Weak and Strong Sustainability in the SEEA: Concepts and Measurement

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Abstract

In this paper, we explain how the latest international handbook on environmental accounting, the System of Integrated Environmental and Economic Accounting or SEEA (United Nations *et al*., 2003), can be used to measure weak and strong sustainability. We emphasise the importance of understanding the conceptual differences between weak and strong sustainability. We then outline what we consider to be current best practice in measurement, all the time flagging the relationship between our discussion and that of the SEEA-2003. This is an important task in our view, because, despite covering a very wide range of relevant conceptual and empirical issues, the handbook is by design not meant to provide clear guidelines for the purpose of measuring sustainability in either its weak or strong version.

1. Introduction

The concept of sustainable development (SD) has won broad appeal because it has resisted a single, accepted interpretation. There can be little disagreement with the ultimate aim of "development that lasts" (Atkinson *et al*., 1997, p3), but, in trying to arrive at a more substantive definition, one must discriminate between a large number of different approaches. In taking an economic approach to the problem, the key choice is whether one believes that natural capital – i.e. the range of functions the natural environment provides for humans and for itself (Ekins *et al*., 2003) – should be afforded special protection, or whether it can be substituted by other forms of capital, especially produced capital. This is the choice between weak sustainability[1] and strong sustainability (hereafter WS and SS respectively).

The System of Integrated Environmental and Economic Accounting (SEEA) is capable of generating a significant volume of environmental and economic data, with which we can derive measures of WS and SS. The latest revised guidance, the SEEA-2003 (United Nations *et al*., 2003), is structured into four categories of accounts. They are:

1. Physical flows of materials (chapters 3 and 4);
2. Environmental protection expenditure (chapters 5 and 6);
3. Physical and monetary accounting of environmental assets (chapters 7 and 8);
4. Environmentally modified macro-aggregates (chapters 9 and 10).

All are in some way useful to the measurement of WS and SS and we will flag the relevant parts of the SEEA-2003 throughout the paper. SD is writ large in the SEEA-2003, appearing prominently in the introductory chapter as a motivating factor behind the idea of integrated accounting. Three basic approaches to SD are outlined, including the so-called 'capital' approach that concerns us here. However, as one would expect of such an extensive volume that is also to a greater or lesser extent the product of consensus between experts with differing views, the clarity of SD concepts and measurement techniques becomes lost thereafter. There are perhaps two chief aspects to this. Firstly, in the detail of the handbook – even in chapter 11 where policy applications are synthesised across all four categories of accounts – there is little systematic

[1] We use the terms sustainability and sustainable development interchangeably.

structure to the treatment of WS and SS and their measurement. Secondly, when presented with competing methods for measuring WS and SS, the handbook usually declines to commit one way or the other. This is forgivable, but we feel it is important to relay, where possible, the relative pros and cons of particular methods with greater certitude.

In section 2, we discuss the WS and SS paradigms and the sustainability rules each suggests. Section 3 moves on to outline current best practice, as we see it, in the measurement of WS, including the key issues of monetised resource depletion and environmental degradation that are deliberated at great length in the SEEA-2003 with no conclusive outcome. Section 4 performs the same role for the measurement of SS. A large number of indicators have been proposed that are compatible with notions of SS, but we emphasise the merits of those suited to monitoring the protection of so-called ‘critical’ natural capital. Section 5 provides a brief summary.

2. Weak versus strong sustainability

Economic approaches to sustainability frame the issue in terms of human wellbeing (utility). An apparently simple intergenerational rule is that development is sustainable “if it does not decrease the capacity to provide non-declining per capita utility for infinity” (Neumayer, 2003, p7). The capacity to provide utility is conceptually embodied in four forms of capital: produced, natural, human and social. Hence this can also be regarded as the ‘capital’ approach to SD, as exemplified in chapter 1 of the SEEA-2003.

The WS paradigm was effectively founded in the 1970s (there was no such sustainability terminology at the time) by extending the neoclassical theory of economic growth to account for non-renewable natural resources as a factor of production (Dasgupta and Heal, 1974; Hartwick, 1977; Solow, 1974). These highly aggregated growth models considered the optimal use of income generated from the extraction of a non-renewable resource and sought to establish rules on how much to consume now and how much to invest in produced capital to increase consumption later. The key question posed in these pioneering studies was whether optimal growth, as it is defined above, was sustainable in the sense of allowing non-declining welfare in perpetuity? This was shown to be unlikely in a model including a non-renewable resource as a factor of production. The basic result was that, save for great optimism about how little the economy is constrained by the natural resource, consumption falls to zero in the long run (Solow, 1974).

Therefore it became necessary to establish specific rules allowing non-declining welfare over all time based on some maintenance of the capital stock, including natural capital. This was addressed by Hartwick (1977), who derived the intuitive rule that the rents from non-renewable resource depletion should be reinvested in produced capital[2]. This can be generalised into a WS rule, which requires that total net capital investment, or in other words the rate of change of total net capital wealth, not be allowed to be persistently negative (Hamilton, 1994). Total net capital investment includes gross investment in all forms of capital that can be feasibly measured, minus depreciation or capital consumption.

Crucially, the Hartwick-Solow models of the 1970s imputed non-renewable and renewable natural resources into a Cobb-Douglas production function, which is characterised by a constant and unitary elasticity of substitution between factors of production. This entailed the assumption that natural capital was similar to produced capital and could easily be substituted for it. In fact, in validating the WS paradigm, it must be true that either:

- natural resources are super-abundant;
- or the elasticity of substitution between natural and produced capital is greater than or equal to unity (even in the limit of extremely high output-resource ratios: Neumayer, 2003);
- or technological progress can increase the productivity of the natural capital stock faster than it is being depleted.

Proponents of SS argue that natural capital is to a greater or lesser extent non-substitutable. In order to understand why, it is necessary to discuss in more detail the meaning of natural capital as SS sees it. Following Ekins *et al*. (2003) and Pearce and Turner (1990), natural capital performs four categories of functions. Firstly, it provides the raw materials for production and direct

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[2] Though, to avoid foreclosing other WS perspectives, this need not mean that *all* the rents from resource extraction be invested. El Serafy (1989) argued that a portion of the proceeds from resource extraction can be consumed. See section 3 for further discussion.

consumption such as food, timber and fossil fuels. Secondly, it assimilates the waste products of production and consumption. Thirdly, it provides amenity services, such as the visual amenity of a landscape. Fourthly, it provides the basic life-support functions on which human life, as well as the first three categories of natural capital functions, depends. Hence this fourth category is not only a direct determinant of human welfare; it is of primary value – “a ‘glue value’ that holds everything together” (Turner *et al*., 1994, p38) – whereas the first three categories are of secondary value.

There may be considerable substitution possibilities between the first category of natural capital functions – raw materials for production and direct consumption – and produced capital. Indeed, in the past the economy has consistently overcome production and consumption resource constraints (Neumayer, 2000a; 2003), although this is no guarantee of future performance and substitution is likely to become very difficult as resource efficiency becomes very high. If WS is apt, it is here though it should be bounded. It may also be possible to substitute some natural waste assimilative capacity and some natural amenity services. However, basic life support systems are almost certainly impossible to substitute (Barbier *et al*., 1994). Most importantly, this means the global environmental and ecological system that provides us with the basic functions of food, water, breathable air and a stable climate. They should hence be subject to an SS rule (see below).

We may wish to pursue SS for other reasons. Firstly, there remains considerable risk, uncertainty and ignorance attached to the way in which natural capital such as the global carbon and biogeochemical cycles works. It follows that we cannot be sure what effect damaging it will have. As Atkinson *et al*. point out, risk, uncertainty and ignorance are “always a reason for being cautious, unless society can be deemed to be indifferent to risk or positively to welcome it” (1997, p14). Secondly, the loss of some natural capital may be irreversible. Thirdly, since there is evidence to suggest we are more averse to losses in utility than we are keen to gain it (Kahnemann and Tversky, 1979), this might imply that we are highly averse to losses in natural capital functions that directly provide us with utility. Basic life support systems are obviously included, but so are amenity functions. Fourthly, there is an ethical argument for non-substitutability, which posits that increased future consumption is not an appropriate substitute for natural capital losses (e.g. Barry, 1990). Ultimately, both paradigms are non-falsifiable under scientific standards since both rest on assumptions and claims about the (distant) future that are non-refutable (Neumayer, 2003). However, we have made some suggestions about the circumstances in which one is more plausible than the other.

Because SS is a more diffuse paradigm than WS, a number of rules have been suggested that seek to operationalise it. Neumayer (2003) identifies two main schools of thought. One requires that the value of natural capital be preserved. In the case of non-renewable resources, extraction must be compensated by an investment in substitute renewable resources of equivalent value (e.g. wind farms to replace fossil fuels in generating electricity). More generally, Barbier *et al*. (1990) suggested that natural capital depreciation should be balanced by investment in so-called shadow projects. The interesting feature of this conception of SS – and its fallibility – is that it assumes unlimited substitutability between forms of natural capital. Surely certain forms of natural capital cannot be substituted by other forms of natural capital. The second SS strand requires a subset of total natural capital be preserved in *physical* terms so that its functions remain intact. This is so-called 'critical' natural capital (CNC). Like SS in general, it is rather difficult to define CNC concisely, but following the arguments for SS just made, we may 'ring-fence' as critical any natural capital that is strictly non-substitutable (also by other forms of natural capital), the loss of which would be irreversible, would entail very large costs due to its vital role for human welfare or would be unethical. Clearly, CNC must in some way be evaluated as 'important' to humans. Thus classifying CNC will require a mixture of ecological, economic and social criteria (see De Groot *et al*., 2003) and will depend on spatial scale.

3. Weak sustainability measurement and the SEEA-2003

In measuring WS, the key point is that, because it assumes the substitutability of different forms of capital, we need to estimate what the SEEA-2003 terms an 'environmentally adjusted macro-aggregate'. In other words, we need to enter the realms of green accounting. Therefore we have to value natural capital depletion (i.e. the economic value of a *quantity* reduction in a natural resource) and degradation (i.e. the economic value of damage to natural capital *quality*). Otherwise, the sustainability planner cannot know whether natural capital losses are being compensated by equivalent or greater capital investments elsewhere in the economy. In this respect, the key chapters in the SEEA-2003 are 8-10. Nevertheless, it is precisely on this topic, the 'greening' of conventional SNA[3] aggregates, that the SEEA-2003 is most tentative.

At the outset, it is important to emphasise that the SEEA-2003, in keeping with much of the sustainability literature, is practically focused on produced and natural capital. Scant mention is made of human capital; even less of social capital, which is very difficult to value in practice. Therefore what we can measure based on the SEEA-2003 refers to the economic and environmental pillars of sustainable development, but not the social pillar. The green accounting literature is by now relatively large and diverse. Atkinson *et al*. (1997) provide a useful theoretical comparison of different approaches. Although the common building block is GDP/GNP, various adjustments are made from this point that result in fundamentally different measures (i.e. of welfare, of net product, or of net capital wealth).

3.1. Environmentally-adjusted net product and genuine saving

Influential early empirical studies, such as that by Repetto *et al*. (1989), estimated environmentally adjusted or green net national product (eaNNP or gNNP):

$$eaNNP = GNP - Dp - Dn \qquad (1)$$

$$Dn = RD + ED \qquad (2)$$

where Dp is depreciation of produced capital and Dn is depreciation of natural capital. Dn in turn is equal to resource depletion, RD, plus environmental degradation, ED. eaNNP relates to WS, because it equates to Hicksian income (Hicks, 1946): i.e. the maximum amount of produced output that can be consumed at some point in time while maintaining constant wealth. Examples of its calculation in practice are given in chapter 11 of the SEEA-2003. However, Hamilton (1994) argued that neither eaNNP, nor its growth rate compared to the growth rate of GNP, produces directly useful policy signals on SD. Furthermore, it has subsequently been pointed out that, since eaNNP is an *instantaneous* measure, it cannot conclusively tell us whether the

[3] The System of National Accounts (Commission of the European Communities *et al*., 1993).

economy is on a WS path (Asheim, 1994; Pezzey and Withagen, 1995). In fact, this is true of all related green accounting measures, but in such circumstances an approach to measuring WS with a simple policy signal is to adopt an overall saving rule as indicated above, according to which total net capital investment is not allowed to be persistently negative. This is at least a necessary, if insufficient, condition for the attainment of WS. The 'genuine' saving (GS) indicator (Hamilton, 1994), which equals eaNNP minus consumption (C), applies this saving rule:

$$GS = GNP - C - Dp - Dn \tag{3}$$

Where population growth is placing additional pressure on resources, it is possible to make a relatively simple calculation of per capita GS, as in Hamilton (2003):

$$\frac{d}{dt}\left(\frac{GS}{P}\right) = \frac{\frac{dGS}{dt}}{P} - \frac{\frac{dP}{dt}}{P}\frac{GS}{P} \tag{4}$$

where P is population[4].

The World Bank (various years) now regularly publishes a comparatively comprehensive GS measurement exercise for over 150 countries. It calculates GS, which it now calls 'adjusted net saving' (after Pearce and Atkinson, 1993) as follows:

> GS = investment in produced capital – net foreign borrowing + net official transfers – depreciation of produced capital – net depreciation of natural capital
> + current education expenditures

Net depreciation of natural capital equals resource depletion plus environmental degradation. The Bank estimates resource depletion for a range of fossil fuels (oil, natural gas, hard coal and brown coal), minerals (bauxite, copper, iron, lead, nickel, zinc, phosphate, tin, gold and silver), and one

[4] Having said that, there is an emerging discussion over whether the adjustment is, in fact, so simple. Dasgupta (2001) and Arrow *et al*. (2003) treat population as a capital asset, rather than simply dividing through by population. Where the population growth rate is non-constant (i.e. not exponential), this will yield a different formula.

renewable resource (forests). Estimates of environmental degradation have been based solely on carbon dioxide emissions, though particulate emissions are a recent addition. The Bank also adds an estimate of human capital formation: current education expenditures. This can be estimated using elements of the SNA. As we have said, the SEEA-2003 is not useful in this respect.

Although GS is the most practical and, at least within academic work, most popular of the environmentally adjusted macro-aggregates in terms of SD policy, it is worth noting that the SEEA-2003 makes scant mention of it (save for a few paragraphs in chapter 11). This may be a by-product of the aim to present an unbiased overview of all the major green accounting models, but it does come at the expense of clarity on WS measurement. Similarly, although the calculation of GS involves some key decisions on the valuation of resource depletion and environmental degradation that are covered in chapters 8-10 of the SEEA-2003, it is characteristic of the handbook that it stops short of actually making these decisions, instead presenting readers with the available options. While this is an understandable approach to a consensual document such as the SEEA-2003, we will now briefly outline the key points as we see them.

3.2. Resource depletion

The SEEA-2003 recommends that depletion should, in principle, be calculated as the net present value (NPV) of resources extracted, which equals the actual net return on the resources extracted less the interest gained on the remaining capital. We endorse this recommendation to national statistical offices. However, for lack of data, the World Bank-sponsored work on genuine savings, which calculates the value of resource depletion for a large number of countries over a long period of time, has fallen back on the 'net price', which is simply the current rent per unit of the resource (price minus marginal cost of extraction) multiplied by the amount of resource extracted. Other methods have been suggested, notably the El Serafy method (El Serafy, 1981, 1989) based on so-called 'user costs'. It in effect partitions the rent from resource extraction into the 'user cost' of resource extraction – that is, the share of resource receipts that should properly be considered capital depreciation – and sustainable/Hicksian income. The El Serafy method produces lower estimates of resource depletion than the net price method, on the premise that it is not appropriate to classify all the income generated by resource extraction as depreciation.

Although a significant number of non-renewable resources are measured in the depletion component of GS, a common critique of GS is its less than comprehensive coverage of renewable resources. As indicated above, the only renewable resources currently included are forests. This is due to a lack of data. For a detailed discussion of the difficulties inherent in valuing renewable resources (albeit stock levels rather than depletion), see especially chapter 8 of the SEEA-2003.

3.3. Environmental degradation

The task in estimating natural resource depletion is primarily to extract what is already implicit in the SNA and can be largely based on observable data (e.g. gross operating surpluses of extractive/harvesting industries). In contrast, valuing environmental degradation is a more difficult issue. While some of the impacts of environmental degradation will already be recorded in the conventional SNA (e.g. losses in agricultural productivity) or in depletion-adjusted net product (e.g. non-growth of non-cultivated assets such as timber), the major effects of environmental degradation relating to human health, environmental amenities and global environmental problems (e.g. biodiversity loss and climate change) are not recorded in markets or insufficiently so. Thus shadow pricing is a necessity in addition to making explicit what is already included in the conventional SNA.

There are two basic approaches to valuing degradation presented in chapter 9 of the SEEA-2003. The first is a cost-based approach, which, broadly speaking, values degradation at the cost that would have been incurred if it were abated (internalised). Within the cost-based approach, three methods of pricing are presented: (i) estimating structural adjustment costs, (ii) estimating marginal or average abatement costs and (iii) estimating restoration costs. The second approach is to value the damage caused by degradation in human-welfare terms, which almost always requires prices to be inferred either through revealed preference or stated preference techniques (contingent valuation and choice modelling).

In this case, there are advantages and disadvantages to both approaches. To begin with, the estimation of structural adjustment costs should be eliminated from consideration, because it ordinarily requires modelling (either *ex ante* or counter-factual *ex post*) and thus belongs to what we term 'hybrid' indicators of sustainability (Neumayer, 2003) – see also below. In practice, it is often easier to estimate abatement costs than to undertake damage-based pricing. In theory, either marginal abatement costs or marginal damage costs are supported in the estimation of environmental degradation for a saving measure of SD. However, the key point in our view was made by Hamilton and Atkinson (1996) on the relationship between these costs. In a partial efficient equilibrium, marginal abatement costs are equal to marginal damage costs, but in the wholly realistic situation of market failure leading to over-pollution, marginal abatement costs are below optimum costs and damage will be underestimated, while marginal damage costs are above the optimum and damage will be overestimated. In these circumstances, the prudent course of action is to apply marginal damage costs.

3.4. The Index of Sustainable Economic Welfare (ISEW) Family

A separate tradition of WS measurement has developed that seeks to generate indicators of sustainable economic welfare. Here, the focus in the year of estimation shifts from maintaining the capacity to provide non-declining welfare in the future (embodied in capital) to maintaining non-declining welfare itself in the present. This has been the essential aim of the family of welfare indicators known variously as the Index of Sustainable Economic Welfare (ISEW), the Genuine Progress Indicator (GPI), the Sustainable Net Benefit Index (SNBI) and the Measure of Domestic Progress (MDP)[5]. Welfare is understood to be a fully comprehensive measure of the utility of private consumers in the economy. What is understood by sustainability is not as easy to explain. Almost certainly these indicators were intended to support the propositions of SS. However, by assuming that the diverse components of comprehensive utility can be simply added together in arriving at an overall indicator, they are a measure of WS, not SS. The underlying assumption is that an increase in one component can compensate for a decrease in another. Though different authors have calculated sustainable economic welfare in different ways, the core components can be generalised follows:

[5] See Dietz and Neumayer (2006) for an up-to-date review.

Sustainable economic welfare =

Personal consumption weighted by income inequality
+ domestic labour
+ non-defensive public expenditure
– defensive private expenditure
– difference between expenditure on consumer durables and service flows from consumer durables
– costs of environmental degradation
– depreciation of natural resources
+ capital adjustments

The basic welfare measure taken from the SNA is personal consumption expenditure, which is weighted with an index of income inequality in order to embrace the notion that extra money could be of greater marginal utility to the poor than to the rich. From here, it is easiest to understand the additions and deductions made in terms of Fisher's (1906) notion of income (Lawn, 2003): it is the services that give consumers utility that count, not the products that yield the services.

Thus service flows that provide utility but are not included in personal consumption expenditure need to be added. These include non-defensive public expenditure on, for example, health, education and roads and an estimate of the value of domestic labour services from housework and parenting. One also adds growth in capital and net foreign lending/borrowing. This sits rather awkwardly with our explanation in terms of consumer welfare. In fact, these components are added, because the family of indicators is concerned not only with welfare but also with sustainability (but see below for a major note of caution).

Other service flows are included in personal consumption expenditure but should not be, because they are not associated (directly) with consumer utility. Hence defensive private expenditures on such things as health, education, commuting and personal pollution control tend to be deducted, as well as the difference between expenditure on consumer durables and the flow of services they provide. Other components are not included in personal consumption but still need to be deducted, because they reduce the welfare of consumers either now or in the future. These include, firstly, the costs of environmental degradation. This typically includes such things as air pollution, water pollution, ozone depletion and the long-term environmental damage resulting from climate change. Secondly, one deducts resource depletion, including non-renewable mineral and fossil fuel resources, the loss of natural habitats such as wetlands and the loss of farmland. Private expenditures on personal pollution control, plus the cost of environmental damage and resource depletion, constitutes the greening of consumer spending undertaken by these studies.

In relating the calculation of the ISEW to the SEEA-2003, it is important to note that a wide variety of methods have been used in the literature to estimate its various components, including some fairly eccentric means of calculating the costs of (especially though not exclusively) environmental degradation and the depreciation of natural resources (see Neumayer, 2000c, 2003). The basic estimate of personal consumption expenditure can be taken from the SNA, as can the relevant public expenditures, capital adjustments etc. There is no reason to our minds why estimates of the depreciation of natural resources and of the costs of environmental degradation should not follow the same logic as presented in sections 3.2 and 3.3, though in practice some altogether different methods have been employed. The deduction of defensive expenditures on environmental protection is a controversial and highly problematic topic that is dealt with in chapter 10 of the SEEA-2003, though chapters 5 and 6 are also relevant[6]. Beyond these issues, there are further components of the ISEW that must be based on estimates beyond the scope of both the SNA and the SEEA-2003, such as the choice of income inequality weight and estimates of the rate of depreciation of consumer durable goods. Interested readers are directed to the detailed reports of the various ISEW calculation efforts. An up-to-date review is provided in chapters 7 to 9 of Lawn (2006).

In fact, it is questionable whether these indicators of sustainable economic welfare actually measure sustainability in an adequate way (Neumayer, 2004). This is because what affects

[6] Although some studies take the concept of defensive expenditures much further. There are both conceptual (Commission of the European Communities *et al*., 1993, p14; Mäler, 1991) and practical (Brouwer and Leipert, 1999; Steuerer *et al*., 1998) problems with deducting defensive expenditures that ultimately make the endeavour, in the view of some, a “dead end” (Brouwer and Leipert, 1999, p196).

current well-being need not affect sustainability and vice versa. Consider the case of non-renewable resource depletion: consuming resources extracted at the present time enhances our current welfare, while at the same time (possibly) reducing the ability of future generations to enjoy at least as much welfare. This extraction is welfare-enhancing but unsustainable. It is necessary to argue that current consumers hold an altruistic concern for future generations if welfare and sustainability are to pull in the same direction here. As a result, it is unclear whether increases in a combined indicator of current welfare and sustainability reflect increased or decreased welfare, or increased or decreased sustainability.

In addition, major questions have been raised about the methodologies most studies have relied on. Neumayer (2000c, 2003) argues the apparently striking finding that ISEW growth falls away from GNP growth after hitting a ‘threshold’ (Max-Neef, 1995) is built into the methodology, almost inevitably leading to the results found. Seemingly, more unequal income distributions, increasingly unsustainable resource exploitation and long-term environmental degradation are driving the wedge between GNP and the ISEW. Neumayer (2000c, 2003) argues, however, that the methods used for measuring resource depletion and long-term environmental degradation are highly problematic and constructed in a way that almost inevitably leads to a threshold effect. In other words, the threshold effect is not robust to alternative, and arguably more reasonable, calculations of these components. For these reasons, we consider GS to be best practice in the measurement of WS.

4. Strong sustainability measurement and the SEEA-2003

The SS position is that natural capital cannot be substituted by other forms of capital, either in its entirety or at least as concerns so-called ‘critical’ forms of natural capital, so it is insufficient for the measurement of SD to value investment in various forms of capital. The focus must be on specific natural capital stocks and flows, which is the subject of chapters 3-4 and 7-8 of the SEEA-2003. Either we measure the total value of all natural capital, or we measure whether physical CNC is decreasing. In section 2, we questioned the former SS rule. We believe it is inappropriate to assume natural capital cannot, on the one hand, be substituted by produced capital but can, on the other hand, be substituted by another form of natural capital. However, some SS indicators do effectively and implicitly make this assumption (see below).

Protecting the physical integrity of CNC is a more promising sustainability rule. In this case, it is necessary to define for each capital function what is the critical level in order to set the SS constraint. For example, specific species need to be conserved above a safe minimum standard and renewable resource extraction needs to be kept below the maximum sustainable yield of the resource (see Ekins *et al*., 2003). Obviously, based on ecological, economic and social judgements of what is CNC, a primarily ecological assessment needs to be made to set SS constraints. Thereafter, the physical resource accounting measures suggested in the SEEA-2003 (chapter 3-4 and 7-8) can in some cases be used to measure whether they are being breached and the economic cost of respecting them. The lines along which this can proceed are quite clear for comparatively homogenous production and consumption resources such as timber. Chapters 7 and 8 go into considerable detail regarding the construction of relevant physical accounts.

While the physical accounting procedures of the SEEA-2003 can be of significant general use in measuring SS, it is worth discussing in more detail three prominent methods of measuring SS from the literature. The first is the 'ecological footprint' (suggested as a policy analysis application of the SEEA-2003 in chapter 11), which in fact makes the very assumption about the substitutability of natural capital that we have criticised. The remaining two have the potential to be consistent with protecting CNC. These are, secondly, material flow accounts and, thirdly, 'hybrid' indicators. We do not discuss indicators of ecosystem resilience here, because the SEEA-2003 is not able to generate useful data, at least based on the way resilience has been measured up until now (e.g. Hazell, 1989). However, it is argued to be an important factor in maintaining the many welfare-relevant functions of ecosystems (Holling, 1973, 1986), especially their primary value. Ecosystem resilience is the ability to maintain 'self-organisation' and therefore absorb stresses and shocks.

4.1. Ecological footprints

Ecological footprints (EFs) build on a tradition of attempts to measure the amount of carrying capacity that is appropriated by human activity (e.g. Vitousek *et al*., 1986). Carrying capacity is the maximum population size that can be supported by a given set of resources. EFs express this notion in terms of land area by translating economic activity into the area required to produce the resources consumed and to assimilate the wastes generated by a given region (Wackernagel et al 2000, 2002). Various components of consumption are identified and measured, typically including: crop and animal-based products; timber-based products; fish; built infrastructure; and fossil fuels (chapters 3 and 4 of the SEEA-2003). An estimate is then made of the land area needed in order to generate the resources consumed, using yield and equivalence factors (thus taking the analysis beyond the realms of integrated accounting). The complete EF of the region is compared with the actual size of the region to indicate either an ecological deficit (i.e. appropriates more land than is available domestically) or an ecological surplus (i.e. appropriates less land than is available domestically). An important difference with WS indicators is that the required land area is attributed to the resource consumer rather than the producer. So, for example, non-renewables extracted in a developing country and exported to a developed country count towards the developed country's EF.

As a rhetorical device, the EF seems to convey a notion of 'living beyond our means' in an intuitive way. The World Wide Fund for Nature calculated that the global EF exceeded the world's ecological capacity by around 20%. The average per capita EF of high income countries was 6.4 hectares/person, which dramatically exceeded global per capita availability of productive land, which was only about 1.8 hectares/person (WWF 2004). EFs have also been calculated for various cities, always with the result that the city's EF is greater than its size. But what is the purpose of finding that a region lives beyond its means? For cities and other highly urbanised regions, interpreting an ecological deficit as a sign of unsustainability precludes sustainability altogether: such regions could never live within their own ecological carrying capacity. The fact that these regions have ecological deficits whilst sparsely populated regions enjoy surpluses can be seen as part of the normal trade of goods, to the mutual benefit of both (van den Bergh and Verbruggen, 1999). The same applies in principle to regions of any size as well as countries. In some sense, the only level at which it is meaningful to measure the ecological footprint against available ecological carrying capacity is the global one.

The EF is an indicator of SS that assumes the substitutability of different forms of natural capital, because it assumes different natural capital goods are additive in terms of land area. We have stated our belief that this is a serious shortcoming. Other criticisms of the EF have been made by Ayres (2000), IVM (2002), Neumayer (2003), van den Bergh and Verbruggen (1999) and van Kooten and Bulte (2000). A very significant issue is the calculation of the land appropriated by fossil fuel consumption. Empirically, this tends to be the most important constituent of a region's total EF, responsible, for example, for slightly less than half of the global EF in 1999, but the methodology used has been criticised. It has been calculated as the *hypothetical* land area needed to sequester in forests the carbon emissions from fossil fuel burning. However, one can equally find other, much less land-intensive ways to hypothetically avoid carbon emissions. Fossil fuels could be replaced with renewable energy, particularly wind and solar power, or the carbon emitted could be captured and stored. Of course, the economic cost of doing so on a very large scale might also be very large, but given that EFs are blind to monetary valuation and therefore costs, its proponents cannot argue against considering the land required for renewable energy or carbon capture and storage as hypothetical substitutes for afforestation.

4.2. Material flow accounts

Material flow accounts (MFA) were first developed to give expression to the objective of a steady-state economy, in which the scale or material throughput of the economy should be held constant. MFA are very similar to the physical flow accounts in the SEEA-2003, in which all the materials drawn into the economy and all the residuals produced as waste are accounted, sector-by-sector. Chapter 3 (especially section D) provides an exposition that should imbue the reader with a sound knowledge of the accounting basis of MFA.

In this respect, the construction of MFA in the sustainability literature has typically comprised two departures from the SEEA-2003. Firstly, MFA tend to aggregate all annual material inputs and outputs by weight in order to derive across-the-board indicators such as Total Material Requirement (TMR) and Total Material Output (TMO). These are discussed in chapters 3 and 11 as a potential extension of the SEEA-2003. Thus within the economy, less detail is required than national accountants will be familiar with. A reduction of TMR and TMO has been promoted as a good candidate for one single long-term goal in environmental policy (Hinterberger and Wegner, 1996, p. 7) and has given rise to the so-called 'factor four movement' that advocates reducing aggregate material flows, at least in the developed world, by a factor of four (von Weizsäcker *et al*., 1996). There has even been a factor ten club. Secondly, MFA require that indirect or hidden flows within the environment (e.g. mining overburden) are accounted for. These hidden flows make up the so-called 'ecological rucksack' of a good taken into the economy.

The key outcome of empirical MFA studies is that, in a sample of developed countries (the EU-15, Japan and the United States), TMR and TMO have increased, despite the material intensity of output decreasing (Adriaanse and World Resources Institute, 1997; Matthews *et al*., 2000). In other words, the decoupling of material flows from output has not been strong enough to bring about absolute reductions in TMR or TMO.

While this is a significant finding, the use of TMR and TMO as sustainability criteria has been subject to criticism (see Neumayer, 2003). Importantly, to aggregate very different material flows by weight without adjustment for their environmental impact leads to nonsensical results. Two forms of material throughput cannot be meaningfully added together without knowledge of their environmental impacts. Hence the result that TMR and TMO have increased says little about how overall environmental impact has changed. There is much more potential in MFA once the practice of complete aggregation is abandoned and accounting is limited to flows with sufficiently similar environmental impacts. In doing so, we are moving towards a method of measuring sustainability that protects CNC.

4.3. Hybrid indicators

By taking the additional step of including the economic implications of material flow limits, we can develop an integrated environmental and economic measure of sustainability, albeit one that measures cost-effectiveness rather than efficiency. This is what a family of indicators and modelling exercises does, which Neumayer (2003) has called 'hybrid' (i.e. physical and monetary). The pioneering work behind hybrid measures was carried out by Hueting (1980).

Starting from the basic premise that one cannot meaningfully monetise natural capital depreciation (cf. section 3), Hueting set out to construct a workable alternative that measures the cost of reaching pre-specified SS standards (i.e. obeying SS constraints). He went on to suggest Sustainable National Income (SNI), which equals national income less the technical and structural costs of meeting SS standards (and less defensive expenditures on the environment).

Though Hueting's SNI is now somewhat dated, several propositions have sought to build on the idea. The most notable of these are Sustainability Gaps (SGAPs: Ekins and Simon, 1999), Greened National Statistical and Modelling Procedures or GREENSTAMP (Brouwer *et al*., 1999) and updated procedures for measuring SNI itself undertaken by Gerlagh *et al*. (2002). For a range of natural capital functions, an SGAP is constructed by calculating the physical gap between specific SS standards and the status quo. The physical impacts that produce an SGAP are allocated to the different economic sectors in the national accounts, based on physical flow accounting as in the SEEA-2003 (chapters 3 and 4). This paves the way, in principle, for monetising the SGAP (producing an M-SGAP), based on calculated abatement/avoidance costs (chapter 9 of the SEEA-2003). Cost-effectiveness will be achieved if the lowest cost options are chosen. However, M-SGAPs have not yet been estimated, because considerable data collection needs to be undertaken.

Ekins and Simon (2001) correctly warn against calculating SNI based on SGAPs, because they appreciate the SGAP is a partial, static measure. In other words, actually falling into line with SS constraints requires both time and a major shift in economic activity, such that prices would change and current prices become irrelevant. In empirically estimating SGAPs for the UK and the Netherlands, Ekins and Simon (2001) unsurprisingly found substantial gaps between current practice and pre-specified SS standards. Recently, Ekins *et al*. (2003) have outlined a framework for the estimation of SGAPs in respect of CNC.

GREENSTAMP is a modelling exercise that seeks to estimate feasible economic output in a future situation where SS constraints are obeyed. It applies a dynamic general equilibrium model[7] to this task, which constitutes its major advancement over Hueting's SNI and SGAPs,

[7] Though other general economy models not assuming optimality can be applied.

because the methodology is able to account for economy-wide price changes. Gerlagh *et al.*'s (2002) updated estimates of SNI follow a similar approach, in this case modelling feasible economic output subject to SS constraints in a counter-factual past. This leads some discussions of SD to classify these hybrid approaches as separate from the measurement of WS and SS altogether. Instead, they are introduced as SD modelling. In the SEEA-2003, they are classified as a subset of the wider cost-based approaches to monetising environmental degradation (chapter 10, section D) and the resulting estimates of feasible economic output are termed 'greened' GDP or geGDP. However, as we have shown, the methodology is consistent with SS, in particular the favoured CNC conception of SS.

There are some weaknesses to the hybrid approach though. As exercises in the hypothetical avoidance of CNC depreciation, many contestable assumptions must be made (they are too numerous to be discussed here). One also needs to be careful in interpreting the estimated monetary value of the SGAP, the estimated feasible economic output in the case of GREENSTAMP and the estimated SNI, respectively (Neumayer, 2003). A high value/large difference can mean one of two things. Either the actual economy is by a large margin unsustainable or it is close to fulfilling the norms, but doing so would be very costly. The environmental implications can therefore be quite different for the same monetary value. And, in a similar argument to that made vis-à-vis MFA, calculating economy-wide M-SGAPs and their GREENSTAMP/SNI equivalents masks all-important detail about the relative achievement of sustainability from one natural capital function to another. It could be that certain norms are drastically violated while others are almost achieved, or it could be that the economy is equally far away from achieving all norms.

5. Conclusion

We have presented in our view the best options available to researchers in the measurement of WS and SS based on the SEEA-2003's considerable data-generating capacity. This is an important task: although the SEEA-2003 portrays itself as particularly suited to the capital approach to sustainability, and although there is indeed a wealth of information in the SEEA-

2003 of relevance to the measurement of WS and SS, the handbook is not meant to support a particular paradigm of sustainability or the use of accounts for its measurement.

WS and SS differ in their assumptions about the substitutability of natural capital. If one subscribes to the WS view that natural capital can be substituted by produced capital, then we recommend estimating GS. If one subscribes to the SS view that at least a portion of natural capital is non-substitutable, then one has to choose from the diffuse definitions of SS and two basic rules that ensue: either maintain the value of total natural capital or maintain CNC. We conclude that only the latter rule is plausible. Therefore, if one wishes to make measurements of sustainability with detailed policy relevance, the best available technique is to set SS constraints and model the economic cost of respecting them with one of the hybrid indicators discussed above.

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