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A single indicator of strong sustainability for development: Theoretical basis and practical implementation

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A single indicator of strong sustainability for development: Theoretical basis and practical implementation[1]

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Abstract

This Scoping Paper discusses options and approaches for design of a single indicator of strong environmental sustainability for development, in light of current proposals for sustainability indicators generally. It also discusses possible approaches for practical implementation of such an indicator. We make the following contributions:

- We show that there are practical and theoretical reasons to favour a strong sustainability approach, and after reviewing existing sustainable development indicators that a key question remains: are existing environmental indicators capable of showing whether progress is being made towards environmental sustainability?
- We provide a theoretical framework to define environmental sustainability, and argue that to reflect the extent to which countries are close to environmental sustainability, indicators need to meet three conditions. First, they need to take the form of a distance-to-target indicator, i.e. the indicator needs a reference point against which performance can be compared. Second, this reference point needs to represent the conditions under which the provision of critical functions of natural capital is maintained. Third, the indicator needs to be defined at the national level, as is the level at which most environmental policy is implemented.
- We propose the Environmental Sustainability Gap (ESGAP) framework, which is intended to fill the indicator gap described above. It represents a dashboard of environmental sustainability indicators that provides a thematic overview of the extent to which a country can be considered environmentally sustainable across a wide range of environmental and resource issues.

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[1] Authors' Note: This paper represents work in progress and should not be interpreted as definitive of the authors' views. It incorporates a synthesis of published work by the lead author over some 20 years, which is acknowledged in the attached list of references. Some text, tables and figures have been taken from this earlier work and are reproduced in the current paper. However, the paper also contains considerable new research, not least to bring the earlier work up to date, such that as a whole it can be regarded as an original articulation of the state of the art in this area. Additional work is required to strengthen the linkages between the proposed single indicator structure and methodology, with recent work of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Sustainable Development Goals indicator framework and related initiatives.

Keywords: Indicators of sustainability, operationalisation of sustainability, sustainability gap, sustainability standard

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A single indicator of strong sustainability for development: Theoretical basis and practical implementation

Scoping Paper for Agence française de développement (AFD)

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Executive Summary

1. This Scoping Paper discusses options and approaches for design of a *single indicator of strong sustainability for development*, in light of current proposals for sustainability indicators generally. It also discusses possible approaches for practical implementation of such an indicator, including associated data requirements. The principal findings of the Scoping Paper, which are preliminary and subject to further consultation, are as follows:

Capital, sustainable development and associated indicators

2. Human well-being and wealth creation rest in the combination of four types of capital: manufactured, social, human and natural capital. However, the Brundtland definition of sustainable development – "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" – does not clarify whether in order to ensure that future generations can thrive, the capital stock as a whole should be non-declining or whether the individual types of capital, or some parts of them, should be non-declining as well. The issue of substitutability between different types of capital has been discussed at length in the literature, especially with regard to natural capital. *Weak environmental sustainability* assumes full substitutability between natural and other types of capital, while *strong environmental sustainability* considers that there is limited substitution capacity due to the inability of non-natural capital to fulfil several environmental functions of natural capital. In the main text we show that there are theoretical and practical reasons to favour the latter approach.

3. Sustainable development indicators adopt, implicitly or explicitly, different positions with regard to weak versus strong sustainability. Aggregated monetary indicators such as Green GDP, Genuine Progress Indicator, and the Genuine Savings Indicator transform flows from natural capital into a monetary metric leading to an adjusted GDP. This leads to some counterintuitive messages, such as the Genuine Savings indicator suggesting that EU countries are sustainable, which is in conflict with the conclusions of regional environmental assessments. Other sustainable development indicator frameworks such as those adopted by Eurostat, OECD and more recently the UN through the Sustainable Development Goals (SDGs) adopt a strong sustainability position by representing environmental indicators as a separate dimension beyond economic and social dashboards. In practice, the position of sustainable development composite indicators such as Human Development Index or the unofficial SDG Index depends on the methodology adopted in the aggregation process. Beyond the adoption of a strong environmental sustainability position, a key question remains: are existing environmental indicators capable of showing whether progress is being made towards environmental sustainability?

Environmental sustainability indicators

4. Major global environmental assessments—for example the UN Environment Global Environment Outlook (GEO) and the assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)—highlight the extent to which human activities result in a widespread and increasing degradation of the components of natural capital. For development to be environmentally sustainable, it should ensure that critical environmental functions provided by natural capital are maintained over time, which requires maintaining the capacity of the natural capital stock to provide those functions. To reflect the extent to which countries are close to environmental sustainability thus defined, indicators need to meet three conditions. First, they need to take the form of a distance-to-target indicator, i.e. the indicator needs a reference point against which performance can be compared. Second, this reference point needs to represent the conditions under which the provision of critical functions of natural capital are maintained. Third, the indicator needs to be defined at the national level, as this is the level at which most environmental policy is implemented.

5. We have reviewed the suitability of several distance-to-target dashboards and indicators against these criteria, namely the EEA indicators used to assess progress towards the 7th Environmental Action Programme, the environmental dimension of the SDG Index, the Environmental Performance Index (EPI), the Ecological Footprint (EF) and the Planetary Boundaries dashboard. The EEA indicators, SDG Index and EPI address the national level, but measure performance against policy targets and/or best performing countries. As long as policy targets and the performance of the frontrunners are not aligned with science-based standards, these indicator systems cannot be considered to reflect environmental sustainability. EF intends to represent some aspects of environmental sustainability at the global level, but suffers from important

shortcomings that reduce its credibility. The Planetary Boundaries framework, on the other hand, uses environmental sustainability reference points to measure progress, but so far attempts to downscale the framework to the national scale have limited consistency.

6. The above review reveals the continuing absence of a credible environmental sustainability indicator system at the national level, which could be used to inform policy makers. Above all, countries still lack a single indicator of environmental sustainability that can give overall guidance as to the use of the environment, as GDP gives summary information about the level of economic activity, and the Human Development Index summarises important information about economic development more broadly.

The Environmental Sustainability Gap

7. The Environmental Sustainability Gap (ESGAP) framework is intended to fill the indicator gap described above. It represents a dashboard of environmental sustainability indicators that provides a thematic overview of the extent to which a country can be considered environmentally sustainable across a wide range of environmental and resource issues. Because of the difficulty of identifying the critical elements of natural capital that need to be sustained over time, the framework adopts broad principles that help operationalise the requirements of environmental sustainability. These principles can be mapped to the main functions of natural capital (Source, Sink, Life-Support, and Human Health and Welfare). Table 3 in the main text contains an illustrative set of science-based environmental standards that can be used to compute the ESGAP.

8. The ESGAP idea can be developed further to give an indication of the time that would be taken, on present trends, to reach the standards of environmental sustainability, thereby deriving a Years-to-Sustainability indicator. Furthermore, assuming that ESGAP does not represent an irreversible effect, it will be possible, through abatement or avoidance activities (for environmental pressures) or restoration activities (for environmental states) to reduce the ESGAP such that the sustainability standard is achieved. The associated cost may be termed the monetary ESGAP (M-ESGAP) when referring to each environmental topic and Gross ESGAP (G-ESGAP) for the economy as a whole. This could then be used to indicate the economic 'distance' to environmental sustainability in relation to the present situation and practices. Expressed as a ratio, G-ESGAP/GDP may indicate the 'intensity of environmental monetary unsustainability'.

9. Beyond the theoretical considerations, data availability remains the major limitation towards the computation of the indicators that form the ESGAP framework. Currently, the EEA and its European Topic Centres, the JRC and Eurostat produce a wealth of environmental data and indicators that can be used to partially compute the physical ESGAP in Europe. Data availability in other countries and regions is changing rapidly and could be clarified through feasibility studies, in the context of efforts in ~50+ countries to implement standardised environmental-economic accounts. Relevant datasets at national

and global scales have also been produced through a wide range of environmental research efforts.

Recommendations

10. Our principal recommendations are that the ESGAP, in the context of AFD's international development activities or more broadly, could enable high-level measurement of progress towards environmental sustainability if advanced in the near term through practical implementation activities focusing on:

11. *Refinement of the ESGAP structure and compilation methodology* proposed in this Scoping Paper, including clear articulation of linkages and interrelationships with the Sustainable Development Goals (both Targets and Indicators), UN System for Environmental-Economic Accounting (SEEA), Framework for Development of Environmental Statistics (FDES), IPBES Conceptual Framework including the revised 'Nature's Contributions to People' typology of ecosystem goods and services, and other relevant efforts;

12. *Pilot compilation of the ESGAP* in selected 'data-rich' countries, coupled with detailed feasibility assessments for selected countries where data availability is uncertain;

13. Development of *technical process guidance* for the compilation and use of the ESGAP or an equivalent single indicator, that is designed to be relevant to diverse national capacities and circumstances, and informed iteratively by lessons learned during the recommended pilot activities described above; and

14. *Engagement* with key international stakeholders—including UN agencies, UN regional commissions and others—focusing on discussion of how the ESGAP or other equivalent single indicator could be embedded in national capacity building and policy-making, concerning implementation of the SDGs and other relevant commitments in relation to the environment and sustainable development.

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1. Introduction

1. We have been asked to prepare a scoping paper that provides a 'rigorous basis for discussion of a *strong sustainability indicator* in the light of experience with sustainability indicators to date; and permitting the indicator to be taken forward to practical implementation if wished.' This Paper is intended to serve that purpose and is structured as follows:

2. In Section 2 we discuss the theoretical basis for sustainability focusing on the concepts of capital and associated flows of goods and services. The word sustainability is now used in a wide variety of contexts, but the idea of 'strong sustainability' is always applied to the *environmental* dimension of sustainable development, in contrast to the idea of weak sustainability, to indicate limitations to the substitutability of physical and human capital for natural capital. Weak sustainability assumes a high level of substitutability, and is often implemented through valuations of human, physical and natural capital, adding together the resulting valuations to derive a single number for net capital gain or loss. This is the methodology used by the World Bank in its calculations of 'genuine savings' and, more recently, by this and other bodies in calculations of 'inclusive wealth'. A common occurrence in these calculations is that they show net natural capital loss over the period concerned, but these are offset by human capital gains (often computed as the expenditure on education), so that most countries show positive 'genuine savings'.

3. Section 3 discusses the concept of sustainable development, focusing on the distinction between weak sustainability as discussed above, and strong sustainability which for theoretical and practical reasons is considered to be preferable as a paradigm for assessment of progress towards sustainable development. Strong sustainability proceeds from the perception that many aspects of natural capital are *not* substitutable by physical and human capital, in terms of the importance or replicability of the services they provide, and that therefore valuation of these aspects is inappropriate: the gain or loss of these aspects of natural capital need to be accounted for in their own terms.

4. Section 4 focuses on the measurement of sustainable development, and includes a summary review of aggregated indicators of weak sustainability, frameworks of indicators for sustainable development, and the aggregation of such indicators. It is possible to construct an index of the indicators (or some of them), that lie beneath the Sustainable Development Goals (SDGs), and indeed this has been done (see Sachs et al. (2017)). This is a fascinating and useful undertaking, but it is not clear that the index that emerges is an indicator of 'strong sustainability'. On the contrary, the 2017 SDG Index and Dashboards Report found that "reporting was particularly weak on the environmental SDGs 12-15, and goal 17 (international partnership)". It is clear that the SDG Index as reported in this publication gives a very partial view of the extent to which 'strong' environmental sustainability is being achieved as long as the underlying targets do not reflect the maintenance of relevant environmental functions provided by natural capital.

5. In Section 5 the challenge of environmental sustainability is discussed, followed by an appraisal of selected indicators in terms of the extent to which they enable measurement of progress towards this outcome. Given the heterogeneity of natural capital, and the desire for a single indicator of sustainability, the inability to express the services of natural capital (and therefore the stock of natural capital) in terms of a single numeraire (e.g. money), means that attempts to aggregate different kinds of natural capital will require them to be expressed as a dimension-less index (like the Human Development Index, HDI, which aggregates indicators of income, health and education). It is generally acknowledged that HDI, seeking to account for various aspects of income, health and education, is a great improvement on just using GDP as an indicator of development, but nevertheless still omits important non-environmental aspects of development (e.g. levels of poverty, energy access, gender issues), which are included in the SDGs, and is highly correlated to GDP. This means that there continues to be a need for the indicator envisaged by AFD, if its desire for a strong environmental sustainability indicator that can give clearer insight into the extent to which the environmental SDGs (and strong sustainability more generally) are being achieved, is to be realised.
6. In Section 6 we propose the *Environmental Sustainability Gap* (ESGAP) framework to address the current absence of sustainability indicators that are directly focused on strong sustainability. The ESGAP comprises a dashboard of environmental sustainability indicators across relevant environmental and resource issues. Present trends can be used to give an indication of the time that would be taken to reach the standards of environmental sustainability, thereby deriving a Years-to-Sustainability indicator. When the ESGAP does not represent an irreversible environmental effect, it will be possible to estimate the costs of meeting the sustainability standards resulting in a *Monetary ESGAP* (M-ESGAP). The ratio between the sum of M-ESGAP across the environmental and resource indicators and GDP (G-ESGAP) may indicate the 'intensity of environmental monetary unsustainability'.
7. Key conclusions and recommendations of the Paper are summarised in Section 7.

2. A theoretical basis for sustainability

Main messages**:**

- Human well-being and wealth creation are underpinned by four types of capital asset: manufactured, human, social and natural.
- Each of the capital stocks produces a flow of services that is used to generate goods and services, but also 'bads' in the form of depreciation and pollution/wastes. To maintain the overall stock, the latter need be compensated for by investment.
- Environmental sustainability is characterised by the maintenance of the capacity of natural capital to provide relevant goods and services.

8. In economics a natural way in which to frame the idea of sustainability is in terms of a capital stock and the goods and services that flow from it. The value of the capital stock is that of the discounted present value of the flows from it over its lifetime, and the sustainability of the flows will depend on the whether the capital stock is maintained over time, with investment making good any depreciation.

9. In its narrowest interpretation the capital stock is normally conceived in terms of manufactured goods which themselves produce, or facilitate the production of other goods and services. This kind of capital is referred to as manufactured or physical capital, and consists largely of machinery, buildings and built infrastructure. However, it is clear that flows of benefits derive from many other sources than manufactured capital, so that the concept of capital has been extended in a number of directions. Ekins (1992, pp. 147-51) has put forward a '4-capitals model', distinguishing between manufactured, human, natural and social/organisational forms of capital (described in Box 1) and relating them to the process of production and the generation of human welfare. The same model seems to have commended itself to Serageldin and Steer (1994, p. 30) of the World Bank, who write of the 'need to recognise at least four categories of capital', as already identified. This model was elaborated further in Ekins (2000, pp. 51ff), as shown in Figure 1.

Box 1: Four Types of Capital

Manufactured Capital

Manufactured (or human-made) capital is what is traditionally considered as capital: produced assets that are used to produce other goods and services. Some examples are machines, tools, buildings, and infrastructure.

Natural Capital

In addition to traditional natural resources, such as timber, water, and energy and mineral reserves, natural capital includes broader natural assets, such as biodiversity, endangered species, and the ecosystems which perform ecological services (e.g. air and water filtration) that absorb and neutralize human wastes. Natural capital can be considered as the components of nature that can be linked directly or indirectly with human welfare, and has been formally defined as "the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions" (NCC, 2014, p.21).

Human Capital

Human capital generally refers to the health, well-being, and productive potential of individual people. Types of human capital include mental and physical health, education, motivation and work skills. These elements not only contribute to a happy, healthy society, but also improve the opportunities for economic development through a productive workforce.

Social Capital

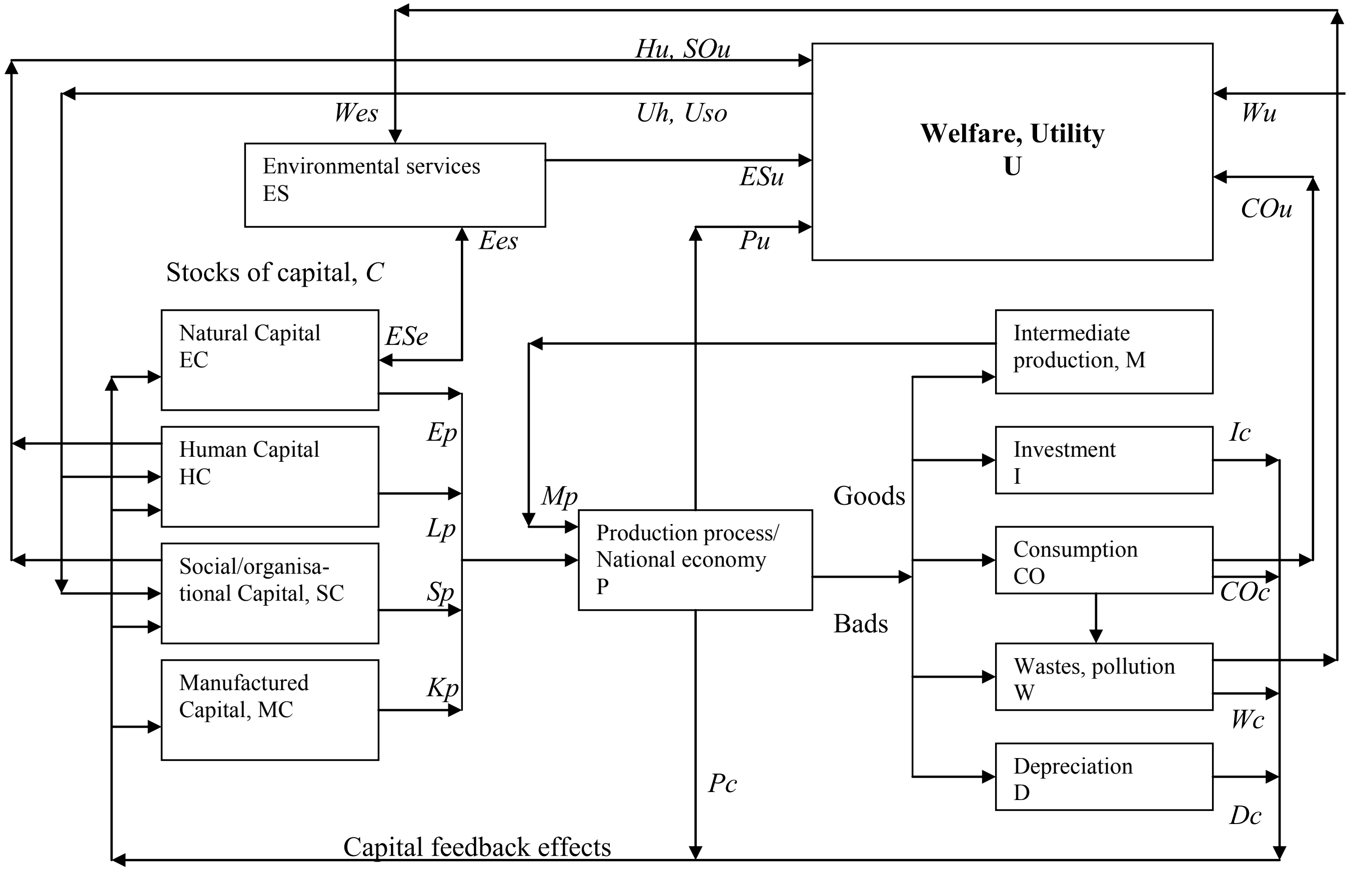
Social capital, like human capital, is related to human well-being, but on a societal rather than individual level. It consists of the social networks that support an efficient, cohesive society, and facilitate social and intellectual interactions among its members. Social capital refers to those stocks of social trust, norms and networks that people can draw upon to solve common problems and create social cohesion. Examples of social capital include neighbourhood associations, civic organisations, and co-operatives. The political, financial and legal structures which promote political stability, democracy, economic and government efficiency, and social justice (all of which are good for productivity as well as being desirable in themselves) are also part of social capital.

10. Figure 1 suggests that wealth creation is the product of the joint application for productive purposes of these different kinds of capital (this is least true of natural capital, which generates many benefits independently of humans). There is no need here to describe in detail the flows in Figure 1, but briefly it can be seen that each of the capital stocks produces a flow of services into a production process, to generate goods and services, but also 'bads' in the form of depreciation and pollution/wastes, which feedback negatively into the capital stock, and which need to be compensated for by investment if the level of the stock is to be maintained. Natural capital has the additional special characteristic that some forms of it (e.g. renewable energy, biomass) can renew themselves and some of the goods and services feed directly into human welfare without going through a production process. The nature and further characteristics of the goods and services emanating from natural capital are a major topic of this paper and are discussed in more detail below.

11. The four types of capital can be ranked in order of temporal priority, if not of present economic importance. Natural capital came first, providing the conditions for the evolution of humans and other life on earth. Humans then used their human capital to fashion tools and other kinds of manufactured capital out of natural capital, and grouped together to create social and organisational capital, including laws of property and a legal system to enforce them, institutions for the management of natural resources, the economy and society generally, and financial capital and the financial system through which it acts. In a modern, complex economy, the interactions between the different kinds of capital are such that it is effectively impossible to identify and separate out their individual productive capacity.

12. In this conception, environmental sustainability then becomes the maintenance of the goods and services emanating from natural capital, and its measurement will depend on an accurate characterisation of that flow over time. The detail of how this may be achieved is described further below. First, however, given that it is an indicator of sustainability for development that is being sought, it is necessary to place the idea of environmental sustainability in a broader context, that of sustainable development.

Figure 1: A Four-Capital Model of Wealth Creation through a Process of Production



Note: In the flow descriptors, the upper case letters denote the source of the flow, lower case letters denote the destination. Those relating to the various capital stocks have the C omitted for simplicity.

Source: Ekins (2000)

3. Sustainable development

Main messages:

- Weak environmental sustainability assumes full substitutability between natural and other types of capital. Strong environmental sustainability, on the other hand, considers that there is limited substitution capacity.
- There are both theoretical and practical reasons to choose strong environmental sustainability as a starting point.

3.1 Background and definitions

13. Since it was first brought to prominence by the report of the World Commission on Environment and Development (WCED), *Our Common Future*, also known as the Brundtland Report after the WCED Chairman (WCED, 1987), the concept of sustainable development has achieved and maintained a high profile in public policy formulation. In 1992 it brought together, in the UN Conference on Environment and Development (UNCED) – the Rio Summit, – the then largest ever gathering of heads of state and government. Treaties on climate change and biodiversity were agreed, and Agenda 21, a worldwide programme for sustainable development, was adopted. The UN Commission on Sustainable Development (CSD) was set up to advise on, monitor and co-ordinate implementation of this programme. The European Union agreed a sustainable development strategy for all its Member States in 2001 (EC, 2001), which was revised in 2006 (Council of the European Union, 2006). In August/September 2002 a 'Rio+10' World Summit on Sustainable Development (WSSD) took place in Johannesburg. In 2012 the Rio+20 Conference, again in Rio de Janeiro, set in train the process that in 2015 was to lead to the adoption of the Sustainable Development Goals (SDGs) as the central component of the United Nations' Agenda 2030.

14. In the early days of its elevation to a major theme in public policy, sustainable development was subject to so many definitions and interpretations that it sometimes seemed that it could be used to mean practically anything. Thus Pearce et al. (1990) were able to cite a 'gallery of definitions'. The ensuing lack of clarity of discussion about the idea led some commentators to dismiss it altogether; Beckerman (1992, pp. 491-2) concluded that the question 'how do we achieve sustainable development?' is 'unanswerable and meaningless'.

15. Fortunately for those who felt that sustainable development had a useful role to play in public policy, this situation did not last. By 1999 Jacobs was able to write that sustainable development, like other political terms such as democracy, liberty and social justice, had two levels of meaning: a core of fundamental ideas which commanded consensus as to their relevance to the concept, and a secondary level of contested interpretations of these ideas (Jacobs, 1999, p. 25).

16. In his core of ideas that are fundamental to sustainable development, Jacobs lists:

- *Environment-economy integration*: the requirement in policy making to consider the economy and the environment together.

- *Futurity*: the requirement in policy making to consider the impact of current activities on future generations.
- *Environmental protection*: the requirement to reduce the depletion and degradation of environmental resources.
- *Equity*: the requirement to seek social justice within and between generations.
- *Quality of life*: the recognition that human quality of life is not a function just of economic growth.
- *Participation*: the requirement that people are enabled to be involved in the decisions and processes, which affect their lives.

17. The Brundtland report famously defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". However, nowhere in the Brundtland Report is a definition given of 'human needs' or how it might be ascertained as to whether they are being met. Moreover, human need is a deceptively complex concept. It has a basic intuitive meaning that is easily grasped, but one that quickly dissolves on closer investigation into layers of conflicting interpretation and social contextualisation. It is in this context that sustainable development came to be framed, by economists at least, as a non-declining, and perhaps increasing level of human welfare (see, for example, Pezzey (1992, pp. 55ff)), something that can easily be related to the conception of wealth creation set out in Figure 1. If human welfare must be non-declining, then presumably the goods and services flowing from the capital stocks must also be non-declining, and hence the capital stock itself should be non-declining.

18. However, given that there are different forms of capital, this immediately raises the question as to whether it is the capital stock as a whole that should be non-declining or whether the individual types of capital, or some parts of them, should be non-declining as well. This is the difference between weak and strong sustainability.

3.2 Weak and strong sustainability

19. The distinction made in the literature between weak and strong sustainability, which will be briefly reviewed here, is the subject of a book length treatment by Neumayer (2003). Weak environmental sustainability derives from a perception that welfare is not normally dependent on a specific form of capital, and can be maintained by substituting manufactured for natural capital, though with exceptions. Strong environmental sustainability, on the other hand, derives from a different perception, that substitutability between different kinds of capital, for example manufactured for natural capital, is seriously limited by such environmental characteristics as irreversibility, uncertainty and the existence of 'critical' components of natural capital, which make a unique contribution to welfare. An even greater importance is placed on natural capital by those who regard it in many instances as a complement to man-made capital (Daly, 1992, pp. 27ff).

20. Having made the semantic distinction, the key issue is which perception most validly describes reality. Resolving this issue should be an empirical rather than a theoretical or ideological matter. However, if weak sustainability is assumed *a priori*, it is impossible to show *ex post* whether the assumption was justified or not, for the following reason. The assumption underlying weak sustainability is that there is no essential difference between different forms of capital, or between the kinds of welfare which they generate. This enables, theoretically at least, all types of capital, and the services and welfare generated by them, to be expressed in the same, perhaps monetary, unit. In practice, there may be insuperable difficulties in performing the necessary monetisation and aggregation across the range of issues involved, but the theoretical position is clear and strenuous efforts are being made to make it operational. But the numbers that emerge from these efforts can only show whether or not weak sustainability has been achieved, i.e., whether overall welfare has been maintained. They cannot shed any light on the question as to whether the assumption of commensurable and substitutable capitals was justified in the first place. In assuming away any differences at the start, there is no way of establishing later on whether such differences were important.

21. The strong sustainability assumption does not suffer from this severe defect in scientific methodology. In keeping different kinds of capital distinct from each other from the outset, it can examine each type's particular contribution to welfare. The examination may reveal that in some cases the welfare derived from one type of capital is fully commensurable with other welfare from production and can be expressed in monetary form. In these cases, substitutability with other forms of capital exists, and the weak sustainability condition of a non-declining aggregate capital stock, is sufficient to maintain welfare. In other cases, the outcome of the examination may be different. The important point is that, starting from a strong sustainability assumption of non-substitutability in general, it is possible to shift to a weak sustainability position where that is shown to be appropriate. But starting from a weak sustainability assumption permits no such insights to enable exceptions to be identified. In terms of scientific methodology, strong sustainability is therefore greatly to be preferred as the *a priori* position.

22. In respect of natural capital, there are other theoretical reasons for choosing the strong sustainability assumption, in addition to the practical reason of the sheer difficulty of carrying out the necessary weak sustainability calculations for complex environmental effects. Victor (1991, pp. 210-1) notes that there is a recognition in economics, going back to Marshall, that manufactured capital is fundamentally different from environmental resources. The former is human-made and reproducible in the quantities desired; the latter is the 'free gift of nature' and in many categories is in fixed or limited supply. The destruction of manufactured capital is very rarely irreversible (this would only occur if the human capital, or knowledge, that created the manufactured capital had also been lost), whereas irreversibility, with such effects as species extinction, climate change, or even the combustion of fossil fuels, is common in the consumption of

natural capital. Moreover, to the extent that manufactured capital requires natural capital for its production, it can never be a complete substitute for resources.

23. Victor et al. (1998, p. 206) identify the elements of natural capital that are essential for life as we know it, as water, air, minerals, energy, space and genetic materials, to which might be added the stratospheric ozone layer and the relationships and interactions between these elements that sustain ecosystems and the biosphere. Some substitution of these essential elements by manufactured and human capital can be envisaged, but their wholesale substitutability, as assumed by weak sustainability, appears improbable, certainly with present knowledge and technologies. In fact, if the process of industrialisation is viewed as the application of human, social and manufactured capital to natural capital, to transform it into more human and manufactured capital, as suggested above, then it is possible to view current environmental problems as evidence that such substitutability is not complete. If our current development path is unsustainable, it is because it is depleting some critical, non-substitutable components of the capital base on which it depends.

24. Summarizing this literature, Dietz and Neumayer (2007, p. 619) list four reasons why the strong approach to sustainability may be preferred to the weak: risk and uncertainty; irreversibility; risk aversion; and the ethical non-substitutability of consumption for natural capital. The various indicator efforts that have sprung up to measure progress towards sustainable development have sought to capture different aspects of these ideas in different ways as will now be seen.

4. Measuring sustainable development

Main messages:

- Existing aggregate monetary indicators such as Green GDP, Genuine Progress Indicator or Genuine Savings adopt weak sustainability assumptions when adjusting GDP with monetary measures relating to natural capital.
- Other frameworks and indices of sustainable development commonly adopt a strong sustainability position, but do not yet comprehensively or adequately represent environmental sustainability.

4.1 Aggregated indicators of weak sustainability

25. The distinction between weak and strong sustainability carries over into the two main approaches to constructing measures, or indicators, of sustainability and sustainable development.

26. Starting from an assumption of weak sustainability, and using techniques of environmental valuation, environmental indicators can be expressed in monetary form and, once expressed in this form, they can be added up according to some theoretical position. Some calculations are based on economic welfare theory (see Nordhaus and Tobin (1973) for an early example), and these have been developed into proposals for the calculation of a Green GDP (see Ekins (2001) for a

discussion of the theoretical problems associated with this). The Index of Sustainable Economic Welfare (ISEW) (first proposed by Daly and Cobb (1989)) starts from consumer expenditure and then adds various social or environmental impacts (which can be positive or negative) to arrive at a supposedly more realistic assessment of changes in human welfare than that represented by changes in GDP. ISEW has been calculated for a number of countries (see Posner and Costanza (2011, p. 1973), for a list of studies), while the Friends of the Earth website called 'Measuring progress' (see http://www.foe.co.uk/community/tools/isew/) enables people to calculate their own ISEW.

27. ISEW was further developed into the Genuine Progress Indicator (GPI), which has been calculated for a number of countries, US states, and other sub-national entities (again, see Posner and Costanza (2011) for a list). All the methods based on giving monetary values to different impacts essentially take the weak sustainability approach in the terms discussed earlier, assuming that the different aspects of sustainable development, and the different forms of welfare associated with them, are commensurable and can therefore be expressed in the same numeraire. As was noted earlier, the implementation of this assumption does not permit any subsequent attempt to assess whether it was justified, except in terms of the plausibility of the results and conclusions to which it leads.

28. The situation is well illustrated by the World Bank's Genuine Savings indicator (World Bank, 2000, 2006), which is one of the best known of the methods that has sought to express different aspects of sustainable development in monetary terms. The indicator is explicitly based on a capitals methodology such as that described above. According to the calculations of genuine savings in World Bank (2000, table A1, p.10), all OECD countries and the great majority of developing countries have positive genuine savings. This picture is broadly confirmed in the follow-up genuine savings calculations in World Bank (2006, p. 41) and World Bank (2011), with in addition the East Asian countries showing strongly positive genuine savings rates and Latin America and the Caribbean also positive rates (except for a brief period in the 1980s). Only North Africa and the Middle East emerges as a region with consistently negative genuine savings rates 'reflecting high dependence on petroleum extraction', with the extent of this result being of course highly dependent on the oil price (the higher the price, the higher the calculated cost of oil depletion to be subtracted from other savings categories).

29. While a negative genuine savings rate is a clear sign of unsustainability, World Bank (2006, p. 38) advocates caution in the interpretation of a positive genuine savings rate. This is because a number of important environmental issues are not included in the calculations of natural capital, because of a lack of data. Notwithstanding this, if the genuine savings rate truly is 'a sustainability indicator', as both World Bank (2000, p. 2) and World Bank (2006, p. 36) appear to claim, this would seem to indicate that most countries, and all OECD countries, are sustainable. If this is true, then the issue of sustainability is much less important than often seems to be supposed in policy-making (it is not clear, for example, why the EU needs a 'sustainable development strategy', if all EU

countries are already sustainable, as the genuine savings indicator suggests), which is in conflict with the messages arising from major environmental assessments (Millennium Ecosystem Assessment, 2005; UNEP, 2012). This appears to put in question either the weak sustainability assumption on which the indicator is based, or the methodology by which it has been computed.

30. Those who wish to start from a strong sustainability approach will therefore wish to go beyond the Genuine Savings indicator and assess sustainability separately across the different capitals to see whether the broad sustainability conclusions of the Genuine Savings indicator are revealed as justified. Approaches which keep environmental capital separate in order to assess strong environmental sustainability are described further below.

31. Beyond the distinction between weak and strong sustainability, there are two main approaches (not exclusive) to constructing indicators of sustainable development: the framework approach which sets out a range of indicators intended the cover the main issues and concerns related to sustainable development[1]; and the aggregation approach, which seeks to express development-related changes in a common unit (normally money), so that they can be aggregated. A limitation of the first approach is that unless all the indicators in the framework are moving in the same direction (i.e., all making development more, or less, sustainable), it is not possible to say whether, in total, sustainable development is being approached. In respect of the second approach, Kumar (2010) is a recent exposition of the issues that arise with the economic valuation of the environment, while Foster (1997) explored many of the same issues more than 10 years earlier. While such valuation can be both meaningful and important, a major limitation is that it is often impossible, very difficult or very controversial to convert all changes of interest to money values, or any other common numeraire, and this limitation applies most strongly to precisely the largest environmental effects that are therefore of most policy interest. With the valuation approach, therefore, the change in respect of sustainable development may be expressed as a single number, but the number may lack credibility. Each of these approaches fulfil different, yet complementary roles: An index is well-suited for awareness raising and for communication purposes, while a dashboard could be more suited for granular priority setting.

4.2 Frameworks of indicators for sustainable development

32. In 1996 the UNCSD published its first set of sustainable development indicators (SDIs), comprising 134 economic, social, and environmental indicators (UN, 1996). The indicators were structured in a matrix that related Driving Force, State, and Response indicators to the chapters in Agenda 21[2]. Because it felt that not all the indicators were relevant for the European Union, EUROSTAT carried out a study using a subset of 36 of these indicators, publishing the results of the study in 1997 (Eurostat, 1997). UNCSD subsequently produced a 'core' set of

[1] This is the approach proposed by Stiglitz et al. 2009, which lead in France to the creation of 10 indicators of wealth. See https://www.gouvernement.fr/en/new-indicators-of-wealth.

[2] Agenda 21 was the 'Plan of Action' that was agreed at the Rio Earth Summit in 1992

59 SDIs based on its original set, and Eurostat (2001b) did another study involving 63 indicators, which related closely to the UNCSD core set and showed the very wide range of issues that sustainable development is considered to cover.

33. There are many other frameworks of SDIs. Internationally, one of the best known is that produced by the Organisation for Economic Co-operation and Development (OECD). The OECD was given a mandate to work on sustainable development in 1998. Pursuant to this its work has resulted in theoretical, methodological, and policy- and indicator-oriented publications (OECD, 1998, 2000a, b, 2001b, c, d). The first publication in this field (OECD, 1998) was largely environmentally focused, but this was followed by a conference on sustainable development indicators in 1999, the proceedings of which were published in 2000 (OECD, 2000b). This contained a set of 'possible core sustainable development indicators', a number of country case studies on different aspects of sustainable development indicators, and sectoral/environment indicators for the major environmentally significant sectors. It also contained a new set of social indicators, with context indicators, structured according to the themes: promoting autonomy (or self-sufficiency), equity, healthy living (or just health), and social cohesion. Within the themes the indicators were grouped according to social status and societal response (similar to the Pressure-State-Response framework it had used for environmental indicators).

34. Also in the international arena, indicators of development were disaggregated beyond the three components of HDI with the adoption in 2000 of the eight Millennium Development Goals (MDGs), which sought to: eradicate extreme poverty and hunger, achieve universal primary education, promote gender equality and empower women, reduce child mortality, improve maternal health, combat HIV/AIDS, malaria and other diseases, ensure environmental sustainability, and work in global partnership for development.

35. Each of the MDGs had targets and indicators behind them, so that progress towards them could be measured. And over 2000-2015 there was very considerable progress, such that in the Millennium Development Goals Report (UN, 2015) assessing what the MDGs had achieved, the then UN Secretary-General Ban Ki-Moon was able to write: "The global mobilization behind the Millennium Development Goals has produced the most successful anti-poverty movement in history." However, there was no aggregation of the MDGs into a single indicator, such as HDI, so that overall improvements in sustainable development achievement overall, and inter-country comparisons, were not possible.

36. It will be noted that one of the MDGs was "to ensure environmental sustainability". This MDG was defined through just seven indicators: emissions of ozone-depleting substances, the extent of terrestrial and marine protected areas, three indicators on the provision of and access to drinking water, an indicator on access to improved sanitation, and the proportion of the urban population living in slums. While performance against all these indicators had improved very substantially, by no stretch of the imagination can they be said fully to cover the

full set of issues raised by the term 'environmental sustainability'. There was not even any mention of climate change.

37. Another influential indicator framework was that related to the EU Sustainable Development Strategy, adopted in 2006 and reviewed in 2009. This has however been superseded by the Sustainable Development Goals and ongoing EU efforts to implement these.

38. The deficit of the MDGs with regard to environmental sustainability was realised and addressed in the set of objectives that were agreed by the global community to take effect after 2015 – the SDGs – the 2030 Agenda for Sustainable Development[3]. There are 17 SDGs, which set targets to be achieved by 2030, and two main differences compared the MDGs are *(1)* their coverage of resource and environmental issues and *(2)* their universal nature, being applicable to all countries unlike the MDGs which were confined to developing countries. There are SDGs on clean water and sanitation (SDG 6), clean and affordable energy (SDG 7), responsible consumption and production (SDG 12), climate (SDG 13), and life below water (SDG 14) and on land (SDG 15). Numerous environmental commitments are also expressed in Targets under other Goals. As with the MDGs there are now considerable efforts to monitor countries' progress towards the SDGs, and beneath the 17 headline goals there are 169 Targets and 232 indicators. Efforts have already started to track progress towards the achievement of the SDGs, most notably perhaps through the Dashboard and Index developed by the Sustainable Development Solutions Network (SDSN) and Bertelsmann Foundation.

4.3 Aggregation of indicators for sustainable development

39. An advantage of the framework approach to indicators of sustainable development is that each of the many aspects of sustainable development can be specifically reported on in its own terms, and trends for the separate aspects can be identified. However, a disadvantage is that, without combining the indicators in some way, it is not possible to draw any overall conclusions about progress towards sustainable development unless all the indicators happen to be moving in the same direction in relation to that progress. This is most unlikely to be the case.

40. A number of methods have been developed for the aggregation of indicators so that overall impacts can be assessed:

- Aggregation after expression in monetary form: this method was discussed above in relation to the Genuine Savings and Inclusive Wealth indicators. As already noted, such indicators commonly rely on the assumption of weak sustainability (c.f. discussion of the Monetary ESGAP below).

- *Aggregation into environmental themes*: This was the approach underlying the Netherlands National Environmental Policy Plan process. It is described in Adriaanse (1993).

[3] See https://sustainabledevelopment.un.org/post2015/transformingourworld

- *Aggregation across environmental themes*: One method of doing this is to weight the different themes according to perceptions of environmental performance. An example of this method is the Ecopoints system developed by BRE (2008). Another method depends on the setting of sustainability standards for the themes, and then aggregating them according to the distance from the standard. An example of this approach is the concept of the 'sustainability gap', the indicator which is discussed in much more detail below.

41. *Aggregating across environmental and other themes*: This can be implemented by using multi-criteria analysis, or relating the themes to some concept such as Quality of Life or Human Development. The annual United Nations Development Programme's Human Development Index (Box 2) or the SDG Index (Box 3) are examples of this approach. An innovative application of this method was implemented by the Consultative Group on Sustainable Development Indicators (CGSDI, 2007), which was established in 1996 and is an Internet-based working group drawing members from many different institutions and countries. Their Dashboard of Sustainability is not a specific selection of indicators as such, but a way of presenting sustainability indicators in an aggregated form, with the aim of providing an informative and easily grasped and communicated overview of the complex relationships among the social, environmental, and economic dimensions of sustainable development issues. Indicators from the three sustainability dimensions form the basis for aggregated social, environmental, and economic indices, which then are further aggregated into one 'policy performance index' and presented as a pie chart organized in three concentric circles. The outer circle contains the actual indicators, the next level circle contains the three sub-indices, and the inner circle contains the overall policy performance index. Clearly, the index is only as good as the indicators used for it, and the proponents of this methodology stress the continued need for improved and broadened indicators. However, the methodology is being quite widely used, at the local and regional as well as the national level.

Box 2: The Human Development Index

Even in 1987 at the time of the publication of the Brundtland Report, there was considerable dissatisfaction with the common rule of thumb of measuring the level of development through the indicator of income or output (Gross Domestic Product, GDP) per head. So much so that it was in 1990 that UNDP published the first Human Development Index (HDI, UNDP (1990)), which combined into a single indicator measures of income, health and education. The HDI revealed two important facts. First, that levels of health and education are strongly correlated with GDP, so that treating GDP as a proxy for development progress in the absence of HDI had not been so wide of the mark. But, second, that there were important differences in the rankings by country of GDP and HDI – some countries were better at turning GDP into better health and education outcomes than other countries with similar incomes per head. Efforts have been made to incorporate aspects of development beyond HDI's three core issues (income, health, education), including poverty/inequality, gender and the environment.[4] UNDP's Human Development Report now contains an Environmental Sustainability Dashboard, comprised of 10 indicators.[5]

42. The SDG Index (Box 3) is the most recent example of a relevant sustainable development index. Nonetheless, as noted in the introduction, it is clear that the SDG Index gives a very partial view of the extent to which 'strong' environmental sustainability is being achieved. It is to the construction of such an index of strong environmental sustainability that this paper now turns.

Box 3: The SDG Index

The SDG Index was presented in 2016 as a complementary tool to the official activities aimed at measuring progress towards the SDGs. The index uses a set of indicators grouped along the 17 SDGs that is then weighted and aggregated into a single score. The SDG Index is based on official SDG indicators when these meet certain criteria such as data availability, quality or existence of quantitative thresholds. In the remaining cases, the authors used other indicators from the broader scientific literature to complement the set.

The SDG Index in their 2017 report (Sachs et al., 2017) confirms one of the principal findings of the HDI: that the overall ranking is closely correlated with GDP, but there are striking differences. The top four countries are all Nordic: Sweden, Denmark, Finland and Norway. The top 30 countries are European, with the exception of Japan (11), Canada (17), New Zealand (20), Australia (27) and Cuba (29, the only non-OECD country). Some of the surprises are that the Czech Republic (5) is in the place above Germany (6), that little Luxembourg, the richest European country per head, is at 33. And the United States at 42 is below Romania (35) and Ukraine (39). The Dashboard and Index confirm that GDP is indeed an important contributor to achievement of the SDGs, but is far from all that matters. And it is particularly deficient when it comes to performance against the environmental SDGs.

Sachs et al. 2017 also indicates that, despite the greater number of environmental targets in the SDGs than the MDGs, they remain a lower priority for countries than the more conventional development goals. They note (p.1) "reporting was particularly weak on the environmental SDGs 12-15", and in their discussion of the different regions they note that even for the rich countries "the greatest challenges exist on sustainable consumption and production (SDG12), climate change (SDG 13), clean energy (SDG 7) and ecosystem conservation (SDGs 14 and 15)". Many poorer countries face environment-related challenges on food and water as well.

[4] See: http://hdr.undp.org/en/content/inequality-adjusted-human-development-index-ihdi

[5] Focusing on: Fossil fuel energy consumption, renewable energy consumption, carbon dioxide emissions, forest area, fresh water withdrawals, mortality attributed to pollution, water, sanitation and hygiene, and an index of threatened species.

5. Environmental sustainability

Main messages:

- Environmental sustainability requires sustaining natural capital functions over time.
- For an indicator to describe a country's situation with regard to environmental sustainability, it needs to meet three criteria: 1) be a distance-to-target indicator, 2) the target needs to be representative of environmental sustainability conditions, and 3) be defined at the national level.
- Most environmental indicators developed by European institutions do not meet these criteria. Distance-to-target indicators such as the environmental dimension of the Sustainable Development Goals, the Environmental Performance Index or the Planetary Boundaries dashboard also fail to meet at least one the criteria above.
- As a result, there is a lack of credible indicator systems of strong environmental sustainability at country level.

5.1 The need for a change in the direction of development

43. The principal cause of the rise in concern for sustainable development was the growing scientific evidence over the 1970s and 1980s that the combination of economic and human population growth was inflicting damage on the environment that threatened to disrupt some of the most fundamental natural systems of the biosphere, with incalculable consequences. By 1987 Brundtland et al. (1987, pp. 32-33) had formulated its perception of unsustainability in terms of a threat to survival: "There are thresholds which cannot be crossed without endangering the basic integrity of the system. Today we are close to many of these thresholds; we must be ever mindful of the risk of endangering the survival of life on earth."

44. In the run up to UNCED in 1992, several organisations conducted major environmental reviews, which expressed the perceived seriousness of environmental degradation and the unsustainability of current development paths. Thus, the Business Council for Sustainable Development stated in its report to UNCED: "We cannot continue in our present methods of using energy, managing forests, farming, protecting plant and animal species, managing urban growth and producing industrial goods (Schmidheiny and Business Council for Sustainable Development, 1992, p. 5)." The World Resources Institute (WRI), in collaboration with both the Development and Environment Programmes of the United Nations, concluded, on the basis of one of the world's most extensive environmental databases, that: "The world is not now headed toward a sustainable future, but rather toward a variety of potential human and environmental disasters" (WRI et al., 1992, p. 2).

45. The World Bank, envisaging a 3.5 times increase in world economic output by 2030, acknowledged that: "If environmental pollution and degradation were to rise in step with such a rise in output, the result would be appalling

environmental pollution and damage" (World Bank, 1992, p. 9). However, despite UNCED and the expressions of environmental commitment to which it led, there was only limited progress in addressing environmental problems during the 1990s. In Europe, which is generally considered a region with one of the most developed environmental policies, the European Environment Agency (EEA) wrote, in its end-of-century assessment of the European environment, that out of fifteen environmental categories or causes of concern:

- "Only one current pressure on the environment (ozone depletion), and no forecast future pressure, was shown as having an adequate positive development.
- No current or future states were characterised as being adequately positive.
- Six forecasts of future pressures were forecast as having an 'unfavourable development', and a further four were too uncertain to predict."

46. The EEA's overall assessment was of: "... some progress, but a poor picture overall; ... progress in reducing other pressures on the state of the environment has remained largely insufficient [and] the outlook for most of the pressures is also not encouraging (EEA, 1999a, p. 23).

47. Globally, the picture as expressed in the United Nations Environment Programme (UNEP)'s *Global Environmental Outlook* was even less encouraging across a wide range of issues. UNEP's overall conclusion was: "If the new millennium is not to be marred by major environmental disasters, alternative policies will have to be swiftly implemented" (UNEP, 1999, p. xxiii). Thirteen years later the fifth *Global Environment Outlook* was raising a very similar alarm: "As human pressures within the Earth System increase, several critical thresholds are approaching or have been exceeded, beyond which abrupt and non-linear changes to the life-support functions of the planet could occur. This has significant implications for human well-being now and in the future" (UNEP, 2012, p. 194).

48. The reference to critical thresholds in the previous quote reflects one of the major environmental developments of the last ten years, namely the entry into the environmental science literature of the idea of 'planetary boundaries' and a 'safe operating space for humanity' (Rockström et al., 2009b; Steffen et al., 2015) in respect of human impacts on the environment and use of its natural resources. Several major reports and policy documents have made reference to the planetary boundaries idea (EC, 2014; UNEP, 2012), which shows its communication power.

5.2 From sustainable development to sustainability

49. The basic meaning of the word 'sustainability' is 'capacity for continuance'. On its own the word begs the question 'sustainability of *what*?' In line with the argument above, sustainable development would then entail meeting human needs and increasing quality of life now (the *development* part) and in the future (the *sustainability* part). In line with Jacobs' six components of sustainable development listed above, the process can be seen as having economic, social and

environmental dimensions. If there are concerns that current modes of development (meeting human needs and improving quality of life) are unsustainable, it is interesting to consider whether these concerns largely have an economic, social or environmental basis (or some mixture of the three), and whether there are principles or criteria of sustainability which could be applied across these dimensions, to facilitate judgements as to whether development is sustainable or not.

50. With regard to the economic dimension, economists have long had guidelines as to whether economic growth and development should be regarded as sustainable. The rate of inflation, public sector net credit requirement, and balance of payments, among others, are all considered to be important indicators of economic sustainability. The sustainable development idea has brought little new to this particular sustainability dimension.

51. In contrast, the idea of social sustainability is both far less developed and seems much more intractable. Doubtless it is true that social sustainability is affected by such conditions as poverty, inequality, unemployment, social exclusion and the corruption or breakdown of social institutions. But the relationship between sustainability and these conditions is clearly very complex and quite different as between different societies. It seems unlikely that a social sustainability threshold for unemployment or inequality, comparable for example to the target rate of inflation for economic sustainability, will be identified. What seems more important in this case is to ensure that the direction of change is towards what is considered necessary for sustainability, rather than the attainment of some particular number.

52. The environmental dimension of sustainability is different from both the economic and social dimensions, in that it is possible to articulate principles of sustainability, and thence to derive thresholds and standards for environmental sustainability, as discussed below, according to which it is possible to distinguish between sustainable and unsustainable use of the various ways the environment gives benefits to people. These ways, or the benefits deriving from them, have been variously called environmental functions (De Groot, 1992), ecosystem goods and services (EGS) (Daily, 1997; Millennium Ecosystem Assessment, 2005)) and 'nature's contribution to people' (Pascual et al., 2017), and they have been classified in different ways, including Source, Sink, Life Support and Human Health and Welfare functions (Ekins et al. (2003) as explored in more detail below), provisioning, regulating, supporting and cultural EGS (Millennium Ecosystem Assessment, 2005), the Common International Classification of Ecosystem Services (CICES, Haines-Young and Potschin (2013)), while Pascual et al. (2017) stress the need to integrate considerations of intrinsic, instrumental and relational values. The purpose of all these approaches is to clarify the key components and interactions in the multiple dimensions of nature's contribution to people, including significant and irreplaceable future contributions of natural capital that may not in line with current priorities. This paper will proceed on the basis of environmental functions, while recognizing the comparability and validity of the other nomenclatures.

5.3 Functions of natural capital

53. The flows of goods and services from natural capital shown in Figure 1 which make a key contribution of the environment to the human economy, and to human life in general, can be envisaged to take place through the operation of a wide range of 'environmental functions'. This concept was first employed in economic analysis by Hueting, who defined environmental functions as 'possible uses' of the environment (Hueting, 1980, p. 95). De Groot has subsequently defined them as 'the capacity of natural processes and components to provide goods and services that satisfy human needs' (De Groot, 1992, p. 7).

54. Figure 2 gives a schematic illustration of the relationship between the biosphere and the direct and indirect benefits it delivers to human beings. The biosphere is perceived to perform a range of environmental functions related to the provision of resources, the absorption of wastes and the delivery of a range of ecosystem services. These functions are performed for species apart from humans and, over the history of life on earth, have tended to lead to the increase in the complexity and diversity of the biosphere (signified by the positive feedback from the functions box to the biosphere).

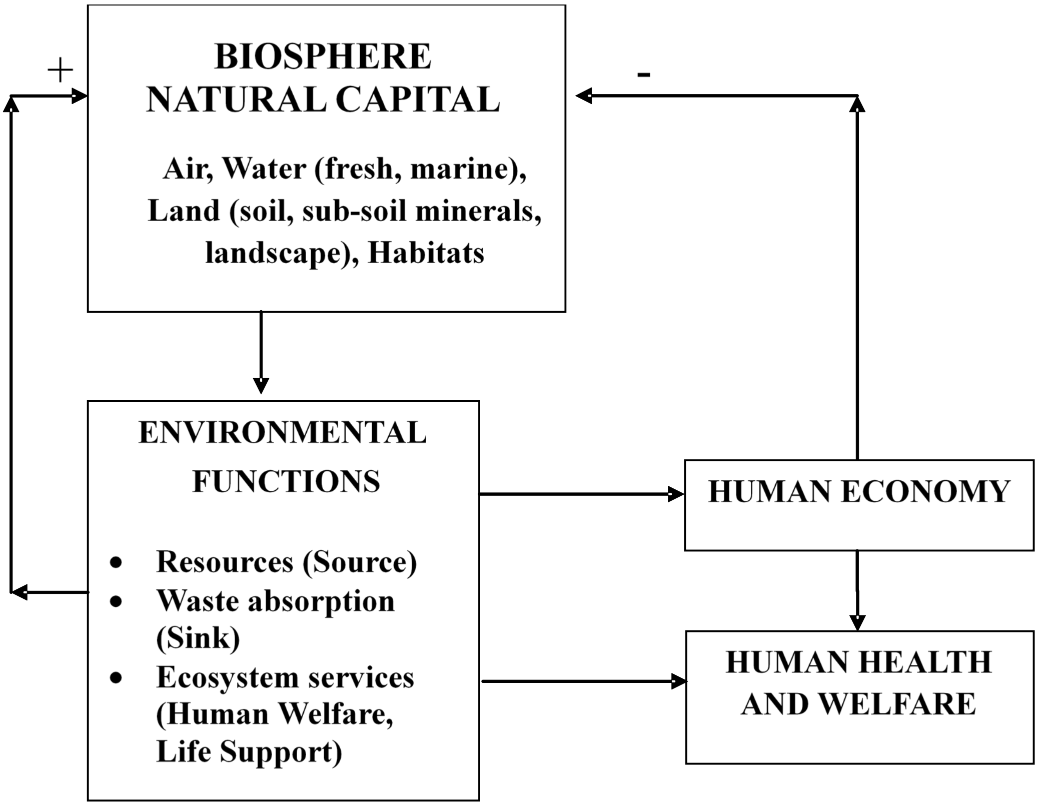
55. As discussed later, the functions provide important benefits for humans, either directly or through processes that support life. The direct benefits include inputs into the economy, and the maintenance of conditions conducive to human health and to human welfare more generally. However, the scale of the human population, and of the economic activity in which it now engages, now causes negative feedback to the biosphere, which reduces its complexity and diversity – and its ability to perform the environmental functions which deliver the human benefits. This negative feedback is what Pigou (1932) referred to as an 'externality'. The level and extent of the negative feedback is now causing climate change and biodiversity loss to such an extent as to pose a serious threat of very great damage to human welfare at a global scale.

56. The economic approach to this issue seeks to calculate the monetary value of the damage to the environmental functions caused by economic activity, measured in terms of the loss of human benefits to which the damage gives rise, to compare this with the benefits from the economic activity, and to equate the marginal loss due to the former with the marginal gain due to the latter in order to maximise the delivery of benefits overall. While this is a reasonable way of proceeding in principle, in practice it encounters a number of major problems, related to the characteristics of the serious environmental disruption/degradation that humanity now seems to be facing:

- The results of the damage are very uncertain, but may be very large (even catastrophic)
- The results may be irreversible
- The results will play out over the very long term
- The results affect every aspect of human life: mortality, morbidity, migration, water/food, cultural and spiritual values.

57. As already noted, not only are the techniques of environmental valuation methodologically fraught when applied to issues with such characteristics, they also assume substitutability between these functions and other values, i.e. they assume weak sustainability. The alternative approach to be explored here is based on the principle of strong environmental sustainability.

Figure 2: The Relationship between Environmental Functions and Human Benefits



58. As shown in Figure 2, the functions of natural capital may be seen as being of four broad kinds: the provision of resources (Source functions), the absorption and neutralization of wastes (Sink functions), the maintenance of important biosphere processes, such as a stable climate (Life Support functions) and contributions to Human Health and Welfare, such as through amenity and recreation services (see Pearce and Turner (1990, p. 35ff) for more detail on this categorization, which are also discussed in more detail below).

59. In terms of Figure 2, environmental sustainability requires the maintenance of important environmental functions and the natural capital which generates them. Important environmental functions may be considered to be those that are not substitutable, those whose loss is irreversible and is likely to lead to 'immoderate' losses (that is, those considerably greater than the costs of maintaining the functions), and those that are crucial for the maintenance of health, for the avoidance of substantial threats (such as climate stability), and for economic sustainability. The natural capital that performs such environmental functions may be called critical natural capital (Ekins et al., 2003).

60. The interactions in Figure 2 also draw attention to a further distinction between environmental functions that needs to be emphasized, a distinction between 'functions for' and 'functions of' (Ekins et al., 2003). The 'functions for' are those environmental functions that provide direct benefits for humans. These are the functions which are generally most easily perceived and appreciated, and towards the maintenance of which most environmental policy is directed.

61. The 'functions of' the environment are those which maintain the basic integrity of natural systems in general and ecosystems in particular (shown in Figure 2 as the positive feedback to the biosphere). These functions are not easily perceived, and scientific knowledge about them is still uncertain and incomplete. What may be said with certainty, however, is that whether science understands these functions or not, and whether people value or are ignorant about them or not, the continued operation of the 'functions of' the environment is a prerequisite for the continued performance of many of the 'functions for' humans. Looked at in isolation, these 'functions of' the environment may appear useless in human terms, and therefore dispensable. Considered as part of a complex natural system, these functions may be essential for the continued operation of other functions of much more obvious importance to humans. The danger is that the isolated view, or scientific ignorance about the complexity of the natural world, may result in 'functions of' being sacrificed for economic or social benefits, without appreciation of the wider implications.

62. Thus, environmental sustainability in this characterization entails the maintenance of the environmental functions at such a level that they will be able both to sustain their contribution to human benefits (the economy, health and welfare) and to maintain the biosphere from which they derive. The requisite level across different environmental functions may be estimated using both environmental science and social preferences for environmental quality. De Groot et al. (2003) put forward the following criteria for the functions to be maintained for environmental sustainability:

- *Maintenance of human health*: functions should be maintained at a level to avoid negative effects on human health. These effects may be physical or psychological, resulting from the loss of environmental quality or amenity.
- *Avoidance of threat*: functions should be maintained if there is any possibility that their loss would entail unpredictably large costs. This criterion is even stronger if there is any risk that the loss of the function would be irreversible. It is most obviously applicable to considerations of biodiversity and the maintenance of ecosystem integrity.
- *Economic sustainability*: functions that provide resources for, or services to, economic activities should be used on a sustainable basis (i.e., one that can be projected to continue into the long-term future).

5.4 Environmental indicators

63. From Figure 1 and Figure 2, a broad definition of natural capital might be everything in nature (biotic and abiotic) capable of contributing to human well-being, either through the production process or directly. Just as with sustainable development, considerable efforts have been invested in recent years developing environmental indicators in a way that was useful for policy processes. In the context of strong sustainability, the key question is whether these sets of indicators show whether key environmental functions of natural capital are maintained at acceptable levels, as argued above.

64. As an early example, Eurostat produced a set of environmental indicators, based on a major expert consultation (Eurostat, 2001a). Up until 2011 the OECD's main source of environmentally relevant data was published as a compendium of indicators (OECD, 2011), structured according to a Pressure-State-Response (PSR) framework, where Pressures include both direct environmental pressures and the indirect pressure of the human activities producing the direct pressures; the States refer to various environmental conditions; and the Responses relate to societal intentions and actions in respect of the environmental conditions, and include general data. In 2001, 10 headline indicators were selected from this compendium (OECD, 2001a), and the indicators were also selected or combined to form the environmental indicators of the OECD sustainable development indicator set (OECD, 1998, 2001a).

65. OECD now publishes a compendium of agri-environmental indicators (OECD, 2013) and an annual 'Environment-at-a-Glance' publication, most recently in 2015, which reports the environmental trends in greenhouse gas (GHG) emissions, carbon dioxide (CO2) emissions, sulphur oxides (SOX) and nitrogen oxides (NOX) emissions, particulate emissions and population exposure, use of freshwater resources, water pricing for public supply, wastewater treatment, biological diversity, use of forest resources, use of fish resources, and municipal waste (OECD, 2015).

66. The European Environment Agency (EEA) developed, similarly to the OECD, the Driver-Pressure-State-Impact-Response (DPSIR) indicator framework (EEA, 1999b, 2003). In the DPSIR framework the environment is characterised by pressure (P), state (S) and impact (I) indicators. The Pressures of the OECD PSR classification are split into two separate categories: the human developments and activities (Drivers, D) that cause the environmental pressures, and the environmental Pressures (P) themselves, which refer to anthropogenic factors such as emissions, physical and biological agents, the use of resources and land, that act as stressors and therefore lead to changes in the state of the environment (EEA, 2003). State metrics (S), also like the OECD, provide a quantitative and qualitative description of physical (e.g. temperature), biological (e.g. fish stocks) and chemical (e.g. atmospheric CO_2 concentration) conditions in an area (EEA, 2003), i.e. they represent the biophysical conditions of the environment. Changes in state affect the environmental functions provided by natural capital, which can at the same time result in changes in ecosystem services that benefit humans. Both changes in environmental functions and ecosystem services resulting from

anthropogenic activities are characterised through impact indicators (I) (Maxim et al., 2009).[6] In 2004 the EEA adopted its core set of indicators, which comprised 37 indicators structured around 10 topics and the DPSIR framework (EEA, 2005). The EEA currently maintains 137 indicators, 42 of which are part of the revised core set of indicators (EEA, 2014). These are grouped according to 6 policy priorities and organised around the DPSIR framework.

67. In Europe, the EEA, Eurostat and the JRC are the most active bodies in maintaining environmental indicator systems. Development of new indicators commonly responds to policy demands. With regard to strong environmental sustainability, the key issue is whether these indicators indicate progress towards or away from environmental sustainability. Two key considerations are important in this context. First, the environmental indicator has to be compared against a reference point. These are the so-called distance-to-target indicators. Second, the reference point has to be indicative of an acceptable level of environmental functions. None of the indicator sets above does this as a general rule, although exceptions exist for specific indicators included in those sets.

5.5 Distance-to-target environmental indicators

68. Here we assess the adequacy of five indicators or indicator frameworks to represent strong sustainability at the national level. These are shown in Table 1.

[6] Maxim et al. (2009) argue that some authors tend to confuse state and impact when addressing environmental functions and ecosystem services. Some consider changes in environmental functions to be part of the state and changes in ecosystem services to be part of impacts (Müller and Burkhard, 2012; Rounsevell et al., 2010). Examples also exist of both changes in environmental functions and ecosystem services having been classified as state metrics (Helming et al., 2013), or as impacts (Xue et al., 2015).

Table 1: Efforts at distance-to-target environmental indicators

Indicator set	Focus	Measures	Scale	Reference(s)
EEA Environment Indicator Report	Environment	Performance against EU targets	National and EU	EEA (2016, 2017a)
SDG Index (Environmental SDGs)	Environment	Performance against internationally agreed targets or best performing countries	National and global	Sachs et al. (2017)
Environmental Performance Index (EPI)	Environment	Performance against internationally agreed targets or best performing countries	National	EPI (2018): epi.yale.edu
Ecological Footprint	Environmental sustainability at global national and other levels	Performance against Earth's regenerative capacity at the relevant level	Multiple levels	Borucke et al. (2013); Lin et al. (2016)
Planetary Boundaries	Environmental sustainability	Performance against environmental limits	Global	Rockström et al. (2009b); Steffen et al. (2015)

69. In order to support the evaluation of the 7EAP, the EEA published in 2016 and 2017 two reports in which they assessed progress towards the three priority areas of the policy document (EEA, 2016, 2017a). In doing so, they used a set of 29 indicators that measured performance against several (sometimes directional) targets from EU policies. This is similar to the approach adopted in the SDG Index – described previously – where countries assess progress against internationally agreed targets or best performing countries. The indicator dashboard underlying the Environmental Performance Index (EPI) follows the same logic (see Box 4). In its latest edition, the EPI framework organises 24 indicators into ten issue categories and two policy objectives, which are then aggregated into a composite index at country level. When assessing their usefulness as indicators of environmental sustainability, all three frameworks seem to be inadequate, for the references used (targets, best performing countries) in most cases do not necessarily align with science-based targets that reflect the maintenance of environmental functions. After all, environmental policy targets are adopted after weighing scientific evidence, economic costs, social acceptance and other factors, while best-performing countries can rarely be considered environmentally sustainable.

70. Out of the indicator frameworks focused on environmental sustainability, only the ecological footprint addresses nations, but its coverage of environmental issues is very incomplete (for example, lacking biodiversity) and its main purpose is to show the scale of the ecological deficit (if any) at country level (Blomqvist et al., 2013a, b; Rees and Wackernagel, 2013). More importantly, it has shortcomings that seriously reduce its credibility, as briefly discussed in Box 5, and in much more detail elsewhere (Blomqvist et al., 2013a, b; Galli et al., 2016; Giampietro and Saltelli, 2014a, b; van den Bergh and Grazi, 2014, 2015).

71. The Planetary Boundaries define nine environmental issues which the authors believe to be characterised by environmental thresholds or limits. The nine issues are climate change, stratospheric ozone depletion, biosphere integrity, biochemical flows, freshwater use, land-system change, atmospheric aerosol loading, ocean acidification, and novel entities. Steffen et al. (2015) consider that the planetary boundaries that define a 'safe operating space' for human activities have already been crossed in respect of climate change, genetic diversity loss, and biochemical flows, with climate change and land-use change in zones of increasing risk. This kind of analysis is clearly related to, but is distinct from, the concept of environmental sustainability as developed here in three ways. First, it does not explicitly differentiate between the different kinds of functions (Source, Sink, Life-Support, Human Health and Welfare) provided by natural capital, nor does it explicitly consider the contributions of these functions to the human economy and human welfare. Implicitly, the framework covers life-support and (partially) sink functions as defined previously. Second, planetary boundaries are defined at global level. So far, attempts to downscale the framework to the national scale (Cole et al., 2014; Dao et al., 2015; Hoff et al., 2014; Nykvist et al., 2013), which is the level at which most environmental policy is implemented, have limited consistency (Häyhä et al., 2016). Last, the dashboard is not aggregated into a single composite index that can aid communication. This is a relevant feature for indicators at national level.

72. This brief review therefore reveals the continuing absence of a credible environmental sustainability indicator system at the national level, which could be used to inform policy makers. Above all, countries still lack a single indicator of environmental sustainability that can give overall guidance as to the use of the environment, as Gross Domestic Product (GDP) gives summary information about the level of economic activity, and the Human Development Index (HDI) summarises important information about economic development more broadly. Showing how such an index can be developed is the subject of the rest of this paper.

Box 4: Environmental Performance Index (EPI)

The Yale Center for Environmental Law & Policy with different collaborators set up EPI to replace the Environmental Sustainability Index, which was considered to provide insufficient support to national governments for being too broad and not being indicative of current environmental performance (Hsu and et al., 2016). The index is updated and revised biannually. The 2018 version consists of 24 indicators grouped in 10 issues (Air quality, water & sanitation, heavy metals, biodiversity & habitat, forests, fisheries, climate & energy, air pollution, water resources, and agriculture) that are normalised using internationally agreed targets or best-performing countries as reference. Because countries differ in terms of natural capital endowments, the EPI uses a threshold to ignore those indicators that might not be relevant for a country (e.g. fisheries or marine indicators in landlocked countries).

The aggregation occurs in three steps: first the 24 indicators are aggregated when necessary to the 10 issues mentioned previously. These are then aggregated into two policy priorities (environmental health and ecosystem vitality), which are ultimately aggregated in the EPI. More details about aggregation and weighting are given in Box 6.

EPI, as the name clearly shows, is an index of environmental performance, not environmental sustainability. This is determined by the references used to normalise the indicators. Out of the 24 references used, three can be considered related to environmental sustainability (e.g. those dealing with particulate matter and fisheries). In four cases (e.g. drinking water and sanitation), equating the target to environmental sustainability depends on considerations about acceptable risk. Another four targets (e.g. tree cover loss, wastewater treatment) are preconditions for environmental sustainability, but are insufficient as sustainability standards. The remaining 13 cannot be considered environmental sustainability standards, as they either measure intensities (e.g. energy consumption and different emissions related to climate), or because the targets are arbitrary (e.g. Aichi targets).

Box 5: Ecological Footprint

The Ecological Footprint (EF) has won an enviable global reputation as the kind of overall indicator of environmental sustainability for which this chapter is advocating.

The basic problem with EF is that, despite claiming to measure “how much nature we have and how much nature we use” such that “National Footprint Accounts provide a comprehensive way to understand the competing demands on our planet’s ecosystems”[7], it actually omits many issues. Two sources (Blomqvist et al., 2013a; Giampietro and Saltelli, 2014a) give an account of how the EF is actually calculated, and provide the basis of this brief overview of the issues raised.

First to Giampietro and Saltelli’s list of issues that the EF does not address (p.617), here much abridged: water flows; soil health; abiotic resources, i.e. minerals etc. subject to depletion; disturbance of bio-geochemical cycles (e.g. nitrogen and phosphorus); pollution of all kinds, except for carbon emissions from energy and industrial use; genetic modification; and biodiversity loss.

What the EF does do is consider five different, and competing, real land uses that

[7] https://www.footprintnetwork.org/our-work/ecological-footprint/

provide goods and services to humans (cropland, pasture, forests, built infrastructure and marine fisheries), and one hypothetical land use (the amount of land hypothetically required by forests to sequester net anthropogenic carbon emissions), and weight the different calculated land areas according to their productivity to find for each use the number of average 'global hectares' (gha) for each use, and then aggregate them to produce a total number of gha used for human consumption. This total is then compared with the EF calculation of the number of gha available, which is called the 'biocapacity'. The computation may be carried out for any territory (sub-national, national, global), and the global figures are used to compute Earth Overshoot Day, which "marks the date we (all of humanity) have used more from nature than our planet can renew in the entire year". Again, this is a grossly misleading and inaccurate claim, given both what the EF leaves out, as noted above, and how it is actually constructed, as shown by Giampietro and Saltelli (2014a).

Giampietro and Saltelli (2014a, p. 612) have a graph which shows that the sum of the five 'real' land uses in the EF from 1961-2006, as calculated by the Global Footprint Network itself, was more or less unchanged, and remains well within the world biocapacity over the entire period. The detail of their explanation as to how this has come about is beyond the scope of this chapter but it is worth noting, as they do, that this unchanged EF is over a 45-year period over which, according to the Millennium Ecosystem Assessment (MEA), "human population has doubled, food production has more than doubled, and the size of the world economy has increased 6 fold" (ibid. pp.612-3), leading the MEA to conclude: "Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth." (Millennium Ecosystem Assessment, 2005, p. 1). And yet, remarkably, the EF over this period for the sum of the land for crops, pasture, forests, built environment and fish is largely unchanged. The EF for these categories of land use would seem to be completely at variance with the results of one of the most authoritative scientific reports on the state of the world's ecosystems yet produced.

This remarkable result is partly due to the calculation method of some of these different land uses whereby, as land productivity increases, the amount of consumption which can be sustained by a given land area also increases. To take cropland as an example, as is shown mathematically in Giampietro and Saltelli (2014a, pp. 614-5), if the quantity of crops consumed is converted to land area through average land productivity (the EF for crops) and the biocapacity is computed according to the area required to grow those crops at average productivity, as is the case, the EF and biocapacity in this case are bound to be equal. And indeed, this is what the table provided in Wackernagel et al. (2002, p. 9268) in the paper produced that describes the "ecological overshoot of the human economy" actually shows. For pasture and timber, the calculation method is different and the same table shows that actual demand for pasture and timber is substantially less than the actual areas available.

How, then, does the EF produce the fabled "ecological overshoot of the human economy" (the phrase comes from Wackernagel et al. (2002), estimated at the time of writing to be a full 0.7 times "what Earth can regenerate each year", so that "Today humanity uses the equivalent of 1.7 Earths to provide the resources we use and absorb our waste."?

The answer lies entirely in the sixth land use category, the hypothetical land use calculated as that required to absorb humanity's net carbon emissions, which have, of course, increased greatly since 1961. Both Blomqvist et al. (2013a) and Giampietro and Saltelli (2014a) submit the complex methodology used to calculate this hypothetical land area to detailed analysis and show it to be based on largely arbitrary and extremely problematic assumptions, all of which are subject to considerable uncertainty, and a change to which could dramatically reduce (or increase) the ecological overshoot. In any case, there would seem to be absolutely no need to convert real carbon emissions to hypothetical global hectares, because there is a robust scientific literature that plots their increase in their natural units (tonnes CO_2) and calculates the extent to which they need to be reduced in order to attain a sustainable climate.

The EF is therefore not adequate as an indicator of environmental (un)sustainability. But the rationale for such an indicator remains: the need for a 'dashboard' of indicators indicating progress or otherwise towards environmental sustainability, with the option of aggregating these indicators into a single index to get a summary overview of the situation, and of expressing this aggregate in monetary terms in order to compare it, and its change over time, with GDP and economic growth.

6. The Environmental Sustainability Gap

Main messages:

- The Environmental Sustainability Gap (ESGAP) framework intends to fill the indicator gap described above.
- The ESGAP comprises a dashboard of environmental sustainability indicators across relevant environmental and resource issues.
- Present trends can be used to give an indication of the time that would be taken to reach the standards of environmental sustainability, thereby deriving a Years-to-Sustainability indicator.
- When the ESGAP does not represent an irreversible effect, it will be possible to estimate the monetary costs of meeting the sustainability standards (M-ESGAP). The ratio between the sum of M-ESGAP across the environmental and resource indicators (G-ESGAP) and GDP may indicate the 'intensity of environmental monetary unsustainability'.
- Data availability remains the main limitation towards the computation of the indicators that form the ESGAP framework. Detailed data availability scoping is recommended as the next step towards practical implementation.

6.1 Principles of environmental sustainability

73. From a human point of view what matters about the environment is not particular stocks of natural capital *per se*, but the ability of the capital stock as a whole to be able to continue to perform the environmental functions which make an important contribution to human welfare. Hence it is logical, as described above, to define environmental sustainability as the *maintenance of important environmental functions*, and hence the *maintenance of the capacity of the capital stock to provide those functions*. This is towards the strong end of the

weak-strong sustainability distinction referred to above. It does not envisage as necessary a completely non-declining natural capital stock (i.e. it is not in line with 'very strong' sustainability), because some may be redundant in respect of some environmental functions, and environmental functions are not necessarily uniquely performed by particular stocks of natural capital. It may be that other types of capital may engender flows that are acceptable substitutes for some environmental functions. Nor does it envisage the maintenance of all environmental functions, because equivalent welfare may be generated over the long term by other capital stocks (i.e. there is some substitutability between natural and other capitals), while it also need not be assumed that all environmental functions are so important for human welfare that they must be maintained.

74. However, substitutability between different kinds of capital needs to be empirically shown before such substitution is brought about, especially if it is irreversible; and continuing ignorance about many aspects of ecosystem function argues for precaution in permitting the loss of natural capital. The different categories of environmental functions also relate to very different aspects of the natural capital providing them, and therefore criteria for their importance, or criticality, and sustainable use need to be assessed in very different ways, bearing in mind also that each of the criteria needs to be interpreted in a way that reflects the essentially dynamic nature of ecosystems.

75. In a situation of complete knowledge about the contribution of different functions to human welfare, their importance could be evaluated in these terms and the functions thereby deemed to be of high importance related back to the particular stocks of environmental capital which are responsible for them. Unfortunately, there is enormous uncertainty about which functions are important for human welfare and why, especially Life-Support functions, which compounds the difficulty of quantifying their contribution to human welfare. Although techniques of monetary valuation can capture some environmental values, both the techniques and the numbers they produce remain contested and fraught with problems of interpretation, as has been seen. Rather than using such techniques it seems preferable to identify as 'important', or critical (and therefore essential for environmental sustainability), any environmental functions:

- Which cannot be substituted for, in terms of welfare generation, by any other function, whether environmental or not;
- The loss of which would be irreversible;
- The loss of which would risk, or actually entail, 'immoderate losses'.

76. The simultaneous coincidence of uncertainty, irreversibility and possible large costs, or immoderate losses, has long been recognised as an important consideration for environmental policy. Ciriacy-Wantrup (1952)'s classic work prefigured many of the current concerns of sustainability with his development of the concept of 'the safe minimum standard' (SMS).

77. Bishop (1993, p. 73) brings the SMS approach into the context of current environmental discourse by relating it to sustainability: "To achieve sustainability policies should be considered that constrain the day to day operations of the economy in ways that enhance the natural resource endowments of future generations, but with an eye towards the economic implications of specific steps to implement such policies." Here the safe minimum standard has been converted into a sustainability standard. In the terms previously discussed, those activities that entail the possibility of irreversible effects and immoderate costs are now identified as environmentally unsustainable. The SMS approach suggests that policies that constrain or transform those activities towards sustainability should be considered in a framework which seeks to avoid intolerable costs and to achieve the sustainability standard in a cost-effective way, rather than trying to derive the standard itself from normal principles of cost-benefit analysis.

78. If the key consideration for environmental sustainability is the maintenance of the functions that are important for human welfare, then in the first instance at least it is on the 'functions for people' on which attention should be focused. It was noted above that the principal contributions of these functions related to the economy (with a further convenient division into Source and Sink functions), human health and other kinds of human welfare. It was also seen that the 'functions for people' were fundamentally dependent on the Life-Support 'functions of nature'. This suggests that principles of environmental sustainability will need to maintain important environmental functions as follows:

- Source functions — the capacity to supply resources,
- Sink functions — the capacity to neutralise wastes, without incurring ecosystem change or damage,
- Life-Support functions — the capacity to sustain ecosystem health and function, and
- Other Human Health and Welfare functions — the capacity to maintain human health and generate human welfare in other ways.

79. With the present uncertain state of knowledge about ecosystems, and environmental functions generally, it is very difficult to judge which are critical and which are not. It is likely, for example, that *all* the Life-Support 'functions of' natural capital are critical, because it is not clear how natural systems would operate with impaired functions, although research has for some time suggested the existence of environmental thresholds and irreversible change when resilience is lost (Carpenter, 2001; Holling et al., 1996; Holling et al., 1995; Kates and Clark, 1996; Scheffer et al., 2001). There is likely to be some, and perhaps considerable, ecological redundancy — not all species that occur in a given habitat are actually critical to the functioning of that habitat. However, it is not at all clear ex ante which species are, or might be, redundant, but which actually contribute to ecosystem resilience. Science therefore suggests great caution in categorising environmental functions (and, by extension, elements of natural capital such as individual species) as 'non-critical', because of the danger that the loss of such functions may give rise to unsustainable effects.

80. However, in many cases, what counts as an 'unsustainable effect' rather than a sustainable economic cost is a matter of judgement which can only partially be resolved by science. Ethics and the attitude to risk also play a significant role here. It is important that the basis of judgement is articulated clearly, especially as to who is responsible for the effects and who is bearing the costs, and differentiating the contributions played by science, ethics and risk acceptance or aversion.

81. On the basis of these broad criteria, a number of principles of environmental sustainability have been put forward which relate to the generic environmental functions of resource supply, waste absorption and life support. For example, Daly (1991), working with a 'strong' to 'very strong' sustainability framework, has suggested four principles of sustainable development:

    1. Limit the human scale (throughput) to that which is within the earth's carrying capacity.
    2. Ensure that technological progress is efficiency-increasing rather than throughput-increasing.
    3. For renewable resources harvesting rates should not exceed regeneration rates (sustained yield); waste emissions should not exceed the assimilative capacities of the receiving environment.
    4. Non-renewable resources should be exploited no faster than the rate of creation of renewable substitutes.

82. These principles are also among the rules that Turner (1993, pp. 20-21) has formulated "for the sustainable utilisation of the capital stock", the others of which are: correction of market and intervention failures; steering of technical change not only to increase resource-using efficiency but also to promote renewable substitutes for non-renewable resources; taking a precautionary approach to the uncertainties involved.

83. Of these rules, the correction of failures, the nature of technological progress and the steering of technical change are more do to with achieving sustainability than defining principles for it, and are best handled separately. Moreover, rules 2, 3 and 4 may be seen as elaborations of rule 1 relating to carrying capacity. However, in view of the complexity of applying the concept of carrying capacity to human activities, it seems desirable to express it more specifically in terms of those environmental problems that appear most pressing. Such considerations enable the Daly/Turner rules to be reformulated into a set of seven sustainability principles which cover the four core categories of environmental functions (shown in brackets after them) and which are intended to ensure the maintenance of those that are critical, identified by the type of their contribution to human welfare:

    1. Anthropogenic destabilisation of global environmental processes such as climate patterns or the ozone layer (in these cases from excessive polluting anthropogenic emissions into the atmosphere) must be prevented. (*Life Support)*

2. Critical ecosystems, habitats and ecological features must be absolutely protected to maintain biological diversity (especially of species and ecosystems). (*Life Support)*
3. The renewal of renewable resources must be fostered through the maintenance of soil fertility, hydrobiological and biogeochemical cycles and necessary vegetative cover and the rigorous enforcement of sustainable harvesting. *(Source)*
4. Depletion of non-renewable resources should seek to balance the maintenance of a minimum life-expectancy of the resource with the development of substitutes for it. *(Source)*
5. Emissions into air, soil and water must not exceed their critical load, that is the capability of the receiving media to disperse, absorb, neutralise and recycle them, without disturbing other functions, nor may they lead to life-damaging concentrations of toxins. *(Life Support/Human Health)*
6. Landscapes of special human or ecological significance, because of their rarity, aesthetic quality or cultural or spiritual associations, should be preserved. *(Human Welfare)*
7. Risks of life-damaging events from human activity must be kept at very low levels. Technologies which threaten to cause serious and long-lasting damage to ecosystems or human health, at whatever level of risk, should be foregone. *(All)*

84. As noted, of these seven sustainability principles, 3, 4 and, to some extent, 2 seek to sustain resource functions. 5 seeks to sustain waste-absorption functions; 1 and 2 seek to sustain life-supporting environmental services, and 6 other services of human value; and 7 acknowledges the dangers associated with environmental change and the threshold effects and irreversibilities mentioned above.

85. These relations between environmental functions and the sustainability principles (slightly re-ordered) are shown in Table 2 and related to environmental themes. The illustrative principles give clear guidance how to approach today's principal perceived environmental problems. They may need to be supplemented or adapted as new environmental problems become apparent.

86. The application of these sustainability principles permits critical environmental functions, and the critical natural capital which performs them, to be tentatively (because of uncertainties) identified. In this identification it is necessary to pay close attention to the space and scale over which the function is being performed. Given the interconnections between ecosystems, it is possible that what seems like quite a 'local' environmental function is in fact dependent on environmental factors and processes that operate a considerable distance away, or are part of global or regional environmental systems. The application of these principles to environmental functions and the natural capital stock which gives rise to them enables critical natural capital (CNC) to be identified.

Table 2: Functions of natural capital and environmental sustainability principles

Function	Sustainability Objective	Sustainability Principle	Description
Life-Support	Maintain the capacity to sustain ecosystem health and function	Maintain biodiversity (especially species and ecosystems)	Critical ecosystems and ecological features must be absolutely protected to maintain biological diversity, which underpins the productivity and resilience of ecosystems.
		Apply the precautionary principle	Uncertainties should result in a precautionary approach in the adoption of safe minimum standards.
Sink	Maintain the capacity to neutralise wastes, without incurring ecosystem change or damage	Prevent global warming, ozone depletion	Anthropogenic destabilisation of global environmental processes, such as climate patterns or the ozone layer, must be prevented.
		Respect critical loads for ecosystems	Emissions into air, soil and water must not exceed their critical load, that is the capability of the receiving media to disperse, absorb, neutralise and recycle them, without disturbing other functions.
Source	Maintain the capacity to supply resources	Renew renewable resources	The renewal of renewable resources must be fostered through the maintenance of soil fertility, hydrobiological and biogeochemical cycles and necessary vegetative cover and the rigorous enforcement of sustainable harvesting. The latter implies basing harvesting rates on the most conservative estimates of stock levels for such resources as fish; ensuring that replanting becomes an essential part of forestry; and using technologies for cultivation and harvest that do not degrade the relevant ecosystem and deplete neither the soil nor genetic diversity.
		Use non-renewables prudently	Depletion of non-renewable resources should seek to balance the maintenance of a minimum life-expectancy of the resource with the development of substitutes for it.
Human Health and Welfare	Maintain the capacity to maintain human health and generate human welfare in other ways	Respect standards for human health	Emissions into air, soil and water must not exceed dangerous levels for human health.
		Conserve landscape/amenity	Landscapes of special human or ecological significance, because of their rarity, aesthetic quality or cultural or spiritual associations, should be preserved.

Source: Adapted from Ekins and Simon (1999); Ekins et al. (2003)

87. Clearly these sustainability principles interact at a deep level with many economic and social dimensions, which are beyond the scope of this paper. Guiding human economies and societies to operate in line with these principles will require many other economic and social factors to be taken into account, and may not be feasible without fundamental changes in human aspirations, institutions and modes of social organisation.

6.2 Deriving environmental standards

88. In order to make the above sustainability principles operational, environmental reference points need to be defined against which current environmental states, pressures or impacts may be compared. These reference points may be environmental limits, environmental standards, or environmental targets.

89. An *environmental limit* represents a point beyond which non-linear dynamics significantly change the functions and/or structure of an ecosystem. Not all ecosystems are subject to such behaviour (Schröder et al., 2005), as the sensitivity of ecosystems to pressures can vary greatly. There is some degree of normative judgement involved in the identification of environmental limits. Environmental sustainability reference points are considered limits when their transgression leads to non-linear dynamics that result in undesired consequences. What constitutes an undesired consequence may be significant deviations from natural conditions (e.g. from the natural variability of the Holocene climate (Rockström et al., 2009a; Steffen et al., 2015)) or net losses in the provision of goods and services. Beyond those judgements, locating the position of the limit is a task for natural science. Nevertheless, limits are not universally fixed values, since the concrete position of a tipping point is influenced by other relevant biophysical parameters, the type of pressure or receptor or the resilience of the system itself (Bobbink and Hettelingh, 2011; Scheffer, 2009; UBA, 2004).

90. *Environmental standards* are intended to depict the stock and quality of natural capital required to provide the necessary goods and services for society, while keeping a safe distance from environmental limits, taking account of the associated uncertainties. Like environmental limits, environmental standards are primarily science-based although value judgements are needed to define what a safe distance and acceptable service levels are. The decision in respect of the former depends on how society deals with risk and uncertainty, irreversibility and the threat of immoderate losses. As for the latter, there are different ways of defining an acceptable level of ecosystem goods and services. For instance, one could set such a level based on minimum material and emission requirements for a decent life (Di Giulio and Fuchs, 2014; Lamb and Rao, 2015; Rao and Baer, 2012; Steinberger and Roberts, 2010), projections of future demand (Tilman et al., 2011; UNEP, 2011), health concerns (WHO, 2000, 2005; WHO Regional Office for Europe, 2013) or a range of ecosystem valuing techniques (de Groot et al., 2002). Once information on acceptable functioning levels is available, environmental standards can be determined based on the benefits-stock

relationship that relates the ecosystem goods and services provided by natural capital to its quantitative and/or qualitative status.

91. *Environmental targets* usually deviate from the previous science-based reference points, as the adoption of targets is the result of weighing not only environmental concerns, but also issues associated with technological feasibility, economic consequences and other politically relevant factors. Targets are derived from policy documents and reflect people's desires to the extent that policies are aligned with social preferences.

92. Because environmental limits fall short from representing all the relevant functions of natural capital, and because scientific knowledge is one of many factors considered when adopting environmental targets, environmental standards seem more appropriate to characterise environmental sustainability. For life-support and sink functions, renewable resources, and standards based on human health-related principles can be derived from physical sciences, although the knowledge base in each of these areas differs considerably. Functions related to maintaining a minimum life-expectancy of non-renewable materials or amenity are subject to broader social preferences. In all cases, standard setting leaves significant room for value judgements when defining the level at which environmental functions need to be maintained and/or how risk and uncertainty are dealt with (precautionary principle).

93. Thus standards relating to the sustainability principles 1-5 above will need to be derived principally from environmental science. The sixth principle is rooted entirely in aesthetic and cultural considerations, which are outside the realm of environmental science. It is not therefore possible to specify in general terms which landscapes should, or should not, be conserved. On the other hand, it is also not possible to conceive, in the contemporary context, of an environmentally sustainable society that makes no attempt to identify outstanding landscapes or to conserve the ones that have been identified. Most countries have now enacted landscape designations of various kinds, internationally, nationally and at sub-national levels. Standards under this principle would assess the extent of these designations, and the rigour with which they were observed. The seventh principle is essentially a statement of adherence to the Precautionary Principle, and acknowledges that an environmentally sustainable society will choose to forego even quite large benefits rather than run even a very small risk of incurring potentially catastrophic costs in the future. Environmental science is, again, the best source of insight into the existence of such risks, and the standards of environmental quality which are necessary to avoid them.

94. While the ideas of critical natural capital and strong sustainability are intended to avoid the routine trade-offs associated with weak sustainability, yet even within this concept, trade-offs need to be confronted and choices made. Pearson et al. (2012), building explicitly on Brand (2009) and Spash et al. (2009), distinguish between the utilitarian (based on consequentialist reasoning) and 'protected' (based on deontological reasoning) motivations that may be differently reflected in the principles. They usefully differentiate between tragic decisions, which involve trade-offs between protected values; taboo decisions, which involve a

trade-off between protected and utilitarian values; and routine decisions, where the trade-off only involves utilitarian values. As environmental damages become more serious, and environmental prognoses become more threatening, trade-off decisions of all three kinds, even related to critical natural capital, are likely to become more frequent and unavoidable.

95. Setting environmental standards is not a straightforward task. The maintenance of important environmental functions would normally be related to impact indicators. However, in practice it is not always possible to define environmental sustainability in terms of impacts, as the current knowledge base is insufficient to identify the environmental functions that can be considered critical or to define the acceptable level at which some of those functions should be maintained. Likewise, the dynamics governing the relationship between state and impacts are often not only complex and of a non-linear nature, but also subject to temporal and spatial variability. For these reasons, Ekins (Ekins and Simon, 1999; Ekins et al., 2003) used the broad sustainability principles of Table 2, that relate to generic functions, as a provisional way of deriving environmental standards across a wide range of relevant environmental and resource issues, with the standards expressed as indicators of the state of the natural capital or as the pressure exerted upon it. There is a broad, yet scattered, literature on environmental standards. Table 3 provides an illustrative compilation of available standards and maps them against the sustainability principles presented previously. The extent to which these standards are based on observed data or are based on expert judgement varies from case to case. No standards have been found for the Source functions of non-renewable materials such as fossil fuels, metals or non-metallic minerals based on minimum-life expectancy.

96. Of course it is desirable that, in seeking to meet one environmental standard, other environmental standards are not violated. The existence and extent of trade-offs of this kind will vary between different issues.

Table 3: Environmental sustainability principles, standards and indicators

Function	Principle	Topic	Pressure/State	Standard	References	ESGAP Indicator
Source	Renew renewable resources	Forest resources	Annual fellings	Fellings / Net Annual Increment	EEA (2017b)	Forest utilization rate
		Fish resources	Condition of fish stocks	Fishing mortality consistent with Maximum Sustainable Yield Spawning stock biomass consistent with Maximum Sustainable Yield	EC (2010)	Fish stocks within safe biological limits
		Groundwater resources	Status of groundwater body	Good quantitative status as defined in European legislation	EC (2009)	Groundwater bodies in good quantitative status
	Use non-renewables prudently	Soil	Soil erosion rate	Tolerable soil erosion rate	Huber et al. (2008); Jones et al. (2004); Verheijen et al. (2009)	Area with tolerable soil erosion
Sink	Prevent global warming, ozone depletion	Climate change	Greenhouse gas emissions	Per-capita GHG emissions consistent with global climate targets	EC (2018)	Emissions / annual allowance
	Respect critical loads for ecosystems	Terrestrial ecosystems	Concentration of air pollutants in terrestrial ecosystems	Critical levels of O_3	Mills et al. (2007)	Cropland area exposed to safe ozone levels
				Critical levels of O_3	Karlsson et al. (2007); Karlsson et al. (2003)	Forest area exposed to safe ozone levels
			Load of air pollutants in terrestrial ecosystems	Critical loads of heavy metals	Hettelingh et al. (2017); Hettelingh et al. (2015)	Ecosystems not exceeding the critical loads of cadmium / lead / mercury

				Critical load of eutrophication	CLRTAP (2017)	Ecosystems not exceeding the critical loads of eutrophication
				Critical load of acidification	CLRTAP (2017)	Ecosystems not exceeding the critical loads of acidification
		Surface water bodies	Chemical status	Good chemical status as defined in European legislation	European Parliament and European Council (2008)	Surface water bodies in good chemical status
		Groundwater	Chemical status	Good chemical status as defined in European legislation	EC (2009)	Groundwater bodies in good chemical status
Life support	Maintain biodiversity (especially species and ecosystems)	Terrestrial ecosystems	Local Biodiversity Intactness Index	Local Biodiversity Intactness Index	Steffen et al. (2015)	Terrestrial area with acceptable biodiversity levels
		Freshwater ecosystems	Ecological status	Good ecological status as defined in European legislation based on biological, physicochemical and hydromorphological parameters	EC (2003)	Surface water bodies in good ecological status
			Blue water consumption	Blue water consumption / Mean quarterly flows	Raskin et al. (1997)	Freshwater bodies not under water stress
Human health and welfare	Respect standards for human health	Air pollution	Concentration of air pollutants	Critical levels of air pollutants	WHO (2005)	Population exposed to safe levels of $PM_{2.5}$, PM_{10} and NO_2
		Drinking water	Water samples	Safe drinking water criteria as defined in European legislation based on microbiological, chemical and other parameters	European Council (1998)	Samples that meet the drinking water criteria

	Conserve landscape and amenity	Bathing waters	Concentration of bacteria	‘Excellent’ quality criteria as defined in European legislation based on the concentration of Intestinal Enterococci and Escherichia Coli in recreational waters	EC (2002)	Recreational water bodies in excellent status
		Natural and mixed world heritage sites	Conservation outlook	Good conservation outlook based on three elements: the current state and trend of values, the threats affecting those values, and the effectiveness of protection and management	Osipova et al. (2014)	Natural and mixed world heritage sites in good conservation outlook

6.3 Calculating the Sustainability Gap

97. Once the standards according to these principles and criteria have been defined, then the difference between these standards and the environmental state or pressure indicator showing the current situation may be described as the 'Environmental Sustainability Gap' (ESGAP), in physical terms, between the current and a sustainable situation (see Ekins and Simon (1998, 1999, 2001, 2003) for further discussion of the thinking behind the ESGAP concept and details, also summarised below, as to how the indicator may be derived). ESGAP indicates the degree of consumption of natural capital, either in the past or present, which is in excess of what is required for environmental sustainability. For the state indicators, the gap indicates the extent to which natural resource stocks are too low, or pollution stocks are too high. For pressure indicators, the gap indicates the extent to which the flows of energy and materials which contribute to environmental depletion and degradation are too high. ESGAP indicates in physical terms the extent to which economic activity is resulting in unsustainable impacts on important environmental functions.

98. The ESGAP idea can be developed further to give an indication of the time that would be taken, on present trends, to reach the standards of environmental sustainability. Thus Ekins and Simon (2001, pp. 11ff) use calculations of various stresses across seven environmental themes in the Netherlands for two years, 1980 and 1991, measured in various 'theme equivalent' units (taken from Adriaanse (1993)), to derive both ESGAPs and Years-to-Sustainability (YS) indicators for each theme.

99. Assuming that ESGAP does not represent an irreversible effect, it will be possible, through abatement or avoidance activities (for environmental pressures) or restoration activities (for environmental states) to reduce the ESGAP such that the sustainability standard is achieved. These activities may have a cost. For every (non-irreversible) ESGAP, therefore, there will in principle be a sum of money corresponding to the least cost, using currently available technologies, of reducing the physical ESGAP to zero. This cost, for each function, may be termed the monetary ESGAP, or M-ESGAP. It may be computed by compiling an ascending marginal abatement (or resource efficiency) cost curve for the technologies which need to be deployed to reach the sustainability standard. Such a curve has become familiar through that for CO_2 compiled both globally and for different countries by McKinsey (2007).

100. Because the M-ESGAPs for different functions are all expressed in the same unit, it would be convenient to aggregate them to compute an overall Gross ESGAP, or G-ESGAP, for the economy as a whole. This could then be used to indicate the economic 'distance' to environmental sustainability in relation to the present situation and practices. Assuming the standard remains unchanged, the G-ESGAP will decrease either as the environment improves (reducing the 'physical' sustainability gap), or as technologies of abatement, avoidance or restoration become cheaper. Expressed as a ratio, G-ESGAP/GDP may indicate the 'intensity of environmental monetary unsustainability'.

101. The purpose of this family indicators would be both to suggest targets for public policy, the achievement of which would indicate a situation consistent with environmental sustainability, and to indicate the costs of that achievement, on the basis of current technologies, which is clearly of interest for policy making. It would also enable the overall environmental impacts of different economies to be compared.

102. This is how a strong sustainability indicator could deal with environmental issues, but there is of course an open possibility of including consideration within the indicator of social and economic issues that contribute to well-being. This would substantially increase the challenge of developing a single indicator, because well-being, like development, is a very complex concept that has multiple qualitative dimensions that are difficult to capture in numbers and that have few thresholds that are comparable to environmental sustainability standards. Much easier would be to combine the strong environmental sustainability indicator with the HDI, to capture the development dimension, to create a 'super-index' of 'environmentally sustainable development' which was, however, easy to disaggregate into its component parts.

6.4 Illustrative example of the ESGAP

103. Columns 1 and 2 of Table 4 show Adriaanse's environmental stresses, measured in theme-equivalent units, such as CO2e for greenhouse gases. Column 3 gives his sustainability standards – some of which are policy targets –, calculated from an assessment at the time of sustainable environmental pressures or states (where the standards relate to global environmental issues such as climate change, the Netherlands' standard assumes corresponding standards for other countries – the Netherlands, or any other country, cannot effectively address such issues on their own). The next two columns calculate the ESGAP for each theme for each year, where ESGAP is the distance in theme equivalent units between current conditions and the sustainability standard. Thus in the ESGAP columns the standard is subtracted from the stress for each year. The next two columns normalise this ESGAP (N-ESGAP) as shown. It can be seen that the N-ESGAP for climate change, for example, was reduced by 17% from 1980-91, while that for disturbance increased by 30%. Thus, for climate change, on a continuation of the 1980-91 trend, the Netherlands would reach its calculated sustainability standard in 54 years. Clearly, whether the climate change problem overall was 'solved' in this period would depend on whether the standard for the Netherlands turned out to be sufficiently stringent, as well as whether other countries also reduced their emissions to attain their corresponding standard by the end of the period. The total N-ESGAP is obtained by simply summing the individual ESGAPs, implying that, in the absence of a robust weighting methodology, all the environmental issues have the same importance for sustainability. It can be seen that the total N-ESGAP over 1980-91 was reduced by 18% over this period. (Box 6 discusses issues related to weighting an aggregation in relation to the calculation of indexes.) The final column gives the years required to reach the sustainability standard (to reduce ESGAP and N-ESGAP to zero) for each environmental theme, given the trend established from 1980-91. It can be seen that the total N-ESGAP will be reduced to zero after 51 years, although

individually climate change, eutrophication, dispersion and waste disposal will still not have reached their sustainability level by then.

Table 4: Various Sustainability Measures for the Netherlands

	Environmental stress (ES)		Sustainability standard (SS)	Sustainability Gap (ESGAP) (ES-SS)		Normalised ESGAP (100*ESGAP /SS), EPeq		Years to sustainability YS
	1980	1991		1980	1991	1980	1991	
Climate change, Ceq	286	239	10	276	229	2760 100[1]	2290 83	54
Ozone depletion, Oeq	20000	8721	0	20000	8721	na	na	8.5
Acidification, Aeq	6700	4100	400	6300	3700	1575 100	925 59	16
Eutrophication, Eeq	302	273	86	216	187	251 100	217 86	71
Dispersion, Deq	251	222	12	239	210	1992 100	1750 88	80
Waste disposal, Weq	15.3	14.1	3	12.3	11.1	410 100	370 90	102
Disturbance, Neq	46	57	9	37	48	411 100	533 130	never
TOTAL	na	na	na	na	na	7399 100	6085 82	**51**

Notes: [1] The second entry in this column has converted the N-ESGAP to index numbers, with 1980=100. the units of each environmental theme are theme-equivalent units, e.g. for greenhouse gases CO2e.

Source: Ekins and Simon (2001)

104. It may also be noted from Table 4 that the various measures cannot all be derived for all the environmental themes. For ozone depletion, the sustainability standard of 0 means that no figure for normalised ESGAP can be derived, although there is no problem computing the years to sustainability (YS). For disturbance the increasing trend from 1980-91 means that no figure for YS can be given. However, in this case there is no problem with normalising the stress, and the increasing trend is factored into the total normalised figures, increasing the length of time before sustainability overall will be reached (removing disturbance from the total actually reduces the time before sustainability is reached to 43 years). Both the trend in the normalised ESGAP (N-ESGAP) and Years-to-Sustainability (YS) indicators give useful information on the achievement of sustainable development.

105. Alternatively, the overall years to sustainability (YS) figure could be taken to be the maximum of the various themes, although in Table 4 the increasing trend for Disturbance would on this basis suggest that environmental sustainability would never be achieved. A further undesirable result of this interpretation might be to concentrate policy maker attention on this indicator rather than the full range of environmental issues.

106. In any case the most important message from these indicators is not so much the level of a particular indicator in a certain year, but how the indicator develops over time: whether the ESGAP, YS and M-ESGAP are decreasing, and how fast.

107. The reduction in N-ESGAP in relation to some base year (here 1980) and the YS indicators could provide easily communicable information against which progress towards environmental sustainability could be monitored, both by individual environmental theme and in aggregate. There have been increasing calls for such an indicator to compare with, and offset the influence of, GDP[8]. An index like N-ESGAP, and the trends derived from it, do not require scientifically dubious conversions of different environmental impacts to a common environmental unit (such as, for example, the 'global hectare' unit of the 'ecological footprint', developed by Wackernagel and Rees (1996), as discussed above), but still enables aggregate progress towards environmental sustainability to be expressed, analogously to the way the UNDP's Human Development Index in its annual *Human Development Report* (UNDP, 2016a) combines indicators of income, health and education to indicate progress on human development, as described earlier. Some such way of simplifying the message presented by frameworks of indicators in the environmental field is likely to be necessary if the policy objectives of the environmental dimension of sustainable development are to be widely understood.

Box 6: Weighting and aggregation

When constructing a composite index, the weighting and aggregation processes are particularly sensitive and subjective, and therefore open to external criticism in view of the lack of consensus on the best method. As noted by Hsu et al. (2013), the weighting is as much of a political as a scientific process. The selection of the weighting and aggregation method leads to inevitable judgements on the importance of and substitutability between the different types and functions of natural capital represented in the underlying dashboard. In the following paragraphs, we review briefly the choices made by the three main composite indicators addressed in this report, namely HDI, EPI and SDG Index.

Weighting

The weights assigned to the indicators that will be aggregated is, a priori, a reflection of their importance, yet this does not necessarily represent how much they impact the final score (Becker et al., 2017). HDI assigns the same importance to each of the three components of the final index and the two components of the education dimension (UNDP, 2016b). This is also the case for the SDG Index. After several expert consultations, Sachs et al. (2017) did not manage to find an agreement around the

8 See, for example, Stiglitz et al. 2009

weighting issue. For this reason, they decided to assign equal weights to all the indicators within each SDG and to all SDGs. In contrast, the EPI (Yale University, 2018) describes a more complex weighting process, EPI has a three-step weighted aggregation system to translate the information in the (1) dashboard of indicators to environmental issues, (2) environmental issues to policy priorities (environmental health and ecosystem vitality), and (3) policy priorities to the single composite index. In the 2018 edition, weighting within environmental issues and the policy priority related to 'environmental health' is based on the relative contribution of each indicator to global disability-adjusted life-years. Within the other policy priority (ecosystem vitality) weighting is more subjective, but tries to reflect the relative seriousness of each issue. Within each issue, the same weights are used except when referring to climate where indicators for GHGs are weighted based on their contribution to current climate forcing. Finally, the 'environmental health' and 'ecosystem vitality' policy priorities are weighted 40% and 60% respectively, compared to equal weighting in the 2016 edition (Hsu and et al., 2016). This decision is informed by the variance of each policy priority.

Aggregation

The choices made in the aggregation process are representative of the stand taken in the weak/strong sustainability debate. With the weighted arithmetic mean poor performance in one dimension is linearly compensated for by high achievement in another one and is therefore best suited for weak sustainability where full substitution between different types of capital is assumed. With a weighted geometric mean, on the other hand, low scores in any dimension are directly reflected in the final composite indicator. Thus, a geometric mean seems more appropriate when limited substitution capacity is assumed, i.e. the strong end of the weak-strong sustainability continuum. Last, strong sustainability (i.e. no substitution) is best characterised when using the lowest score as only value in the aggregation process. In such cases, a country's performance would equal its performance in the worst dimension.

Historically, HDI used an arithmetic mean to aggregate its three components, but shifted to a geometric mean in 2010 (UNDP, 2010). By doing so, they ensured that poor performance in any of the pillars of HDI (health, education and income) would not go unnoticed. Still, the aggregation used to generate the score for the education dimension uses an arithmetic mean. EPI opted for a weighted arithmetic mean in all steps. As they argue, "EPI sacrifices sophistication in favor of transparency" (Yale University, 2018). The 2017 SDG Index (Sachs et al., 2017) aggregates indicators within and across SDGs. In the first step (aggregation within), they generate single scores using an arithmetic mean arguing that each of the underlying indicators refer to complementary priorities. When aggregating across SDGs to generate the final SDG Index, the authors favoured a geometric mean to avoid assumptions of perfect substitutability. Nonetheless, given that the country ranking using the geometric and arithmetic means only varies minimally, they ended up using an arithmetic mean to ease the interpretation of the results.

6.5 Practical analysis of critical natural capital and strong sustainability

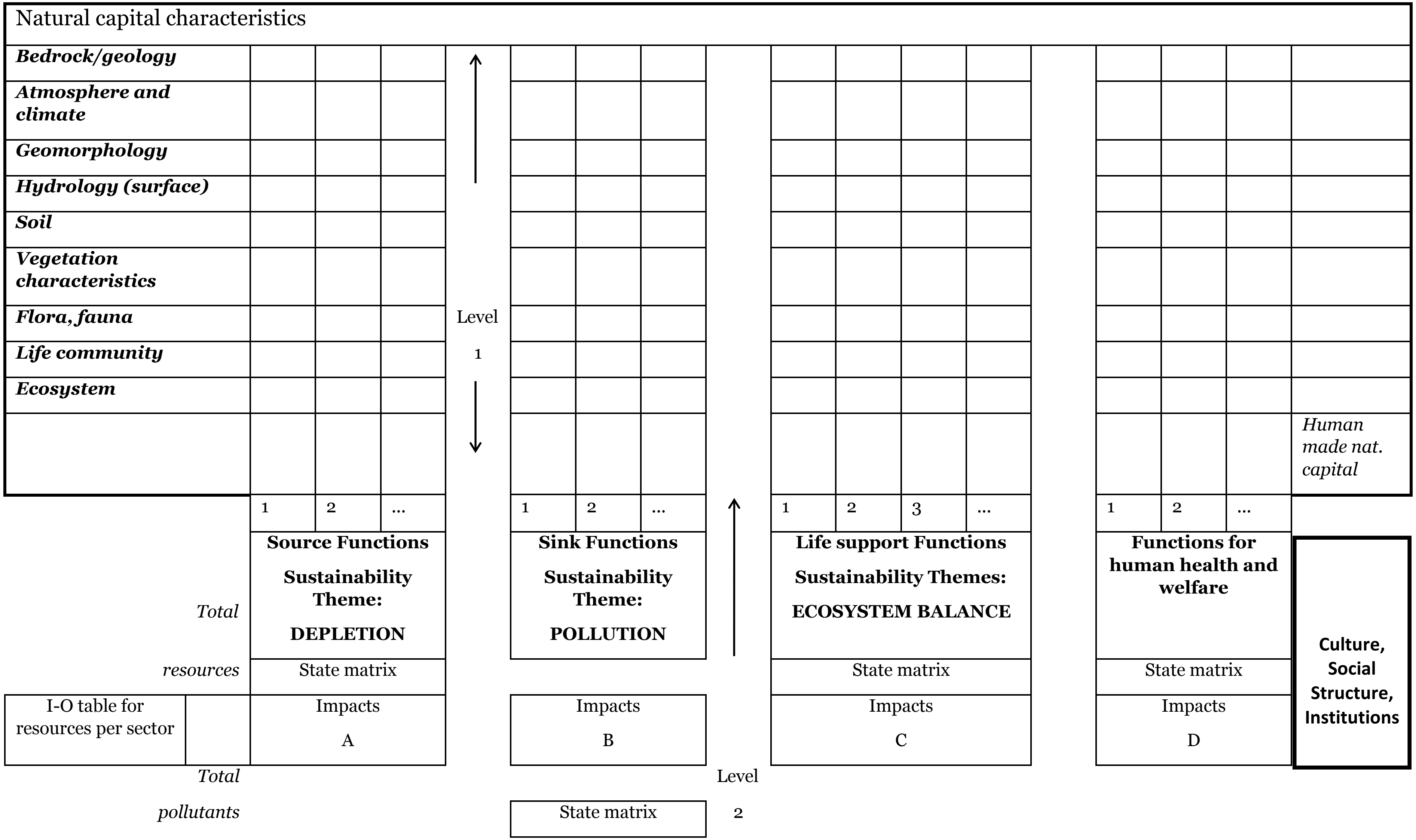
108. These ideas have been drawn together previously into a framework (called the CRITINC framework, after the project that developed it, see Ekins et al. (2003)) for the classification of critical natural capital (CNC) as set out in Figure 3. This framework remains illustrative and in the context of practical ESGAP

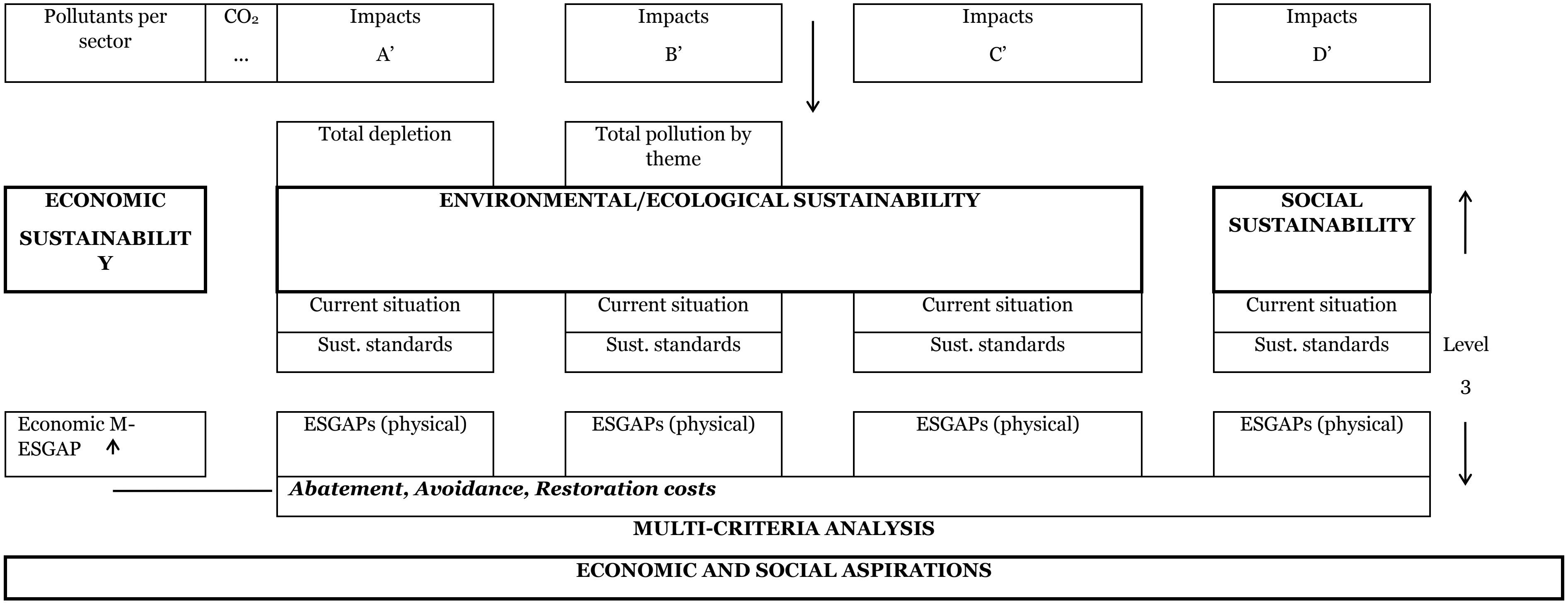
implementation would benefit from further development considering the ongoing progress on Experimental Ecosystem Accounting within the UN-SEEA, and on the global and regional assessments of biodiversity and ecosystem services undertaken by IPBES.

109. The upper rows of Level 1 in Figure 3 are the nine major ecosystem characteristics (see Ekins (2011)) which give rise to the environmental functions emanating from natural capital, including cultivated natural capital. Below these ecosystem characteristics (and on the right of Figure 3) are characteristics of the non-living human-made environment (e.g. landscape features such as stone walls, or features of the built environment), which also give rise to environmental functions.

110. The functions emanating from the identified environmental characteristics are classified in four categories: source (the capacity to supply resources), sink (the capacity to neutralise wastes, without incurring ecosystem change or damage), life support (relating to ecosystem health and function) and functions for human health and welfare. Thus the first three sets of functions are purely environmental in their formulation, while the fourth function category is specifically concerned with impacts on people. The matrices in Level 1 show which characteristics give rise to which functions. The entries in the matrices may be descriptive and/or quantitative. They are likely to contain state indicators of the natural capital stock from which the relevant function emanates. The functions deriving from the non-living human-made environment are likely to be largely functions in the fourth category connected to history, culture, amenity and aesthetic appreciation.

Figure 3: Overall view of the CRITINC framework




Pollutants per sector
CO₂
...
Impacts
A’
Impacts
B’
Impacts
C’
Impacts
D’
Total depletion
Total pollution by theme
ECONOMIC
SUSTAINABILIT
Y
ENVIRONMENTAL/ECOLOGICAL SUSTAINABILITY
SOCIAL SUSTAINABILITY
Current situation
Sust. standards
Current situation
Sust. standards
Current situation
Sust. standards
Current situation
Sust. standards
Level
3
Economic M-ESGAP
ESGAPs (physical)
ESGAPs (physical)
ESGAPs (physical)
ESGAPs (physical)
Abatement, Avoidance, Restoration costs
MULTI-CRITERIA ANALYSIS
ECONOMIC AND SOCIAL ASPIRATIONS

111. Moving down to Level 2, the sustainability concern (or theme) with regard to the source functions is *depletion*. It may be that particular state indicators from the Level 1 matrices encapsulate the resource provision from particular functions (e.g. stocks of fish), in which case these indicators can be reproduced here to give a matrix of state indicators for the source functions. Similar matrices of state indicators may be produced for the sink (e.g. concentration of a pollutant in a lake), life-support (e.g. species diversity in an ecosystem, landscape patchiness/mosaic, number of reserves or similar elements in the landscape that can provide ecological memory to disturbed areas, the number of corridors for birds, plants, wildlife, etc.) and human health and welfare (e.g. existence of human-made landscape features) functions.

112. Depletion is caused by economic activities of production and consumption. On the left of Level 2 is a physical economic input-output (I-O) table. The rows of the I-O table are of depletable resources and, further down, of polluting emissions. The columns of the I-O table are of the usual economic sectors and final demand categories (including households). The resource rows show the inputs of the various resources into the different economic sectors and final demand, giving entries for the depletion of the source functions by particular economic activities, and the totals then feed across to the source functions, to form Impact Matrix A. Depleting activities can also affect sink functions (Impact Matrix B). The classic example is the depletion of water resources. For example, reducing the water flow in a river can greatly reduce the river's ability to neutralise pollution. Depleting activities can also have an impact on life-support functions (where, for example, it reduces biodiversity) and human health and welfare functions (e.g. where water abstraction dries up rivers, or construction projects destroy valuable landscapes), and these are represented in the Impact Matrices C and D (see Ekins and Simon (2003)).

113. The relationship of the economic accounts to environmental flows in this way is generally consistent with the approach advocated within UN–SEEA, including considerable development of physical I-O tables (PIOT), and environmentally extended input output (EEIO) accounting, to match the monetary I-O tables which are a standard feature of national economic accounting. The Netherlands was a pioneer in generating environmentally extended input-output (EEIO) tables in the late 1980s (de Haan and Keuning, 1996) where originally emissions are disaggregated by economic sector and presented very much as shown in the left-hand section Figure 3. Since then, the compilation of certain environmental accounts such as GHG emissions, air pollutants, material and energy flows has become mandatory in Europe (European Parliament and European Council, 2014).

114. Other recent developments of EEIO accounting may be mentioned here, although detailed discussion of this topic is beyond the scope of this paper. Around 10 years ago, several international projects started compiling multi-regional EEIO tables, which go beyond the activities of national statistical offices by reconciling and trade-linking monetary supply and use tables from different countries into a single database (Tukker and Dietzenbacher, 2013). These databases commonly

contain more environmental data than official datasets and may include among others land use, water use, biodiversity-related data. Thus, multi-regional EEIO databases allow the estimation of a variety of environmental footprints. It may be noted that the calculations of Table 3 are based on territorial (production) impacts or emissions, but in principle such a table could also be computed on a consumption basis if desired, although data limitations in many (especially developing) countries would make such exercises challenging and very approximate in practice.

115. Figure 3 is therefore very much in line with and a supplement to, rather than a departure from, current environmental-economic accounting practice, in which these physical flows are related not only to the economic sectors from which they derive, but also to the environmental functions on which they impact.

116. In addition to causing depletion of resources, and their resulting impact on environmental functions, economic activities also emit pollutants, and these are shown in Figure 3 in the 'Pollutants per sector' matrix, where the rows are different pollutants, and the columns are the economic sectors feeding down from those of the I-O table. At the right of the 'Pollutants per sector' matrix is a column totalling all the different pollutants (including net exports and imports of pollutants). The different pollutants that are the rows of the 'Pollutants per sector' matrix then feed across to the different environmental functions. They may have an impact on the source functions (e.g. acid pollution may kill trees, water pollution may kill fish), and these impacts are recorded in Impact matrix A'. The total depletion of source functions, recorded below Impact Matrix A', is therefore made up of the depletion recorded in both matrices A and A'.

117. The pollutants will be received by different environmental media and this is recorded in Impact Matrix B', as per the sink functions. The columns of pollutants in this matrix, appropriately weighted, will add to give the total pollutants per environmental theme. The pollutants may also have an impact on life-support functions (e.g. carbon dioxide on climate regulation) and these are recorded in Impact Matrix C'. Pollution may also have impacts on human health and welfare functions (e.g. air quality and respiratory disorders, making places unsuitable for recreation, or reducing the visibility of landscapes). These impacts are recorded in Impact Matrix D'. So far the information system described has simply recorded the impacts of activities of depletion and pollution on different environmental functions. Level 3 of Figure 3 introduces the concept of sustainability.

118. As noted at the start of this paper, sustainability with reference to human situations is widely recognised to have economic and social, as well as environmental, dimensions. However, the focus of this paper is environmental sustainability, and the economic and social dimensions of sustainability are only considered where they are affected by the use of natural capital. Thus economic sustainability, on the left of Figure 3, is only relevant here insofar as it is affected by the negative impact of human activities on environmental functions. Similarly, on the right of Figure 3, social sustainability is only relevant here insofar as it is affected by the negative impact of human activities on environmental functions

for human health and welfare (e.g. the loss of recreation opportunities in the natural environment may lead to vandalism or other anti-social behaviour).

119. In line with the seven principles of environmental sustainability laid out earlier, it is possible to derive sustainability standards for the use of the Source and Sink functions, and sometimes for the Life-Support and Human Health and Welfare functions. Some of these standards will be locally specific (e.g. critical loads of particular ecosystems); some will be framed in national terms (e.g. air quality standards for human health); some may be related to global impacts (e.g. carbon emissions consistent with climate stability). These standards may be expressed in terms of state or pressure indicators, where the former shows the minimum threshold of the natural capital stock that is necessary for the function to be maintained, and the latter shows the maximum pressure that the natural capital stock can withstand, while maintaining the function[9].

120. The difference between the current situation, the state of the natural capital stock, or the pressure being put upon it, and the sustainability standard, may be described as the 'environmental sustainability gap' (ESGAP) for that function, as discussed above. ESGAPs will be expressed in physical terms and may be interpreted as the physical 'distance' to environmental sustainability in relation to the present situation and practices. It is these physical 'distances' that indicate that critical natural capital (CNC) is being depleted[10]. The purpose of the framework of Figure 3 is to enable the actual stock of CNC which is being depleted to be identified, by tracing back the functions to the environmental characteristics from which they derive. The framework also permits the depleting activity to be identified so that policy can be targeted where desired.

6.6 Data availability and other practical issues

121. In taking forward the question of whether and how to construct and make fully operational an indicator of strong environmental sustainability, there are many practical issues that would need to be addressed. There is, for example, the question of whether the index should be related to some defined 'sustainable' level such as the ESGAP, discussed in detail above, or whether it should be expressed in terms of an absolute level of environmental goods and services. In the former case, as with the ESGAP, the indicator could be expressed in terms of a

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9 It may be noted that this is in fact the way practical policy making has proceeded in a number of areas. For example, the UNECE Second Sulphur Protocol was intended to reduce depositions of sulphur dioxide across Europe such that no ecosystems would experience exceedance of their critical load (see http://www.unece.org/env/lrtap/fsulf_h1.htm); and the Copenhagen Accord of 2009 (see http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf) acknowledged that emissions of greenhouse gases (GHGs) should be controlled such that the global average surface temperature rise was limited to 2°C. This implies a maximum further emission of GHGs of something less than half a trillion tonnes of carbon (Allen et al. 2009), which in principle could be divided between different countries. Such calculations underpin the sustainability standards in Table 3.

10 It needs to be stressed that environmental sustainability is a dynamic concept. Ecosystems that generate goods and services or functions develop, evolve, go through cycles of build-up, deterioration, and reorganisation. Hence, the physical 'distances' indicated by ESGAP may vary both in time and space. Policy makers need to monitor and understand the dynamics of the ecosystems that generate the flow of goods and services and interpret the ESGAP figures accordingly.

'distance to target', which is a desirable kind of indicator for policymakers, because they are used to setting targets (indeed, they routinely do so for all issues they consider to be important), and because 'sustainability' is then defined in terms of these targets, allowing the indicator to show whether progress in a given period is towards or away from environmental sustainability, what the distance to the sustainability goal is and how long it will take to get there on current trends, or, indeed, whether environmental sustainability has been achieved.

122. Quite apart from the sustainability standard itself, there is then the issue of the *levels* or *scales* at which environmental sustainability could be defined. Some issues (e.g. climate change, the high seas) are global issues; some are regional issues (e.g. major watersheds and rivers, regional seas); some are national or local issues. Overwhelmingly, however, environmental policy making is carried out at a national level (with, in Europe, the European Commission playing an important role), and that is the level at which policy makers will be most able to act on the sustainability indicator to be developed. That means that global, regional and local issues will need to be translated to a national-level equivalent. This is a key and potentially controversial issue. A number of approaches to downscaling global issues have been proposed, and sensitivity analysis around different approaches could be carried out to see how they affected the ESGAP, with a view to adopting a central approach that seemed to command the most scientific or other consensus. For example, in respect of climate change, there is agreement that all countries will need to get to net zero emissions at some point in this century. We could compute different countries arriving at net zero by different dates in line with the principle of CBDR–RC[11]. These sorts of decisions should be made in consultation with stakeholders.

123. There are also important issues of data availability in terms of the ability actually to construct the sustainability indicator for different countries. Here a pragmatic approach would be to proceed with the data resources of those countries that have access to the most detailed data (e.g. the EU), in order to construct the best possible indicators and couple this with a detailed scoping of data availability in other carefully chosen country contexts. In the 'data-rich' countries, an 'ideal' ESGAP would be constructed taking into consideration a range of indicators for all the important environmental functions. For countries with less data, the structure of environmental functions would be maintained, but fewer indicators would be available to feed into it. The 'lead' indicators for each function would be those that were available for every country, so that a similar ESGAP, with the same indicators, could be constructed for each country. Other indicators would then be included in the ESGAP structure for those countries where more data was available to enrich the overall functional representation.

124. The global availability of data relevant to the ESGAP should be regarded as being in a state of flux, given the wide range of existing initiatives focusing on compilation and creation of environmental data—for example the ongoing efforts

[11] Common but differentiated responsibilities and respective capabilities, as enshrined in the UN Framework Convention on Climate Change, Paris Agreement on Climate Change, and many other international agreements.

in 50+ countries in accordance with SDG17.19 and 15.9 to compile environmental accounts using the UN–SEEA standard, the experimental ecosystem accounts (EEA) and complementary Framework for Development of Environmental Statistics.

125. The above approach was taken with both the SDG indicators, and the European Commission's indicators for resource efficiency (see EC (2011)). Currently, the EEA and its European Topic Centres, the JRC and Eurostat produce a wealth of environmental data and indicators that can be used to compute the physical ESGAP. Following the structure of Table 3, Table 5 provides a list of data sources that can be used to compute the ESGAP. In many cases, these indicators show the policy gap, i.e. the distance between current performance and a policy goal. Under these circumstances, the computation of the ESGAP requires processing the raw data reported by countries under different policies so that the ultimate indicator can be aligned with science-based standards instead of with policy targets. In other areas such as biodiversity, the data required is found elsewhere.

Table 5: Potential data sources to compute the physical ESGAP

Function	Topic	Pressure/State	Data sources
Source	Forest resources	Annual fellings	EEA (2017b)
	Fish resources	Condition of fish stocks	EEA (2018b, 2019b)
	Groundwater resources	Status of groundwater body	EEA (2018a)
	Soil	Soil erosion rate	Borrelli et al. (2017)
Sink	Climate change	Greenhouse gas emissions	Eurostat (2019)
	Terrestrial ecosystems	Concentration of ozone in terrestrial ecosystems	Horálek et al. (2015, 2016a); Horálek et al. (2016b, 2018)
		Load of acidification, eutrophication and heavy metals in terrestrial ecosystems	Hettelingh et al. (2015); Hettelingh et al. (2017)
	Surface water bodies	Chemical status	EEA (2018a)
	Groundwater	Chemical status	EEA (2018a)
Life-support	Terrestrial ecosystems	Local Biodiversity Intactness Index	Usubiaga-Liaño et al. (2019)
	Freshwater ecosystems	Ecological status	EEA (2018a)
		Blue water consumption	EEA (2018c)
Human health and welfare	Air pollution	Concentration of air pollutants	Horálek et al. (2015, 2016a); Horálek et al. (2016b, 2018)
	Drinking water	Water samples	EC (2016)
	Bathing waters	Concentration of bacteria	EEA (2019a)
	Natural and mixed world heritage sites	Conservation outlook	Osipova et al. (2017); Osipova et al. (2014)

Suitability in policy context

126. The novel indicators that form the ESGAP framework represent an advance in measuring progress towards strong environmental sustainability. Nonetheless, their ultimate impact will be influenced by a wide range of factors. The BRAINPOoL project ('BRinging Alternative INdicators into POLicy') provided key insights on criteria for Beyond GDP indicators to succeed in influencing policy (Whitby et al., 2014). This is adapted to the context of the ESGAP in the following paragraphs.

127. Whitby et al. (2014) argued that perceived relevance depended on the compatibility of the underlying message with the vision of decision makers. It is also important for decision makers to be able to influence what it is measured. This should be the case with the ESGAP – at least in the EU –, since all the environmental and resource areas covered can be easily mapped to environmental policies or strategies.

128. When dealing with the broader audience, narratives are particularly important. Effectiveness is likely to increase when an indicator leads to a simple and attractive narrative that links to a meaningful concept. It should, in principle, be possible to build such a narrative using the different components of the ESGAP. While the dashboard of physical ESGAP indicators helps to highlight which elements of natural capital are in need of better management, years-to-sustainability delivers a simple message as to whether a country is moving in the right direction. Additionally, the G-ESGAP can be placed in the context of GDP to show the unsustainability intensity.

129. Credibility is another important factor that affects the potential impact of an indicator. Data quality and the soundness of the underlying methodology are critical in this regard. In the context of the ESGAP, the aggregation and weighting process when building the physical ESGAP, as well as the theoretical foundations of the M-ESGAP are areas that demand special attention. As stated by Whitby et al. (2014), being neutral is generally regarded as the best route to achieving legitimacy, which is particularly important when considering the normative judgments inevitably embedded in the choice of some environmental sustainability standards. When appropriate, solely relying on science-based targets should increase the legitimacy of the ESGAP. Establishing environmental sustainability standards for more subjective issues such as landscapes of special interest might prove more difficult.

130. Engaging with the audiences at whom the indicators are targeted and encouraging participation is also seen as a key success factor, arguing for the organisation of workshops for policy makers and others to gain familiarity with the indicators. While this workshop can be seen as a first attempt at this, additional efforts would be eventually required when launching the ESGAP family of indicators.

7. Conclusions and recommendations

131. The preliminary conclusions of this Scoping Paper can be summarised as follows:

132. *Indicators for Sustainability* — Weak environmental sustainability assumes full substitutability between natural and other types of capital. Strong environmental sustainability, on the other hand, considers that there is limited substitution capacity. There are both theoretical and practical reasons to choose strong environmental sustainability as a starting point. Existing aggregate monetary indicators such as Green GDP, Genuine Progress Indicator or Genuine Savings adopt weak sustainability assumptions when adjusting GDP with monetary measures of flows from natural capital. Other frameworks and indices of

sustainable development commonly adopt a strong sustainability position, but do not yet comprehensively or adequately represent environmental sustainability.

133. *Indicators for Strong Environmental Sustainability* — Strong environmental sustainability requires sustaining natural capital functions over time. For an indicator to describe a country's situation with regard to environmental sustainability, it needs to meet three criteria: *(1)* be a distance-to-target indicator, *(2)* the target needs to be representative of environmental sustainability conditions, and *(3)* be defined at the national level. Most environmental indicators developed by European institutions do not meet these criteria. Distance-to-target indicators such as the environmental dimension of the Sustainable Development Goals, the Environmental Performance Index or the Planetary Boundaries dashboard also fail to meet at least one the criteria above. As a result, there is a lack of credible indicators of strong environmental sustainability at country level.

134. *The Environmental Sustainability Gap Framework* — is intended to fill the indicator gap described above. The ESGAP comprises a dashboard of environmental sustainability indicators across relevant environmental and resource issues. Present trends can be used to give an indication of the time that would be taken to reach the standards of environmental sustainability, thereby deriving a Years-to-Sustainability indicator. When the ESGAP does not represent an irreversible effect, it will be possible to estimate the costs of meeting the sustainability standards (M-ESGAP). The ratio between the sum of M-ESGAP across the environmental and resource indicators (G-ESGAP) and GDP may indicate the 'intensity of environmental monetary unsustainability'. Data availability remains the main limitation towards the computation of the indicators that form the ESGAP framework.

135. Our principal recommendations are that practical implementation of the ESGAP or equivalent, in the context of AFD's international development activities or more broadly, could be advanced in the near term through work focusing on: *(1)* refinement of the ESGAP structure and compilation methodology, including clear articulation of linkages and interrelationships to the Sustainable Development Goals (including Targets and Indicators), UN–SEEA/FDES, IPBES Conceptual Framework, and other relevant efforts; *(2)* pilot compilation of the ESGAP in selected 'data-rich' countries, coupled with detailed feasibility assessments for selected countries where data availability is uncertain; *(3)* development of technical process guidance for ESGAP compilation, informed iteratively by lessons learned during pilot activities, *(4)* engagement with key international stakeholders, including UN agencies, UN regional commissions and others leading on capacity building for national SDG implementation.

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