4. Indicators of sustainability

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1. INTRODUCTION

If a political or geographical entity such as a nation-state, a region or a city is committed to sustainable development, then measuring sustainability becomes very important. Only with the help of such measurement will it be able to assess whether and if so which policy measures are necessary to achieve sustainability. I will mainly concentrate on the nation-state level here and inquire how one can measure whether the economy of a country is sustainable and what such measurement tells us. As will be seen, there are many indicators aspiring to answer this question and they come to starkly differing conclusions. For example, some indicators tell us that most countries, particularly the developed ones, have no apparent problem with sustainability, whereas others suggest that the economies of many countries, and the developed ones in particular, are clearly unsustainable.

Part of the reason why existing indicators come to such differing conclusions is that they differ in their understanding of sustainability and thus differ in what they measure. To start with, on a very fundamental level, most indicators focus exclusively on intergenerational equity, that is equity between generations. However, at least one of the indicators I look at, namely the index of sustainable economic welfare (ISEW), explicitly tries to combine intergenerational equity with intragenerational equity, that is, equity within the current generation. Furthermore, sustainability, even where it refers exclusively to intergenerational equity, comes in two main forms, namely weak sustainability (WS) and strong sustainability (SS). I define WS as the requirement to keep per capita utility non-declining at any moment in time, that is over the whole future development path, which represents a common economic definition.[1] WS is based on the often implicit assumption of unlimited substitutability of natural capital in the production of consumption goods and the generation of utility through other forms of capital such as man-made (produced) capital and human capital.[2] SS holds that natural capital is non-substitutable either in its entirety or at least with reference to certain so-called critical functions of natural capital. It is sometimes defined in value terms as the requirement to keep the value of natural capital intact. Such a definition is somewhat problematic as it does not

constrain substitutability amongst various forms of natural capital itself. A different definition therefore sees SS as the requirement to maintain all or at least some of the critical functions of natural capital intact. This would call for setting standards in physical terms and for specific forms of natural capital, which would have to be obeyed. This clearly constrains substitutability within natural capital. It typically implies keeping human impact within the natural regenerative capacity of the environment – see Neumayer (1999a, 2003) for a more extensive discussion. SS is often focuses on environmental sustainability. One must not forget, however, that, like WS, SS is also driven by considerations of intergenerational equity as the assumption is that keeping the value of natural capital at least constant or maintaining specific forms of natural capital is necessary to protect the welfare of future generations (Daly, 1992).

Some of the indicators I look at try to measure WS whereas others are indicators of SS. The indicators can of course be criticized partly not for what they are and how reliable they are in their measurement, but for what they are supposed to indicate, namely WS or SS. I will not engage in such a discussion and have made my view clear in Neumayer (1999a, 2003). Instead, I take the indicators for what they are supposed to measure and provide a critical analysis of how well they achieve this task.

I will distinguish between monetary indicators, physical indicators and hybrid approaches, which try to combine physical standards with monetary valuation. All indicators of WS are monetary indicators. This is not surprising as the assumption of unlimited substitutability allows commensurability such that all values can be expressed in monetary terms. SS, on the other hand, with its focus on environmental sustainability, is measured either with physical indicators or with hybrid ones.

Inevitably, not all indicators can be covered. For example, I do not include the so-called Green Accounting Research Project (GARP) (Markandya et al., 2000) since its main objective is not to construct a sustainability indicator, but is confined to producing damage cost estimates mainly for air pollution. Similarly, I do not discuss any environmental indicator systems, whose main objective is environmental monitoring without a clear sustainability rule attached to it, such as, for example, the pressure-state-response indicator set of the Organisation for Economic Co-operation and Development (OECD, 2001). The same is true for accounting tools such as physical input–output tables used in, for example, the national accounting matrix including environmental accounts (NAMEA) (see, for example, Steenge, 1999).

I also do not cover the concept of environmental space (Hille, 1997). Some of its basic ideas are taken on board in ecological footprints and material flows, but it is less well known than these two other indicators, which are discussed. Vitousek et al.'s (1986) famous indicator of the human appropriation of net primary productivity is similarly not included. The concept of

ecological footprints is inspired by and partly built upon this indicator. The same is true for energy-based indicators called emergy/exergy based on thermodynamics (see Odum,1996; Herendeen, 1999; Ferrari et al., 2001; Dincer, 2002). No doubt many others could be listed here as being omitted from the analysis, but I hope to cover the best known and most popular indicators of both weak and strong sustainability.

Pezzey and Toman (2002a, p. 213) in their assessment of progress and problems in the economics of sustainability come to the conclusion that 'theoretical work has vastly outstripped empirical work'. I agree with this assessment. Partly, the gap between theoretical and empirical work is to be explained by data problems – both in terms of missing data and in terms of poor quality of existing data. Often, heroic assumptions and crude simplifications need to be made for empirical indicators to resemble even faintly the theoretical ideal. But theory is most useful if it can be applied in reality and substantial effort has already been undertaken on developing empirical indicators of sustainability. It is the objective of this chapter to review and critically assess these efforts, always conscious of the limits and problems such indicators encounter in putting a theoretical ideal into practice. Having noted the data problem, I will mainly concentrate on methodological aspects in the critical analysis. It will be seen that all empirical sustainability indicators encounter substantial methodological and other criticism.

This chapter thus extends the more theoretically oriented contributions published before in this series, such as Aronsson and Löfgren (1998) and Pezzey and Toman (2002a), with a distinctively empirically oriented analysis. It is organized as follows: section 2 starts with genuine savings and the index of sustainable economic welfare as monetary indicators of weak sustainability. Section 3 discusses ecological footprints and material flows as physical indicators in the spirit of SS. As hybrid approaches, I deal with the concept of sustainability gaps, the Greened National Statistical and Modelling Procedures project, better known under its acronym GREENSTAMP, and the 'sustainable national income according to Hueting' (SNI) in section 4. All these are indicators of SS. Section 5 concludes.

2. MONETARY INDICATORS

2.1 Genuine Savings

2.1.1 Justification and basic idea

Genuine savings (GS) is an indicator of WS within the welfare-theoretic approach to the economics of sustainability, building upon Solow's (1974) and Hartwick's (1977) path-breaking work. The term 'genuine' was introduced by

Hamilton (1994) to distinguish genuine savings, which refers to changes in all utility-relevant stocks of capital including natural capital, human capital as well as (in principle at least) social capital,[3] from traditional net savings, which refers only to man-made or produced capital.[4] Assume a framework in which population is constant and the social welfare function is a discounted utilitarian function with a constant rate of discount. Also assume that dynamic welfare is maximized such that the competitive economy develops along the intertemporally efficient path with all externalities optimally internalized – see, for example, the dynamic optimization or optimal economic growth models in Hartwick (1990), Hamilton (1994, 1996) and Neumayer (1999a, 2003). Further, assume that the productivity of the economy is fully captured by all capital stocks, a condition formally known as stationary technology (Asheim, 2003). For example, all technological progress is captured in man-made capital and human capital. Finally, the assumptions of weak sustainability need to hold, namely that either other forms of capital can substitute for the depletion of natural capital without limit or that natural capital is superabundant or that technical progress can always overcome any apparent resource constraint (Neumayer, 1999a, 2003).[5] Within such a framework, it can be shown that the economy of a country cannot be weakly sustainable if its GS rate is below zero (Pezzey, 2002; Pezzey and Toman, 2002b). The policy recommendation following from this result would be to keep GS above zero: invest into all forms of capital at least as much as there is depreciation of all forms of capitals.

2.1.2 Empirical studies

Early crude attempts to estimate GS figures have been undertaken by Pearce and Atkinson (1993). Comprehensive GS accounting is, however, confined to estimates undertaken by the World Bank (1997, 2002). Given Kirk Hamilton's affiliation with the World Bank's Environment Department, it is perhaps not surprising that the Bank has been the main proponent of GS as an indicator of WS and has estimated GS figures for most countries in the world from 1970 onwards.[6] GS data are now included in the annual updates of the Bank's World Development Indicators.[7] In the most comprehensive formulation of GS, it is made operational by the Bank as follows:

GS = investment in man-made capital – net foreign borrowing + net official transfers
– depreciation of man-made capital – net depreciation of natural capital
+ current education expenditures

Two observations are immediately apparent from this definition: first, (net) investment in human capital is simply approximated by current education

expenditures.[8] This is certainly rather crude, but it is difficult to see how investment in human capital could be estimated otherwise for so many countries over such a long time horizon. Dasgupta (2001a, p. C9f.) argues that it is an overestimate since human capital is lost when people die. Against this one might object that part of the human capital might have been passed on so that the human capital is not really lost once individuals die or, to be precise, leave the workforce. In any case, such correction would be difficult to undertake and I will not bother further with the calculation of net investment in human capital here. Second, social capital is not included due to the insurmountable difficulties in measurement.

Gross investment in man-made capital is already included in the national accounts as it forms part of gross national product (GNP) or gross domestic product (GDP). Depreciation of man-made capital is less commonly estimated since net national product (NNP) or net domestic product (NDP) play a less prominent role in macroeconomics. Still, some estimations exist, on which one can build. What is much more difficult and contested is measuring the depreciation of natural capital. Natural capital can be depreciated mainly due to two human activities: resource extraction or harvesting and environmental pollution. To start with the latter, the Bank only includes the estimated damage of carbon dioxide emissions, where each ton of carbon emitted is valued at US$20 per metric tonne of carbon. The value is taken from Fankhauser (1995) and is often regarded as a consensus estimate. As concerns depreciation of natural capital due to resource extraction, the Bank includes the following resources: oil, natural gas, hard coal, brown coal, bauxite, copper, iron, lead, nickel, zinc, phosphate, tin, gold and silver. Forests is the only renewable resource taken into account.

How should depreciation of natural capital due to resource extraction be measured? This question is controversially debated in the relevant literature (Hartwick, 1977, 1990; Hartwick and Hageman, 1993; El Serafy, 1981, 1989, 1991; Vincent, 1997; Santopietro, 1998; Davis and Moore, 2000). It does have a very simple answer, however, as long as one stays in the framework of a competitive intertemporally efficient economy (Hartwick, 1990; Hamilton, 1994, 1996; Neumayer, 1999a, 2003). In this framework natural capital depreciation is equal to total Hotelling (1931) rent:

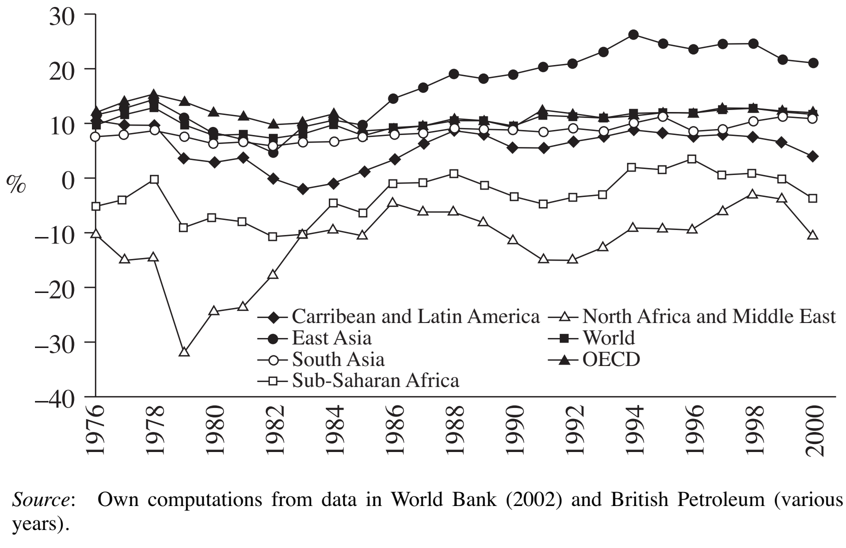
$$(P - MC) \cdot R \tag{4.1}$$

where P is the resource price, MC is marginal cost and R is resource extraction. In the case of a renewable resource, R would be resource harvesting beyond natural regeneration. One of the major difficulties of applying this theoretically correct method in reality is that data on marginal cost are frequently unavailable. Average costs are more available. The World Bank

therefore replaces marginal cost with the more readily available average costs and calculates depreciation according to the following formula:

$$(P - AC) \cdot R^9 \qquad (4.2)$$

What are the main results of GS computations? Figure 4.1 shows the development of GS relative to GNP for regions over the period 1976 to 2000. The OECD countries as well as East and South Asia never have negative GS rates. The same is true for the world as a whole. The Latin American and Caribbean region touches zero and slightly below only some time in the early 1980s. The problematic regions are Sub-Saharan Africa, whose GS rates go negative in the early 1980s, and North Africa and the Middle East with GS rates that are negative throughout the whole period, with few exceptions. At this level of regional aggregation, it already becomes clear that the regions with the greatest natural resource extraction are the most problematic ones. Indeed, if one looks at individual countries, those with major dependence on natural resource extraction are also the ones that often have negative GS rates. The main message from the Bank's GS computations is therefore that many developing countries that are dependent on resource exploitation are weakly unsustainable (see Hamilton and Clemens, 1999 for more detail). In the case of Sub-Saharan Africa, it is noteworthy that their net savings before natural capital depreciation are often already negative such that their economies are on a weakly



Source: Own computations from data in World Bank (2002) and British Petroleum (various years).

Figure 4.1 Genuine savings rates in per cent of GNP

unsustainable path quite independently of depreciation due to natural resource exploitation.

2.1.3 Critical assessment

The concept of GS itself as well as the way it is measured in practice by the World Bank has encountered much criticism. I can only briefly analyse some important aspects here. A more comprehensive discussion is provided in Neumayer (1999a, pp. 154–77). To start with some conceptual problems, the framework in which GS is derived as an indicator of WS is very restrictive. The assumption of intertemporal efficiency is hard to defend as actual economies are highly unlikely to develop along the optimal path. If environmental and other externalities are not internalized, then existing prices and quantities differ from the optimal ones. In this case, positive GS rates can go hand in hand with unsustainable resource exploitation and environmental degradation. This is one of the reasons why positive GS cannot be taken as indicating achievement of WS (Asheim, 1994; Pezzey and Withagen, 1998). Furthermore, even if efficient, an economy need not be sustainable. If it is not, then shifting towards sustainability will change prices. Pezzey and Toman (2002b, p. 17) therefore suggest that 'sustainability prices and sustainability itself are thus related in a circular fashion: Without sustainability prices, we cannot know whether the economy is currently sustainable; but without knowing whether the economy is currently sustainable, currently observed prices tell us nothing definite about sustainability.'

Even if the economy developed along an optimal path as assumed in the derivation of GS, then positive GS at any moment of time does not indicate WS since WS is defined in keeping per capita utility at least constant over all time, whereas GS at any moment of time merely presents a point measure of sustainability. The upshot of all this is that GS is at best a one-sided indicator of sustainability: negative GS rates signal unsustainability, but positive GS rates cannot be interpreted as an indication that WS has been achieved. Whilst this point is acknowledged by Hamilton and the Bank, it is likely to be ignored by policymakers and others. The danger is that positive GS rates are taken as proof for the achievement of WS.

The assumption of a stationary technology is similarly unrealistic. This assumption breaks down if technological progress is partly exogenous in the sense that it is not fully captured by total capital (Weitzman, 1997; Aronsson and Löfgren, 1998). The same is true for changing terms of trade in open resource-trading economies (Hartwick, 1994; Asheim, 1986, 1996; Sefton and Weale, 1996). Developing natural-resource-exporting countries with negative GS might still be weakly sustainable if exogenous technical progress or future terms-of-trade improvements raise future consumption possibilities. The GS rate becomes similarly ambiguous if the discount rate is not assumed to be

constant throughout. For this case Asheim et al. (2003) show that even negative GS rates at any moment of time need not imply weak unsustainability.

The GS rule also becomes much more complex if the unrealistic assumption of constant population is abandoned. Results depend on whether population growth is assumed to be exponential and whether social welfare only depends on per capita utility or also on population size (see Hamilton, 2003; Asheim, 2002; Arrow et al., 2003). Not surprisingly, the many developing countries with strong population growth appear to be even less weakly sustainable once population growth is accounted for.

On the more practical side, the weak unsustainability of many natural-resource-dependent developing countries crucially depends on the way the Bank calculates natural capital depreciation. Neumayer (1999a, pp. 164–77) and Neumayer (2000a) argue in favour of what has become known as the El Serafy (1989, 1991) method instead of equation (4.2). The formula for the El Serafy method is:

$$(P - AC) \cdot R \cdot \left[\frac{1}{(1 + r)^{n+1}} \right], \tag{4.3}$$

where r is the discount rate and n is the number of remaining years of the resource stock. For simplicity, this is often set equal to the static reserves-to-production ratio, which is the number of years the reserve stock would last if production were the same in the future as in the base year. If $r > 0$ and $n > 0$, then (4.3) will produce a smaller depreciation term for resource extraction than (4.2). If either n or r is large, the depreciation will be rather small.

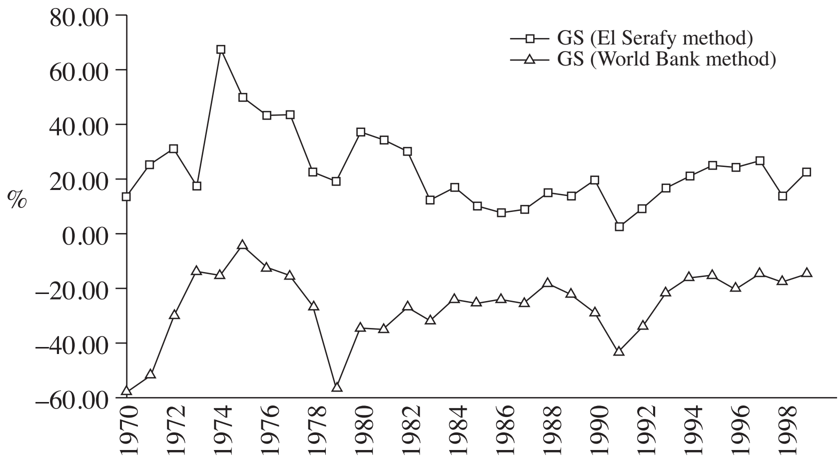
Equation (4.3) is also called the 'user cost' of resource extraction since it indicates the share of resource receipts that should be considered as capital depreciation. The formula for the El Serafy method is derived from the following reasoning: receipts from non-renewable resource extraction should not fully count as what El Serafy calls 'sustainable income' because resource extraction leads to a lowering of the resource stock and thus brings with it an element of depreciation of the resource capital stock.[10] Whilst the receipts from the resource stock will end at some finite time, 'sustainable income' by definition must last forever. Hence, 'sustainable income' is defined as that part of resource receipts which if received infinitely would have a present value just equal to the present value of the finite stream of resource receipts over the lifetime of the resource. Natural capital depreciation is then the difference between resource rents and 'sustainable income'. Appendix 1 shows why this reasoning leads to equation (4.3).

There exists a range of arguments why it might be better to use the El Serafy method than the World Bank method in real-world computations of

natural capital depreciation. First, Hartwick and Hageman (1993) show that the El Serafy method can be understood as an approximation to equation (4.1), which, to repeat, is the theoretically correct depreciation in a framework of a competitive intertemporally efficient economy. Its main advantage over the World Bank method in equation (4.2) is that the El Serafy method can use average cost without apology as it does not depend on marginal cost. The World Bank method, on the other hand, needs to replace marginal cost with average cost as marginal cost is not readily available. Due to the replacement of marginal with average cost it can also merely represent an approximation to the theoretically correct method. Which of the two methods creates the greater bias is not clear in general. Under certain assumptions about the resource extraction cost function, the two methods can be shown to be two polar cases of the true depreciation value and the bias depends on the elasticity of the marginal cost curve with respect to the quantity extracted (Vincent, 1997; Serôa da Motta and Ferraz do Amaral, 2000). The upshot of this is that even within a framework of a competitive intertemporally efficient economy the El Serafy method can provide a better approximation to natural capital depreciation than the World Bank method.

Second, the true appeal of the El Serafy method stems from the fact that it does not depend on the assumption of efficient resource pricing – resource rent growing at the rate of interest according to Hotelling's (1931) rule – because it is not dependent on an optimization model. In other words, it does not depend on the assumption of a competitive economy developing along the intertemporally efficient path. It is an 'ex post approach, capable of accounting for any entrepreneurial decisions regarding extraction' (El Serafy, 1997, p. 222). The World Bank's method, on the other hand, depends on efficient resource pricing. Now, none of the data the Bank uses are guaranteed to be the ones that would be generated if a country's economy developed along an optimal path and the Bank does not estimate any shadow values. Hence, for consistency reasons it might be better to use a method such as the El Serafy method, which does not depend on efficient resource pricing either. Interestingly, in Atkinson et al. (1997, p. 60f.) the same authors on whose work the World Bank is built admit that since 'there is little evidence for efficient pricing of resources in the ground', it 'may be advisable to value resource depletion as a user cost with a non-zero discount rate' according to the El Serafy method.

Third, the World Bank method leads to implausible results for many resource-dependent countries. Take Saudi Arabia as an example. Figure 4.2 plots the GS rate of Saudi Arabia over the period 1970 to 1999, once as computed with the World Bank method and once with the El Serafy method using a discount rate of 4 per cent. The message could not be more different: Saudi Arabia is hugely unsustainable if one applies the World Bank method,



Source: World Bank (2002).

Figure 4.2 Genuine savings rates for Saudi Arabia in per cent of GNP

but has no apparent problems with WS if the El Serafy method is employed. Application of the World Bank method leads to results that are hard to believe. The World Bank (2003) estimates the total natural capital wealth of Saudi Arabia in 1994 at about US$ 807 billion as a low estimate and US$ 2.3 trillion as a high estimate. This contrasts with a total value of natural capital depreciation of Saudi Arabia over the period 1970–99 estimated at US$ 1.5 trillion To be fair, it has to be said that the way the World Bank estimates a country's natural capital stock itself is methodologically different from the way it estimates the depreciation of it (see World Bank, 1997, pp. 18f. and 37f.). The natural capital stock is underestimated relative to its depreciation. Still, the World Bank method paints a picture of Saudi Arabia that is hard to believe. The El Serafy method, on the other hand, takes into account the country's enormous oil and natural gas reserves and thereby comes to an entirely different conclusion about the WS of the Saudi Arabian economy. These enormous reserves are simply ignored in the World Bank method due to its assumption of efficient resource pricing. But, as El Serafy (2001, p. 205) stresses, 'there should clearly be a fundamental difference for national accounting between extracting a given volume out of a large or a small stock. Extracting the same volume amounting to 5 per cent of the stock has different implications for income and sustainability from extracting the same quantity if it amounts to 50 per cent of the stock.'

The change in results with regard to GS once the El Serafy method is employed is not restricted to Saudi Arabia. Instead, many of the countries which appear unsustainable according to the World Bank no longer are once the El Serafy method is used. This is not true for all countries, but true for most of them and in particular those with substantial reserves (Neumayer, 1999a, 2000a). Hamilton (2000, p. 5) admits that the World Bank method 'arguably over-estimates the value of resource depletion, particularly for countries having large reserves to production ratios'. But the GS figures are published by the Bank without any such qualification.

Of course, the El Serafy method is not without problems either. To start with, one needs to choose a discount rate and it is far from clear what the right discount rate should be. A prudent rule would be to choose a rate of discount that approximates the real rate of return to investing the receipts from resource extraction into other forms of capital. Also, one needs to estimate n, the remaining lifetime of the resource stock. Given uncertainty about the future, it is not clear what n should be. A simple rule of thumb is to set n equal to the static reserves-to-production ratio, which becomes updated in every period of accounting as information about the level of extraction and the stock of remaining reserves changes. Since estimates of reserve stocks are sometimes difficult to establish for some resources in some countries, the exact value for n can be contentious, and a prudent accountant should use a lower-bound estimate. For example, only reserves that can be economically exploited at current technology should be included.

As a further criticism of the way resource depletion is accounted for, one could argue that the resources depleted in poor developing countries with high resource exploitation go to rich developed countries for their benefit and that therefore the rich countries are responsible if resource exploitation is unsustainable. Proops et al. (1999) have shown that if natural capital depreciation is attributed to the country of resource consumption, then not surprisingly the GS position of resource-exporting developing countries improves, whereas that of resource-importing developed countries is not so safely positive any longer. There are good arguments why resource exploitation should be attributed to the extracting country itself and not to the consuming country, however. This is because the purpose of resource accounting is to try to measure whether and by how much the natural capital stock of a country is depreciating. It simply does not matter who is 'responsible' or to 'blame' for its depreciation. Furthermore, even in terms of justice one could argue that a resource-rich country is endowed with an extra capital asset by nature. It is up to this country to make sustainable use of it. If it burns all resource rents in consumption instead of investing them into the human capital of its people and in manufactured capital of its economy, this is its own fault. It is the responsibility of each country to keep its own capital stock intact.

A different criticism of the World Bank estimates of GS relates to the way environmental pollution is accounted for. Obviously, carbon dioxide is by far not the only and, as some would argue, not the most relevant of all pollutants. Similar concerns can be raised with respect to renewable resources, as currently forestry is the only one included. Such vital renewable resources as water, soil, fish and, more generally, biodiversity are missing due to lack of adequate data. The Bank is not ignorant in this respect, but sees itself unable to compute environmental damage costs for other environmental pollutants and other renewable resource degradation due to lack of data.

One of the dangers is that the WS position of major polluters, particularly the developed countries, is overestimated. That the more developed countries by and large do not become detected as weakly unsustainable is mostly to be explained by their usually quite high net saving rates. Nevertheless, these countries would no longer have such outstandingly good WS performance if more pollutants were taken into account. Indeed, Atkinson et al. (1997, p. 93) show that the WS position of developed countries becomes less comfortable and in a few instances there are even signs of unsustainability if nitrogen oxide, sulphur dioxide and particulate matter emissions are taken into account in addition to carbon dioxide.

As a final criticism, it is not entirely clear what specific policies should be undertaken following the detection of negative GS rates. There are many ways to increase GS, from reducing resource depletion and environmental pollution to increasing investment in manmade capital. Surely, bringing pollution or resource exploitation down to zero, for example, cannot be a sensible policy as it would be a highly inefficient way of raising GS. The World Bank seems to favour raising investment in man-made capital as the way out of negative GS rates, as becomes clear in the following quotation from World Bank (1997, p. 35): 'The depressed rates of genuine saving . . . represent an opportunity not seized. . . . [I]t is often the gross saving effort that is insufficient in these countries, which points the finger squarely at broader macroeconomic policies'.

2.2 Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI)

2.2.1 Justification and basic idea

The basic idea of the Index of Sustainable Economic Welfare (ISEW), also known under the name Genuine Progress Indicator (GPI), is to provide a substitute indicator for GNP or GDP, which are regarded as misleading indicators of both current welfare or instantaneous utility and sustainability. It stands in the tradition of and indeed partly builds upon earlier attempts to provide a more comprehensive indicator of welfare and to incorporate environmental and/or sustainability aspects into such an indicator – see, for example, Nordhaus and

Tobin's (1972) Measure of Economic Welfare (MEW), Zolotas's (1981) Economic Aspects of Welfare (EAW) and Eisner's (1990) Total Incomes System of Accounts (TISA).[11] The MEW and the EAW take some environmental aspects into account. The MEW adjusts the welfare measure for 'disamenities of urban life' such as 'pollution, litter, congestion, noise' based on hedonic valuation studies.[12] The EAW subtracts air pollution damage costs together with half of the estimated control costs for air and water pollution and the full control costs for solid wastes from the welfare measure. It also deducts the costs of resource depletion. The TISA, on the other hand, does not include any environmental aspects into its measurement, but like the MEW and the EAW seeks to broaden the concept of capital and investment accounted for.

Daly et al. (1989) and Cobb and Cobb (1994) were the first to propose and develop an ISEW for the USA. Building upon their work, computation of an ISEW usually starts from personal consumption expenditures. These expenditures are weighted with an index of income inequality. Then, certain welfare-relevant contributions are added, whereas certain welfare-relevant losses are subtracted. As an example, take the US study of Cobb and Cobb (1994): after having weighted personal consumption expenditures by a modified Gini coefficient of pre-tax income distribution data, they add the estimates of the value of the services from household labour, consumer durables and streets and highways. They also add net private investment into man-made capital and changes in the net international investment position of the USA. They subtract most expenditures on health and education because these are regarded as mostly defensive expenditures. They also subtract expenditures on consumer durables, estimates of the costs of commuting, car accidents, and the costs of environmental degradation such as water, air and noise pollution, loss of wetlands and farmlands, the depletion of non-renewable resources and long-term environmental damages due to CO2 emissions. The ISEW is simply the sum of the weighted personal consumption expenditures and all the mentioned corrections.

The guiding idea of these adjustments is to subtract items regarded as contributing to either welfare or sustainability, and to deduct items that reduce either welfare or sustainability. Like GS, the ISEW is an indicator of WS since in adding up environmental and non-environmental values substitutability of natural capital is implicitly assumed. This is somewhat ironic given that most proponents of the ISEW, and Herman Daly in particular, are also proponents of SS.

The policy recommendation is to ensure that the ISEW is not decreasing. One can interpret the ISEW loosely as a kind of extended or greened net national product (gNNP), which is defined as 'comprehensive consumption' plus GS, where comprehensive means that all utility-relevant flows are included in the consumption vector, not just the consumption of material

goods. The theoretical sustainability foundation of the ISEW then follows from the fact that under certain assumptions preventing GS from becoming negative is equivalent to preventing gNNP from falling (Pezzey and Toman, 2002a, p. 184; Asheim, 2003).

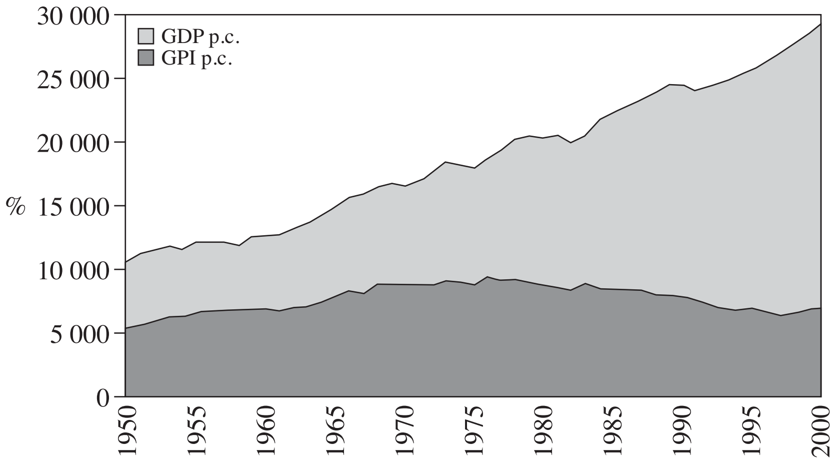
2.2.2 Empirical studies

An ISEW has been constructed for Austria (Stockhammer et al., 1997), Chile (Castañeda, 1999), Germany (Diefenbacher, 1994), Italy (Guenno and Tiezzi, 1998), the Netherlands (Rosenberg et al., 1995), Scotland (Moffatt and Wilson, 1994), Sweden (Jackson and Stymne, 1996), Thailand (Clarke and Islam, 2003) and the UK (Jackson et al., 1997). Sometimes these studies come, with only slightly changed methodology, under the name of Genuine Progress Indicator (GPI), as, for example, in the case of Australia (Hamilton, 1999) and the US (Redefining Progress, 1999, 2001). For Australia there also exists a related measure, which comes under the name of sustainable net benefit index (SNBI) (Lawn and Sanders, 1999). The specific methodology employed changes a bit from country to country depending on data availability and the preferences of the authors, but all studies come to the same basic conclusion: starting from around the 1970s or the early 1980s, depending on the country, the ISEW or GPI no longer rises very much or even falls, whereas GNP or GDP continues to rise. As an explanation for this widening gap between ISEW or GPI on the one hand and GNP or GDP on the other, Max-Neef (1995, p. 117) has put forward the so-called 'threshold hypothesis': 'for every society there seems to be a period in which economic growth (as conventionally measured) brings about an improvement in the quality of life, but only up to a point – the threshold point – beyond which, if there is more economic growth, quality of life may begin to deteriorate'. This 'threshold hypothesis' is referred to in almost every study of ISEW or GPI and Max-Neef (ibid.) himself regarded the evidence from these studies 'a fine illustration of the Threshold Hypothesis'.

Figure 4.3 provides a nice illustration of the so-called threshold effect looking at the US GPI, which is basically the updated version of the US ISEW. It shows the development of the United States GPI per capita in comparison to GDP per capita. Whilst the two graphs roughly move in parallel with each other, from around the 1970s increasing divergence can be observed. Whereas GDP is still increasing, the GPI is no longer increasing or even slightly falling. This picture is typical for practically all ISEW or GPI studies.

2.2.3 Critical assessment

As pointed out above, the ISEW can be interpreted as a kind of gNNP and under certain assumptions preventing GS from becoming negative is equivalent to preventing gNNP from falling. Whilst this provides the sustainability



Source: Redefining Progress (various years).

Figure 4.3 United States GDP versus GPI per capita (US$ of 1996)

foundation for the measure, it also means that all the critical points raised in our discussion of GS similarly apply to the ISEW. I will not discuss them again here, but concentrate on the problematic aspects specific to this measure.

Many authors have criticized various aspects of the ISEW (see Nordhaus, 1992; several authors in Cobb and Cobb, 1994; Atkinson, 1995; Neumayer, 1999a, 1999b, 2000b). The criticism ranges from general conceptual points to detailed methodological aspects. Before coming to the detailed methodological criticism, let us note two fundamental points. First, contrary to GS, the ISEW is not rigorously derived from a theoretical model. Thus, whilst it has a basic theoretical foundation as pointed out above, the specific adjustments undertaken and their justification are often somewhat *ad hoc* as will be seen in our discussion of some specific components of the ISEW below. Indeed, with the notable exception of Lawn (2003), proponents of the ISEW and related indicators have devoted comparatively little effort to theoretically justifying their measure. Second, similar to GS, it is not quite clear what specific policies are to be undertaken if the ISEW or GPI is falling as many different policies could raise it. Ironically, one might even suggest stronger growth in consumption expenditures as these usually form the starting point for the corrections undertaken.[13]

Let us now turn towards specific components of the ISEW and the method employed for their valuation. I will mainly concentrate here on the two aspects, which are directly and significantly responsible for the 'threshold

effect', namely the way in which energy resource depletion and long-term environmental damage are computed. We will see that in both cases the computations depend on arbitrary or even flawed assumptions. Before that, let us briefly discuss two other contested components, however, namely intragenerational income inequality and defensive expenditures.

2.2.3.1 Income inequality As mentioned in the introduction, the ISEW and GPI stand out from other indicators of sustainability in that they try to include intragenerational equity considerations as well. Most studies use the Gini coefficient, where usually one year is set as the base year for the index. In the US GPI, for example, 1968 is set as 100, because 'it represented the lowest Gini coefficient over the 1950–1998 period, thus the least income inequality. All other years are then compared to this benchmark' and an index is created (Redefining Progress, 1999, p. 14). The inequality-adjusted consumption expenditures are reached via dividing unadjusted expenditures by this index and multiplying by 100. However, the inclusion and valuation of intragenerational income inequality has encountered many criticisms. Critics such as Mishan (1994, p. 172) argue that 'all efforts to adjust the welfare index to accommodate changes in distribution . . . must be regarded with misgivings. They are either arbitrary or politically biased and are, therefore, invariably a focus of attack.' At the least, there is no consensus that less inequality is always better than more inequality. Even if there was a consensus, doubts remain whether such a value judgement can be easily monetized.

2.2.3.2 Defensive expenditures With regard to defensive expenditures, the very concept is elusive and what should count as a defensive expenditure is rather arbitrary. Cobb and Cobb (1994, p. 53) exclude most expenditures for education because they believe that education 'contributes little to productivity'. In their perspective it should therefore not count as investment. This is clearly at odds with the importance attached by most economists to human capital and education. However, more relevant to this section here is that Cobb and Cobb do not want to count education as consumption either since 'most schooling appears to be defensive. In other words, people attend school because others are in school and the failure to attend would mean falling behind in the competition for diplomas or degrees that confer higher incomes on their recipients' (ibid., p. 54).

Following this line of argument, one could classify many if not most expenditure items as defensive in character. For example, if health expenditures are defensive expenditures against illness, why should food and drinking expenditures not count as defensive expenditures against hunger and thirst? Are holiday and entertainment expenditures to be considered defensive expenditures against boredom? Daly et al. (1989, p. 78) defend their concept of

subtracting defensive costs by saying that ' "defensive" means a defense against the unwanted side effects of other production, not a defense against normal baseline environmental conditions of cold, rain and so on'. But even accepting Daly et al.'s definition, one could argue that at least part of food, drink, entertainment and holiday expenditures are caused by the stressful, exhausting and boring modes of modern production that make these expenditures necessary as a defence against their unwanted side-effects. As the revised *System of National Accounts* points out: 'Pushed to its logical conclusion, scarcely any consumption improves welfare in this line of argument' (Commission of the European Communities – et al., 1993, p. 14).

2.2.3.3 Resource depletion With regard to resource depletion, studies differ in that some use the resource rent method, whereas others use the replacement cost method. Those using the resource rent method, such as Daly et al. (1989), Stockhammer et al. (1997), Diefenbacher (1994) and Guenno and Tiezzi (1998) deduct total resource rents from consumption expenditures according to equation (4.2); that is, in the same way that the World Bank computes depreciation of the natural capital stock for its GS rates. As we have seen in the discussion of GS, there might be good reasons to employ the El Serafy method instead, which leads to lower estimates of the true depreciation of natural capital due to resource exploitation. However, much more problematic is the replacement cost method, which has been used by the majority of studies and I will concentrate the discussion on this.

Cobb and Cobb (1994) were the first to use the replacement cost method. Each barrel of oil equivalent was valued at a replacement cost which was assumed to escalate by 3 per cent per annum in real terms between 1950 and 1990 and was anchored around an assumed cost of $75 in 1988. Castañeda (1999), Rosenberg et al. (1995), Moffatt and Wilson (1994), Jackson and Stymne (1996), Jackson et al. (1997), Hamilton (1999) and Redefining Progress (1999) have all followed Cobb and Cobb's example with slight modifications. It is already questionable to assume that all non-renewable energy resource consumption needs to be replaced fully by renewable resources given that there are still huge reserves of non-renewable resources available for many years to come (British Petroleum, 2002). I will concentrate on the 3 per cent escalation factor, however, which clearly gives rise to a threshold effect if resource consumption is not falling and GNP/GDP is not rising too much. As a rationale for this assumption of constantly increasing replacement costs, Cobb and Cobb (1994, p. 267) refer to the costs per foot of oil drilling which they report to have increased by about 6 per cent per annum in real terms during the period of high oil prices in the 1970s, which triggered the exploration and drilling of more difficult to exploit oil fields. They reason that 'when the limits of a resource are being reached, the cost of extracting the next

unit is more costly than the previous unit' and that 'this principle presumably applies also to renewable fuels, though not as dramatically as to oil and gas', which is why the escalation factor is assumed to be 3 per cent in real terms instead of 6 per cent. Especially with respect to renewable energy resources, such reasoning might be erroneous, however. The most likely candidate for replacing non-renewable fuels is renewable solar energy, with solar energy influx many times exceeding current world energy demand. Also, costs for solar energy use are currently high because the technology is still in the early stages of development, but costs will fall over time as technology improves. Instead of assuming replacement costs to escalate by 3 per cent per year, it might therefore be more appropriate to assume that replacement costs are falling over time. Neumayer (2000b) has shown that if replacement costs are not assumed to escalate, then depletion of energy resources no longer contributes to a 'threshold effect'.

So far, I have not made clear whether resource use refers to the domestic extraction or the domestic consumption of resources, which could to a large extent be imported. The reason is that studies differ on this respect. On the one hand, all studies using the resource rent method value the extraction of resources. This is correct, as the resource rent method attempts to determine the sustainable parts of an income stream derived from resource extraction. Only rents from resource extraction, not from consumption, enter the national income accounts. Therefore, to deduct the value of consumption instead would mean to deduct something that has never been added in the first place.

On the other hand, the studies using the replacement cost method are not consistent in their reference point. Whereas the revised US ISEW in Cobb and Cobb (1994) and the US GPI estimate the cost for replacing national *extraction*, the Australian GPI and the Chilean, Dutch, Scottish, Swedish and UK ISEW estimate the cost for replacing national *consumption* of non-renewable resources. Methodologically correct is the valuation of consumption, not extraction. This is because the rationale behind the method is to replace non-renewable resource use. Where these resources come from, whether they are imported or domestically extracted, simply does not matter. The idea behind the replacement cost method is not to cancel out non-sustainable income streams, as it is with the resource rent method. Instead, the idea is to estimate the costs of replacing all non-renewable resources in use for the production of goods and services.

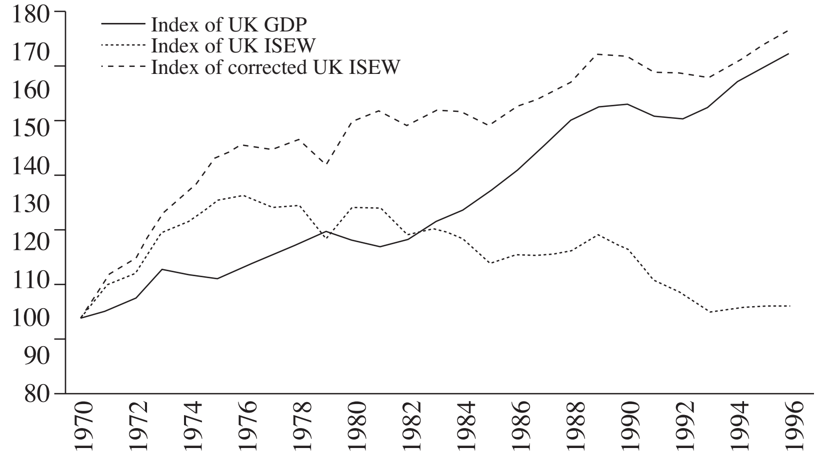
2.2.3.4 Long-term environmental damage Even more problematic is another component of the ISEW/GPI. Almost all studies compute annual values of long-term environmental damage, or the costs of climate change as this item is sometimes also called. Strangely, however, all studies but the Australian GPI let this annual damage accumulate over time. Most studies follow the approach taken by Daly et al. (1989) and Cobb and Cobb (1994) in

valuing each barrel of oil equivalent of annual non-renewable energy resource consumption at $0.50 in 1972 dollars. This value is deducted from the ISEW in this year, but also in all following years. Similarly, in any given year not only the value for current resource consumption is deducted, but the values from all past years as well. Cobb and Cobb (1994, p. 74) provide as justification for this accumulation approach that they

> imagined that a tax or rent of $0.50 per barrel-equivalent had been levied on all non-renewable energy consumed during that period and set aside to accumulate in a non-interest-bearing account . . . . That account might be thought of as a fund available to compensate future generations for the long-term damage caused by the use of fossil fuels and atomic energy.

Jackson et al. (1997, p. 23) realize in their computation of the UK ISEW that 'the major problem with this approach . . . is the arbitrary way in which a charge is calculated'. Instead they purport to value each tonne of greenhouse gas emissions with its marginal social cost, which they correctly define as reflecting 'the total (discounted) value of all the future damage arising from that tonne of emissions'. Strangely, however, they follow Cobb and Cobb's (1994) lead in letting this damage accumulate over time. Stockhammer et al. (1997) similarly compute marginal social damage costs for the Austrian ISEW – and let the estimated damage accumulate over time. This is simply wrong, however, as the marginal social cost per tonne of carbon emitted already derives from the total present discounted value of all future damage caused by this tonne of carbon. Accumulation of the annual damage therefore leads to multiple counting of the same effect. Accumulation leads to an almost exponentially increasing term to be deducted from consumption expenditures, and Neumayer (2000b) demonstrates that if long-term environmental damage is not accumulated, then it no longer gives rise to a 'threshold effect'.

2.2.3.5 An example: the UK ISEW As an example of the extreme sensitivity of results with respect to changing the methodology for computing resource depletion and long-term environmental damage, let us have a look at the case of the UK. Figure 4.4 shows the development of GDP and the original ISEW, indexed with base year 1970 (data taken from Jackson et al., 1997). Whilst the ISEW grows faster than GDP at the beginning, the ISEW starts falling in the early 1980s and there is a rising gap apparent between GDP and the ISEW – a fine example of the alleged 'threshold effect'. If, however, the costs of replacing resource depletion are no longer escalated and long-term environmental damage is not accumulated, then one can see that the new, corrected ISEW is rising in line with GDP, and indeed faster. In particular, there is no longer any evidence for the 'threshold effect', which has completely disappeared.



Note: 'Corrected' means ISEW without 3 per cent escalation factor for resource depletion and without accumulation of carbon dioxide damage.

Source: Jackson et al. (1997) and own computations from World Bank (2002).

Figure 4.4 Index of GDP, ISEW and corrected ISEW for the United Kingdom (1970 = 100)

3. PHYSICAL INDICATORS

3.1 Ecological Footprints: Measuring Sustainability by Land Area

3.1.1 Justification and basic idea

The concept of ecological footprint (EF) focuses on environmental sustainability rather than intergenerational equity more generally. Its objective is to translate all the ecological impact of human economic activity into the 'area required to produce the resources consumed and to assimilate the wastes generated . . . under the predominant management and production practices in any given year' (Wackernagel et al., 2002, p. 9266). Since the focus is on consumption, the required land area is attributed to the consumer rather than the producer since the consumer rather than the producer is deemed responsible for the impact. That is, for example, resources extracted in a developing country, but exported to a developed country, count towards the ecological footprint of the developed country. Land rather than money is taken as the unit of accounting since, according to its proponents, 'monetary analysis is misleading as it suggests substitutability, allows for the discounting of the

future and focuses on marginal rather than absolute values' (Wackernagel et al., 1999, p. 376f.). EF is regarded by its proponents as an indicator in the spirit of SS.[14]

If the EF exceeds the bioproductive land area available, then the carrying capacity of the land area is exceeded. This is called an ecological deficit and the economic activity causing the EF is judged to be unsustainable. The EF is linked to the somewhat older concept of a sustainable population size. If the EF of a country, for example, exceeds the bioproductive land area available, then this can also be interpreted to the effect that the area's population is bigger than its sustainable size at given levels of per capita ecological footprints. Ironically, from this perspective there would be unsustainable 'over-population' in the developed countries, which as will be shown below typically have ecological deficits, rather than in the developing countries. Proponents of EF usually do not emphasize the link to sustainable population size, possibly because they want to stress that consumption levels causing the high EF are unsustainable rather than blaming 'over-population'.

The concept of EF builds on earlier measures of the impact of humans on ecosystems such as Vitousek et al.'s (1986) measure of human appropriation of so-called net primary productivity (NPP) and Odum's (1996) accounting of energy flows. The following impacts are included (Wackernagel et al., 2002): (1) crop growing for food, animal feed, fibre, oil and rubber; (2) animal grazing for meat, hides, wool and milk; (3) harvesting of timber for wood, fibre and fuel; (4) fishing in oceans and freshwater; (5) infrastructure for housing, transportation, industrial production and hydro-electric power; and, finally, (6) fossil fuel burning. In addition, 12 per cent of the bioproductive land area is reserved for biodiversity conservation. Due to data problems, neither waste production nor freshwater withdrawal are included. Also note that the extraction of non-renewable mineral resources is not included at all and non-renewable energy resources are taken into account only with respect to the land area required to cope with the environmental damage of fossil fuel burning (see below). The reason is probably that it is difficult to convert non-renewable resource extraction into a required land area.

Obviously, not all bioproductive land is the same. All land area is therefore standardized into one common global measurement unit using yield and equivalence factors. Equivalence factors make different categories of land use roughly comparable with each other, whereas yield factors make land of the same land use category, but with differing productivity, comparable. Proponents of EF emphasize that, wherever possible, they use publicly available governmentally approved data and that their calculations are conservative in the sense of under- rather than overestimating the EF (Wackernagel and Silverstein, 2000; Wackernagel and Yount, 2000; Wackernagel et al., 2002).

Of all the human impacts, accounting for fossil fuel is the most important

one, responsible for slightly less than half of the global EF in 1999. This so-called energy footprint is the one that has grown fastest over the last decades and in which the disparity between the developed and developing countries is largest. It is also the most contested component of EF, however. It is calculated as the forest land area required to hypothetically sequester enough carbon from the atmosphere to avoid any increase in the atmospheric concentration of carbon. This is done under the assumption that about 35 per cent of carbon emissions are absorbed by the world's oceans[15] and, somewhat strangely, that nuclear energy and fossil energy are treated equally 'because of inconclusive data about the long-term area demand of nuclear power' (Wackernagel et al., 2002, p. 9267).[16]

It is perhaps counter-intuitive that the estimated land area can exceed the actually existing ecologically productive land area on earth. For example, a forest logged down at twice its regeneration rate is accounted for at twice its area (Wackernagel et al., 2002). This is taken as a sign of unsustainability: 'humans are consuming resources at a rate that would require more land than actually exists' (Wackernagel and Yount, 2000, p. 26).

3.1.2 Empirical studies

The global bioproductive land area is estimated at about one quarter of the earth's surface (WWF, 2002). The most recent comprehensive study tracking the ecological impact of human activity on a worldwide scale comes to the conclusion that 'humanity's load corresponded to 70 per cent of the capacity of the global biosphere in 1961, and grew to 120 per cent in 1999' (Wackernagel et al., 2002, p. 9266). In per capita terms, an EF of 2.33 ha per capita stands in contrast to existing global biocapacity of only 1.91 ha per capita. An EF has also been calculated for nations, regions and even cities (see Chambers et al., 2000, pp. 133–44). Some nations and regions, particularly the developed ones, have a much larger EF than bioproductive land area available and therefore an ecological deficit. Not surprisingly, all cities examined also run such a deficit. Table 4.1 lists the ecological footprint and the ecological deficit of a selection of countries in per capita terms.

3.1.3 Critical assessment

A whole range of methodological and other aspects of EF has encountered criticism – see, for example, van den Bergh and Verbruggen (1999), Ayres (2000) and IVM (2002). On a very fundamental level, one could argue that EF adds up apples and oranges in adding such diverse items as actual land use for agricultural products and purely hypothetical land use for the absorption of carbon dioxide emissions.

I will concentrate here on more specific points, however. The first criticism addresses the way in which the EF for fossil fuel use is computed. Ayres

Table 4.1 Ecological footprint and deficit of selected countries and the world (ha per person).

	Ecological footprint	Ecological deficit
United Arab Emirates	10.13	8.88
USA	9.70	4.43
Canada	8.84	_5.40
New Zealand	8.68	–14.28
Australia	7.58	–7.03
Belgium/Luxembourg	6.72	5.59
UK	5.35	3.70
Ireland	5.33	–0.81
Netherlands	4.81	4.02
Japan	4.77	4.06
Germany	4.71	2.96
Russia	4.49	–0.35
Brazil	2.38	–3.65
World	2.28	0.38
Gabon	2.12	–26.57
China	1.54	0.51
Central African Republic	0.92	–8.13
India	0.77	0.09

Note: A negative ecological deficit repesents an ecological surplus.

Source: WWF (2002).

(2000) argues that there are many more technical possibilities to sequester carbon from the atmosphere than land-intensive forestry. He mentions pumping compressed carbon dioxide into empty oil and gas wells or liquefied carbon dioxide into the deep oceans. One might dismiss these as merely potential future possibilities, which might or might not be possible and might have undesirable environmental side-effects. More importantly, however, the fossil fuel could be replaced with renewable energy, particularly wind and solar energy.[17] Whilst this would be prohibitively costly, the required land area would be much lower than under the forestry option as renewable resources are far more land-efficient. Wind turbines and photovoltaic generators could even be placed on land that is not bioproductive or already in use, such as at sea or in deserts or on top of buildings. Such land use would not subtract from the bioproductive land available at all. IVM (2002) has calculated that the energy footprint becomes negligible with little impact on the overall EF if, hypothetically, 50 per cent of world energy demand were satisfied with renewable energy, which

IVM (2002) claims to be technically possible, and for the remaining energy demand mainly low carbon fuels such as natural gas are used. To repeat, the economic cost at the current state of technology would be enormous, but given that EF is blind towards monetary valuation and therefore costs, its proponents cannot argue against considering renewable energy as a hypothetical solution to the carbon dioxide emission problem. It is also no argument against this alternative computation that the use of renewable energy on such a large scale is purely hypothetical at the moment. The same argument would apply to the forestry option employed by the proponents of EF, which is equally purely hypothetical. If the energy footprint becomes negligible, then the global EF is well within the limit of bioproductive land area available. Similarly, many developed countries no longer exhibit an ecological deficit.

The second criticism is not directly targeted at EF itself, but at a certain interpretation following from the concept of an ecological deficit, which is derived from an EF. Whereas such a deficit would commonly be regarded by economists as a normal exchange of goods, in which trading partners have differing comparative advantage, to the mutual benefit of both partners (van den Bergh and Verbruggen, 1999), proponents of EF see ecological deficits as inherently dangerous and undesirable, particularly at the level of nation-states. The main reason for this anti-trade bias is that 'trade reduces the most effective incentive for resource conservation in any import region, the regional population's otherwise dependence on local natural capital' (Rees and Wackernagel, 1996, pp. 238f.). As a result, a 'restoration of balance away from the present emphasis on global economic integration and interregional dependency toward enhanced ecological independence and greater intraregional self-reliance' is recommended (ibid., p. 241). Willey and Ferguson (1999, p. 2) are even more explicit in proclaiming that 'all nations should live within their own ecological capacity'. Against this, van den Bergh and Verbruggen (1999, p. 66) maintain that national boundaries are geopolitical and cultural artefacts and therefore have no environmental meaning.

A third criticism is that it is not quite clear what the policy recommendation of EF analysis is. Certainly, from the perspective of its proponents, an EF greater than the bioproductive land area available is unsustainable in the spirit of SS. But is an EF just smaller than this area enough? Wackernagel and Yount (2000, p. 38) insist that 'footprint assessments are not intended to advocate maximum reduction of human load', but what exactly is advocated then?

As a last criticism, it is doubtful whether EF really represents an indicator of SS. EF does not constrain substitutability within natural capital. This does not conflict with the first definition of SS, which refers to the value of total natural capital, but it does conflict with the second definition of SS, which constrains substitutability within natural capital as well and requires maintaining critical functions of natural capital intact. Furthermore, in making total

available bioproductive land area the yardstick against which hypothetical land use is measured, human activities, which are clearly not strongly sustainable, need not be indicated as such by the EF measure. We have seen above that the land area required to hypothetically absorb carbon dioxide emissions can be much reduced if renewable energy production is taken as the hypothetical option rather than reforestation. Doing so would then suggest that the global EF is well within the global bioproductive land area available, even though carbon dioxide emissions would still be clearly beyond the natural regenerative capacity of the global atmosphere, which violates the SS requirement. Even with the reforestation option, the fact that a global ecological deficit exists and EF therefore indicates a violation of SS is purely coincidental. This is because if only there were more bioproductive land area available globally, then according to current EF methodology the world as a whole need not have an ecological deficit. Global human impact would still be in violation of strong sustainability, however, but it would not be indicated as such by EF.

3.2 Material Flows: Measuring Sustainability by Weight

3.2.1 Justification and basic idea

The concept of material flows (MF) is inspired by early work by Ayres and Kneese (1969) on industrial metabolism.[18] Its starting point is a deep dissatisfaction with environmental policies that focus mainly on emissions and waste products. Its proponents maintain that many environmental problems are caused long before pollutants are emitted and waste is produced because MF need to be moved in order to produce products. It is the sheer size of MF that creates environmental problems, according to its proponents, and this size needs to be reduced substantially in order to lower the pressure on the environment. Reduction of MF is propagated as a good candidate for a 'one single long-term goal in environmental policy' (Hinterberger and Wegner, 1996, p. 7).

Similar to EF, the concept of MF is regarded by its proponents as an indicator in the spirit of SS (Hinterberger et al., 1997, p. 12). From their perspective, 'a core environmental condition of sustainability is a physical steady-state system, with the smallest-feasible flows of resources at the . . . input and output boundaries between the technosphere and the ecosphere' (Spangenberg et al., 1999, p. 492). The concept of MF, first developed by Schmidt-Bleek (1993a, 1993b), is inspired by Herman Daly (1977) and his emphasis on the growing scale or material throughput of the economy as the main cause of environmental degradation. It therefore shares Daly's emphasis on optimal scale and a limit to or reduction of throughput in a 'steady-state' economy rather than efficient allocation as the priority for environmental policymaking. Daly likes to illustrate the importance of scale by invoking the metaphor of a ship that sinks if it is too heavily loaded even if the cargo is efficiently allocated on board. The

emphasis on scale rather than efficiency also partly explains why weight is used as the unit of accounting rather than money. The other reason has to do with the perceived difficulties of monetary valuation of environmental degradation, on which more below.

From the perspective of MF, the focus needs to shift from the 'sink' side of the economy to the 'source' side. This is so for a number of reasons. First, the preoccupation with emissions and waste tends to ignore that all consumption goods come with a hidden 'ecological rucksack', which is defined as 'the sum of all the materials that are not physically included in the economic output under consideration, but have been necessary for production, use, recycling and disposal' (Spangenberg et al., 1999, p. 498). These typically occur at the resource extraction or harvesting stage. Examples would be earth and rock displaced during non-renewable resource extraction and soil erosion in agriculture (Matthews et al., 2000, p. 1). Second, the precautionary principle is invoked to justify giving priority to a reduction of MF (Hinterberger et al., 1997). Given that uncertainty and ignorance render a precise assessment of the ecological impact of pollutants difficult and imply that many forms of environmental damage cannot be known in advance, reducing MF is seen as a promising alternative as it will reduce the pressure on the environment across the board. Third, Spangenberg et al. (1999) also argue that no environmental policy will ever be able to efficiently control the thousands of substances emitted into the environmental sinks. Their monetary valuation, which is necessary for finding the efficient level of pollution, is regarded as an impossible task. In comparison, it would be much easier to control mineral and energy materials entering the economic system, the number of which are estimated between 50 and 100 in the case of Germany.

The aim and policy recommendation is to reduce MF by a factor of four (von Weizsäcker et al., 1997) or, more ambitiously, by a factor of ten (Factor 10 Club, 1994), at least in developed countries, over the next 40 to 50 years, which is regarded as technically feasible (Hinterberger et al., 1997).[19] All material inputs are classified into five main categories: abiotic raw materials (mineral and energy resources), biotic raw materials, moved soil (agriculture and forestry), water and air. MF reduction should be achieved in all categories (Hinterberger et al. 1997). However, in most empirical studies such as Adriaanse et al. (1997) and Matthews et al. (2000) water flows are excluded because they 'are so large that they would completely dominate all other material flows and would obscure the meaning and, thus, the usefulness of the indicators' (Matthews et al., 2000, p. 8).

3.2.2 Empirical studies

The most prominent of empirical studies is that of Adriaanse et al. (1997), which computed MF for Germany, Japan, the Netherlands and the USA over

the period 1975 to 1994. This study has been updated to 1996 in Matthews et al. (2000) and extended to cover Austria as well. Matthews et al. (2000) also distinguishes between MF from different economic sectors as well as MF into different environmental media, namely air, land and water. It also allows us to establish which MF remain in the economy longer than one year and which are dissipative and therefore difficult to recover and recycle. In Adriaanse et al. (1997, p. 7) the hidden flows of imported primary natural resources and semi-manufactures are attributed both to the country of final consumption of materials and to the country exporting the materials for further use in another country. In Matthews et al. (2000, p. 43) it is recognized, however, that this would lead to double-counting among trading countries. Hidden flows are therefore attributed solely to the importing country (ibid., pp. 14 and 43).

In all five countries under study in Matthews et al. (2000), MF have increased by between 16 (Netherlands) and 28 (USA) per cent between 1975 and 1996. These absolute increases in weight have occurred despite substantial reductions in the material flow intensity of GDP, which has fallen between 26 (USA) and 42 (Japan) per cent. In other words, the decoupling of MF from GDP has not been strong enough to bring about absolute reductions in MF. In cross-country comparison, one is not surprised to find that the Japanese economy has the lowest per capita MF (11.2 million tonnes per capita in 1996), whereas the USA has the highest (25.1 million tonnes per capita in 1996). Note that for these figures MF refers to what Matthews et al. (ibid., p. 7) call domestic process output, that is, materials extracted from the domestic environment plus imported materials used in the domestic economy and flowing to the domestic environment. It does not include domestic hidden flows, which do not themselves enter the domestic economy.

A similar picture emerges if the analysis is extended to 15 European Union member states over the period 1980 to 2000, for which Table 4.2 provides information. The decoupling of MF from GDP has not been strong enough to prevent absolute increases in MF in most countries as well as the EU as a whole. Note that in this table the definition of MF differs slightly from those presented above.

Other studies have been undertaken for other countries as well as for certain regions, sectors and even infrastructure projects by the Wuppertal Institute for Climate, Environment and Energy and by the Sustainable European Research Institute (SERI), Vienna. Both institutes are major proponents of the concept. The basic idea of MF has also sparked interest in national statistical agencies, particularly in Germany and the Netherlands (see, for example, de Haan, 1999 and Tjahjadi et al., 1999). Dahme et al. (1998) have proposed ranking countries according to their MF and to use these data to construct an extension to the United Nations Development Programme's Human Development Index (HDI), called 'Sustainable Human Development Index' (SHDI).

Table 4.2 Relative change (%) in MF and MF intensity in 15 EU member states, 1980–2000

Country	DMI	DMC	DMC per capita	DMI per capita	DMC/euro	DMI/euro
Austria	17	2	–5	9	–36	–27
Belgium, Luxembourg	41	1	–4	35	–35	–9
Denmark	28	5	1	23	29	13
Finland	14	8	–1	5	–36	–32
France	3	–4	–12	–6	–38	–33
Germany	–1	–9	–13	–6	–40	–35
Greece	52	49	35	38	11	13
Ireland	31	25	12	18	–58	–56
Italy	9	1	–2	6	–31	–26
Netherlands	16	–6	–17	3	–43	–30
Portugal	45	39	32	38	–23	–20
Spain	54	48	39	44	–14	–11
Sweden	8	–4	–10	2	–35	–27
United Kingdom	11	–1	–7	5	–40	–32
EU 15	5	3	–3	–1	–34	–33

Note: DMI: all materials extracted for use in a country plus imported materials; DMC: DMI less exported materials.

Source: Eurostat (2002, p. 16).

3.2.3 Critical assessment

The most important criticism of the concept of MF is that it adds up apples and oranges (Gawel, 1998). From an ecological point of view, two forms of material throughput with differing environmental damage impacts cannot be meaningfully added together just because one can express both in weight terms. Without further analysis of what the material throughput consists of and what are its environmental implications, there is no reason to presume that, say, Japan's MF of 11.2 tonnes per capita is any better than the MF of the USA at 25.1 tonnes per capita. Indeed, one could argue that the very statement that the MF of the US is 25.1 tonnes per capita in 1996 is entirely void of meaning. Similarly, it is pointless simply to rank countries according to the size of their MF.

In its prescription to reduce general MF across the board, the concept seems to draw the erroneous conclusion from the difficulties of valuing environmental damage that one cannot distinguish successfully according to differences in environmental damage at all. It is simply not true that, as Hinterberger and

Luks (1998, p. 7) suggest, 'in most cases it is impossible to distinguish between 'good' and 'bad' throughput'. In its call for general MF reduction across the board, the concept goes from a rejection of one extreme belief, namely the possibility of comprehensive environmental valuation, to the other extreme, which is seemingly blind towards admittedly incomplete attempts at valuation. The call for general reductions in MF is not guaranteed to be ecologically effective, but is guaranteed to be highly economically inefficient with respect to whatever reduction in environmental damage might be achieved (Gawel, 2000). The failure to appreciate the importance of valuing benefits and opportunity costs unnecessarily renders the concept largely unattractive. Because general reductions in MF are not guaranteed to be ecologically effective, it is also doubtful whether MF can really function as an indicator of SS. Following the policy recommendation of reducing general MF by a certain factor need not reduce the stress on critical functions of natural capital if the specific MF, which are threatening these functions, are not directly addressed.

Having presented our criticism of general MF reductions, there is much more potential in the concept once one abandons the idea of such across-the-board reductions. For example, it is true that an environmental policy that merely focuses on the 'sink' side of the economy will tend to neglect the many environmental problems that are caused during the entire production process and MF is to be credited with redrawing our attention to this. Furthermore, once one starts distinguishing between more and less dangerous materials, then reductions in those material flows that tend to threaten critical functions of natural capital moves us towards SS.

The proponents of MF have started to take these criticisms more seriously. For example, Matthews et al. (2000, p. 3) states that 'we recognize that it is at the level of sub-accounts – the examination of specific material flows, and categories of like flows – that materials flow analysis will have most relevance to detailed policy-making'. The same document also developed a pilot study for the United States, in which material flows are distinguished according to their physical and chemical properties. Similarly, Hinterberger et al. (1999, pp. 364f.) recognize a need for differentiating material flows and suggest that MF reductions need to be regarded as complementary to fine-tuned environmental policies tackling problems at the 'sink' side of the economy rather than substituting for them. Gawel (2000, pp. 165–7) is right, though, in arguing that proponents of MF need to be clear whether they see general MF reductions as the panacea for most if not all environmental problems, or regard differentiated MF reductions as a policy tool complementary to environmental policies targeting specific pollutants at the 'sink' side of the economy.

4. HYBRID APPROACHES

Hybrid approaches are those that combine physical indicators with monetary valuation. Typically, no monetary values are put upon items of natural capital. Rather, only the monetary costs of achieving the standards computed. Roefie Hueting's (1980, 1991) work is the starting point for a number of hybrid approaches. I will look at the three most important ones: the so-called sustainability gaps, the Greened National Statistical and Modelling Procedures (GREENSTAMP) and the 'sustainable national income according to Hueting' (SNI).

4.1 The Starting Point: Hueting's Pioneering Work

Hueting's point of departure is the suggestion that human impact has reached a level that threatens the integrity of environmental functions, which represents a 'new scarcity' unknown before (Hueting, 1980). His proposal was to define standards that maintain vital environmental functions intact, to estimate the costs of achieving these sustainability standards and to subtract these costs from national income. Also subtracted should be all those expenditures that are defensive and, according to Hueting, are wrongly counted as value added in the national accounts: compensatory, restoratory and preventive environmental expenditures. The resulting 'sustainable national income' (SNI) is defined as 'the maximum attainable level of production and consumption, using the technology of the year under review, whereby the vital functions, that is possible uses, of the physical surroundings remain available forever' (Hueting and de Boer, 2001, p. 24). Hueting is well aware that his is a 'partial equilibrium and static approach' since effects on other sectors of the economy are not taken into account (Hueting, 1991, p. 205).

As Hueting (ibid., p. 204) points out, his proposal was provoked by the need for a practical indicator in the face of insurmountable problems of creating a theoretically correct indicator:

> In the course of a working visit to Indonesia in 1986, I was provoked by the following remark made by the Indonesian minister for Population and Environment: 'In my policy making I need an indicator in money terms for losses in environment and resources, as a counterweight to the indicator for production, namely national income. If a theoretically sound indicator is not possible, then think up one that is rather less theoretically sound.'

Hueting therefore regards his proposal as a workable, if second-best, alternative to the theoretically correct, but in his view practically impossible, valuation of environmental functions with the help of shadow prices.[20] As we shall see, all the three hybrid approaches dealt with here share this basic conviction.

4.2 Indicators Based on Hueting's Work

4.2.1 Sustainability gaps

4.2.1.1 Justification and basic idea The concept of 'sustainability gaps', developed by Ekins and Simon (1999, 2001), is based on Hueting's work even though his work is strangely never cited by Ekins and Simon. Similar to Hueting, the proponents of the concept of sustainability gaps reject the welfare-theoretic approach to the economics of sustainability due to insurmountable problems of measuring natural capital depreciation. Its basic idea is to measure the gap between pre-specified environmentally sustainable standards and current violation of these standards in physical terms and to translate this gap into monetary terms via valuation techniques. Environmental sustainability is defined as 'the maintenance of important environmental functions' (Ekins and Simon, 1999, p. 39). The concept thus provides a measure of SS. The suggested standards are as follows (ibid., p. 47):

- Stable climate.
- Undepleted ozone layer.
- Biodiversity at current levels.
- No loss of function for non-renewable resources.
- Sustainable harvest at desired level for renewable resources.
- Limiting emissions to critical loads in order to protect human health.
- Maintenance of an unspoilt countryside.
- Maintenance of environmental security in restricting environmental risks to low levels.

Once the standards are defined, the resulting gap between the standards and current practice can be calculated. One can also calculate the years it would take at current trends to achieve the standards. Going one step further, one can, in principle at least, transform the sustainability gaps into monetary values by estimating the opportunity costs necessary to achieve the sustainability standards. First, one needs to establish the necessary measures to achieve the standards. These measures can be either in the form of reducing the output of certain goods and services whose production causes environmental degradation, or in the form of input substitution and pollution abatement in production processes, or finally in the form of direct restoration and preservation. Next, cost curves have to be established for the implementation of each measure. Then all measures are sorted with respect to their marginal cost in order to arrive at an overall cost curve for achieving the sustainability standard. Hypothetically, the measure with the least cost is undertaken first, then the measure with the next highest cost and so on. In so far as there might

be practical obstacles for following this sequence of least-cost measures, the estimate for the sustainability gap is too low.

Ekins and Simon (2001, p. 20) warn very explicitly against the idea of subtracting the monetized sustainability gap from GNP or GDP and against an interpretation of the gap as the actual amount of money that would need to be spent to achieve sustainability: the calculation of sustainability gaps 'is very much a static, partial equilibrium calculation, representing at a moment in time the aggregation of expenditures that would need to be made to reduce the various dimensions of the physical sustainability gap to zero'. If these expenditures were actually undertaken, however, then prices would change, which contradicts the partial equilibrium assumption.

4.2.1.2 Empirical studies Ekins and Simon (2001) provide empirical estimates of the sustainability gap for the UK and the Netherlands. The one for the UK refers to carbon dioxide and some other air pollutants only, whereas the one for the Netherlands covers more environmental areas due to better data availability. Not surprisingly, their study finds substantial gaps between current practice and the pre-specified environmental standards. In many cases it would take decades to achieve the standards at current trends and for some environmental aspects sustainability standards could never be achieved without reversing current trends. No monetary valuation is attempted due to lack of comprehensive data. Ekins and Simon (2001, p. 21) point out that 'considerable statistical effort is still needed' to derive a monetary value of sustainability gaps 'across all relevant environmental themes'.

4.2.2 Greened National Statistical and Modelling Procedures GREENSTAMP)

4.2.2.1 Justification and basic idea The Greened National Statistical and Modelling Procedures (GREENSTAMP) are the result of a research project financed by the European Community over the period 1994 to 1996. The starting point of GREENSTAMP is also a rejection on mainly practical grounds of the welfare-theoretic approach to the economics of sustainability as represented, for example, by GS (Brouwer et al., 1999). Its proponents believe that it is practically impossible to value depreciation of natural capital reliably and comprehensively, as required by the welfare-theoretic approach. To follow such an approach would be 'largely illusory for providing a meaningful indicator of sustainability' (ibid., p. 14).

Instead, proponents of GREENSTAMP want to estimate with the help of multi-sector national economic models what the feasible economic output would be if pre-specified environmental standards were to be achieved. In specifying environmental standards, which have to be obeyed, GREENSTAMP is also an

indicator of SS. In estimating the opportunity costs of obeying these standards, the approach is inspired by Hueting. However, its proponents deviate from Hueting's original proposal to deduct the costs of achieving the environmental standards from actual national income. They believe that such an approach would estimate a 'sustainable' income that 'is probably lower than the national income that could be obtained, and maintained durably, while respecting the norms' (Brouwer et al., 1999, pp. 15f.). Since achieving the pre-specified environmental standards would imply non-marginal changes, for which the partial equilibrium framework becomes untenable, general equilibrium modelling is the preferred alternative. According to GREENSTAMP proponents, the hypothetical national income that could be obtained while obeying the norms can therefore only be estimated if the feasible economic output itself is subject to modelling (O'Connor and Ryan, 1999).

4.2.2.2 Empirical estimations The GREENSTAMP methodology has been tested with the help of the so-called M3ED (Modèle Economie Energie Environnement Développement) multi-sectoral dynamic simulation model. Model runs have been undertaken, among others, for France (O'Connor and Ryan, 1999) and the Czech Republic (Kolar and O'Connor, 2000). One of the advantages of the modelling approach is that the model can be run with different assumptions about the environmental standards. The modelling is explicitly dynamic and future oriented (*ex ante* approach). Modelling the transition to the specified environmental standards forms an important part of the analysis. The feasible economic output is therefore estimated over a period of time and projected into the future, which can be done with appropriate assumptions made future values. Accepting that any environmental standards set or assumptions taken about the future are always subjective, GREENSTAMP is defended by its proponents as a valuable exercise to better understand the conditions of achieving sustainability, however defined: 'The information of most value is not found in the aggregate figures themselves – which are always open to alteration through changing assumptions – but in the richness of information and understanding obtained through construction and comparison of the different model outputs and scenarios' (O'Connor and Ryan, 1999, p. 130). The model runs for France, for example, have been undertaken for four distinct scenarios ranging from very pessimistic to very optimistic assumptions about technological advances and from very lenient to very stringent environmental standards.

4.2.3 'Sustainable national income according to Hueting'

4.2.3.1 Justification and basic idea The calculations of a 'sustainable national income according to Hueting' (SNI) for the Netherlands, undertaken

by a group of researchers at the Free University Amsterdam and the Wageningen University, also build on Hueting's work, which this time is very explicitly acknowledged. Like GREENSTAMP, the proponents of SNI realize that the adjustments to national income following the observance of externally imposed environmental standards can only be undertaken in a general equilibrium framework.

Contrary to GREENSTAMP's dynamic and future- as well as transition-oriented modelling approach, the SNI explicitly follows a static comparative or *ex post* approach. It is defined as 'the situation of the economy after an instantaneous change towards sustainable resource use' (Gerlagh et al., 2001, p. 3). The aim is to establish what the income for a given year would have been if the economy had had to obey the environmental standards. Transition dynamics do not matter as two static situations are compared with each other: once before and once after the sustainability standards are imposed upon economic activity. This follows from a desire that 'the SNI calculations should not be burdened with transition costs' (Gerlagh et al., 2001, p. 3).

In the process of calculation, a range of simplifying assumptions is made (Gerlagh et al., 2001, 2002). For example:

- As already mentioned, all transition or adaptation costs are ignored as 'in a way of speaking, it is assumed that the change to a sustainable economy is foreseen in advance, long enough that economic agents are able to integrate this transition in the planning of their investment decisions' (Gerlagh et al., 2002, p. 164).
- Abatement costs are assumed to be the same for all sectors as no sector-specific data are available.
- 'Defensive' expenditures, that is expenditures whose aim is environmental restoration, prevention of environmental degradation or compensation for such degradation are subtracted from national income if they enter the national accounts as value added. This follows from the consideration that actual and potential expenditures to reach the specified sustainability standards are essentially substitutes.
- Costs for remedying environmental problems, which have accumulated over a long time, are also distributed over a long time period instead of attributed to one year only.
- The labour supply is supposed to be inelastic and the labour market clears through an adjusting wage rate, thus ensuring employment neutrality.
- The income and price elasticities of various goods need to be specified.
- The trade balance is assumed to be equal to the national savings

balance, which is in turn assumed to constitute a constant share of national income.

- With respect to price changes in world markets, two variants are calculated: one in which prices on the world market do not change, whereas in the other price changes on the world market are presumed to be proportional to price changes in the Netherlands.
- Similarly, because prices will change following the imposition of environmental standards, the SNI can be compared to national income based either on the initial prices or on the new prices. Together with the two scenarios about price changes on the world market, this creates a total of four variants for the general equilibrium model.

4.2.3.2 Empirical studies Gerlagh et al. (2002) calculate different variants of a Dutch SNI for the year 1990 in an applied general equilibrium model with 27 production sectors. Nine environmental themes are covered: climate change, ozone depletion, acidification, eutrophication, particulate matter and volatile organic compound emissions, heavy metal dispersion into water, dehydration of land and soil contamination. For all these themes, environmental sustainability standards are set such that emissions stay within the natural regenerative capacity of the environment. For the last two themes, this rule translates into a standard of zero dehydration and zero soil contamination. Then abatement cost data based on currently available technologies are collected to estimate the costs of reaching the specified standards. Abatement costs consist of operation and maintenance costs for technical abatement measures in the first place and value added from output losses otherwise where these technical measures have been exhausted and output reductions are the only way left to reduce emissions.

In their calculations, Gerlagh et al. (2002) find that the costs of reducing greenhouse gas emissions represent the highest share of the costs of achieving the sustainability standards. They estimate that to reach less than 70 per cent of the sustainability standards is relatively cheap, reducing national income only by about 10 per cent. Further improvements quickly become very expensive, however. Whereas the conventional net national income is estimated at about 450 billion guilders, the SNI, that is, the income where 100 per cent of the sustainability standards are obeyed, is calculated at about 250 billion guilders.

In Hofkes et al. (2002) the calculations are repeated for the year 1995 and a comparison is drawn with the calculations for 1990. They find that 'SNI improves substantially from 1990 to 1995. Growth rates in sustainable income levels exceed growth rates in national income. . . . Over the period 1990–1995 an absolute delinking of economic growth and environmental pressure has taken place' (Hofkes et al., 2002, p. 21).

4.3 Critical Assessment

Similar to Hueting's original proposal, the monetary valuation of the sustainability gaps suffers from its partial equilibrium approach for establishing the cost curves. The costs for the implementation of each measure are estimated under the *ceteris paribus* assumption. However, if all those measures that are necessary to achieve the sustainability standards were effectively undertaken, then the *ceteris paribus* assumption would become fictitious. The relative prices of consumption goods and input factors would change, as would the extent and structure of environmental degradation. Economic restructuring, feedbacks and interlinkages would have to be considered in a total equilibrium analysis of the economy. This task can only be achieved with comprehensive modelling as undertaken by the other two hybrid approaches.

It is also unclear what the appropriate timeframe is for achieving certain sustainability standards. This holds especially true with respect to standards for non-renewable resources. Simon and Ekins postulate that the use of non-renewable resources must not diminish their 'function', which can be achieved via more efficient use, repair, reuse, recycling and substitution with renewable substitutes. However, it is unclear whether the maintenance of functionality must be achieved instantaneously or over a long time period. The latter would be more sensible as there is no immediate danger of running out of non-renewable resources.

With respect to GREENSTAMP and SNI, the modelling approach is their chief advantage as it avoids the implausible partial equilibrium assumptions. The hypothetical character of the estimated feasible economic output as the result of a modelling exercise also represents the greatest weakness of these indicators, however. The results and indeed the whole modelling exercise are difficult for laymen to understand. Moreover, the model dependency of the estimates means that the results crucially depend on the underlying assumptions made. The section on the SNI has illustrated this point in listing a number of assumptions needed, all of which are contestable, of course.

GREENSTAMP and SNI are therefore more valuable with respect to the research they generate on how to construct abatement cost curves, how to deal with environmental defensive expenditures and what is needed in terms of environmental statistics and reporting both at the firm and at the macroeconomic level. Another important property is that they help to focus the discussion on which environmental standards are considered sustainable. This is explicitly acknowledged by the proponents of GREENSTAMP, which do not regard their calculations as providing one single, all-encompassing indicator of sustainability, but rather as a way to improve the many building stones needed for a better informed policymaking towards sustainability. The SNI, on the other hand, is more ambitious. Whilst it is not supposed to replace national

income, certainly in the eyes of Roefie Hueting it is meant to provide a real alternative to it.

With all three hybrid approaches, one needs to be careful in interpreting the estimated monetary value of the sustainability gap, the estimated feasible economic output in the case of GREENSTAMP and the estimated SNI, respectively. A high value for the sustainability gap, a great difference between actual and estimated feasible output or between national income and the estimated SNI can mean either of two things. It can either mean that the actual economy is far away from the sustainability norms or that the economy 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. Similarly, a given monetary value for the sustainability gap, a given difference between actual and estimated feasible output or between national income and SNI does not tell us anything about the relative achievement of sustainability with respect to different norms. 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. Also, a constant or falling value of the sustainability gap, a closing of the gap between actual and feasible economic output or between national income and the SNI tells us nothing about the state of the environment in itself. This is because this could be *either* the consequence of the economy moving closer to fulfilling the sustainability standards *or* the consequence of a lowering of costs for achieving the standards due to, for example, technical progress. Detailed knowledge of the sustainability norms and the economy's distance from these norms is therefore essential and one should never rely on the aggregate monetary calculations alone.

The reader might wonder why I have not said anything critical on the concept and treatment of defensive expenditures in hybrid approaches. The reason is that our main concern that I raised in the discussion of the ISEW or GPI, namely the essential arbitrariness of what constitutes a defensive expenditure, is much less pronounced here. This is because such expenditures refer only to environmental expenditures and have a clear reference point in the form of the environmental standards set.

5. CONCLUSION

This chapter has reviewed the most prominent indicators of WS and SS. It has presented the basic idea and justification for each indicator, has reviewed empirical studies and has discussed the criticisms they encounter. Much emphasis has been placed on the critical and problematic aspects. This is not to say that these indicators do not also have strengths and point to aspects of

sustainability that are worth paying attention to. The basic point of GS is that resource-dependent developing countries need to ensure they invest enough in alternative forms of capital to be weakly sustainable, and it is certainly a valid one. The ISEW rightly claims that GNP/GDP are poor indicators of either current welfare or sustainability. In their defence, it should be noted that they were never constructed as indicators of welfare or sustainability. The revised system of national accounts states this with unambiguous clarity: ‘Neither gross nor net domestic product is a measure of welfare. Domestic product is an indicator of overall production activity’ (Commission of the European Communities et al., 1993, p. 41). Still, the proponents of ISEW are correct in arguing that policy makers, the media and some economists in their simplified models literally equate GNP/GDP with welfare.

Ecological footprints and material flows remind us that the environmental impact of the goods and services we consume go far beyond what is contained in them or directly observable from their use. Both caution us against such fallacies as, for example, believing that a car fuelled by liquid hydrogen is a zero emissions car, as the German car manufacturer BMW claims in one of its advertisements. Sustainability gaps, GREENSTAMP and SNI induce us to think about which environmental standards one would want to impose on economic activity and to calculate a first-approximation estimate of their opportunity costs.

Having said that all indicators make some valid basic point, the devil lies in the detail. Problems start when these indicators try to come up with a concrete measurement of sustainability. With respect to WS, it is true that resource-dependent developing countries might have problems with achieving sustainability, as GS claims. But do most of them have massive problems, as the World Bank’s method for computing natural capital depreciation would suggest, or do only some of them have less drastic problems, as the El Serafy method would suggest? The World Bank method certainly overestimates natural capital depreciation, but the El Serafy method might underestimate it. An indicator that comes to radically different conclusions for quite a few countries depending on which method is used, with none of them obviously superior, is equally obviously problematic. Indeed, I have dealt with two popular methods, but there are others with different merits and problems. A panel on ‘Integrated Environmental and Economic Accounting’ in its report to the US Congress came to the conclusion that ‘no single valuation method has been shown to be free of problems’ (Nordhaus and Kokkelenberg, 2000, p. 102). This represents a huge setback to efforts at providing reliable and relatively non-contentious estimates of the monetary value of natural capital depreciation. It is a sure recipe for confusion amongst policymakers.

The ISEW studies claim that even developed countries have massive problems in achieving WS. However, this claim was shown to be the consequence

of a dubious, perhaps even flawed, methodology for computing natural resource depletion and long-term environmental damage. Unless these methodological shortcomings are corrected, the ISEW cannot be taken seriously. Even then, questions remain with respect to the treatment of income inequality and so-called defensive expenditures. The exclusion of welfare-enhancing factors such as increasing life expectancy, leisure time and consumer-good quality and the like are other aspects which I could not deal with in detail and which are discussed in, for example, Neumayer (1999a, 1999b, 2003).

One cannot exclude the possibility that (some) developed countries are weakly unsustainable, but we know for certain that they are not strongly sustainable. Indeed, we know this with such certainty that one wonders why anyone would bother to construct an indicator such as EF, whose very objective seems to be demonstrating just this. I have explained above how the overshoot of the EF beyond the bioproductive land area available crucially depends on its method of translating carbon dioxide emissions into land area. As a matter of fact, carbon dioxide emissions are well beyond the natural absorptive capacity of the atmosphere and are on the rise. This cannot be strongly sustainable as it will disturb and in many cases destroy the natural functions of the global atmosphere. But we knew this a long time ago and we did not need EF to tell us what we knew all the time with what is arguably the result of a complex methodological artefact. Outspoken critics of the concept maintain that due to methodological flaws, EF does not have 'any value for policy evaluation or planning purposes' (Ayres, 2000, p. 349) and is 'unsuitable as a tool for informing policy-making' (van den Bergh and Verbruggen, 1999, p. 71). As long as the methodology for computing the land area necessary to bring carbon dioxide emissions within the natural absorptive capacity is unchanged, I have to agree with this judgement. Even if the methodology became changed on these aspects, doubts regarding the validity and reliability of the EF computations remain for reasons I have no space to go into here (see the special issue of the journal *Ecological Economics*, Volume 32, Issue 3, 2000).

Proponents of the concept of MF are correct in pointing out the misery of an environmental policy that is obsessed with emissions and waste and ignores the environmental damage created along the whole production and consumption process of goods and services. Also, there is some fundamental truth in the statement that 'unless economic growth can be dramatically decoupled from resource use and waste generation, environmental pressures will increase rapidly' (Matthews et al., 2000, p. v). However, there are certainly more effective and more efficient ways to achieve SS than to reduce MF across the board by a factor of ten (or four or twenty or whatever, for that matter). When material flows are differentiated according to their potential to threaten critical

functions of natural capital, then the comprehensive coverage of potential environmental impacts 'from cradle to grave' has much to offer. I fully agree with Hinterberger et al. (1999, p. 371) that the concept of MF is still in its infancy and might well have great potential if future research pushes it in the right direction. The general importance of material flows and its potential promise is therefore not contested here. What is contested is whether material flows can be aggregated by weight and whether the recommendation to reduce material flows across the board makes either economic or ecological sense.

All hybrid approaches provide interesting information on how far away an economy is from reaching pre-specified environmental standards. Problems start where monetary valuation begins. The concept of sustainability gaps suffers from the untenable *ceteris paribus* clause. With large-scale abatement undertaken, quantities and prices change, which defeats the partial equilibrium assumption. Only general equilibrium modelling can overcome this problem, and both GREENSTAMP and SNI provide interesting exercises in modelling the costs of reaching pre-specified environmental standards. However, because general equilibrium modelling is required, many assumptions need to be made, which by necessity are contentious. As some of their proponents readily admit, hybrid approaches 'whatever concept they engage, are highly sensitive to model calibration, specification of environmental standards, technological change and other assumptions used' (O'Connor et al., 2001, p. 16).

The SNI calculations roughly point out that to achieve SS would cost about 50 per cent of national income in the case of the Netherlands. This is quite a substantial cost, which renders it very doubtful whether any country would be willing to incur such a cost. Fortunately, the SNI provides an upper-bound estimate. This is because the comparative static SNI approach necessarily overestimates the true costs of achieving SS as it is based on current technology. SS could only be achieved over a long period of time, however, in which technology would change, which would make the move towards SS much cheaper.

All in all, our critical review of sustainability indicators paints a rather bleak picture. One can live with the fact that there are two opposing paradigms of sustainability that need their own indicators. What is more disturbing is that there is no entirely convincing and reliable way of measuring to what extent WS or SS is achieved. As concerns WS, I believe that the GS approach with the El Serafy method employed holds the greatest promise. As concerns SS, the hybrid approaches are also promising, in spite of their various difficulties and problematic aspects. The quest for developing better sustainability indicators is far from over. An important step, which I have not dealt with in detail, would be to provide more comprehensive and better-qual-

ity resource and environmental data. As mentioned in the introduction, empirical indicators of sustainability face the problem of missing as well as poor quality data. National and international statistical agencies are still far from providing the necessary data at sufficient quality. Better data will not cure methodological flaws, however, and I hope that the analysis here has helped to focus the minds of interested researchers on where most work still needs to be done to develop more valid and reliable indicators of sustainability.

APPENDIX 1: DERIVATION OF USER COSTS ACCORDING TO THE EL SERAFY METHOD

The formula for computing user costs according to the El Serafy method can be derived as follows: let P be the resource price, AC average extraction cost, R the amount of resource extracted, r the discount rate and n the number of remaining years of the resource stock if extraction was the same in the future as in the base year; that is, n is the static reserves-to-extraction ratio. Then the present value of total resource rents $RR \equiv (P - AC) \cdot R$ is equal to:

$$\sum_{i=0}^{n} \frac{RR}{(1+r)^i} = \frac{RR\left[1 \frac{1}{(1+r)^{n+1}}\right]}{1 - \frac{1}{1+r}}. \qquad (4A.1)$$

The present value of an infinite stream of 'sustainsable income' SI is

$$\sum_{i=0}^{\infty} \frac{SI}{(1+r)^i} = \frac{SI(1+r)}{r} = \frac{SI}{1 - \frac{1}{1+r}}. \qquad (4A.2)$$

Setting (4A.1) and (4A.2) equal and rearranging expresses SI as a fraction of RR:

$$SI = RR\left[1 \frac{1}{(1+r)^{n+1}}\right]$$

The user costs, representing the depreciation of the resource stock, would thus be

$$(RR - SI) = RR\left[\frac{1}{(1+r)^{n+1}}\right] = (P - AC)\cdot R\left[\frac{1}{(1+r)^{n+1}}\right].$$

NOTES

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1. Pezzy and Toman (2002a) prefer to define sustainability in terms of current utility not exceeding its maximum sustainable level for all time, but note that their definition is implied by the one we use here. For simplicity, we will also not distinguish between non-declining utility and non-declining capacity or opportunities to provide utility.
2. Natural capital means everything in nature providing utility to human beings. Human capital is skills and knowledge.
3. Social capital is difficult to define. It refers to things like the amount of trust, the extent of social networks, the willingness of individuals to cooperate with each other and their 'civic engagement' in social groups such as churches and unions (Putnam, 1993).
4. In our view, which is shared by Dasgupta (2001a, 2001b), genuine investment would be a better term to use than genuine savings. The reason is that in macroeconomics, savings is often defined as private savings. For example, in a closed economy, savings is equal to investment plus government expenditures minus taxes. Savings in the usage of genuine savings instead refers to the sum of private plus public savings (taxes minus government expenditures), which generates the equality between total savings and investment.
5. Asheim et al. (2003) argue that the Hartwick rule and therefore GS as an indicator of WS does not depend on the assumption of substitutability of natural capital. However, their counter-example depends on the assumption that production is based on the extraction of a renewable resource within the limits of the maximum rate of natural regeneration. No actual economy fulfils this criterion, hence one is justified in arguing that the relevance of the Hartwick rule depends on the assumptions of WS.
6. Missing are mainly some small countries.
7. It is highly ironic, however, that at the same time that GS has become an established term in the academic literature, the Bank now calls its published data 'adjusted net saving' rather than GS. We will stick to the term GS.
8. Note that in the traditional national accounts capital expenditures on education are already counted towards investment in man-made capital.
9. In the case of forestry, the depreciation term is equal to the stumpage value (market price minus logging costs) times the quantity of timber and fuelwood commercially harvested beyond regeneration rates. Dasgupta (2001a, p. C10) criticizes this, stating that if the logged land were converted into farmland, then the 'social worth of the land as farm should be included as an addition to the economy's capital base'. This would be difficult to do in practice and since the value of forest depletion is minor compared to the other resources, we will not further pursue this criticism here.
10. The same reasoning applies to renewable resources if harvesting exceeds natural regeneration.
11. See Eisner (1990) for an overview.
12. Such studies derive the value from environmental disamenities in comparing, for example, house prices from real estate, which is similar in all respects but the environmental disamenity.
13. Admittedly, the proponents of ISEW and GPI would counter-argue that such an option would be self-defeating as raising consumption expenditures would also raise many of the deduction items, which would then more than compensate any expected increase in the ISEW and GPI.

14. Even from the perspective of their proponents, EF is not fully compatible with SS, however, as it does not directly require compensating future generations for past and current fossil fuel use with an alternative energy resource (Wackernagel and Silverstein, 2000, p. 392).
15. Initially, the absorptive capacity of the oceans was not included, which sparked a lot of criticism (for example Ayres, 2000).
16. Taking out nuclear energy lowers the global EF by between 4 per cent (Wackernagel et al., p. 9268) and 7 per cent (IMV 2002, p. 18). These two different groups of authors have a controversy about the exact amount.
17. It is unclear why some proponents of EF who recognize that 'a more sound basis for the "energy footprint" is the required area of land needed to produce the specified energy renewably', as Ferguson (2002, p. 310) does, want to restrict the alternative computation to biologically grown resources (sugar cane/ethanol), which are much more land-intensive than wind and solar energy.
18. See Fischer-Kowalski (1998) and Fischer-Kowalski and Hüttler (1999) for an intellectual history of material flows covering the period 1860 to 1998.
19. Hinterberger et al. (1999, p. 368) suggest that various countries as well as over 100 companies, which are members of the World Business Council on Sustainable Development (WBCSD), have stated their commitment to reduce material flows.
20. In some sense, the hybrid indicator approach is reminiscent of Baumol and Oates's (1971) standards–prices approach in the economics of pollution control, where standards are set somewhat arbitrarily given that the efficient level of pollution is often difficult if not impossible to establish.

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