Int J Life Cycle Assess (2015) 20:1625–1639
DOI 10.1007/s11367-015-0970-z

ENVIRONMENTAL LCC

A transdisciplinary review of the role of economics in life cycle sustainability assessment

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Received: 18 December 2014 / Accepted: 21 September 2015 / Published online: 15 October 2015

Abstract
Purpose This paper reviews the use of economic values in life cycle assessment (LCA) and the justification for environmental life cycle costing (ELCC) as the 'economic pillar' of life cycle sustainability assessment (LCSA).
Methods A transdisciplinary review of economic values in LCA was undertaken and structured with a series of research questions. The review considered the philosophy of science and focussed on the concept of value as a point of synthesis among the disciplines of LCA, economics and ethics. An example from the ELCC Code of Practice was reviewed to highlight the challenges and alternative approaches explored.
Results and discussion 'Value choices' and the role of decision makers have been a long-standing and largely unresolved discussion in LCA. Over the past two decades, LCA has been dominated by a utilitarian concept of ethics and valuation based on willingness to pay. This has a number of limitations which are further exacerbated in ELCC and its accounting definition of cost. ELCC struggles to address social costs, and the focus on the decision maker may define values that are not compatible with sustainability. John Rawls' 'justice as fairness' and Amartya Sen's capability approach were considered to reappraise the use of UN Conventions considered in early LCA literature on values. It was argued that there is an ethical basis to prioritise minimum standards in LCSA to address primary social goods as well as uncertainty in evaluations.
Conclusions This paper questioned the reliance of LCA on utilitarianism and valuation using willingness to pay and, in particular, the claim of ELCC as the economic pillar of LCSA. Concepts of fairness and capability may overcome some of these limitations and provide a basis for integration of social, economic and environmental pillars of sustainability. Although the ethical justification of prescriptive values may only reach agreement on minimum conditions for social and economic cooperation, it was argued that this may provide a reasonable starting point given the global sustainability challenges over the coming decades. A two-stage approach for the implementation of economic values in LCSA was suggested for further debate and discussion.

Keywords Capability approach · Consequentialism · Ecological economics · Economics · Environmental life cycle costing · Ethics · Fairness · Life cycle assessment · Life cycle sustainability assessment · Planetary boundaries · Rawlsian social contract · Sustainability · Utilitarianism · Value

1 Introduction

Environmental life cycle costing (ELCC) is presented as the economic pillar of life cycle sustainability assessment (LCSA) (Kloepffer 2008; UNEP 2011). This paper seeks to address whether ELCC captures economic values that support LCSA and is coherent with existing applications of economics in life cycle assessment (LCA).

The attraction of economics, according to Daly and Farley (2011), is the ability to make results meaningful. Reap et al. (2008a) suggest that social and economic life cycle information can improve the relevance for decision making by

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exploring trade-offs. This also underpins the argument for the development of ELCC as the economic pillar of sustainability (Klöpffer and Ciroth 2011). This has the potential to address long-standing challenges in LCA of communicating results to decision makers (Margni and Curran 2012; Zamagni et al. 2012).

However, LCA has had a long and uneasy relationship with economics. On the one hand, economics has been used to address issues of allocation—but only as the method of last resort in LCA standards—and to provide values for weighting—but not as part of standardised LCA. This highlights long-standing challenges in LCA regarding the use of values. These issues have not been resolved in LCA but simply limited in their extent and application. Yet, the development of ELCC focuses on economics and, as part of LCSA, requires values that support sustainability. This means that the relevance of ELCC to a decision maker may limit the relevance to sustainability.

This has led to a questioning of the role of ELCC as the economic pillar of sustainability. In particular, Jorgensen et al. (2010) questioned the relationship of costs to sustainability, which appears particularly acute when externalities (an unintended and uncompensated loss or gain in welfare of one party from an activity from another party) (Daly and Farley 2011) are excluded. This form of ELCC potentially provides relevant information to a consumer and business at the risk of only including environmental and social issues that are already captured in the market. On the other hand, inclusion of externalities led to the critique of double counting when coupled with LCA and SLCA (Jorgensen et al. 2013; Wood and Hertwich 2013). While the argument appears intractable, there are also a number of common limitations which may provide a way to resolve or at least re-state the problem. Both existing arguments draw upon the values of welfarism and the ethics of utilitarianism to some degree—with the concept of welfare restricted to the utility of the consumer and business decision maker in the case of Klöpffer and Ciroth (2011). The situation is a little more complicated with Jorgensen et al. (2013) who not only draws on welfare for the framework of natural capital but also considers capability and freedom from Amartya Sen as well as needs from the Brundtland report—none of which is necessarily in agreement in their values and ethics. This paper argues that the challenge of defining the scope of ELCC relates in part to the ontology and epistemology of economics and its relationship to a normative concept such as sustainability (with these terms defined in Sect. 2).

This critique may also contribute to the development of an integrated approach which has been noted as a need in LCSA (EC-JRC 2012). Huppes et al. (2012) concluded that a discussion of environmental evaluation at the conceptual level is required to take the next steps towards sustainability. It has also been questioned whether LCSA is a suitable framework for the emerging discipline of sustainability science (Sala et al. 2013a; Sala et al. 2013b). It was argued that there were a number of philosophy of science challenges and there was a need to be more holistic and system wide, transdisciplinarity, multi-scale (for both temporal and geographic) and participation of stakeholders. This in turn questions the ability of LCSA to address global sustainability challenges over the coming decades, such as the contribution of LCSA to Rio + 20 (Valdivia et al. 2013).

To date, there has not been a review of economic philosophy of science to inform the integration of an economic pillar into LCSA. Sala et al. (2013b) considered the ontology and epistemology of LCSA but excluded the literature from social sciences. This has been partly addressed in a recently submitted critical review of the philosophy of science for SLCA (Hall 2015, under review). Yet, there remains the challenge for incorporating knowledge relevant to ELCC and LSCA, unless it can be assumed that economic and physical science papers on sustainability are already transdisciplinary. However, in a review of transdisciplinary literature on sustainability, Schoolman et al. (2012) suggest that physical science was actually the least transdisciplinary. Economics, although it had a lower number of papers on sustainability, was reported as the most transdisciplinary. This suggests that economic literature may be a good starting point for integration. However, the ontology and epistemology of economics with regard to sustainability is a contested and active area of debate (e.g. Baumgärtner and Quaas 2010; Birkin and Polesie 2013; Martins 2011; Scerri 2012; Söderbaum 2007; Spash 2012). This in turn suggests that LCSA cannot simply adopt economic methods without an appreciation of its limitations.

The review was similar to a mixed method literature review and sought a critical evaluation rather than a summary of all literature (Hesse-Biber 2010). A critical review of a transdisciplinary subject can overcome the practical issues of the volume of literature across a number of disciplines (Gaziulusoy and Boyle 2013) as well synthesise knowledge to address a particular problem, as discussed in the Sect. 2. Figure 1 provides a summary of the topics concerning economics and LCA and the research questions for each topic. The review progressed by characterising the challenge regarding values in each stage of LCA—starting from goal setting through to weighting. This drew upon papers that explicitly considered values in LCA, approaches recommended by LCA standards and LCA applications of economics. The review then considered ELCC as a method that seeks to include economic values in LCA methodology. A detailed example from the ELCC Code of Practice (Swarr et al. 2011) was reviewed to consider existing debates in ELCC, compatibility with values in LCA and compatibility with values for sustainability. Key concepts in ecological economics were then briefly reviewed to consider how it may address limitations of ELCC. The Discussion then develops the critique by drawing upon philosophy of science and ethical critiques of consequentialism and

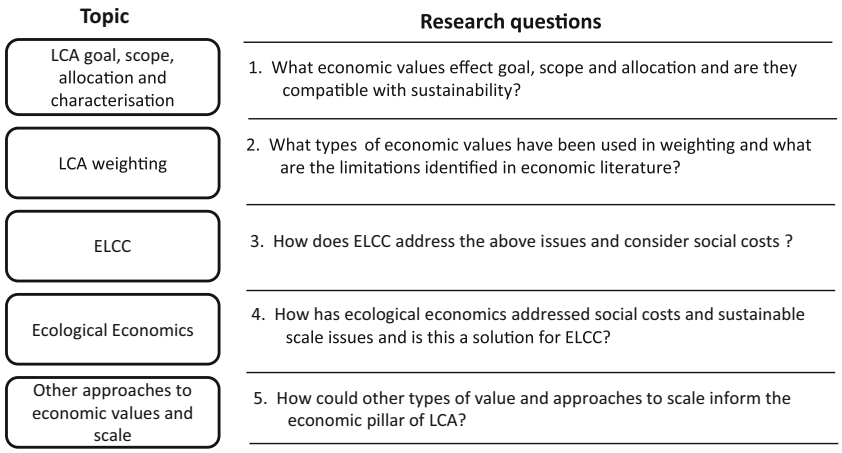

Fig. 1 Summary of topics and research questions in the critical review of the role of ELCC as the economic pillar of life cycle sustainability assessment

considers possible alternatives for an economic pillar of sustainability.

2 Method—transdisciplinary framework for the review

A number of researchers (Carew and Wickson 2010; Gaziulusoy and Boyle 2013; Ingebrigtsen and Jakobsen 2012; Mauser et al. 2013; Max-Neef 2005; Wickson et al. 2006) have noted the need for a transdisciplinary approach to consider sustainability. In fact, considering a complex problem in isolation of other disciplines is considered as part of the problem itself and the reason for the emergence of transdisciplinary research. Transdisciplinary methods and heuristics are themselves an active area of research (Brandt et al. 2013; Huutoniemi and Tapio 2014). This review focuses on developing mutual understanding and theoretical concepts as a means of integrating disciplines to address sustainability (Pohl and Hirsch Hadorn 2008). This first step is perhaps more 'interdisciplinary' (Huutoniemi and Tapio 2014). The concept of 'value' was reviewed to facilitate integration and provides a basis for further transdisciplinary research. Before embarking on the review, a general picture of the types of questions that different disciplines can answer and their epistemological basis gives some context for the focus on value as the concept for understanding the relationship between ELCC, economics and sustainability. In particular, sustainability and, hence, LCSA are normative concepts. The introduction of ELCC as an 'economic pillar' for LCSA introduces epistemological questions for the relationship of economics to the values of sustainability. For example, Max-Neef (2005) suggests that economics—along with other disciplines such as sociology, ecology, physics and chemistry—addresses the question of 'what exists'. Ethics and moral philosophy address the question of 'what we must do'—which is the basis for normative concepts such as sustainability. However, an economist that assumes that 'price' is the same as value will have significant implications for ethics (Brennan and Eusepi 2010). In turn, a physical scientist that draws upon economics for 'value judgements' will adopt these underlying limitations. This highlights that concepts that are defined within a discipline (and may be coherent in this context) may have different meanings and cause confusion in transdisciplinary research. It also highlights a common attempt to make economics and LCA value free. The characterisation of economics as value free by Max-Neef (2005) reflects the dichotomy between positive and normative economics. However, from 'Adam Smith to John Maynard Keynes economics was widely understood as a moral science' (van Staveren 2009). The need to situate the economy in a moral and ethical framework to consider sustainability has also been acknowledged generally within economics (Besley 2013), in particular evaluative frameworks such as cost benefit analysis (Baum 2012) and emerging fields such as sustainability economics (Söderbaum 2007).

2.1 Value

To enable a transdisciplinary review, this paper adopts a pluralist definition of value based upon a variety of ways of caring about something (modes of valuation). Values are defined as the standards that an individual accepts for evaluation. Evaluation is the process of judging how far and in what ways the standards are met (Anderson 1993). This definition supports the development of a conceptual framework for value in LCSA which draws upon economics and ethics. Note that the LCA standards limit the concept of evaluation to the 'element within the life cycle interpretation phase intended to establish confidence in the results of the life cycle assessment' ISO (2006a). In addition, a pluralistic view of value provides a challenge for a monistic concept of value in economics (Lo 2014). This is not to argue that an economic concept of value based on marginal changes in preference and measured by price is not suitable in many applications. Rather, this

approach recognises that quantification of values into a single measure may not always be possible or desirable, such as the qualitative evaluation in social LCA. Baron and Spranca (1997) refer to values that resist quantification and trade-offs as 'protected values'. Using the market instead of morals to value something can lead to inappropriate commodification and corrosion of value itself (Anderson 1993; Sandel 2012). The definition also recognises that 'decision frames' will draw upon norms and ideals and be subject to cognitive biases that effect preferences (Tversky and Kahneman 1980). Cognitive science also provides some insight into ethical theories using concepts of sympathy and group selection to provide a basis for lower and higher social values (Changeux 2012). The following discussion also builds upon LCA literature for the importance of decision making for discussing values in LCA (Finnveden 1997; Hertwich et al. 2000; Hofstetter et al. 2000; Tillman 2000; Werner and Scholz 2002). As a point of clarification, Steen (2006) notes that weighting is not the same as values. Values provide the moral standard, acceptable or not in terms of Steen (2006), whereas weighting in the following discussion is considered as evaluation—the process of measuring against a standard of value (Anderson 1993).

Ethical theories provide the justification for values and enable a critical review of the use of economics to address sustainability. The following brief descriptions provide an introduction to the terms and ethical theories that are used in the review. Normative ethical theories underpin the discussion of values and can be divided into four groups in Western moral philosophy, namely, consequentialism, deontology, virtue ethics and contractual ethics. A very limited description of each theory is given to introduce the terms and their relationships to one another. Volumes are written about each theory, and the reader is referred to the literature for detail and recent discussions, e.g. Hiller et al. (2014). Consequentialism is an ethical theory that judges value based upon the outcomes. Utilitarianism is a form of consequentialism that draws upon welfarism (Hiller 2014) and is the ethics underpinning orthodox economics. The focus on economic literature in this paper means that the strengths and limitations of utilitarianism receive particular attention. An important limitation of utilitarianism is that it only permits one type of value—which is itself a challenge for a pluralistic concept of value as well as for maximising utility itself (Sen 1979). Other ethical theories are then considered for addressing limitations of utilitarianism. Deontology is an ethical theory that evaluates an action based upon rules and principles regardless of the consequences (Engel et al. 2008). Kantianism is an important form of deontology—with the 'categorical imperative' crudely translating as 'do unto others as you'd have them do unto you' (Engel et al. 2008). Virtue (traits of character) ethics draws upon the Greek philosophers of Plato, Socrates and Aristotle and can be crudely summarised as 'nothing in excess' (Engel et al. 2008). Flyvbjerg (2001) draws upon Aristotelian ethics and emphasises the importance of values and power in social science, which has important implications for considering decision making of different actors. Contract ethics formulates principles for personal and social duties based on mutual agreement (Engel et al. 2008). Rawls' 'justice as fairness' is an example which defines principles for the rules of society and equity. The capability approach of Sen builds in part on the work of Rawls and is particularly relevant for UN development goals as noted by Jorgensen et al. (2013) as well as recent application to sustainability (Sen 2013).

3 Review of economic values in LCA

The discussion of value in LCA has a depth and longevity with articles ranging from philosophical (Finnveden 1997) and ethical discussions (Volkwein et al. 1996; Volkwein and Klöpffer 1996) through to recent discussions about criteria to evaluate weighting methods (Johnsen and Lokke 2013). Steen (2006) notes the contested discussion of values in LCA and the need for consensus in ISO Standards led to statements limiting the use of weighting for comparison of performance. This follows a long-standing 'fact-value' demarcation of physical and social sciences (Fischer 1980; Flyvbjerg 2001; Gimbel 2014). However, the LCA standards go further by asserting that economic and social aspects are typically outside of the scope of LCA and other tools should be used for a more comprehensive assessment (ISO 2006a). The standards also preference natural science above economics and social science and place conditions on the use of 'value choices' (ISO 2006a) which are 'not scientifically based' (ISO 2006a). Interestingly, the standards make a distinction between economics and social science and value choices with the former given priority because of their 'scientific basis' (ISO 2006a). This appears to overlook the values inherent in various economic and social sciences as well as within natural science itself (Hertwich et al. 2000). The introduction of economic and social pillars into a normative conceptive such as LCSA brings these unresolved issues back to the fore. The following review applies the method to the research questions and topics outlined in the Sect. 1.

3.1 Decision maker, goal and scope, allocation and characterisation

Hertwich et al. (2000) argue that values cannot be neatly separated from physical science in LCA and along with a number of other authors identify values inherent in the stages of LCA prior to weighting (e.g. Tillman 2000; Werner and Scholz 2002). Economic values enter the LCA at the stage of scope and goal definition, and Steen (2006) notes that the decision to undertake an LCA and the goal may be based solely on economic reasons. LCA standards simply require 'decision-

making in accordance with the goal and scope of the study' (ISO 2006a, pvi) and highlight the role of the decision maker and the potential influence of their economic goals. LCA standards directly identify various institutional decision makers including industry (product development, marketing, strategic planning) and government (public policy), but consumers and citizens are not directly mentioned. In contrast, the consumer is a focus of a demand-driven economy and the consumer's preferences, value orientations and worldviews inform some LCA discussions of values (e.g. Hofstetter et al. 2000).

Hertwich et al. (2000) consider the effect of values in characterisation such as global warming potentials and the discounting of future impacts. Hellweg et al. (2003) review economic reasons for discounting and conclude that discounting based on 'pure time preferences' should not be applied in LCA for ethical reasons. The type of ethics is not specified but appears to be connected to the notion of intergenerational equity. Nonetheless, it is acknowledged that decision makers often use discount rates based on pure time preference (defined by Hellweg as 'impatience'). Hellweg et al. (2003) also note that any application of a 'time cost of money' to physical flows assumes monetisation and a range of other conditions such as compensation of future generations and an approach to uncertainty. The type of decision maker and their goals will also affect the choice of discount rate (typified by the private or social discount rate). The article does not directly address the potential limitations upon decision makers for choosing discount rates, which may be based more upon risk, debt profiles and access to finance rather than any ethical perspective. In addition, the discount rate and monetisation assume a consequentialist concept of value with trade-offs which may not be morally acceptable using other concepts of value, e.g. Kant (see McShane 2014).

Economic values also play a role in procedures such as allocation. The LCA standards prioritise physical allocation but allow the use of 'economic values' as a secondary approach (ISO 2006b, p15). Market prices or 'exchange values' are used in the examples given in ISO (2000), but a broader interpretation of economic values was not considered. However, while a market price may be applicable for a financial decision in business, other economic values may be more appropriate for a decision maker considering social policy, especially when addressing market failures such as environmental deterioration. Pelletier and Tyedmers (2011) note that market prices may contain little information about environmental issues. Pelletier and Tyedmers (2011) argue that a physical limit on a company's total emissions may be a more effective mechanism for reducing environmental impact than allocation using market prices.

The role of the decision maker may constrain the values considered and create a tension between information relevant to their role as decision maker and information that is relevant for sustainability. While it can be argued that a role of government is to address market failures (such as environmental impacts and inequality and more positively in terms of capability, e.g. Nussbaum 2011), the role of business has no such imperatives. Businesses may adopt a broader set of values, but the ethics for these values appear to be external to the business model. Solomon (2005) notes that business ethics is a relatively new field and follows a long history of condemnation of business in philosophy and religion. Solomon (2005) does not attempt to develop an ethic based on the business model but simply asserts that business has to yield when its practices conflict with the morality and well-being of society. One way to introduce values and promote business ethics is to situate people in the business who are more likely to behave ethically (Craft 2013; Ford and Richardson 1994; O'Fallon and Butterfield 2005). However, any values introduced are subject to their effect on business performance. For example, Porter and Kramer (2002) suggest that corporate philanthropy can improve the competitiveness of a business—which also suggests that the business performance is the standard of value and corporate philanthropy may be evaluated differently if it degrades business performance. This is not to deride corporate initiatives and may even make their efforts appear more commendable given the challenge of the role of business and the values of sustainability. Indeed, the responsibility of the business for the type of production can also be questioned in a demand-driven economy. The consumer as decision maker will be considered in the following section in terms of valuation of environmental preferences and the heuristics of decision making.

3.2 Weighting

Finnveden (1997) highlighted the general division of ontological and teleological ethical theories and discussed the implications for LCA. Early discussion of values and weighting in LCA also considered 'intrinsic value', 'safeguard subjects' (Beltrani 1997) and 'rights' (Finnveden 1997; Volkwein et al. 1996; Volkwein and Klöpffer 1996). Finnveden (1997) notes that a mix of ontological and teleological positions can be taken in practice. Other early papers, e.g. Powell et al. (1997), focus upon different approaches to setting weights such as distance to target and cost of environmental protection. The actual values—the standard and the ethical position—were not discussed.

However, more recently, a utilitarian concept of value and even particular methods of monetisation such as willingness to pay (WTP) have come to dominate discussions of value in LCA. Reap et al. (2008b) provide a review of monetisation in LCA with a focus on the use of WTP. Rabl and Holland (2008) assert that its shortcomings result from a misunderstanding of WTP as a measure. They claim that WTP 'has nothing to do with intrinsic value' and is simply an amount that people will pay to avoid losing the item in question. This approach is

pragmatic for developing weights and considering trade-offs but risks the connection to utility and the ethical basis for valuation. Because LCA does not generate WTP estimates, this pragmatic approach can be vulnerable to misapplication as well as misunderstanding of the limitations and uncertainty of WTP estimates. Rabl and Holland (2008) note that it would be 'highly desirable to establish a catalogue of burdens and typical costs per burden' and suggest the use of multicriteria analysis where such information is not available. Rabl and Holland (2008) also describe spatial and temporal challenges and note that representative values can be more appropriate than site-specific values for many policy applications. However, some caution is required for transferring benefit valuation given the differing types of values and differing concerns in differing locations (Spash and Vatn 2006). For example, Spash and Vatn (2006) noted that species that are considered rare and highly valued in one location can be considered pests in another. This is also considered in the ELCC example in the following section. Ahlroth and Finnveden (2011) use WTP in EcoValue08 and note limitations for applying estimates to other locations for some impact valuations. Huppes et al. (2012) suggest a flexible meta-method for weighting and advocates WTP as the only method of economic valuation to provide consistency for the evaluation. However, WTP presents its own inconsistencies and limitations and it is suggested that directly considering the multiple ethical positions, environmental attitudes and social norms may provide more insight for policy than WTP estimates themselves (Ryan and Spash 2011; Spash et al. 2009). The questioning of the measure of WTP (Spash et al. 2009) was built upon the work of the cognitive models for decision making—in particular, Kahneman and Tversky (Kahneman 2011; Kahneman and Tversky 1973; Kahneman and Tversky 1984; Kahneman and Tversky 2003; Tversky and Kahneman 1974; Tversky and Kahneman 1980). This has important implications for WTP estimates as well as the use of complex LCA information for consumer choice or other decision makers. If time and cognitive effort is limited, then dual-process models of persuasion suggest that heuristics will be used in decision making (Vaughan and Hogg 2011). Kahneman (2011) describes three principal heuristics and discuss their potential biases. The need to simplify information to fit the heuristics of decision making may justify the use of weighting and labels. However, it further emphasises the need for a set of values and ethical framework which are accepted for the purpose of weighting.

Notwithstanding issues of valuation, other authors have sought to position LCA with other tools to provide a more comprehensive assessment. Weidema (2006) also considers WTP estimates and a variation that uses average income as the constraint for monetising quality-affected life year. Weidema (2006) concludes that the advantage of this approach is the completeness of LCIA-based cost-benefit analysis (CBA). However, the ethical limitations were not addressed nor the significant economic literature that questions the values of CBA (Ackerman and Heinzerling 2002; Anderson 1993; Baum 2012; Hansson 2007; Posner 2001; Sen 2000; Wegner and Pascual 2011). Although there may be practical reasons for using a budget constraint, the relationship to the value of a human life and the implications of income inequality for valuation were not addressed. A number of other authors also seek to integrate LCA and CBA on the assumption of monetisation of impacts without addressing assumptions regarding values, e.g. Simões et al. (2013). This is not to argue that CBA is not a useful framework, but rather that other concepts of value may be relevant to address some of its limitations. For example, Robinson (2013) notes that although well-being analysis itself requires further development, it may provide a complement for CBA approaches (albeit still within a utilitarian ethic). Ahlroth et al. (2011) review the use of weighting and valuation in a selection of environmental system analysis tools but although a variety of weighting methods (such as distance to target) are considered, only monetary valuation is considered. Environmental system analysis tools also draw upon the concept of thresholds and standards which is considered in the discussion.

In addition to valuation using WTP, 'Pigovian taxes' have also been used in LCA for valuing externalities. Finnveden et al. (2006) discuss the use of EcoTaxes with the noted assumption that existing taxes are a reflection of social values in a functioning democracy. From the normative perspective of sustainability, this assumption is somewhat self-defeating because it implies that sustainability challenges are currently addressed and captured in taxation policy. If this is not the case, then a rationale for values and evaluation for sustainability is still required. Finnveden et al. (2006) also claim that EcoTaxes overcome issues of discounting because decision makers may have considered discounting when developing the tax. While this might be true, it does not resolve the issue of discounting or the differing rationales for appropriate discount rates for different types of decision maker (but simply adopts assumptions from elsewhere). Again, the criticisms relevant to CBA stand for EcoTaxes especially when taxation policy is based on CBA. In addition, Eurostat (2013) highlight not only the difficulty of calculating the marginal social cost but also that taxes may be developed with other fiscal motives in mind—also reviewed more generally in Barbier and Markandya (2013). They note that the tax rate should consider the price elasticity of demand and be weighted compared to Pigovian components based on the marginal cost of public funds (Eurostat 2013). While existing taxes may be available for some environmental impacts in particular countries, even then, it is not clear to what degree they reflect long-term sustainability considerations such as a biophysical 'safe operating space' (Rockstrom et al. 2009).

Finally, Wood and Hertwich (2013) provide an alternative approach by attempting to exclude environmental and social values from economic indicators in LCSA. This was proposed to avoid double counting with environmental and social measures in LCSA and to focus on economic measures. Wood and Hertwich (2013) adopt a concept of value based on the value in exchange. The concept of value added, and its aggregate across the economy, GDP, was suggested as an economic indicator. Some qualification was given to the weighting of factor costs which were considered as value judgements (and existing environmental and social protection could also be identified as a separate factor cost following (Leontief 1986)). While GDP is an important economic indicator, the assumption of 'welfare' and its relationship to well-being is less accepted (Stiglitz et al. 2009) (interestingly, Sen 1979 directly refers to Leontief regarding the shortcomings of welfare economics). GDP can also reflect positively for events with negative well-being or utility; e.g. the Bhopal disaster could be counted as an increase in GDP (Ibrahim 2014). Increases in GDP also do not capture issues of equity and distribution, as Stiglitz (2012) notes that 'rent seeking' in the USA has resulted in a redistribution of wealth so that increases in GDP have gone to the minority (rather than the greatest number) over the past two decades. Other suggested relative measures such as efficiency are also problematic for concepts of equity—'Pareto efficiency' and equity are considered as trade-offs by neoclassical economists (van Staveren 2009). This is not to say that structural economic issues such as innovation and technology are not important; however, they do not necessarily provide insight into whether or not a goal is achieved. While Wood and Hertwich (2013) avoid double-counting environmental and social impacts, the approach runs contrary to the call to situate economics within a moral framework to consider sustainability—as noted in the Sect. 2. Nonetheless, the use of economic models such as input-output analysis provides a link to consequential LCA and can consider rebound effects as noted by Wood and Hertwich (2013). Input-output analysis can also be used for environmental social accounting matrices and may provide an alternative to isolating economics from environmental and social measures, e.g. Martinez-Anguita and Wagner (2010).

3.3 Environmental life cycle costing

The challenge of classifying environmental, social and economic pillars in LCSA was noted by Bachmann (2013). The following example considers ELCC as the economic pillar of LCSA and the limitations imposed by the definition of relevant costs in light of the preceding review. This distinction dates back to Norris (2001) who provides an early example of the attempt to integrate LCA and life cycle costing. Operationalising this distinction is difficult because ELCC adopts a financial definition of costs which limits the values considered. For example, Hunkeler et al. (2008) define cost as 'The cash or cash equivalent value sacrificed for goods and services that are expected to bring a current or future benefit to the organization' (Hansen and Mowen 1997). This is similar to other accounting definitions, e.g. OUP (2010), which focuses on expenditure and classification of costs from the perspective of an organisation for the purpose of tracking and reporting. In comparison, a business perspective broadens the definition of cost to allow quantification other than monetisation and considers the business goal (Law 2009). Interestingly, Swarr et al. (2011) note that despite the long history of LCC, that its use in practical decision making is limited—which ironically was one of the reasons for the development of ELCC and the attempt to integrate LCC with LCA (Klöpffer and Ciroth 2011; Norris 2001). The lack of adoption may be explained in terms of the business goals—costs for the use of a product are not borne by the producer and are only indirectly relevant via the decisions of the consumer. Moving beyond business to the scale of the economy, cost can be defined as 'the value of the inputs required to produce any good or service, measured in some units or numeraire, usually money' (Black et al. 2012). This definition removes the focus on the organisation, and the inputs could be defined by supply chains that draw on the whole economy. Similarly, the goal of an organisation is replaced with a reference to the concept of value. This definition lends itself to a calculation of inputs and outputs and a utilitarian concept of value. This definition appears to fit Steen et al. (2008) who consider externalities as value changes and considered that a social LCA 'mandates, that anticipated environmental, social and economic externalities will be included'. Resolving value conflicts and, in particular, integrating external impacts into life cycle costing were identified in the ELCC Code of Practice as a future need (Swarr et al. 2011). Although ELCC could simply adopt an economic definition of cost to support the role as economic pillar of sustainability, the current definition reflects some of the current ontological and epistemological challenges. As noted in the review, existing monetisation and the values of the decision maker need to be treated with caution to ensure concordance with sustainability. These challenges are viewed thought reconsidering the automobile example in the ELCC Code of Practice.

Swarr et al. (2011) presented a comparison of the environmental life cycle costs of a range of cars from the perspective of a consumer, manufacturer and policy maker. Different costs were considered relevant to the three types of decision makers. While a different scope of costs may be justified in terms of the relevance for a cost-effectiveness decision of the particular decision maker, the relationship to sustainability was less clear. The ELCC Code of Practice is partly aware of this challenge and recommends that LCC is not used as a unique sustainability tool but rather viewed as one of the pillars of sustainability and complemented by LCA and LCSA (Swarr et al.

2011, p18). Nonetheless, the concept of sustainability from an economic perspective appears to be relative to the decision maker. Although considering costs to the consumer over the life cycle may coincide with environmental considerations such as fuel efficiency, it does not inform the consumer of the range of externalities associated with car use. In fact, in the absence of policy, externalities will not be considered and the direct cost to the consumer may actually be a reflection of unsustainable practices. It appears difficult to justify that the current market and policy failures should be used to define the costs for the economic pillar of sustainability. An alternative perspective is to consider all costs relevant to sustainability whether internalised or not. The ELCC Code of Practice suggests that externalities that are expected to be internalised in the decision relevant future should be included in LCC (Swarr et al. 2011). Alternatively, costs relevant to sustainability should be included regardless of the estimated likelihood of their implementation in policy. This changes the role of ELCC from cost-effectiveness for a decision maker to CBA and a broader range of economic values (the latter considered in the Sect. 5).

CBA expands the scope of the economic evaluation by attempting to identify and monetise externalities. Parry et al. (2007) provide an economic review of the nature and magnitude of externalities from automobiles with a focus upon the USA. The review not only considers the implications of global and local pollutants (including noise) but also impacts from congestion, accidents, road maintenance, dependency on oil and urban sprawl (noting lack of consensus for valuation for the latter and not including the cost of geopolitical conflicts over oil). In a similar way, Swarr et al. (2011) considers local health costs due to pollution for the policy perspective.

Monetisation of impacts can provide insight into the broad breakdown of costs—notwithstanding limitations for the concept of value—and also presents a number of challenges. For example, Parry et al. (2007) estimated a total external cost of US$0.1/mile with congestion, accidents and local pollution representing 80 % of the external cost. In contrast, greenhouse gas emissions accounted for 3 % of total external costs. Although this evaluation may change based on the projected impacts of climate change, it highlights that local impacts, and their local evaluation, can be a significant component of externalities. For example, Timilsina and Dulal (2011) review urban road transport costs from the perspective of developing countries and note that valuations can vary not only with different methods but also from country to country. Health impacts from air pollution were noted to be a greater fraction of GDP in many developing compared to industrialised countries because the latter already have pollution control policies (Timilsina and Dulal 2011). Conversely, accident costs were lower as a reflection of valuation based on greater health and productivity costs in industrialised countries (Timilsina and Dulal 2011). This highlights that direct costs for a decision maker may simply reflect current policy and economic shortfalls and provide limited insight as the economic pillar of sustainability. It also suggests that LCA production chains that span the planet will require valuation that is context specific. The challenge of monetisation can also be seen with regard to the value of human life and suggests that other concepts of value may be more appropriate in some circumstances. For example, the World Health Organisation (WHO) estimated global annual road deaths of 1.24 million and another 20–50 million people receiving non fatal injuries (WHO 2013). This is a staggering number of deaths and injuries at a scale similar to global conflicts. Monetising the deaths seems somewhat at odds to the moral objection of the loss. In fact, the process of monetisation is also morally objectionable not least because the injuries in developed countries may be valued higher (Timilsina and Dulal 2011) despite the greater rate and number of people dying in low- and middle-income countries (WHO 2013). Alternatively, minimum safety requirements to avoid the unnecessary loss of human life (often those not driving the vehicle) could also be argued as an ethical constraint on car use. It is important to stress that the sustainability and ethical challenges arise not from the purchase of a single car but from the system created by the many millions of cars in the world. A global perspective and minimum conditions are explored in the discussion.

4 Review of concepts in ecological economics

While it is beyond this review to summarise the literature of ecological economics, some insight is gained from the general understanding of its ontology, epistemology and methodology and the implications for value. The following summary draws largely upon Daly and Farley (2011).

Over several decades, ecological economics has developed a heterodox branch of economics, and while it still draws upon some of the same theory as neoclassical economics (epistemology), it starts with a different pre-analytic vision (or ontology)—namely that the economy is a subset of the environment and there are limited resources and sinks (Daly and Farley 2011). This has implications for the scope of values and the efficiency of 'allocation of scarce resources amongst competing ends' as well as implications for growth, which needs to stay within ecosystem/planetary limitations and consider social costs. Policy for both social costs and sustainable scale is required to address market failures and achieve a steady-state economy. As a result, the epistemology required to address these issues is more transdisciplinary than neoclassical economics (NCE) or environmental economics (Beder 2011). In short, the ontology of NCE conflicts with physical science despite claims made for scientific 'positive' or value-free epistemology.

Daly and Farley (2011) draw upon generalised models of biotic resources to illustrate how overuse can diminish resource flows and lead to collapse. It also shows the diminishing returns for overuse with increasing effort *as well as* increasing social costs (which together give the total social cost). The comparison of the rate of total social costs with the rate of return from a yield curve suggests an optimal point. This point is different to the maximum ongoing yield for a population because it also considers social costs. This illustrates that not considering social costs leads to an inefficient use of the resource. Costanza and Daly (1992) broaden this concept to natural capital and suggest a constant natural capital stock as a safety measure against dire environmental consequences given the uncertainty in assessing the condition. The point is particularly important to counter yields that may be profitable even though they push a population to collapse. This use of business costs corresponds to ELCC when neither ecosystem limitations nor social costs are considered.

Ecological economics classifies resources as stock-flow and fund service resources. The life cycle inventory (LCI) typically considers stock-flow resources—defined as materials that are used as an input and materially transformed into a product, can be used at any rate and used up or stock piled. However, it is not until some assessment of scarcity that LCA considers the meaning of the stock-flow resource. Economics has a markedly different approach to material stocks with the appraisal of scarcity affected by assumptions about technology, substitution and elasticity and discounting.

The LCI does not directly consider fund-service resources—defined as resources that are not consumed, can only be used at a given rate, cannot be stock piled and are worn-out and not used up. The latter lends itself to ideas of capital and concepts such as natural capital and ecosystem services (Costanza and Daly 1992; Liu et al. 2010). Characterisation and impact models in LCA may potentially provide impacts upon the fund services. Again, the impacts are not given meaning or value until the physical unit is evaluated. This can lead to double counting in LCSA if the impact on fund services is also considered in ELCC as noted by Wood and Hertwich (2013). Conversely, double counting could be avoided if LCI were used for calculations of social costs in ecological economics and not reported separately.

However, there are significant challenges for ecological economics and even greater challenges for the application of ecological economics in LCA. Despite a clear conceptual difference between the optimum use of the ecosystem with and without fund-services resources, there is large uncertainty that may make it difficult to discern in practice. The uncertainty exists in both estimates of the ecological impacts and dynamics as well as the value of ecosystem services.

Uncertainty for social costs can potentially be addressed at a project level by collecting relevant site information for ecological impacts and social costs. However, the challenge is much greater in LCA because of the many sites in global supply chains and the temporal feature of the life cycle itself.

5 Discussion

Daly (1968) notes that

> 'it is better to make imprecise statements about unmeasurable but relevant magnitudes (use value, total utility) than to make more precise statements about the measurable but irrelevant magnitude (for evaluating total welfare) of exchange value' (p 395).

Despite the advances in nonmarket methods and availability of estimates (Barbier and Markandya 2013), this statement still applies for estimating many nonmarket values (Brouwer 2000; Ryan and Spash 2011; Spash and Vatn 2006). The discussion explores the use of alternative ethical frameworks for defining values. A tentative approach is suggested for making more precise statements about 'relevant magnitudes'.

The discussion returns to the use of UN conventions, introduced in LCA some 20 years ago (Volkwein et al. 1996; Volkwein and Klöpffer 1996), to explore its ethical basis and application to current challenges in ELCC. Almond (2005) argues that the concept of rights only provides a summary of ethical arguments that have been agreed upon and codified into policy and law, rather than a system of ethics itself. Others note that human rights and environmental sustainability may not always agree (Woods 2010) nor capture all aspects of well-being (Sen 2005). In addition, defining 'basic needs' is considered a challenge for the concept of sustainability in the Brundtland report (Benton 1999).

The work of Rawls is important for considering the economic pillar of LCA not least because he is claimed as the most influential moral and political philosopher of the last 100 years, but he 'is one of the very few moral philosophers taken notice of by economists' (Bojer 2009, p426). Rawls asserts that 'justice *denies* that the loss of freedom for some is made right by a greater good shared by others' (Rawls 1999, p3) (my italics to draw the distinction to consequentialism). Justice as fairness is based upon the argument that principles of justice come *before* and are given *priority* because they are the basis of social cooperation. Rawls uses the thought experiment of the 'original position' where people must decide on the rules governing society without knowledge of the role that they will play. Rawls argues that the fairness of original position would lead to a set of social rules that would be just and could form a social contract. These social rules take priority to the pursuit of individual ends because they are the basis of social cooperation. In addition, Rawls develops the 'difference principle' which provides a further rationale for a focus on the least advantaged group and their primary social goods. The

difference principle not only is egalitarian but also acknowledges that the way that the total is distributed may affect how much there is to distribute and defines sharing that is more equal than a utilitarian distribution (Bojer 2009). Rawls defines primary social goods as those that underpin intentions for pursuing ends and are roughly categorised as rights, liberties and opportunities, and income and wealth (Rawls 1999).

Amartya Sen is a Nobel Prize-winning economist who pioneered the 'capability approach' and also provides insight into sustainability (Sen 2013). Despite a reluctance to codify a list of basic needs, Sen (1999) does consider 'basic capabilities' in terms of the threshold to avoid poverty. The distinction is that although income can be used to quantify the threshold, it is only instrumentally important and only one of the factors, and it is the loss of freedom that is intrinsically important (Sen 1999). A misplaced focus on means rather than ends is part of the Sen (2005) critique of the Rawlsian difference principle. Other developers of the capability approach advocate lists of basic capabilities and draw a close relationship to human rights (Nussbaum 2011). Picketty (2013) also notes that the work of Rawls and Sen has a similar intent and basic logic as the rights contained in the US Declaration of Independence.

From an operational perspective at the project/policy level, Sen (2000) summarises the challenge for CBA as a trade-off between easier useability through locked up formulae and more general acceptability through allowing parametric variations. This summary is also applicable to the challenge for weighting and values in LCA. While this challenge is unlikely to be fully resolved, there appears to be an ethical basis for minimum standards, focussing on primary social goods and possibly concepts of safety or emergency as outlined by Benton (1999). The fact that moral limits have historically been placed on markets (Sandel 2012; Sandel 2013) and underpin the 'free market' itself (Chang 2011) should provide LCSA the confidence to consider these value choices in economics. At the project/policy level, examples of such moral limits can be seen in US regulation for CBA. Nou (2013) notes that 'Congress can preclude agencies from the consideration of costs for specific regulatory actions, or otherwise constrain the use of CBA, by specifying substantive and exclusive criteria, such as "safety" or standards "requisite to protect the public health." (p1706). Rawls has also been given a 'crude representation' in a social welfare function termed the 'safety standard' (Goodstein 2011) and has also been considered in terms of equity and sustainability by other leading economists, e.g. Pearce (1988), and noting that Rawls was not a welfarist (Bojer 2009). The concept of safety may provide a way of expanding the prescriptive approach—such as US Congress safety requirements as well as Safe Minimum Standards (SMS) for resources of high uncertain future value (Goodstein 2011) and safety for natural capital to account for uncertainty (Costanza and Daly 1992). It may also be possible to extend the approach to other minimums such as basic freedoms and planetary boundaries. The latter has parallels to Rockstrom et al. (2009) who consider 'safe operating conditions' for the planet which have been used to redefine sustainability, e.g. Griggs et al. (2013). That said, the extension of the concept of safety itself requires caution and should be viewed as a constraint that focuses on primary social goods and accounts for uncertainty. Overextending the concept may limit freedom and result in unnecessary inefficiency.

Figure 2 provides a tentative approach for useability to address relevant magnitudes such as primary social goods and planetary boundaries as well as the flexibility to optimise economic values. The approach focuses on step 1 global sustainability challenges, such as poverty and climate change

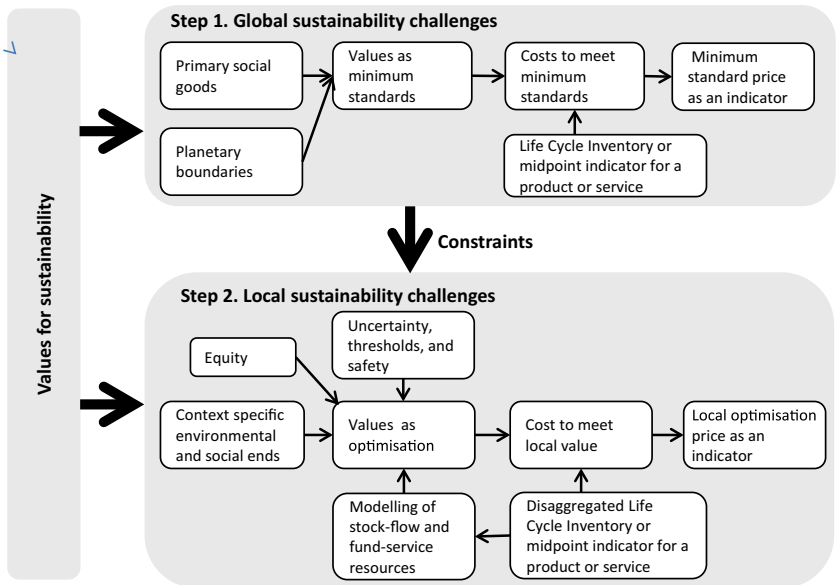

Fig. 2 Proposed two-step process for operationalising economic values in LCSA

(Morrow 2013; Tukker 2013), to provide the 'useability' noted by Sen. The approach follows a similar rationale as Rawls' ordering of ethical rules. Step 1 is a priority that cannot be traded off and provides a constraint for further resolution of economic values. This may also be expressed in terms of act and rule consequentialism (the latter is different to 'rule-based' ethics such as Kant where the value is intrinsic). Act consequentialism evaluates the consequences directly from an action while rule consequentialism evaluates an action indirectly by evaluating the consequences of a set of rules (Hiller and Kahn 2014). For example, drawing upon Rawls, it could be argued that rules for fairness are required for sustainable social and economic cooperation and provide a constraint for optimisation based upon act consequentialism.

The minimum standards may be expressed in market exchange prices. The use of exchange price allows costs for minimum standards to be added to the cost of production to provide an economic indicator. It is important to stress that market prices are an *indicator* of the gap between current practice and the minimum standard. This follows the OECD definition of an indicator, namely a parameter that provides information about a state and with significance extending beyond the parameter value (OECD 2003). It also provides the two indicator functions of reducing the number of parameters and measurements to describe the state as well as simplify the communication process (OECD 2003). This also has a number of points regarding the use of ethics and prices that require clarification. Firstly, the standard or value is defined by the ethics such as the Rawlsian social contract. The price is not an evaluation because by definition in step 1, it is a minimum standard that must be met. Prices are used as an indicator because they are easily communicated and can also be added together. Secondly, this is different to economic modelling which may seek to define a target using marginal costs and benefits. It may also seek to calculate the economic effect of changes in costs as a 'shock' which may lead to a new equilibrium and set of prices. In this case, the standard is utilitarian and the evaluation uses economic modelling to consider prices and welfare.

An estimate of exchange prices could use the marginal cost to meet the minimum standard. An environmental example is the use of marginal abatement cost curves (MACC) to estimate the price for greenhouse gas emissions, noting limitations for its development and application (Kesicki and Ekins 2012; Klepper and Peterson 2006; Morris et al. 2012). A social example is additional payments to labour required to provide primary social goods. This definition may be open to debate but can draw upon standards such as the ILO Social Protection Floor (ILO 2011, 2012, 2015). Again, economic modelling for the effect of changes in labour input costs would not be considered because the priority is to calculate an indicator of the minimum conditions in the social contract. LCA may express these minimum standards for a product over its life cycle by coupling its inventory to the price to meet minimum standards.

Local sustainability challenges (step 2) in Fig. 2 are not the focus of the proposed approach and are considered largely in terms of the constraints imposed by step 1 and factors to consider for optimisation and economic modelling. It also shows the position of LCA in relation to values and other disciplines. This step builds upon the review which suggests caution for LCA application of economic value and valuation especially given the challenges of uncertainty and aggregation. As Webb (1995) notes, the ontological basis and the epistemological ability to predict 'true' social consequences are questionable. In addition, Spash and Vatn (2006) note the high uncertainty for the transfer of information from natural science, such as dose-response functions, when used out of context and with excessive aggregation also noted in LCA (Pennington et al. 2004; Rosenbaum et al. 2008). The uncertainty of predictions has implications for consequential ethics as discussed in detail by Hiller et al. (2014). Use of average LCA data without site-specific information and expressed as an aggregate over a product chain and life cycle is likely to compound issues of uncertainty associated with benefit transfer evaluations. Ecological economics has discussed criteria for the validity of benefit transfer (Spash and Vatn 2006), and this type of protocol may also be required for LCA. Concepts of uncertainty, thresholds and safety may also be important as part of the optimisation. In addition, the term 'optimisation' was used to highlight the need to consider equity as opposed to efficiency gains measured in dollar terms (Goodstein 2011). Rawls' difference principle provides a starting point for this consideration. Sen (2013) argues that 'capability' is the sustainability end that needs to be optimised although recent reviews suggest challenges for implementation (Ibrahim 2014). Indeed, the broader the concept of economic ends, the more it overlaps with environmental and social dimensions (or pillars) of sustainability. Economics may provide a synthesis for LCSA if the values considered and the view of the world are broadened to consider ecological and social realities. This synthesis may be supported by the three-pillar approach which draws upon the expertise in each domain. The use of economics as a synthesis may be particularly powerful given the importance of the economy for driving many of the impacts, both positive and negative, for the environment and society.

Finally, the proposed approach has a number of similarities and differences to the ILCD handbook on impact assessment (EC 2010). Similarities include concepts such as 'critical loads' and 'thresholds' for midpoint indicators as well as indicator criteria such as completeness, environmental relevance and scientific robustness and certainty. Differences include the relationship of LCA to other domains and the definition of areas of protection and indicators (EC 2010). Figure 2 is a transdisciplinary approach. LCA provides input of LCI or

midpoint indicators to modelling that considers 'regional factors'. Concepts such as stock flow and fund service may refine LCA areas of protection (AoP) of Natural Environment and Natural Resources (EC 2010). In general, Fig. 2 defines AoP at the *start* of the process and not as the final step of a cause and effect pathway. The 'social' AoP of Human Health from the ILCD handbook is broadened beyond disability-affected life years, and social LCA is considered in more detail in Hall (2015, under review). This tentative framework presents a major change to the methodology of LCA and requires further debate and development.

6 Conclusions

This paper contributes to the development of an economic pillar for LCSA. It reviewed the use of economic values in LCA and considered the philosophy of science underpinning LCA, sustainability and economics which may provide a basis for integrating ELCC into LCSA. A tentative approach was suggested for addressing global-scale sustainability challenges over the coming decades.

Economic values affect the goal and scope of an LCA and may also affect allocation and weighting. Ironically, LCA is not value free and this may be one of the main reasons for its relevance to a decision maker, which was similar to the rationale for developing ELCC. However, the economic values adopted may conflict with the normative goal of sustainability in LCSA. LCA has relied largely upon utilitarianism and forms of evaluation such as willingness to pay. However, there are fundamental ontological differences between NCE and physical sciences regarding finite resources and scale. Epistemological challenges of prediction present uncertainty that questions the application of consequential ethics. This is likely to be further exacerbated due to spatial and temporal aggregation in LCA and the use of benefit transfer for economic evaluation. Ecological economics has presented criteria for the validity of benefit transfer which may also reduce uncertainty in LCA applications.

Alternative ethical and economic approaches may provide a way of addressing global sustainability challenges such as poverty and climate change. In particular, Rawls' justice as fairness prioritises primary social goods as the basis for economic and social cooperation. Economics also presents concepts of safety to address uncertainty for resources and natural capital as well as provide moral limitations on the application of CBA. The development of the science of 'planetary boundaries' may support this approach, and the concept of safety may be expanded for particular rights and freedoms. However, caution is required to maintain freedom to define values and to avoid unnecessary economic inefficiency. A two-stage application of economic values was tentatively proposed. The first step drew upon Rawls' social contract as well as planetary boundaries. This may be expressed in market values and linked with an LCI to provide an indicator of minimum prices for sustainability. This first step was prioritised and acts as a constraint on the second step which seeks to optimise economic values. The optimisation may consider costs and benefits subject to equity considerations such as Rawls' 'minimum difference' principle. This approach not only draws upon ongoing discussions in LCA but also presents a new formulation that explicitly incorporates values. This is a large change for LCA, particularly as defined in LCA standards, and requires further debate and development.

Acknowledgments Many thanks to Professor Anthony Halog from the University of Queensland for his support. Particular thanks to Justine Lacey, CSIRO, for detailed comments.

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