsible actors, and whether these take place before or after the act of impact creation (e.g., production and the transaction to the customers).

In our view the diversity of approaches can best be illuminated by mapping it in on a *value chain* model (expressing the *place dimension* of the sustainability concept, like discussed shortly in Section 1) in combination with the distinction between *before and after* the creation of impacts (the *time dimension* of the sustainability concept). This we do in Fig. 2, where we present in blue a simplified value chain: from mining or farming of natural resources to processing them, producing the final product, retailing of the final product, to its use phase. Then, the product is collected and either disposed of or recirculated.

At each stage in the value chain, impacts or externalities occur. These are visualized through the red arrows and their impacts on the people, planet and prosperity domains (PPP)[8]. The activities and approaches ***before*** the creation of impacts are displayed above the value chain, while activities and approaches ***after*** the creation of impacts are displayed below it. Thus, the monetization methods are categorized into solution-related (prevention-based) and problem-related (damage-based) approaches. Both are connected to the midpoint categories of impacts as resulting from life-cycle methods.

3.4. Need for applying logical models and system thinking

This form of mapping is connected to the application of ***logic models*** in the academic fields of sustainability science, sustainability transitions and (social) impact assessment (see for an extensive discussion Vermeulen, 2018). In logic models, the timing of causes and effects of acts of production and consumption, their resulting outputs (emissions, below poverty line payments), outcomes (increased GHG concentrations, families in poverty) and the impacts (climate change, social isolation, illness, and societal disruption) are respected and separated, and interventions are explicitly connected to the pathway of causes and effects (Cooksy, Gill and Kelly, 2001; Millar et al., 2001; Kneale, Thomas and Harris, 2015). Respecting the (timewise) chain of causes and effects is

[8] For visual purposes, only the impact associated with the first step in the value chain are shown. However, these occur in each of the different value chain steps, we only repeat the arrows with P's.

essential in both environmental and social impact assessment. It is essential for establishing *construct validity*[9] in monetary valuation: assuring that a method actually does measure what it is intended to be measured.

The observed lack of applying logic models in the field of monetization links to another problem: the lack of theoretical underpinnings of the approaches[10]. In our comparison of monetizing approaches, we also need to reflect on ***theoretical foundations*** of the use of the *concept of sustainability* itself and its implications for indicator development. The *concept of 'indicator'* is generally described as a well-justified measurement, representing a wider and more complex reality, but based on a convincing reasoning assumed to be valid for describing that complex reality (Vermeulen, 2018). Sustainability assessment (SA) and sustainability indicators (SI) play an important role as decision-supporting tools in the pursuit of sustainable development (White, 2013; Waas et al., 2014; Zanni et al., 2020), and have five main functions: (1) structuring information, easing decision making and indicating clear pathways for action, (2) simplifying reality, which reduces complexity and therefore facilitates understanding, (3) operationalizing sustainability through the development of indicators and serving as a forum for participation and debate, and (5) providing a social learning process, linked to the notion that sustainable development is not an end-state, but rather an ever-evolving process influenced by social and cultural contexts.

In practice, we see very different approaches, which can be understood from the specific positions that developers of indicator systems hold in the societal governance processes (Parris and Kates, 2003, pp.572–577, Spangenberg, 2014). This creates a **risk** of producing a cacophony. In this context, various scholars have critically reviewed the practices of sustainable development indicators and proposed systematic approaches (Pintér et al., 2018; Dahl, 2018; Boulanger, 2018), proposing steps, requirements, and criteria for creating and applying indicators systems (see for more detailed discussion Vermeulen 2018, pp 64–69). Such systematic approaches often start with the creation of a core structure of the indicator system: defining the scope and core concept as *theoretical underpinning* for 'sustainability'. This then needs to feed and justify choices made in the next steps of indicator development. *Methodological rigor* needs to be established in the steps of operationalization, attribution, data manipulation and in the process of final aggregation into a final composite result. The link between the theoretical and methodological steps is crucial: all methodological choices need to be well founded in systemic core reasoning. The first step of theoretical underpinning is to be seen as guiding to ensure construct validity. Naturally, tension between theoretical soundness versus applicability for engagement will exist; and methodological rigour does not always match data availability.

For our purpose here, this need for theoretical justification translates into the question of which *overarching theoretical perspective* is most suited to the foundations of monetization for sustainability assessment. Sustainability sciences address the complex interactions between the ecological sphere and the social sphere, calling for an overarching approach that connects the parts and their interactions of the physical domain with the parts and their interactions of the social domain. Social-ecological systems need to be viewed with a *systems theory perspective* (Capra and van Steenbergen, 1985; Capra, 2005; Leonard and Beer, 1994; Walby 2007). Systems theory takes a perspective in which the 'whole' is more is than the sum of its parts, stressing the interconnections in systems. The least obvious part of the system, its function or purpose, is often the most crucial determinant of the system's behaviour (Meadows 2009). Applying this to sustainability assessment, system theory stresses the need to apply an inclusive assessment of *all sustainability aspects*, also justified by the comprehensive nature of the UN's Sustainable Development Goals. Selectively using only specific elements of the full set of sustainability aspects results in risks of counter effects and trade-offs. Various scholars have shown that it is essential to maximize synergies between goals while preventing negative trade-offs (ICSU, 2017; Barbier and Burges, 2019; Biggweri et al., 2019; Pham-Truffert et al., 2020). This contrasts with a dominant approach in corporate sustainability practices, where priority aspects are identified, applying *materiality assessments*, mostly based on stakeholder perceptions (Sarena and Azzone, 2012; Munoz-Torres et al., 2012; GRI, 2016, p. 10).

This discussion links to a major division in views on sustainability: between *'strong' and 'weak'* sustainability. Each of these views implies a specific valuation approach, and thus an ethical position, to support monetary indicators of sustainability (Ayres et al., 2001). Neumayer (2013) describes 'weak sustainability' as an extension to neoclassical welfare economics: "it is based on the belief that what matters for future generations is only the total aggregate stock of 'man-made', human and 'natural' capital (and possibly other forms of capital as well, such as social capital), but not natural capital as such. Loosely speaking, according to this, it does not matter whether the current generation uses up non-renewable resources or pollutes the environment as long as enough machineries, roads and ports as well as schools and universities are built in compensation". The elements of sustainability are seen as interchangeable, and plusses and minuses can be aggregated. Neumeyer describes the contrasting vision of 'strong sustainability' as "that natural capital in essence is regarded as non-substitutable, in the production of consumption goods ('source' side of the economy), in its capacity to absorb pollution ('sink' side of the economy) and as a direct provider of utility in the form of environmental amenities". Hence, 'strong sustainability' is also labelled as the 'non-substitutability paradigm'. In the original use of it, it focusses mostly on environmental sustainability, while more recent contributions expand this reasoning also to the 'people' and 'prosperity' elements of sustainability (Spangenberg 2014; Huysveld et al., 2021). Substitution and off-setting between sustainability aspects do have adverse implications for the allocation of health and wealth in societies (Spangenberg 2014). When the sustainability performance scores of the essential different aspects of sustainability are summed and off-set, crucial impacts for some individual and some locations are getting out of sight. This may very well be seen as a form of greenwashing, especially if the impacts are taking place far away from the user/consumer (Ramus 2005; TerraChoice 2010; Parguel et al., 2011). Including 'positive impacts' in LCA studies has increasingly been promoted (like in the recent reformulation of social LCA guidelines (Benoit Norris et al., 2020)), while others suggest strict rules for counting 'positive impacts' (Croes and Vermeulen 2021).

A last crucial aspect around defining the concept of sustainability is the dominant practice of operationalizing the third (economic) pillar of sustainability as Life Cycle Costing (LCC) (Zanni et al., 2020). Remarkably, it has become common practice to include the costs of a product across its entire life cycle as an element of assessment of sustainability (Hunkeler et al., 2008; Swarr et al., 2011; Zanni et al., 2020, p. 67).

[9] Constructs are abstractions that are created by researchers to conceptualize a phenomenon in the social or physical reality. It is necessary to demonstrate that the empirical indicators are logically, as well as theoretically, connected to the construct (O'Leary-Kelly and Vokurka, 1998). Interrelations between theory and empirical analysis are central to construct validity (Laughland et al., 1996). The key principles are provided by measurement theory, which has a history of consistent development over the past hundred years, and which aims to statistically assess if the indicators included in a measure are internally consistent (Strauss and Smith, 2009). These include if a measure leads to a systematic ranking and identification of the population in question (*reliability*); whether the indicators adequately capture the construct in question (*criterion validity*); whether the number and types of dimensions are a good model to classify the indicators (*construct validity*); whether the index and its indicators are comparable across sub-populations (*measurement invariance*) (Nájera Catalán and Gordon, 2020).

[10] The LCA Initiative also applies the logic models in their future outlook (Life Cycle Initiative, 2017–22 Strategy document, UN).

Table 2
Main philosophy and data sources used of FCA methods.

Name	Monetization philosophy and monetary valuation approach(es) used	Data sources (monetary valuation methods)
TIMM (PwC), True Value (KPMG), Total Value (EY), Strategic Impact Assessment (Deloitte)	Summing negative and positive externalities to arrive at net value created to society. These methods use various monetary valuation approaches.	Various, and often specific to the case-study context. Examples of sources: Netherlands Institute for Transport Policy Analysis, the US Environmental Protection Agency (EPA), the Netherlands Ministry of Infrastructure and the Environment, CE Delft's environmental prices, and peer-reviewed scientific articles.
Product Impact-Weighted Accounts	Following the framework, product impact takes place in reach, dimensions of customer usage, environmental use and end of life. The method is impact-based, and uses a hierarchy for the selection of monetization coefficients: (1) market price, (2) estimated cost, (3) averted cost, (4) proxy cost, (5) willingness to pay.	The method uses company-specific (financial) input/output data. Monetization coefficients are then usually based on a literature review, making use of grey literature and academic studies.
TruCost (S&P Global)[1]	TruCost uses monetary valuation to make life-cycle results more tangible for companies. The method applies financial values to absolute impacts that reflect the full costs to society that a company is responsible. For this, a mix of valuation approaches is used.	Several sources and valuation methods. One example: Interagency Working Group on Social Cost of Carbon
True Price	The method takes rights as a starting point for normative choices in its valuation framework: human rights, fundamental labor rights, and environmental rights. Unsustainable external effects are the negative effects of an economic activity that breaches these rights. The remediation cost of a right violation is the cost that should be incurred to remediate the harm caused. The sum of a product's price and the remediation cost of its unsustainable external effects is called "true price". Remediation is operationalized through four types of activities: (1) restoration costs, (2) compensation costs, (3) prevention of re-occurrence costs and (4) retribution costs. These four types of costs are combined according to specific principles, following a decision-tree, in which restoration – where possible - is preferred.	Monetization factors for ten environmental and ten social true price impacts and their footprint indicators and sub-indicators are presented in the document 'monetization factors for True Pricing'. More extensive background documentation is provided online.
Oiconomy Pricing	The method is to be applied by value chain partners, identifying the full value chain and foreground data related to the performance on all people, planet and prosperity aspects. The performance data are translated into preventative costs, either foreground, or if not available based on default values derived from scientific assessments and global databases. The focus on preventative costs is motivated by the need to inform negotiations in the vale chain above joint improvement. Specific rules are applied for identifying positive impacts.	Businesses' direct performance data in combination with various available data sources, like Vögtlander's EcoCosts, WIOD_SEA, FAOStat, Idemat, OpenLCA, Gabi, SimaPro, WageIndicator, Worldbank data, Transparancy International, and more. Various MVC's are self-developed, such as fair inequality, fair minimum wage, corruption prevention.

Efforts to apply LCC within the widely applied LCA philosophy of mid points and end points tend to include standard economic parameters, as production costs, contribution to GDP and labor productivity (Neugebauer, 2016). This is fundamentally in conflict with the basic starting point of the concept of sustainable development, being about the external, hidden costs for society as the result of producing goods. It is remarkable that only few scholars have raised this objection (see the discussion on this in Vermeulen 2018). The 17 UN SDGs and 167 sub-goals do at no point refer to profits, profitability and these primary costs of production (internalities) but include the economic dimension as the need for increasing global fairness and fairness economic institutions. A similar view is underlying calculations of the 'full price', using full cost accounting methods: these are based on hidden externalities along the value chain rather than on profits.

4. Results 2: Comparing current of product-oriented FCA methods

Following the above discussions on monetary valuation methods, their application in the context of LCA and product life cycles, the diversity of approaches used for this, and the theoretical foundations for indicator development brings us to a selection of aspects to investigate in the next part of this article. We stress the strong variability in monetary valuation methods, the inconsistency in current categorizations and need for stronger theoretical justification and underpinning for (sometimes implicit) choices in attribution and aggregation. With this in mind, we compare currently available product-oriented FCA methods. Following the three primary inclusion criteria mentioned in section 2, the following FCA methods were included for further analysis: Strategic Impact Assessment (Deloitte), True Value (KPMG), TIMM (PwC), Total Value (EY), TruCost (S&P Global), Product Impact-Weighted Accounts (Harvard Business School), True Price, and Oiconomy Pricing. Below, we present a brief description of each of the methods, followed by a summary of their most important characteristics in Tables 2 and 3.

4.1. Strategic Impact Assessment (Deloitte), true value (KPMG), TIMM (PwC), Total Value (EY)

The four largest global accounting and consulting firms Deloitte, KPMG, EY and PwC all developed and apply FCA methods. Since their characteristics are largely similar, they are grouped in our analysis. The availability of background documentation differs among the methods, with KPMG's True Value method being the most extensively documented (Coulson 2016). PwCs Total Impact Measurement and Management (TIMM) method is perhaps the earliest, with its background documentation dating back to 2013 (PwC, 2013). The TIMM method is rooted in integrated reporting and integrated decision-making, and aims to create a "new 'language' of decision making that generates hard numbers equivalent to the new ways of evaluating national output and wellbeing" (PwC, 2013). It includes social, environmental, tax (or: fiscal), and economic dimensions. The results of TIMM are presented in a so-called Sustainable Value Map (ASE Group, 2019), presenting monetized impacts on a variety of impact categories. As seen in one of their case studies, these impacts are aggregated (i.e. "the sustainable value we created for stakeholders in 2017 was 9% greater than in 2016.").

KPMG's True Value method was launched in 2014. Its background document 'A new vision of value' explicitly frames the method as contributing to solving the issue that organisations are not fully compensated for positive externalities, and do not pay for negative externalities (KPMG, 2015). Additionally, the risk of increased internalization is presented as a key driver for businesses' needs to get insights into their 'true value'. Several case studies are available online (KPMG,

Table 3
Scoping, aggregation, transparency and validation in interviews of the inventoried FCA methods.

Name	Scoping	Aggregation	Transparency	Validated in interview
TIMM (PwC), True Value (KPMG), Total Value (EY), Strategic Impact Assessment (Deloitte)	Materiality-based.	Yes	Data used in the monetization process are stored privately by the businesses.	TIMM, True Value, Total Value: no. Strategic Impact Assessment: Yes.
Product Impact-Weighted Accounts	Principles-based, using double materiality.	No. While positive and negative elements can be aggregated separately, no aggregation of positive and negative impacts takes place.	Data can be public data or internal company data, in which case it is confidential.	Yes
TruCost (S&P Global)[a]	Fixed	No	Detailed information on choices for monetary valuation methods is available (TruCost, 2015); data held by S&P is not publicly available.	No
True Price	Materiality-based in case where prioritization is necessary.	Positive- and negative externalities are not aggregated, while negative externalities on their own can be aggregated. Positive externalities are only included in some cases, and aggregation of different impact categories does not take place. The underlying idea is that the true price should avoid summing positive and negative impacts, since these can be borne by different stakeholders.	Monetary valuation coefficients are publicly available in online documentation.	Yes
Oiconomy Pricing	Includes all SDG's, while applying an 80:20 rule for mapping value chain partners to be included	10 main categories are shown separately. Negatives and positives are only aggregated per 10 categories.	Methodological justification and datasets are publicly available in online documentation. Guidance on application of standard/method is planned.	Yes

[a] This info here is based on TruCost's valuation methodology, from 2015 – before acquisition by S&P.

2015a; KPMG, 2015b, KPMG, 2015c), in which the True Value method's results are presented as a 'value bridge', aggregating monetized negative- and positive impacts. Academic literature that critically reviews the method (Barter, 2016; Coulson, 2015) and details its fundamentals (Hendriksen et al., 2016) is available.

Similar to KPMG's Value Bridge, EY's Total Value method is described as "a concept that allows companies to measure the most material aspects of their value creation, which otherwise go hidden or unmeasured" (EY, 2018). It is worthy to mention that up-to-date information on the method is no longer available online, with the company now focusing on its "Long-Term Value Framework". However, in the earlier documentation, the framing of the method is also centred around preparing for the risk of internalization, as well as providing impact insights to aid strategic decision-making. In their conceptual presentation of a Total Value analysis, the impacts of the economic, social and environmental domain are aggregated.

For Deloitte's Strategic Impact assessment framework, no publicly accessible information was available at the time of writing. However, from an interview with a responsible staff at the firm, we found that its fundamentals are similar to that of the other methods.

In summary, while being slightly different in exact formulation, the shared goals of these methods are: (1) to identify previously hidden positive externalities as well as negative externalities of companies' activities, through the process of monetization. Results can be used for both target setting, decision-making as well as for communication; (2) strategic preparation for increasingly internalized externalities, posing a risk to corporate value creation. As presented in the summary table, all included accountancy firms apply a mix of monetization approaches-and methods, with sources often depending on the context of application. The methods all aggregate positive and negative externalities from various domains, even though e.g. EY's background documentation states that this is done 'with caution' "as this could lead to an oversimplification of issues and a blurring of the overall view" (EY, 2018). All four methods follow a materiality-based selection of impact domains, meaning that these methods "enable businesses to select only their material impact areas" (PwC, 2013).

4.2. Product Impact-Weighted Accounts (Harvard Business School)

The Product Impact-Weighted Accounts method forms part of the Impact-Weighted Accounts Project by the Harvard Business School (Serafeim et al., 2019). Their mission is driving the creation of financial accounts that reflect a company's financial, social, and environmental performance. The product-level method is developed to provide insights into product and service impact, which refers to the impact to customers that occurs once a company has transferred control of goods or services; this often takes place at multiple stages in the value chain. The framework offers guidance to identify key impacts. The method is rooted in accountancy, and contributes to creating a standard for financial accounts that reflect a company's financial, social, and environmental performance. This will enable investors to make decisions on both financial performance as well as environmental/social performance. In addition to such first-tier transformative implications, second- and third tier transformative implications from applying the method include the increased consideration of non-financial impacts in strategic decision-making, and deep value chain impacts. The monetary valuation methods that are used are damage-based, and the method uses a hierarchy in their selection of which method to apply based on their rigour.

Primary data from companies is used where possible, while a variety of databases is consulted in case this is not available. The method's background documentation presents several ground rules or 'design principles' to the method, related to the scope of the source of impact, scope of stakeholders included in impact accrual and the specificity of impact metrics. Specifically, for the product-level version of the method, five additional rules are introduced (Serafeim and Trinh, 2020). A double materiality approach is applied, meaning that the method includes sustainability matters that are: 1) financially material in influencing business value and; 2) material to the market, the environment, and people. While positive and negative elements can be aggregated separately, no aggregation of positive and negative impacts takes place.

4.3. TruCost (S&P global)

TruCost, founded in 2000, has developed a methodology called TruCost's Valuation Methodology. It is used for natural capital valuations: financial values applied to absolute impacts that reflect the full

costs to society that a company is responsible for. The business was acquired in 2016 S&P Dow Jones Indices. Available background documentation, used here, comes from the time before its acquisition (TruCost, 2015). The method, as used by S&P, is aligned with S&Ps "Task Force on Climate-related Financial Disclosures". However, the materials now published by S&P Global are less extensive than its original background documentation. According to the current information online, S&P's Trucost provides "robust, quality-checked, and standardized environmental data on more than 15,000 companies", and is mainly focused on assisting with investment decision-making by addressing challenges of climate change, water use, waste disposal, and the overexploitation of natural resources. The method is framed to increase resilience to various risks, and while its main focus is on environmental factors, "broader ESG factors" are said to be included.

More technical information is available in (TruCost, 2015). Interesting are its explicit connections with LCA, positioning the method to make LCA results understandable for business. The document lists eight valuation techniques that are used to monetize LCA impacts, stating that all are "equally valid, and TruCost chose valuation techniques based on data availability and suitability." The document provides detailed information on reasoning behind the selection of each of the valuation techniques for each impact category. While the background documentation is not explicit on the issue, available case studies show that included impact domains in the analysis are based on materiality to the business (The Danish Environmental Protection Agency, 2014). No summing of positive/negative impacts takes place, as positive impacts are not included in the scope of the method.

4.4. True Price

True Price was founded in 2012 and has developed a method to calculate the monetized remediation efforts associated with a product that would do no damage to both people and nature. It is an often-applied method, with a variety of businesses using the method, and the opening of a 'True Price store'-project in Amsterdam. In 2018, True Price continued as a non-profit focused on maintaining a standard and community to realize true pricing, while the development of new methods was spun off to the Impact Institute.

As mentioned previously, the method focuses on remediation costs. The underlying philosophy is that the focus on remediation should enable real-world action. Four categories of remediation are proposed: restoration, compensation, prevention, retribution. The method uses a 'decision-tree' for the selection of the appropriate monetization method, which is found in (Galgani et al., 2021). Plenty of background documentation is available, including a document on its rationale, procedures and underlying normative foundations (True Price, 2020). Here, the underlying human rights, labour rights and environmental rights that the method follows are put forward. On the product level, a materiality assessment takes place for reasons of feasibility and prioritization. Since the True Price method focuses on negative impacts specifically, mainly on the product level, no aggregation takes places.

4.5. Oiconomy Pricing

The Oiconomy Pricing method is the youngest of the included full cost accounting methods, developed since 2016, being launched in 2021. The method allows to calculate the preventative cost distance to a sustainable version of a given product. It is therefore explicitly focused on preventative measures throughout a product's value chain. The burden of data collection lies at each of the individual value chain parties, who are, if no data is provided, assigned default values for its prevention costs. Extensive background documentation for the method is available, including scientific articles as well as applied case studies (Croes, 2021; Croes and Vermeulen, 2020; Verschuren et al., 2022). Some of the distinguishing features are the following. Its scope covers environmental, social and prosperity aspects; a fixed set of categories needs to be included, but only applied if applicable in the specific geography of value chain actors; and it uses various global datasets, including Vogtländer's Ecocost Value Ration database for environmental dimension (Vogtländer et al., 2002). The method applies aggregation of costs within the positive cost category and within the negative cost categories, but no net aggregation is allowed. The initiative is designed as an open science project.

5. Discussion and proposed ground rules

5.1. FCA landscape: current challenges

In the previous sections we reviewed the key characteristics of current monetization approaches and FCA methods. Proper theoretical underpinning is essential for establishing construct validity in the measurement of full hidden costs related to sustainability. The results from our review allow us to make observations about the state of the field and its remaining challenges.

The field is in development, with clear room for improvement. We argue, in line with others such as Amadei et al. (2021), that a more theory-based and systematic approach is needed. We suggested to fundamentally distinguish the available approaches according to their comprehensiveness in addressing the concept of sustainability and argued that we need to acknowledge the temporal (time) and spatial (place) dimension. We believe that without an accurate mapping of the full cost accounting landscape (like proposed in Fig. 2), users and consumers of full cost accounting information might misunderstand the variety of approaches and use them incorrectly in their decisions. Arendt et al. (2020) also observe such confusion. They state that while monetization can facilitate the creation of markets for so-far non-marketed goods (e.g., for emission permits or payments for ecosystem services), it currently focuses on determining the associated costs of environmental impacts to society: "distinguishing between these kind of market prices of goods and economic values of impacts is important and is sometimes confused (e.g., when scholars just use the emission permit price of CO2 to determine the associated damages of the emission)" (Arendt et al., 2020).

The publications and practices discussed in sections 3 and 4 call for more guidelines in applying FCA methods, both relating to consistency, as well as to careful presentation of the results. With this review we intent to contribute to this. We observe at least eight challenges, partly related to theoretical foundations, partly to methodological choices. With respect to the theory, we observe that:

1. There is a focus on applying monetization restricted to environmental LCA, however some scholars observe that some first steps are made in the field of social LCA. An inclusive approach is needed connecting all relevant 17 UN SDGs.
2. Within the field of environmental LCA, impact categorization is not well harmonized, despite earlier efforts such as the European Commission's Product Environmental Footprint method and the Recipe project (Huijbregts et al., 2017; Pollock et al., 2021; EC, 2021). Different impact assessment methods in LCA use different impact categories, sometimes making it difficult to compare their results. Increased harmonization is needed.
3. Mixing *costs of prevention* (as activities that take place before an impact occurs with the intention to prevent its occurrence) with *costs of the impacts* (as related to responses needed after the impact to reduce its effect) might lead to outcomes that are difficult to interpret. Both categories relate to different categories of action, with different actors involved and with different abatement and mitigation mechanisms.
4. Several authors express their concern about the blurriness of definitions of the main categories of monetization approaches. At the same time, the time dimension in the assessment of the reviewed methods (before or after a production activity) is often ignored.

Related to the methodologies we see the following challenges:

5. Within recognized impact categories, different MVCs are applied when monetization is used, also based on a variation of valuation methods. Often, perception-based proxy data of costs are used. In the recommendations of the above authors, the common strategy for addressing these issues is to carefully look for each impact category which approach is best suited and thus suggest using various of approaches in parallel. Little attention is given to the question if aggregating cost data (rooted in this diversity of theoretical approaches and related data sources) is logically acceptable, although it is observed that methods are hardly used consistently for the monetary valuation of all impacts assessed in an LCA, e.g. across different LCA 'areas of protection'.
6. The distinction between solution-related (prevention-based) and problem-related (damage-based) approaches has different implications for the attribution challenge. Problem-related (damage-based) approaches need to find solutions for the logical sequence of initial and multiple subsequent impacts and how to attribute this to single economic activities in a specific time and location. Solution-related (prevention-based) approaches need to identify applicable prevention options and allocate costs to possibly multiple problem aspects (like solving both climate related aspects and other affecting other environmental aspects with the same solution).
7. Weighting requires careful attention. Ahlroth (2014) recommended "to provide weighting sets with a declaration of content, providing a clear picture of what is included and what is not, and if possible, also a recommendation of suitable uses of the weighting set." We add that considering weighting needs to acknowledge the fundamental nature of the concepts and the data used to present them: not all types of cost can be logically combined in an equation.
8. Finally, the summing of positive and negative impacts is a topic worthy of attention. Various scholars have provided suggestions for expressing both negative and positive impacts of products for the impact categories for environmental LCA and social LCA (Di Cesare et al., 2018; Norris, 2019; Forum for the Future et al., 2019; Benoit Norris et al., 2020a; Benoit Norris et al., 2020b; Croes and Vermeulen, 2021). Their views on what can be presented as 'positive' impact in the context of impact assessment differ largely, and no decisive guidance is currently available (see also Kühnen and Hahn, 2019).

In order to create construct validity, clarity on the unit of analysis is essential: is it the cause of the emission, the emission itself or the subsequent effects of the emission? From a damage perspective, one could even argue that these subsequent effects may be endless. An example from climate change: ***after*** the act of emitting greenhouse gasses (GHG) these emissions lead to a disturbance of weather patterns, resulting in floods and in droughts, affecting harvests, resulting in migration and poverty. Including the damage costs of such a cause-and-effect chain would likely require setting a cut-off for reasons of feasibility. On the other hand, abatement and mitigation mechanisms ***before*** GHG emissions occur include more direct choices on, for example, energy reduction and the use of renewable energy sources.

Furthermore, the damage costs might be very different depending on the geographical ***location*** where they take place. Arendt et al. (2020) observe that "(…) the methods emphasize the various impact categories quite differently, showing different preference structures. The most influential criterion was the geographical reference area (i.e., the richer the reference area, the higher the results)." This finding calls for a greater recognition of the influence of the place dimension: the variation of impacts along the international value chain (also suggested by Amadei et al., 2021).

5.2. Proposing ground rules

These challenges bring to a first effort to formulate a small set of ground rules, addressing both theoretical and methodological challenges.

1. Be consistent, explicit and comprehensive in the **selection and framing of the sustainability domains** and the impact pathways for each.

The inventoried full cost accounting methods use different monetary valuation approaches and methods, which are not always presented with an underlying theory related to 'sustainability'. We recommend to clearly frame the method's relation to the complexity of sustainability transitions, and to justify its role in the context of the globally elaborated conceptualization of 'sustainable development'. In practice, this means incorporating a wide range of environmental and social impact domains. From this, it follows that *the use of perception-based materiality selections of aspects to be included is to be avoided. If, for whatever reason, sustainability aspects are not included, this limitation of scope should be explicit.* Most inventoried methods use a materiality approach, due to data scarcity, limited resources and preferences of clients. If the analysis is made for internal use, this does not need to be problematic, but when this is used to external audiences, the limited scope should be shown, to avoid greenwashing. We recommend to apply an as complete as possible set of pre-defined impact domains, covering the SDG's. This will make the outcomes more comparable across businesses and will make sure that no hidden impacts are missed.

2. Be consistent and explicit in justifying the choice for **monetary valuation methods** and respect the **time dimension** distinction (costs related to either before or after the activity of production)

Externalities can both be measured as costs after the activity of the economic actor causing the impact takes place, and as costs before, preventing the impact occurring. Most of the full cost accounting methods mainly use damage-related approaches, while some do combine them with prevention costs. For global warming often abatement costs are used throughout different methods (Arendt et al., 2020). Both damage-based and prevention-based approaches have their pros and cons. However, for logical reasons, it is recommended to be consistent within the method and not combine both approaches. When potential preventative activities are allocated to a producer in the calculation of externalities, it is recommended to avoid also attributing damage-related costs to that actor. In an earlier review, Finnveden et al. (2006) concluded that if LCA results are monetized, all impact categories should be monetized using the same cost perspective. We extend this recommendation to the full diversity of sustainability aspects and monetization approaches.

In addition, for costs categories used within each time dimension, preferably, a hierarchy of most preferable data sources would be applied. Various authors referred to such a hierarchy (see Product Impact-Weighted Accounts, True Price, Oiconomy Pricing), but there is not standard for this yet. This preference hierarchy includes the use of foreground versus background data, and the level of directness of the data source (factual expenditures versus perception-based assessments) as well as criteria related to verification and regular updating.

3. Be consistent and explicit in justifying the **inclusion of positive externalities** and **refrain from summing** negative externalities and positive externalities.

Many of the full cost accounting approaches, especially those developed by accounting and consulting firms, offer the monetization of both negative and positive externalities. Private sector businesses are very interested to show their positive impacts on society. In many cases

this relates to the product provided, satisfying consumer needs such as nutrition, shelter, and health, to personal development needs including education, mobility and recreation. Often, companies show their contribution to the SDGs in this way. However, fundamental challenges arise when including this in impact assessments such as LCA. As most impact assessments describe the externalities resulting from economic activities employed in the production of products, the virtues of these products themselves cannot be included in the analysis. These are the internalities, the virtues which make the buyer award the producers the price reflected in the transaction costs. Thus, it is recommended to formulate a set of criteria that determines when positive impacts can be included, and how. Only external benefits that are not reflected in the transaction costs can be included. See for more detailed discussions on this (Kühnen and Hahn, 2019; Croes and Vermeulen, 2021).

A second aspect on this topic relates to summing positive and negative impacts. Various approaches tend to do so, ultimately aiming for 'net-zero' or 'net-positive'. Huysveld et al. 2021 connect this to the (often implicit) choice between strong and weak sustainability. We argued above that the complexity and interrelatedness between the various aspects of sustainability require an approach where all impacts jointly are considered, to avoid trade-offs. In other words, a strong sustainability approach is indispensable: a method should not allow to settle some form of pollution with, for example, a little more or less corruption; or e.g. producing healthy food does not balance out the climate change caused by its production. We therefore recommend refraining from summing negative externalities and positive externalities in full cost accounting methods.

4. Be **fully transparent** about which monetary valuation coefficients and data sources are used.

In our review we were not able to capture all required information about the various methods. For various methods, documentation on the theoretical background and underlying data sources was not available in publications, on their website and after requests by email. We observe that most FCA methods do not explicitly list the use of their underlying monetization approaches, with the exception of Product Impact-Weighted Accounts, True Price and Oiconomy Pricing. Since coefficients can differ substantially given the underlying approach used, we promote increased transparency. As has been observed by others, "(…) methods have various limitations, being based on subjective preferences of individuals in specific socio-economic contexts or market data or even hypothetical market responses also in specific socio-economic contexts." (ISO, 2018). Both for credibility and public use in comparing alternatives it is essential to be transparent about the underlying valuation approach used, and the source and quality of the cost data used.

We present these four points as *provisional* 'ground rules' with the ambition to stimulate scholarly discourse. Our intention is not to superimpose a certain theoretical perspective, but rather call for explicit choices on each of the four ground rules. We invite the diverse academic community to respond by amending, adding or critically rejecting these provisional ground rules. Other perspectives may be valid, but we need to acknowledge the implications of alternative choices. We hope that we can move beyond the current practice of mixing any available method or data source towards a more theory-driven practice.

6. Conclusion and outlooks for further research

This article presents a first zoomed-out reflection on FCA methods, thus it has also been subject to some limitations. Firstly and mainly, the methodology is limited to mainly providing theoretical insights to the monetary valuation context. While we believe this is fundamental to proposing ground rules, the work could be expanded by practically applying some of the selected FCA methods to selected case studies, highlighting differences in their approach and results. Secondly, we did not have access to information exchanges with the developers of all selected methods. Thirdly, since the field is rapidly evolving and growing in popularity, more background documentation might have become available after conducting the research. Our theoretical reflection should therefore be seen as a 'point-in-time' overview.

Our review also shows new trajectories for research. First of all, we see promising avenues for exploring synergies between existing methods. For example, research could study whether the 'remediation' or 'abatement' approaches of some approaches be combined with the 'prevention' approach of others; whether the data from different sources is compatible; and whether scientific and private sector efforts could be joined to widen and refine the data sources available for such approaches. This could be complemented with a 'scoring system' based on the described ground rules, allowing to grade different monetization methods and/or FCA methods, and determining their suitability in the specific situation at hand. Another point for future research is the current availability of conflicting monetary valuation coefficients for the same topic. Joint efforts are needed here to develop harmonized and updated versions of such MVCs. When choosing to calculate externalities as prevention-based costs, one should be aware that the magnitude of these prevention costs does not equal the magnitude of the (prevented) damages. For some aspects the prevention costs might be relative higher and for other lower, if compared to the damage costs. This requires clear communication to users, and has implications for the decision-making by economic actors in corporate sustainability programs. Little research is currently available on how companies use this type of knowledge in their corporate policies and value chain interactions.

Acknowledging the fundamental difference between damage-based and prevention-based approaches also creates an interesting challenge to analyse the difference between the cost of prevention and the damage costs in specific cases of products. A common-sense hypothesis would be that prevention is (far) cheaper than the costs of the damages. Remarkably, little research is available to showcase this. One could expect that such studies would provide results that provide clear guidance to action to policy makers and economic actors.

Finally, if full cost accounting studies become widely used, their implications for policy making can be further elaborated. One example in this direction is the already proposed shift from value-added tax (VAT) or sales tax to a damage and value-added tax (DaVAT) partially based on the life cycle assessment (LCA) of goods and services (Timmermans and Achten, 2018). Wide application of full cost accounting requires, as shown in this review, a step towards a more theory-based and transparent practice. With our provisional ground rules, we intend to enable steps of this promising research community into that direction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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