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The argument against a reductionist approach for measuring sustainable development performance and the need for methodological pluralism

Alexandros Gasparatos *, Mohamed El-Haram, Malcolm Horner

Construction Management Research Unit (CMRU), Division of Civil Engineering, University of Dundee, Fulton Building, Dundee, DD1 4HN, Scotland, UK

Abstract

Both sustainability and sustainable development continue to remain elusive concepts even now, 20 years after the Brundtland Commission report that brought them into prominence. This situation most likely stems from the fact that sustainability science encompasses the need to address a wide set of issues over different time and spatial scales and thus inevitably accommodates opinions from diverse branches of knowledge and expertise. However, despite this multitude of perspectives, progress towards sustainability is usually assessed through the development and utilisation of single sustainability metrics such as monetary tools, composite sustainability indices and biophysical metrics including emergy, exergy and the ecological footprint. But is it really justifiable to assess the progress towards sustainability by using single metrics? This paper argues that such a choice seems increasingly unjustifiable not least due to these metrics' methodological imperfections and limits. Additionally, our recent awareness of economies, societies and ecosystems as complex adaptive systems that cannot be fully captured through a single perspective further adds to the argument. Failure to describe these systems in a holistic manner through the synthesis of their different non-reducible and perfectly legitimate perspectives amounts to reductionism. An implication of the above is the fact that not a single sustainability metric at the moment can claim to comprehensively assess sustainability. In the light of these findings this paper proposes that the further elaboration and refinement of current metrics is unlikely to produce a framework for assessing the progress towards sustainability with a single metric. Adoption of a diverse set of metrics seems more likely to be the key for more robust sustainability assessments. This methodological pluralism coupled with stakeholder involvement seems to offer a better chance of improving the outcome of the decision making process.

Keywords: Sustainability assessment; Sustainability metric; Reductionism; Value

1. Introduction

Governmental bodies, non-governmental organisations, academics and the public are engaged worldwide in policy discussions trying to envision and operationalise a development path that can meet the needs of present and future generations in an equitable manner. The goal of increasing the economic welfare of a population over time is not a new policy objective. However, the acceptance during the past two decades that the state of the environment and the functioning of society are equally as important has led to the formulation of more elaborate policy questions.

* Corresponding author. Tel.: +44 1382 386560; fax: +44 1382 384861.
E-mail addresses: a.gasparatos@dundee.ac.uk (A. Gasparatos), m.elharam@dundee.ac.uk (M. El-Haram), r.m.w.horner@dundee.ac.uk (M. Horner).

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The desired development path that ensures the economic welfare of present and future generations by further considering environmental and social issues has come to be known as sustainable development and was brought into prominence by the Brundtland Commission (WCED, 1987). Even though there is no universally accepted clear cut definition for the term there is a consensus that economic, environmental and social issues together with intra- and inter-generational equity ought to be considered within the framework of sustainable development (Gibson, Hassan, Holtz, Tansey, & Whitelaw, 2005). Furthermore, the importance of considering the significant uncertainties associated with the design of strategies and particularly of those strategies that will span well into the future has been widely acknowledged by academics and policy makers. Incomplete knowledge in social and natural sciences coupled with evolving human preferences and values make a case for acting with a precautionary bias by implementing the precautionary principle (Gibson et al., 2005). Another key element is the involvement of stakeholders, especially those directly affected by a plan/policy/programme, in the planning and decision making process (Meppem, 2000; Meppem & Gill, 1998).

Not surprisingly, measuring sustainable development performance and quantifying the progress towards sustainability is currently at the centre of an ongoing debate that has strong policy implications and is thus progressively moving beyond the academia. Tools and methodologies based on the reductionist paradigm have been used over the past years to measure the progress towards sustainability but very few of them seem to be able at the moment to assess sustainability in a holistic manner (Gasparatos, El-Haram, & Horner, 2008). Tools and descriptive models falling within this reductionist paradigm, according to Munda (2006), make use of a single:

- measurable indicator (e.g. GDP per capita);
- dimension (i.e. one of the economic, environmental or social dimension);
- scale of analysis;
- objective (e.g. maximisation of economic efficiency);
- time horizon.

The majority of such reductionist sustainability assessment methodologies seem to fall within three major categories: monetary tools, biophysical models and sustainability indicators/composite indices (CIs). The advantage of such tools lies in the fact that they can reduce and integrate the diverse issues affecting the progress towards sustainability to a small set of numbers. Such tools can be invaluable to policy makers as they can be used to understand various natural and human systems and summarise a large volume of information to non-experts thus simplifying the decision making process. Understanding a system by simplifying it and offering aggregated information for decision making are in our view the two most critical functions of the reductionist tools that will be discussed. As a result, relevant insights from two new scientific paradigms, complexity theory and post-normal science, will be discussed in Section 2 of our study in order for the reader to appreciate the context within which sustainability assessments are made.

Monetary tools, based on the neoclassical paradigm, have formed the backbone of most sustainability assessment exercises especially for policy making during the past years. However, the most commonly used monetary tools were not conceived specifically for assessing the progress towards sustainability but were rather developed and have matured before the sustainable development debate erupted. Examples include evaluation tools such as market valuation, Contingent Valuation Method (CVM), Hedonic Pricing, Travel Cost Method and aggregation tools such as Cost Benefit Analysis (CBA). The adaptation of extant monetary tools to assess the progress towards sustainability had the great advantage of building from strong theoretical foundations in neoclassical economic theory which has been the dominant paradigm of Economics from the beginning of the 20th Century. However, it soon became obvious that such tools are inadequate in certain situations given that positive progress towards sustainability goes beyond economic efficiency to include equity considerations. Another concern arose through the monetisation of certain environmental and social issues with several criticisms targeting the methodological, conceptual and philosophical aspects of the monetisation procedures adopted.

Such criticisms made the case for developing models with solid foundations in the natural sciences that can quantify resource consumption and subsequent environmental impacts more reasonably (Ecological Economics, 1999; Munasighe & Shearer, 1995). Biophysical models based on a reductionist perspective attempt to elucidate the metabolism of different systems (e.g. production/consumption patterns) by making use of common denominators other than money such as available energy (emergy synthesis and exergy analysis) and land (ecological footprint). Changes of these flows over time offer insights into whether there has been a positive or negative progress towards sustainability (e.g. decreasing the ecological footprint of a system over time implies a positive progress towards sustainability as it will be discussed in more depth in Section 3.2).

Currently there seems to be an active interest in sustainability indicators judging from the large number of sustainability indicator lists published by academics, local authorities, national and international organisations (Esty, Levy, Srebotnjak, & de Sherbinin, 2005; Prescott-Allen, 2001; UN, 2001). These indicator lists usually comprise a series of indicators that capture sustainability issues relevant to the context of the specific assessment exercise. As a result, in most cases, specific indicators lists are not as generally applicable as monetary and biophysical sustainability assessment tools. Indicators in such list are sometimes aggregated to a single composite index in order to reduce the diversity of sustainability issues to a single number. Aggregation choices are usually a trade off between loss of information when aggregated and fuzziness when not aggregated.

Accountants are increasingly required to wrestle with issues of measuring sustainability performance. But sustainable development as an interdisciplinary field of inquiry incorporates insights from a plethora of academic disciplines including the natural, engineering and social sciences. As a result a number of different sustainability assessment tools that have been developed to measure sustainability performance have been published over the past years. Sustainability assessment tools, such as the ones mentioned above, must be accurate, robust and based on sound theoretical foundations backed with empirical evidence if misleading policy messages are to be avoided. With these prerequisites in mind, this article attempts to shed further light on whether it is possible to capture the progress towards sustainability with a single reductionist metric. In particular, this paper exposes some of the strengths and weaknesses of certain tools that follow the reductionist paradigm and have gained some acceptance predominantly between the academic and secondarily between the policy making communities. Key methodological, ethical and philosophical limitations are discussed in greater depth allowing the reader to appreciate their potential for measuring sustainable development performance. In the authors' views, methodological limitations are non-controversial and thus can offer a relatively clear picture of these tools' shortcomings when dealing with sustainable development questions. Philosophical and ethical questions, on the other hand, are much more difficult to be substantiated, and the authors have refrained from exploring them in depth. Nevertheless certain key ethical and philosophical limitations have been discussed in more depth including the monetisation of certain environmental and social issues, the substitution between different sustainability issues and finally how the different concepts of value employed by monetary and biophysical tools affect sustainability assessments.

In our view, employing a variety of reductionist metrics is preferable when holistic sustainability assessments are required because this multiplicity of tools can offer a better view of the overall situation. In this respect this study will build on the work of Gasparatos et al. (2008) and comment on certain philosophical and methodological assumptions of different reductionist sustainability assessment tools that seem incompatible with sustainable development pre-requisites. Our study, further attempts to make stronger the case for methodological pluralism in sustainability assessments as we argue that methodological pluralism with all its strengths and weaknesses should be invoked when holistic sustainability assessments are needed and reductionist metrics are employed.

2. Context of sustainability assessments

Before attempting to answer whether it is possible to measure the progress towards sustainability with a single metric it is useful to understand and appreciate the context within which sustainability assessments are usually performed. Of particular relevance to this are two new scientific paradigms; complexity theory and post-normal science. Complexity theory is preoccupied with understanding a system and post-normal science is concerned with the decision making process during policy formulation in such systems. As a result both paradigms are relevant to what we perceive as the two most important functions of reductionist tools.

Complexity theory seeks to understand and shed light on the mechanisms governing systems which are usually the focus of sustainability assessments. Ecosystems, economic sectors, societies and even cities are increasingly being considered as "social-ecological systems" that are both complex and adaptive whose "*... properties are not fully explained by an understanding of their component parts*" (Gallagher & Appenzeller, 1999, p. 79). Completely understanding the constituent parts of a complex adaptive system does not allow a complete description of it because the interrelations between its parts are also deemed to have a significant effect on its overall behaviour; the progress towards sustainability in our case. Reductionist tools tend to break down the system in smaller components (e.g. energy and matter flows in biophysical metrics, human preferences in economic tools) and understand it but they do little to understand the interrelationships between these components. The importance of understanding the interrelationships has been highlighted in the sustainability literature, e.g. (Gibson et al., 2005; Pope, Annandale, & Morrison-Saunders, 2004). Furthermore, from time to time, change in complex systems can be abrupt and not incremental. During these periods of abrupt change past experience is an inadequate basis for predicting the future state of the system (Folke, Hahn, Olsson, & Norberg, 2005). Another key characteristic of complex systems is their dynamic and non-linear nature where the existence of feedback loops renders the prediction of their future behaviour a challenging task given that small inputs can lead to disproportionally large consequences (butterfly effect) (Lewin, 1999). Another characteristic that constitutes the analysis of complex systems even more problematic is their tendency to be nested. For example, human societies are complex adaptive systems which are in turn embedded in more complex adaptive ecosystems (Limburg, O'Neill, Costanza, & Farber, 2002). It becomes obvious that the interactions across scales become of primary importance. However, tools that focus on a single issue and are based on a steady-state viewpoint interpret changes in the system as incremental and disregard the interaction across scales (Folke et al., 2005). Funtowicz and Ravetz (1994a), by making a distinction between ordinary and emergent complexity claim that emergent complex systems such as the ones mentioned earlier cannot in most cases be fully explained mechanistically and functionally as ordinarily complex systems because at least some of their elements possess individuality, a degree of intentionality, consciousness and morality amongst others.

As has already been mentioned post-normal science is concerned with the decision making process especially in situations where facts are uncertain, values are disputed, stakes are high and decisions are urgent (Funtowicz & Ravetz, 1993). The original policy context for post-normal science was probabilistic risk assessment but it is becoming obvious that the policy context of post-normal science is gradually shifting towards sustainability (Ravetz, 2006). Central to post-normal science is the need to assure the quality of the decision making process through managing the uncertainty and accommodating different perspectives and ways of knowing by engaging an extended peer group (Funtowicz & Ravetz, 1993). Of these insights, the existence of a multiplicity of legitimate perspectives and the need to integrate/incorporate them in the decision making process is of particular importance for the scope of this paper. Funtowicz and Ravetz (1994a) have argued that as a result of emergent complexity "*...No single perspective from within a subsystem of fewer dimensions can fully encompass the reality of the whole system...(a)lthough legitimate in its own terms cannot be sufficient for a complete analysis of its (the system's) properties*" p. 575. As a result one can argue that no single legitimate perspective can provide a comprehensive or adequate vision of an issue (progress towards sustainability in our case) and indeed it would not make sense to exclude all other legitimate perspectives in favor of one. However, a reductionist tool as it is discussed in Sections 4–5 (discussion on concepts of value) is usually a representation of a single legitimate perspective. As a result lack of methodological pluralism can compromise the outcome of the decision making process to a great extent.

3. Methodological limitations

3.1. Monetary tools

There is an overwhelming volume of literature commenting on the use of economic analysis for measuring a shift towards sustainability, e.g. (Goldin & Winters, 1995; Neumayer, 2004; Pearce, 1993a; Pezzey & Toman, 2002). For the purpose of this section only key ethical and methodological criticisms of certain commonly used monetary tools will be discussed in order to explain both some of the limits of economic valuation/aggregation and the discontent that has arisen over the validity of economic analysis in sustainability assessments. A detailed analysis of economic tools such as the Contingent Valuation Method, the Cost Benefit Analysis and the Index of Sustainable Economic Welfare (ISEW), particularly concerning their methodological limitations, is included in Gasparatos et al. (2008).

The root of these criticisms probably stems from the fact that the most widely used valuation and aggregation tools such as Contingent Valuation Method and Cost Benefit Analysis were not developed specifically for sustainability assessments but were rather arbitrarily adapted for such purposes. These tools have their methodological foundations in the neoclassic economic view of humans as economic persons which has, to a certain extent, been criticised by sustainability scholars, e.g. (Ayres, van den Bergh, & Gowdy, 1998).

Ethical criticisms have provided some of the most telling arguments against the monetisation of environmental and social issues in sustainability assessments. Heinzerling and Ackerman (2002) comment on the fact that respondents in

CVM surveys are asked to give their preferences as individual consumers rather than as citizens living and acting within the society. Furthermore, according to Bebbington, Brown, and Frame (2006) monetisation of certain environmental and social sustainability issues (e.g. biodiversity, human health, etc.) can be seen as morally questionable since it might be argued that it devalues these issues by bringing them to a position where they can be compared with other monetised issues and thus be substitutable with them. For example in an investment decision high gains in economic output might offset loss of biodiversity or detrimental effects in human health as a result of increased pollution. This compensability and subsequent substitutability of monetised values are essentially trade offs between sustainability issues within monetary tools and form the core of the debate of strong vs. weak sustainability. It is worth giving a brief overview here of the terms weak and strong sustainability that originated from the debate concerning the substitutability between the environment and the economy. In more detail weak sustainability, also known as Hartwick–Solow sustainability, advocates the perfect substitution between different forms of capital (human, financial, natural, manufactured and social) in order to assure a non-decreasing welfare over time. On the other hand, strong sustainability suggests that the different types of capital should be independently maintained on the grounds that some environmental components are unique and certain environmental processes may be irreversible (Ayres et al., 1998). The interested reader is referred to Neumayer (2004) for a deeper discussion of the two paradigms.

Methodological criticisms show even more strongly and undisputedly the limitations of economic tools for sound sustainability assessments. Venkatachalam (2004) exposes a string of methodological issues that affect the validity and reliability of non-market valuation techniques such as the CVM. Issues such as discrepancies between elicited willingness to pay (WTP)/willingness to accept (WTA) values, provision of information and strategic responses by the respondents, amongst others, cast doubt on the validity of the elicited monetised values. Knowledge of the valuation context and objective judgement on the part of the respondent is also assumed. For example, Costanza (1991), as quoted in Patterson (1998), comments on the dangers arising from that assumption by exposing a number of biodiversity evaluations where consistently higher values were elicited for species with which respondents could empathise such as mammals (dolphins, pandas, etc.) when compared to other species such as invertebrates. Similar criticisms can be found in the literature and for other commonly used valuation techniques such as the Travel Cost Method, Hedonic Price Method, etc. (Pearce, 1993b). An immediate outcome of this is that monetised values fed into aggregation tools such as CBA might be highly uncertain at best or in some cases not make sense at all (Heinzerling & Ackerman, 2002).

Aggregation of monetised values raises new questions on whether the procedures adopted are in accordance with sustainable development considerations such as intra- and inter-generational equity. Gasparatos et al. (2008), comment on the inconsistency of certain methodological choices within the CBA, such as the Kaldor–Hicks criterion and the inability of discounting techniques to take account of equity considerations in an adequate manner. Modifications of the current discounting and aggregation procedures have been proposed by Rabl (1996), Farrow (1998), Padilla (2002), Sumaila and Walters (2005), Saez and Requena (2007) and Zerbe, Bauman, and Finkle (2006) amongst others but the debate about whether equity considerations can be captured by monetary tools still remains open. Perhaps the key reason is that CBA is based on the concept of economic efficiency and not of equity.

3.2. Biophysical models

Biophysical models aim to quantify aspects of sustainable development through a natural science perspective. Such quantifications seem to be more “objective” and accurate especially when it comes to the valuation of environmental issues such as resource depletion, pollution and ecosystem services as they do not depend on human preference but on biophysical parameters that can be precisely measured. Of the large number of biophysical sustainability measures only a handful has been developed to capture several sustainability issues. Three such metrics that have gained some acceptance between academics are emergy, exergy and the ecological footprint.

Emergy and exergy account for the different flows within a system. Despite their different approach they share the same assumptions that in every observable phenomenon there is energy transformation and that all energy transformations within a system can be accounted for with a common denominator: embodied solar energy in the former case (measured in solar emjoules) and available energy or exergy in the latter case (measured in Joules). The ecological footprint quantifies the total area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate its wastes (Rees & Wackernagel, 1996). According to Wackernagel et al. (1999) the ecological footprint methodology assumes that it is possible to keep track of all the materials and human services required to sustain a human population and assimilate its wastes by converting most of them to a corresponding biologically productive area. Since different productive lands produce different commodities and to differing degrees a common denominator, the global hectare (gha), is employed in its calculations.

However, certain methodological limitations raise questions over the validity of biophysical measures. One of the most important limitations is relevant to the allocation rules employed by these models. Such problems are common to all tools that follow procedures similar to that of the Life Cycle Assessment (LCA) which is the case for emergy, exergy and the ecological footprint in particular (Simmons, Lewis, & Barrett, 2000). In a nut shell the allocation of multiple products of a process as co-products or splits can influence the results of the analysis to a great extent and has yet to be resolved in an acceptable manner (Hau & Bakshi, 2004). This problem has been discussed, for example, in the emergy synthesis literature (Bastianoni & Marchettini, 2000).

A second problem arises from the data intensive nature of the biophysical models. Biophysical models usually require a large number of detailed data sets in order to accurately account for the metabolism of the system under study. Usually, the data required includes information on the flows of natural resources (energy, food and material), labour and money within the system. While it is possible to monitor and acquire good quality data in small scales (e.g. process scale), it generally becomes more demanding to acquire reliable data while increasing the scale. In extreme cases such data is not recorded or is conflicting at best.

Furthermore, integral parts of emergy synthesis (solar transformities), exergy analysis (chemical exergies of substances) and the ecological footprint (equivalence/yield factors) have been calculated under very specific and restrictive assumptions. For most sustainability assessments these underlying assumptions are not the same (e.g. reference environment, transformities of global processes, bio productivity of land, etc.) so it is not appropriate to utilise standard values. For example, the chemical exergy of a chemical species (whether an energy carrier, material, waste or pollutant) is defined only subject to a reference environment. Such calculations make use of an ideal or a specific environment that of course is not encountered in all parts of the planet. As a result a certain degree of subjectivity is entering the calculations. However, for the sake of consistency and simplicity such standard values are used freely by analysts because in most cases recalculating them is a prohibitive task (effort and money consuming) and it may not render the results comparable with other case studies.

As a result, biophysical models despite having been developed in response to the need for more “objective” sustainability assessment tools require a significant amount of assumptions and simplifications on the part of the analyst. Thus uncertainties that affect the quality of the final sustainability assessment are unavoidable. Biophysical models usually tackle ensuing uncertainties quite well in smaller scales (better data, more sensible designation of a reference environment, etc.) but they fail to do so in larger scales such as cities, regions and countries. Additionally, according to Sciubba and Ulgiati (2005), as the scale is expanded, higher order terms and perturbations may become predominant with the system’s dynamics being no longer linear and resulting in increased uncertainty.

Furthermore, biophysical tools tend to quantify only a few of the social issues that are deemed important for the progress towards sustainability (Gasparatos et al., 2008; Wackernagel et al., 2005). Of the three biophysical tools discussed only emergy synthesis attempts to quantify certain social issues such as education and culture (Gasparatos et al., 2008). Other important methodological limitations of biophysical tools have been discussed elsewhere in the literature (Brown & Herendeen, 1996; Cleveland, 2005; Cleveland, Kaufmann, & Stern, 2000; Ecological Economics, 2000; Herendeen, 2004; IVM, 2002; Mansson & McGlade, 1993; Sciubba & Ulgiati, 2005; van den Bergh & Verbruggen, 1999) and collected by Gasparatos et al. (2008).

3.3. Sustainability indicators/composite indices

Sustainability indicator lists/composite indices reflect indicator and methodological choices that are quite context specific. Nevertheless, Nardo et al. (2005), have developed a generic framework for the development of composite sustainability indices including the designation of a theoretical framework, selection of the variables, multivariate analysis, imputation of the missing data, normalisation of data, weighting and aggregation of the different indicators, sensitivity analysis, exploration of links to other variables and the appropriate presentation and dissemination of the results. Nardo et al. (2005) acknowledge that the coherence of the whole process is also important with choices made in one step having implications for other steps. Nardo et al. (2005) and Nardo, Saisana, Saltelli, and Tarantola (2005) comment on the methodologies of diverse tools that are usually employed for the development of composite indicators.

Methodological limits while weighing/aggregating the indicators have attracted some attention within the literature. Munda and Nardo (2005a) have shown that weights do not always retain their status as value judgements within a composite index. This is particularly evident in composite indices utilising linear aggregation where the assigned weights end up gaining a trade-off status which implies complete substitutability between the indicators of the composite index. A characteristic example of such composite indices is the Human Development Index (UNDP, 2006). In such a composite index an indicator (e.g. economic output) has the ability to compensate for a lower performance of another indicator (e.g. depletion of natural resources). The substitutability between the components of the CI implies the existence of trade offs and renders aggregated CI weak sustainability tools. The existence of a perfect aggregation technique for ranking alternative options (e.g. alternative designs, policies, etc.) has been questioned by Arrow (1963) as quoted by Munda and Nardo (2005b).

It is evident that whatever form of aggregation is used, a certain degree of compensability and substitutability of the different sustainability issues is unavoidable. This inserts an ethical dimension that must be consistent with the stakeholder views and must be made explicitly clear by the analysts.

4. Conflicting concepts of value

Biophysical and monetary sustainability assessment methodologies employ radically different concepts of value that share several similarities with the two concepts which Adam Smith pioneered and had problems reconciling. At the core of this argument lies Smith's distinction between value and exchange value (exchange value is depending on scarcity and utility). It should be noted here that this discussion on value is a discussion on the deepest assumptions of these tools as it comments on what these tools consider important and thus measure.

Past studies have commented on the implications arising from the utilisation of tools with different concepts of value in Ecological Economics (Patterson, 1998) and ecosystem service valuation (Ecological Economics, 2002; Winkler, 2006). However, similar implications arising in sustainability assessments have yet not attracted significant attention.

According to Smith (1986) the value of a commodity can be a proxy for either the amount of labour embedded in it or the quantity of labour (embedded in other goods) for which it can be exchanged in the market. In this very basic value system Smith assumed that labour is the only scarce factor for the production of commodities and as a result commodities could theoretically be exchanged upon the ratio of labour use. As a result labour was considered as an invariant unit for measuring value and could, in theory, be used as a numeraire (Schumpeter & Joseph, 1978) as cited by Farber, Costanza, and Wilson (2002). Returning to Smith's (1986) two different concepts of value, the former can be perceived as an objective measure while the latter is more of a subjective one usually dependent on the needs, wants and preferences of the buyer and seller.

Patterson (1998) states that these initial observations paved the way for the development of two distinct and at times conflicting concepts of value that have subsequently been employed in economics; the cost of production theory of value and the subjective preference theory of value. Glimpses of these two theories of value, which have been refined over time, are evident within the various economic and biophysical sustainability assessment methodologies and are discussed below. Biophysical models essentially account for the amount of resources in the broadest sense, but usually materials and energy, which have been invested for the production of a good/service. Certain biophysical methods such as emergy synthesis (Odum, 1996) and Extended Exergy Accounting (Sciubba, 2003) have moved beyond that by accounting for monetary and labour inputs in biophysical terms. But whatever flows are considered, biophysical models essentially answer the same question; what and how much of it has been invested for the production of a good/service. This is similar to the cost of production theory of value discussed above. Farber et al. (2002) claim that such a theory of value returns to the classical economist's quest for identifying the "primary" input to production processes that could be used to explain the different exchange values based on production relationships. For emergy synthesis and exergy analysis this "primary" input or scarce factor of production is available energy while for the ecological footprint it is bioproductive land. According to Farber et al. (2002) the concept of available energy, used in emergy synthesis and exergy analysis, has the following characteristics that satisfy the criteria for "primary" input:

- "*it is ubiquitous*;
- *it is a property of all the commodities produced in economic and ecological systems*;
- *while other commodities can provide alternative sources for the energy required to drive systems, the essential property of energy cannot be substituted for*".

Similarly when Wackernagel et al. (1999) mention that "...(E)cological footprint calculations are based on two simple facts: first, we can keep track of most of the resources we consume and many of the wastes we generate; and second, most of these resource and waste flows can be converted to a biologically productive area necessary to provide these functions" p. 377, they seem to imply that the scarce factor of production in their model is bioproductive land. The observation that biophysical models essentially employ a cost of production theory of value is further justified by their tendency to neglect human preferences (Cleveland et al., 2000; Winkler, 2006).

According to Farber et al. (2002) measures of economic value tend to capture the difference that something makes to the satisfaction of human preferences and as a result "*...the basic notion of value that guides economic thought is inherently anthropocentric*" p. 379. Neoclassical monetary analysis quantifies and accounts for the utility that a person is expected to gain from consuming a commodity and given the scarcity of the resources people make decisions aiming to maximise their utility. Utility is not considered a cardinal (i.e. directly measurable) quantity in monetary models despite the belief of John Stuart Mill and other classical and contemporary economists and psychologists to the contrary (Layard, 2005). Instead, monetary tools tend to capture a person's willingness to pay for the consumption of a commodity or its willingness to accept compensation to forfeit the consumption of a commodity. WTP and WTA can in turn be considered proxies of the effect on a person's utility (Farber et al., 2002). Despite the fact that certain of these positions are contested from the new science of Happiness, refer to Layard (2005), the fact remains that the underlying concept of value in economic tools is purely subjective as it mirrors a person's needs and preferences. In that respect the concept of value in monetary analyses is closer to Patterson's (1998) designation of subjective preference theory of value.

An implication of the above is that by utilising these different concepts of value biophysical and monetary tools view the progress towards sustainability from different and in some cases conflicting perspectives. One such illustrative example can be the case of organically and conventionally grown food. Organic products utilize less fertiliser and pesticide than conventional products so in a biophysical assessment organic food seem to have a lower cost of production value because fewer natural resources and human labour have been directly and indirectly invested per unit of product. On the other hand, organic food usually has a higher price in the market place than conventionally grown food which implies a higher exchange value at the margin. As discussed earlier a higher price denotes a higher willingness to sacrifice other things in order to obtain that particular commodity which implies a higher subjective preference value.

As a result adoption and utilisation of a specific sustainability assessment methodology is implicitly a choice of value system which in turn is inherently a choice of perspective. As Funtowicz and Ravetz (1994b) claim, "*...to choose any particular operational definition for value involves making a decision about what is important and real; other definitions* [to monetary price] *will reflect the commitments of other stakeholders*" p. 198.

Composite indicators on the other hand do not seem to have an explicit value system as monetary tools and biophysical models do because every concept of value is lost during the normalisation stage.

5. Is it really possible to capture the progress towards sustainability with a single metric?

Considering the previous findings the answer seems to be no. First of all the approaches discussed earlier tend to be based on reductionist principles. Applicability of a reductionist approach has been criticised both for understanding complex systems and for offering sufficient policy recommendations to facilitate the progress towards sustainability. Complexity theory contemplates complex systems as irreducible while post-normal science emphasises that "*...to take any particular perception, or projection onto subspace, as the true, real or total picture, amounts to reductionism*" (Funtowicz & Ravetz, 1994a, p. 575).

Evaluation of the plethora of sustainability issues is problematic given the great scientific uncertainty and ignorance in many relevant fields of the environmental and social sciences, the subjective nature of monetary valuations and the considerable uncertainties of biophysical models especially when the scale of the sustainability assessment is extended. Furthermore, important information is lost during the subsequent aggregation of the different sustainability issues in composite indices. In certain situations aggregation through monetary tools and composite indices imply compensability and substitutability between different sustainability issues leading to weak sustainability evaluations that might not always be desirable.

As already shown in Section 4 biophysical and monetary tools make use of different concepts of value; cost of production in the former case and subjective preference in the latter case. As a result these tools can answer different questions that fall within the scope of sustainable development. For example biophysical tools can quantify in an objective and meaningful manner the present consumption patterns of natural capital and determine whether the operational principles of sustainable development designated by Daly (1990) have been breached. Herman Daly's first principle of sustainability, *"harvest rates should equal regeneration rates* (*sustainable yield*)" (Daly, 1990, p. 2), refers to physical mass-balance laws and as a result biophysical models which are capable of capturing the real costs of production (particularly those metrics rooted in thermodynamics such as emergy and exergy) are highly relevant (Bastianoni & Marchettini, 2000; Bastianoni, Nielsen, Marchettini, & Jorgensen, 2005). Baumgartner (2004) mentions a string of insights relevant to sustainable development that can be provided by biophysical models, and in particular thermodynamic models, such as materials balance (Planet Earth perspective), irreversibility of economic processes, resource extraction/waste generation, thermodynamic efficiency and limits to growth/substitution. Furthermore, according to Gasparatos et al. (2008) biophysical tools can capture certain aspects of equity albeit with some degree of uncertainty. By accounting for the resources consumed as well as the rate of their use one can gain insights on whether there will be sufficient resources left to satisfy the potential needs of future generations. In a similar manner, by finding a per capita expression of the resources used presently one can compare resource consumption (real wealth) between current members of different societies. Biophysical tools can also account directly or indirectly for the "free" ecological services, their contribution to human economy and the effect on it if their functioning is compromised.

On the other hand, monetary tools provide information on economic efficiency, economic growth and the economic welfare of a population. Economic welfare and growth considerations have always been at the forefront of the sustainable development debate. For example growth revival, changing the quality of growth, poverty reduction and meeting human needs are only a few of the critical objectives for environment and development strategies that follow from the concept of sustainable development (WCED, 1987) and can in a way be captured by economic tools. Monetary tools, through their subjective valuation procedure, can also be a proxy for human preferences given the fact that they account for WTP/WTA that are in effect proxies of the effect on a person's utility.

As a result it can be argued that both monetary tools and biophysical models get complementary snapshots of the progress towards sustainability but not the whole picture. Tools falling within the two categories can offer two legitimate perspectives for sustainability assessment and it would be not appropriate to exclude any of their findings in favor of the other as discussed in Section 2. In this spirit, Patterson (1998) commented that choice of a single theory of value might foreclose other methodological options and can be seen as reductionistic while he refrained from proposing a "*. . .monolithic approach based on a single value*" p. 124.

Another problem arises from the fact that it is probably impossible, especially in complex systems, to derive a single-factor-theory of value, and particularly a "cost of production theory of value", that can adequately explain the value of goods. According to the non-substitution theorem, single-factor-theories of value can be constructed only when all of the four following conditions are met (Baumgartner, 2004):

- there is only a sole primary factor of production;
- this factor is being used in the production of every intermediate or final good/service;
- all production processes are characterized by constant returns to scale;
- every production process is responsible for a sole output (no joint production).

It is immediately obvious that common biophysical currencies such as available energy or bioproductive land cannot meet all these conditions simultaneously. Furthermore, Baumgartner (2004) comments on the fact that biophysical models are purely descriptive and as a result they cannot give comprehensive answers to normative issues such as sustainability.

In the light of these findings it is proposed that the further elaboration and refinement of the current metrics does not seem likely to produce frameworks for assessing the progress towards sustainability in a comprehensive manner. An elaboration of the tools discussed in this paper without a deep restructuring of the underlying assumptions will most certainly not result in more holistic tools for sustainability assessment. As a result adoption of diverse metrics seems more likely to be, at the moment, the key for more concrete sustainability assessments. Knowledge of the limitations and assumptions of the adopted sustainability assessment tools and a conscious attempt to bring together different ways of knowing through methodological pluralism (Norgaard, 1989; Ravetz, 2006) and increased stakeholder participation is envisioned to culminate in better informed policy making.

6. Conclusions

Assessing the progress towards sustainability requires the consideration of a plethora of economic, environmental and social issues and equity. At the moment none of the current popular methodological proposals seems, that fall within the reductionist paradigm, to be able to encompass all these considerations simultaneously. Methodological limitations, different concepts of value and new insights from complexity theory and post-normal science leave little room for believing the contrary. The existence of a value system is a prerequisite of any approach for measuring the progress towards sustainability. However, the difficulty in either finding an absolute measure of value or obtaining consensus about which value system to use creates a controversy which so far has eluded resolution. In answering the question posed earlier we believe that assessing the progress towards sustainability with a single metric in a holistic manner is a very difficult task that seems impossible at the moment and attempting to do so is likely to send misleading policy messages. As a result methodological pluralism coupled with stakeholder participation seems a safer path to tread.

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