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Time for Science-Based National Targets for Environmental Sustainability: An Assessment of Existing Metrics and the ESGAP Framework

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Despite the overwhelming scientific evidence on the ongoing degradation of the environment, there is a clear gap between the urgency of the environmental crisis and the policy measures put in place to tackle it. Because of the role of metrics in environmental governance, the way environmental information is translated into metrics is of utmost relevance. In this context, we propose criteria to assesses the suitability of environmental metrics to monitor environmental sustainability at the national level. After assessing well-known environmental metrics such as the Sustainable Development Goals indicators and the Environmental Performance Index, we conclude that countries still lack robust and resonant metrics to monitor environmental sustainability. In order to bridge this metric gap, we present the Environmental Sustainability Gap (ESGAP) framework, which builds on the concepts of strong sustainability, critical natural capital, environmental functions and science-based targets. Different composite indicators are proposed as part of the ESGAP framework. Through these metrics, the framework has the potential to embed strong sustainability thinking and science-based targets in nations in which these concepts are not currently sufficiently reflected in policies.

Keywords: ESGAP, environmental sustainability, sustainability gap, environmental indicators, Strong Environmental Sustainability Index, Strong Environmental Sustainability Progress Index

1 INTRODUCTION

Major international assessments show that the evidence of widespread environmental degradation is unequivocal (IPCC 2014; IPBES 2019; UN Environment 2019). As stated by UN (2019), "[e]conomic and social progress over the last century has been accompanied by environmental degradation that is endangering the very systems on which our future development—indeed, our very survival—depends." This statement highlights the conflicts between the three pillars of sustainable development. If we generically define sustainability as the capacity for continuance, the first requirement of sustainable development will be to maintain the functions provided by nature–particularly those that support life—given that the environmental dimension underpins the social and the economic ones.

Building bridges between science and policy is critical in this context. The phrase "we cannot manage what we cannot measure" has become part of the vocabulary of those using quantitative tools to produce policy-relevant information. Of course, the statement cannot be taken as an absolute truth. The increasing reliance on quantification in policy can also lead to unintended misuse or even politicization of data with negative consequences (Radermacher 2019; Umbach 2020). Nonetheless, it is generally agreed that it is relevant to have a clear and scientifically sound information base around which decisions can be made. As Esty (2018) argued, "better metrics and data analysis can make the invisible visible, the intangible tangible, and the complex manageable. The "realization" effect of numbers can be transformative."

Whether it is to assess sustainable development, environmental strategies or multilateral environmental agreements, many international and national organizations use environmental metrics to inform and monitor their policies, or to validate the narrative that underlies their vision. Yet despite the overwhelming scientific evidence that feeds into policy, there is a clear gap between the urgency of the environmental crisis and the policy measures put in place to tackle it. One of the reasons for this gap is the limited practical impact the notion of environmental limits has had in policy. Although the concept has gained traction in recent years, it has mainly had a rhetorical—rather than an instrumental—use in policy, partly because there is uncertainty and some normativity in how safe or dangerous levels are defined, and because communities deal with risk differently (Pickering and Persson 2020). As a result, environmental policy targets continue to insufficiently weight scientific evidence of environmental degradation. After all, environmental target setting is a complex process in which besides environmental concerns, technological feasibility, economic consequences, distributional aspects, vested interests and other relevant factors are weighted (Moldan et al., 2012). National pledges for greenhouse gas emission reduction falling short of meeting the global goal set in the Paris Agreement (UNFCCC 2015) is one of many possible examples of how the urgency of tackling environmental degradation is insufficiently weighted in policy responses. Given that the scientific evidence is unequivocal when it comes to stressing the urgency to act, one must wonder whether the way this information is translated into metrics that can ultimately influence the decision-making process through complex mechanisms (Radermacher 2019), can be a contributing factor to the implementation gap. In this context, it is fair to ask whether we are really measuring what matters.

There is ample literature reviewing sustainable development and environmental sustainability metrics (Mayer 2008; Hák et al., 2012; Moldan et al., 2012; Wu and Wu. 2012; Dong and Hauschild 2017; Kwatra et al., 2020). Reviews tend to be quite descriptive, except in a few cases in which results are compared (Wilson et al., 2007; Siche et al., 2008). There are several lessons to be learnt from these reviews, one of which is that in most cases the metrics used represent different understandings of sustainability in general, and of environmental sustainability in particular. A second lesson that comes up several times is the need to contextualize the information provided by these metrics with adequate reference values that can be used to measure progress (Moldan and Dahl 2012; Moldan et al., 2012). Arguably, those reference values should have a scientific foundation if the metrics are to transmit the environmental urgency described by scientists to decision makers and interested stakeholders (Dahl 2012). While the use of both policy- and science-based reference values has increased in the last years in the context of Planetary Boundaries (Rockström et al., 2009; Steffen et al., 2015) and Sustainable Development Goals (SDG) indicators (UN 2020), the extent to which countries have appropriate metrics to monitor environmental sustainability has not been established and therefore demands further exploration. The work of Moldan et al. (2012) represents, to date, the most thorough attempt to answer this question. Nonetheless, it remains outdated as it does not cover the various sets of SDG indicators adopted since 2015. Conversely, others (e.g., Eisenmenger et al. (2020)) have focused on the SDG indicators, but have proposed conflicting criteria for environmental sustainability metrics.

Against this background, this paper makes novel contributions to the literature as follows. First, it assesses whether, despite the continued increase in the availability of environmental data and metrics, a measurement gap still exists when it comes to monitoring environmental sustainability. As argued above, the evidence needed to definitively answer this research question remains incomplete, inconsistent, and scattered, which demands a more systematic assessment of existing metrics. To that end, **section 2** assesses the suitability of well-known metrics to conclude that a measurement gap does indeed still exist. The reader should note that in order to avoid confusion, here we use the term "metric" as an umbrella concept that encompasses indicators, indicator sets and indices. The emphasis on the geographical scale here is set on countries because they remain the central locus for the formulation and implementation of environmental policy, regardless of existing multi-level governance mechanisms at local and international levels.

Second, in order to bridge that metric gap, we present the Environmental Sustainability Gap (ESGAP) framework, which can be used to develop policy-relevant metrics of environmental sustainability for countries. Thus, **section 3** revisits the work undertaken by Ekins (Ekins and Simon 1999; Ekins et al., 2003b) two decades ago in the original Sustainability Gap (SGAP) approach and reflects on which elements have stood the test of time and which ones have prevented the original approach from being implemented more widely. Based on that analysis, we describe the renewed ESGAP framework, which combines some of the elements of the original approach with new ones with the intention of facilitating its implementation. The renewed ESGAP framework builds on already established concepts in ecological economics and environmental science such as strong sustainability, critical natural capital, environmental functions and science-based sustainability reference values.

The third contribution of this paper relates to science-based sustainability reference values. These are gathering momentum at the global and business level through the Planetary Boundaries framework and the Science-Based Target Initiative respectively, but they remain underexplored at the national level. For this reason, **section 4** presents the first overview of science-based sustainability reference values with a focus on countries.

Section 5 and **Section 6** discuss the main implications and conclude.

TABLE 1 | Definitions of environmental sustainability.

Source	Definition
Goodland (1995)	Maintenance of natural capital
Holdren et al. (1995)	Maintenance or improvement of the integrity of the life support system of the Earth
Ekins et al. (2003b)	Maintenance of important environmental functions and therefore, the maintenance of the capacity of the natural capital stock to provide those functions
Sutton (2004)	The ability to maintain the qualities that are valued in the physical environment
Moldan et al. (2012)	Maintaining nature's services at a suitable level

2 DO COUNTRIES HAVE SUITABLE METRICS TO CHARACTERIZE ENVIRONMENTAL SUSTAINABILITY?

2.1 General Approach

In order to answer the research question above, we develop specific criteria for environmental sustainability metrics based on the review of the relevant literature. We start from definitions of environmental sustainability and work our way through the conditions that need to be met for development to be considered sustainable from an environmental perspective. We then assess a set of well-known environmental metrics by interrogating them against each criterion proposed in a step-wise manner.

2.2 Criteria for Environmental Sustainability Metrics

Environmental sustainability has been defined in different ways. A few are shown in **Table 1** for illustrative purposes.

Of course, these definitions are very broad and therefore, developing metrics of environmental sustainability is not straightforward. Two key questions need to be answered to assess whether existing metrics are suitable to characterize environmental sustainability:

- What should be sustained?
- At what level should it be sustained?

A common theme of the definitions above is that some features of natural capital need to be sustained indefinitely. Depending on the definition, these features are the stock of natural capital, its functions, or the benefits obtained therefrom. Given that abiotic resources cannot be replenished when using them, the stock of abiotic natural capital cannot be maintained indefinitely at any given level of use, and since the ability to provide benefits depends on the functioning of natural capital, it seems sensible to conclude that the focus should be set on maintaining the functions of natural capital, or "environmental functions."

Environmental functions were defined by De Groot (1992) as "the capacity of natural processes and components to provide goods and services that satisfy human needs (directly and/or indirectly)." The concept therefore predates the term "ecosystem goods and services," now in more common usage, but is clearly closely related to it. The earlier term is used here because it emphasizes the importance of the environment's *capacity* to produce goods and services, as well as of the goods and services themselves. The typologies of environmental functions tend to cover the provision of resources, the regulation of ecological processes, the maintenance of life support functions and other functions related to human health and welfare (Pearce and Turner 1990) (c.f. **section 3**).

Whether the functions of natural capital are unique or can be replaced by those provided by other forms of capital is at the core of the concepts of weak and strong sustainability (Neumayer 2003). In short, weak sustainability assumes that welfare depends on an aggregate stock of capital that is independent from the type. Thus, under this proposition, the functions provided by natural and manufactured capitals are interchangeable and therefore (weak) sustainability requires only that an aggregate stock of capital be sustained. On the other end, strong sustainability considers that the substitution of natural capital by other types of capital is limited because certain elements of the former provide unique and irreplaceable functions. Thus, under strong sustainability, unique functions of natural capital need to be maintained.

The metrics used to characterize weak and strong sustainability differ. Weak sustainability metrics may be expressed through monetized changes in natural capital as part of macro-economic aggregates. Examples are the Genuine Progress Indicator (Kenny et al., 2019) and Adjusted Net Savings (Lange et al., 2018). The changes in recent years according to the Genuine Progress Indicator and Adjusted Net Savings seem to be at odds with the insights provided by scientists on the state of the environment, partly because of methodological and data limitations related to the valuation of natural capital (Ekins 2011), but also because they fail to highlight the urgency of current environmental challenges. Thus, the global per-capita Genuine Progress Indicator only slightly decreased since 1978 (Kubiszewski et al., 2013). Total global wealth, and the global wealth of natural capital, actually increased in the 1995–2014 period (Lange et al., 2018), even while environmental degradation is acute, continuing and growing (UN Environment 2019). In contrast, strong sustainability metrics represent changes in natural capital from a biophysical perspective. In this context, Giannetti et al. (2015) argued that only biophysical indicators should be used. Eisenmenger et al. (2020) considered that only biophysical indicators expressed in absolute terms can monitor the transgression of environmental limits, thereby automatically discarding indicators expressed as percentages, ratios, or intensities.

Whatever the assumptions of neoclassical economic theory, weak sustainability is an approach ill-suited to a planet with biophysical limits. Elements of natural capital and associated environmental functions for which no substitutes exist include the subjects of the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015), several of which are now being transgressed, coral reefs, many of which are now being degraded (Eyre et al., 2018), and insects, which are now experiencing massive loss (Sánchez-Bayo and Wyckhuys 2019). In this context, it seems sensible to adopt a strong sustainability position to measure environmental sustainability.

The second question relates to the level at which the functions of natural capital need to be maintained. This requires a reference value against which performance can be measured (Moldan et al., 2012; Eisenmenger et al., 2020). Moldan et al. (2012) distinguishes between two types of reference values. The first one reflects environmental sustainability considerations from a biophysical perspective and is therefore the result of a scientific debate. It is linked to concepts such as carrying capacity (Daily and Ehrlich 1996), planetary boundaries (Rockström et al., 2009; Steffen et al., 2015) and science-based targets (Andersen et al., 2020). The second type covers reference values that are set through the policy process and therefore are the result of weighting different perspectives such as cost or political feasibility. As Moldan et al. (2012) argue, environmental sustainability can only be reliably measured through science-based reference values, not least because policy targets often deviate from the conditions required to maintain environmental functions at the desired level indicated by scientific analysis, as, for instance, in the cases of biodiversity (Doherty et al., 2018), climate change (UNEP 2020) and air quality (Kutlar Joss et al., 2017).

Based on the foregoing considerations, we can establish two criteria to measure environmental sustainability across spatial scales. First, the indicators need to be linked to the environmental functions of natural capital. These can either represent environmental pressures, states or impacts (or proxies thereof), or social states when functions are linked, through the goods and services they provide, to human health and other welfare functions. Second, an appropriate reference value is required against which performance can be measured. That reference value should be science-based and ultimately represent the conditions under which the functioning of natural capital is not altered in a way that threatens its capacity to provide ecosystem goods and services in the long-term.

Given the geographical scope of this paper, a third criterion can be added, which is the focus on countries, as justified above.

2.3 Assessment of Relevant Environmental Metrics

In order to assess whether a metric gap exists when measuring environmental sustainability at country level, we interrogate a series of well-known environmental metrics based on the criteria above. These criteria can be expressed as follows:

- Are these metrics related to the various functions of natural capital?
- Do these metrics use science-based reference values of environmental sustainability?
- Are these metrics used at the national level in a consistent manner?

The metrics considered here include composite indicators such as the Ecological Footprint (Borucke et al., 2013; Lin et al., 2016), the Genuine Progress Indicator (Kubiszewski et al., 2013) and Adjusted Net Savings (Lange et al., 2018), as well as indicator sets used in indices and different frameworks. The latter includes the indicators used in the Environmental Performance Index (Wendling et al., 2020b), in the Planetary Boundaries framework (Rockström et al., 2009; Steffen et al., 2015) and in the SDGs (Lafortune et al., 2018; IAEG-SDGs 2019; OECD 2019). Individual indicators that are part of some of these sets (e.g., material flow analysis indicators) are not considered separately, but as part of the set in which they have been included. Given that the ESGAP framework has been implemented for the first time with a European focus (Usubiaga-Liaño and Ekins 2021), we add three additional European indicator sets to the list: the European set of SDG indicators (Eurostat 2020b), the set used in the EEA Environment Indicator Report (EEA 2018)—hereinafter EEA environmental indicators—and the Transitions Performance Index (EC 2020). The list above is not exhaustive, but rather a selection of some of the most relevant metrics based on the authors' judgement. **Table 2** in Appendix presents the results of the assessment.

2.3.1 Criterion 1: Are These Metrics Related to the Various Functions of Natural Capital?

The metrics in **Table 2** in Appendix can be divided into three groups. In the first group, we find composite indicators such as Adjusted Net Savings and the Genuine Progress Indicator that monetize changes in natural capital or other welfare changes, and create a composite indicator that aggregates different types of capital into a single measure. A second group comprises indicator sets and indices of sustainable development, which also includes the new Transition Performance Index. Besides the environmental dimension, these metrics also consider economic, social, and governance aspects. In some cases, the indicators are aggregated into a single index, but for the purpose of this paper, we consider the underlying indicators on their own merit. In a third group, we have purely environmental metrics such as the EEA environmental indicators, the Ecological Footprint, the Planetary Boundaries indicators and the Environmental Performance Index.

As argued before, metrics that monetize natural capital reflect weak sustainability and therefore need to be excluded from consideration here. These metrics do not reflect the particularities of biophysical systems (e.g., non-linear responses that lead to regime shifts occurring as a result of transgressing a tipping points (Biggs et al., 2018)) or the scale of drastic environmental changes described in major international assessments. In the indicator sets that comprise indicators addressing the different dimensions of sustainable

TABLE 2 | Assessment of metrics related to (environmental) sustainability.

Metrics	Type	Criterion 1: Focus				Criterion 2: Reference values	Criterion 3: Scale	Reference
		Dimensions	Tot	Env	NC			
Adjusted Net Saving	Composite	Aggregated capital	-	-	-	None	National and global	Lange et al. (2018)
Genuine Progress Indicator	Composite	Aggregated capital	-	-	-	None	National and global	Kubiszewski et al. (2013)
SDG indicators (UN)	Set	Sustainable development	232	76	22	Internationally agreed targets or best performing countries	National and global	IAEG-SDGs (2019)
SDG indicators (OECD)	Set	Sustainable development	127	41	16	Internationally agreed targets or best performing countries	National	OECD (2019)
SDG indicators (Eurostat)	Set	Sustainable development	106	48	25	EU policy targets	National and EU	Eurostat (2020a)
SDG Index	Index	Sustainable development	114	36	20	Internationally agreed targets or best performing countries	National and global	Sachs et al. (2019)
Transitions Performance Index	Index	Sustainable development	25	6	4	EU policy targets, public-policy considerations or best performing countries	National and EU	EC (2020)
EEA environmental indicators	Set	Environment	29	29	16	EU policy targets	National and EU	EEA (2018)
Environmental Performance Index	Index	Environment	32	32	27	Internationally agreed targets or best performing countries	National	Wendling et al. (2020a)
Ecological Footprint	Composite	Environment	-	-	-	Local, national or Earth's regenerative capacity	Local, national and global	Borucke et al. (2013); Lin et al. (2016)
Planetary Boundaries	Set	Environment	16	16	16	Science-based targets	Global	Steffen et al. (2015)

development, while 24–45% of the indicators are related to the environment depending on the set chosen (see supplementary material for more details), the range decreases to 9–24% if we consider indicators associated with the functions of natural capital. The remaining environmental indicators represent a variety of topics related to environmental policies, behavioral aspects, sustainable consumption and production patterns, and the relationship between humans and nature. Similar findings were reported by Campbell et al. (2020), who concluded that out of the more than 90 environmental indicators in the SDG indicators, only a dozen described "environmental states and trends." Although the latter is a narrower concept than the functions of natural capital, it helps illustrate the point above.

The remaining metrics in **Table 2** in Appendix are related to the environment. Most indicators in the Environmental Performance Index and the Planetary Boundaries are linked to the functions of natural capital, but that is not the case for the EEA environmental indicators. The Ecological Footprint converts all its measures to a hypothetical land construct, the "global hectare," that bears little relation in many cases to actual natural capital.

2.3.2 Criterion 2: Do These Metrics Use Science-Based Sustainability Reference Values?

Except for the weak sustainability metrics, all the metrics in the table above use reference values to measure country performance. These reference values include a variety of policy targets, science-based reference values and statistical measures such as the scores of the best performers. Reference values are used in a variety of ways to contextualize the information of indicators. For instance, one could measure the distance to the reference value, a ratio between the indicator and the reference value or convert the indicator into a unitless measure that can be used to aggregate indicators with different units into an index. The latter is referred to as normalization.

Unequivocally determining whether a reference value is "science-based" is not straightforward, as the term can be interpreted in different ways. Andersen et al. (2020) propose three criteria to determine whether a reference value can be considered science-based: being achievable, being quantifiable, and being supported by a clear, analytical rationale. A further distinction could be made between reference values that represent "sufficient" and/or "necessary" conditions for environmental sustainability. The former describes the conditions that on their own are enough for the maintenance of a given environmental function. A necessary condition, on the other hand, represents a requirement that needs to be met, but that is not enough on its own (e.g., reduction of a pressure from a baseline that does not reflect environmental sustainability conditions). Ideally, reference values should represent sufficient conditions for the maintenance of a particular function that is important for environmental sustainability. In assessing the indicator sets above against the science-based target criterion, we consider the overall approach as described in the documents describing the metrics, which are cited above.

In most cases (all the sustainable development metrics, the EEA environmental indicators and the Environmental Performance Index), the reference values represent policy targets and/or are determined by the performance of the frontrunners. Thus, unless policy targets and best performances are aligned with science-based reference values, as a group, the indicators included in these metrics do not represent environmental sustainability. The unit of measurement of the Ecological Footprint, the "global hectare," is a complex hypothetical construct of doubtful scientific validity and therefore is not suitable to measure environmental sustainability (Blomqvist et al., 2013b; Blomqvist et al., 2013a; Giampietro and Saltelli, 2014a; Giampietro and Saltelli, 2014b; van den Bergh and Grazi, 2014; van den Bergh and Grazi, 2015). The Planetary Boundaries approach, on the other hand, uses a variety of science-based reference values to contextualize the impacts on Earth System processes.

2.3.3 Criterion 3: Are These Metrics Used at the National Level in a Consistent Manner?

Based on the second criterion, only the Planetary Boundaries provide a sound basis to measure environmental sustainability. While there have been several attempts to downscale the Planetary Boundaries framework to the national scale (Nykvist et al., 2013; Cole et al., 2014; Hoff et al., 2014; Dao et al., 2015; Lucas and Wilting 2018), these attempts have limited consistency (Häyhä et al., 2016), which could explain the limited influence of the framework in national policies (Li et al., 2021).

2.3.4 Is There an Environmental Sustainability Metric Gap at the National Level?

The assessment above shows that countries still lack robust and resonant metrics to monitor environmental sustainability. The monetization of natural capital in weak sustainability metrics falls short of representing the biophysical reality as described by scientists. Sustainable development metrics such as the SDG indicators and the Transition Performance Index contain relatively few environmental and natural capital indicators, which in any case, tend to use a combination of policy targets and best performers as reference values to measure the progress of countries. Environmental metrics such as the EEA environmental indicators and the Environmental Performance Index represent the environmental dimension of sustainable development through a variety of indicators, many of which are related to the functions of natural capital, but, as in the case of sustainable development metrics, they measure performance against policy targets and best performers. Thus, the indicators used in these metrics only reflect environmental sustainability to the extent to which policy targets and best performances are aligned with science-based reference values, which, as argued before, is not generally the case. Additionally, the Ecological Footprint methodology has limited scientific validity. Thus, only the Planetary Boundaries indicators use science-based reference values, but the impact of this approach at the national scale remains limited due to the global nature of the framework.

3 THE ENVIRONMENTAL SUSTAINABILITY GAP FRAMEWORK

3.1 The Original Sustainability Gap Approach

The ESGAP framework is based on the SGAP approach originally developed by Ekins (Ekins and Simon 1999; Ekins et al., 2003b). The original approach described how to measure the environmental sustainability gap of countries and progress towards environmental sustainability through indices intended to be easily communicated to high-level policy makers and the general public. To that end, the approach relied on the concepts of critical natural capital—natural capital that performs important and irreplaceable functions—(Ekins et al., 2003a) and strong environmental sustainability, which assumes limited substitutability between natural capital and other types of capital, as well as between the diverse functions of natural capital (Ekins and Simon 1999). Through those concepts, the SGAP approach defined environmental sustainability and the criteria that can be used to characterize it. Although highly cited, the approach was only operationalized once because of lack of adequate data (Ekins and Simon 2001).

Various elements that were part of the thinking behind the SGAP approach have been widely embedded in contemporary policy making, as can be illustrated through a number of examples. Most obviously, the 1.5–2°C targets in the Paris Agreement under the UN Framework Convention on Climate Change seek to maintain the essential functions of climate stability; the provisions in the Montreal Protocol to reduce the emissions of ozone-depleting substances (eventually to zero) were driven by the scientific requirements to close the hole in the stratospheric ozone layer. The Oslo Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution adopted the critical loads approach, such that emission reductions were determined according to "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment does not occur according to present knowledge" (UBA 2004), which is clearly related to the maintenance of environmental function. Regulations in the European Union (EU) that limit exposure of humans to air pollution are informed by the World Health Organization's estimates of levels that will not harm human health. The EU's Water Framework Directive sets its objectives in terms of achieving and then maintaining "good status" of water bodies, defined such that "[t]he values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions" (European Parliament and European Council 2000). Likewise, the levels of pollutants in accordance with "good status" are required to be within "the range established so as to ensure the functioning of the type specific ecosystem and the achievement of the values specified above for the biological quality elements." Where human health is concerned, further regulations are set to ensure safety of, for example, drinking and bathing waters (European Council 1998; European Parliament and European Council 2006). In all these areas policy making has built on science-based reference values following a desire to maintain environmental functions at a level that will ensure ecosystem and human health. These policy approaches reflect strong sustainability thinking, that does not seek to trade off environmental functions for perceived economic or social benefits, and aims to maintain critical natural capital because of a perception that it delivers goods and services that can be provided by other forms of capital only more expensively, or less adequately, or not at all.

The original SGAP approach was based on similar thinking but did not derive a full set of indicators that would enable policy makers at the national level to have a comprehensive view of the extent to which environmental sustainability was being achieved across the full range of environmental issues. This has now been achieved with the ESGAP framework described in the next sections, the essential building blocks of which will now be briefly reviewed.

3.2 Strong Sustainability

Human well-being rests on the flows from the combination of different types of capitals. Ekins (1992) proposed a four-capital model in which natural, manufactured, human and social capital are combined to generate welfare. The substitutability of the different types of capital has been extensively debated, especially in the context of natural capital. As noted earlier, this is at the core of the weak vs. strong sustainability concepts (Costanza and Daly 1992; Neumayer 2003). The proponents of weak sustainability assume that welfare does not depend on a given type of capital, but on the aggregation of all of them, thereby implying that one type can replace the other, although with exceptions. Strong sustainability, on the other hand, assumes that there is limited substitution capacity between different types of capital. In particular, the substitution of the functions provided by natural capital are limited by such characteristics as irreversibility, uncertainty and the existence of "critical" components of natural capital, which make a unique contribution to welfare (Costanza and Daly 1992). Within natural capital itself, the functions provided by specific elements cannot be commonly replaced by those provided by other elements either (Neumayer 2003). The issue of substitutability has implications beyond the measurement of welfare, since it fixes a position on acceptable natural capital depletion and degradation (Barbier and Burgess 2017).

Although often presented as fixed positions, some authors have further split these two categories based on additional degrees of substitutability, thereby giving rise to the following categories: very weak sustainability, weak sustainability, strong sustainability and very strong sustainability (Turner 1993). This allows viewing the weak-strong sustainability proposition not as an absolute dichotomy, but as a continuum where full and no substitutability are the opposite ends.

3.3 Natural Capital

Natural capital represents "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). The benefits provided by natural capital range from the basic processes that regulate the Earth System, to goods such as food or freshwater that are indispensable for human subsistence, or the materials that provide the physical foundations of economic infrastructure.

The stocks or assets of natural capital fulfil different types of functions that ultimately define their capacity to provide ecosystem services (flows). These functions are a subset of the physical, chemical or biological interactions between the components and processes of ecosystems (de Groot et al., 2010). Flows of ecosystem services, on the other hand, represent the "direct and indirect contributions of natural capital to human well-being" (de Groot et al., 2010, p.25). Often the environmental function (the capacity to provide a good or service) is essentially identical to the good or service itself, e.g., the service of providing air compatible with good health from breathing depends on the capacity of the environment adequately to disperse or otherwise remove pollution in a given location. In what follows, therefore, the environmental function may be indistinguishable from the good or service to which it gives rise.

The functions of natural capital, and the flows of goods and services to which they give rise, may be seen as being of four broad kinds (Pearce and Turner 1990), although other classifications exist [e.g., de Groot et al. (2002)]:

- *Source functions* represent the capacity of natural capital to sustain the supply of resources and therefore cover the provision of different type of resources used by humans, which include the formation of topsoil, the provision of space for human activities, the supply of water, minerals, fossil fuels biomass, etc.
- *Sink functions* represent the capacity of natural capital to absorb, disperse or dilute wastes without incurring ecosystem change or damage. This includes the regulation of the chemical composition of the atmosphere and oceans, and the assimilation of wastes.
- *Life support functions* refer to the capacity of natural capital to maintain ecosystem health and function, which covers functions from the provision of quality habitat to the regulation of runoff and climate or the maintenance of biodiversity.
- *Human health and welfare functions* represent the capacity of natural capital to provide other services to humans, very often of a non-economic kind, which maintain health and contribute to human well-being in other ways. These could be related to amenity as in sites that have aesthetic, spiritual, religious or scientific value, or the capacity to provide space for recreation.

The functions are clearly inter-related. For example, the operation of both the source and sink functions are clearly important for the life support functions, and all three of these types of functions can affect human health and welfare. But, as will be seen, the indicators that show the operation of these functions can be made distinct according to this typology. **Supplementary Table S1** in the supplementary material provides more details on the specific functions covered in each broad category.

3.4 Environmental Sustainability

Environmental sustainability has been defined as "the maintenance of important environmental functions and therefore, the maintenance of the capacity of the capital stock to provide those functions" (Ekins et al., 2003b, p. 612). The definition suggests that environmental sustainability should be represented through biophysical indicators related to the functions of natural capital, but it leaves open two key issues: which specific functions need to be maintained and which level would ensure their maintenance in the long-term.

From this definition 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—directly or indirectly—an important contribution to human welfare. In a situation of complete knowledge about the contribution of different functions to human well-being, their importance could be evaluated in these terms and the functions thereby deemed to be of high importance related back to the stocks of natural capital that are responsible for them. De Groot et al. (2003) and Brand (2009) proposed several criteria to identify such "critical natural capital" based on its importance and the threat level natural capital is subject to. Despite the considerable progress that has been made in understanding the contributions of natural capital to human well-being (Millennium Ecosystem Assessment 2005; Díaz et al., 2018), there is still enormous uncertainty associated with the identification of all the functions that need to be maintained in different social contexts and geographical scales. In the absence of such information, it seems preferable to identify as essential for environmental sustainability, any environmental function that cannot be replaced by any other function, or the loss of which would be irreversible or that could (potentially) lead to immoderate costs and impacts on human health and welfare.

Against this background, Ekins and Simon (1999) proposed, building on the work of Daly (1991) and Turner (1993), a set of general principles that could guide the management of natural capital stocks in a way that does not threaten their capacity to provide environmental functions (see **Table 3**). These principles require users of the environment to ensure that renewable resources such as fish or forests are exploited at a level that allows them to be renewed over time, to exploit non-renewable resources at a rate that allows their future use, to keep pollution at a level at which it can be absorbed, dispersed or diluted by ecosystems without incurring more than superficial damage to them, to maintain the capacity of ecosystems to support life, to respect human health standards and to conserve the elements of natural capital that provide additional services to humans. These principles are underpinned by the precautionary principle, especially in the cases where uncertainty and the potential damage from the loss of functions, as in the case of life support functions, are higher.

3.5 Environmental Sustainability Reference Values

In order to make the above sustainability principles operational, quantitative sustainability reference values need to be defined against which current environmental states, pressures or impacts may be compared. Here we distinguish three types of reference values: environmental limits, environmental standards and environmental policy targets. The reader should note that other typologies exist (Moldan et al., 2012; Vea et al., 2020).

TABLE 3 | Functions of natural capital and environmental sustainability principles.

Function	Objective	Principle	Description
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 cycles and necessary vegetative cover and the rigorous enforcement of sustainable harvesting
		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
Sink	Maintain the capacity to absorb, disperse or dilute wastes, without incurring ecosystem change or damage	Prevent global warming, ozone depletion	Anthropogenic destabilization of global environmental processes, such as climate patterns or the ozone layer, must be prevented
		Respect critical levels and critical loads for ecosystems	Emissions into air, soil and water must not exceed their critical level and/or critical load, that is the capability of the receiving media to disperse, absorb, neutralize and recycle them, without disturbing other functions
Life Support	Maintain the capacity to sustain ecosystem health and function	Maintain biodiversity and ecosystem health	Critical ecosystems and ecological features must be absolutely protected to maintain biological diversity, which underpins the productivity and resilience of ecosystems
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 and amenity	Natural capital elements of special human or ecological significance, because of their rarity, aesthetic quality, recreational values or cultural or spiritual associations, should be preserved

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

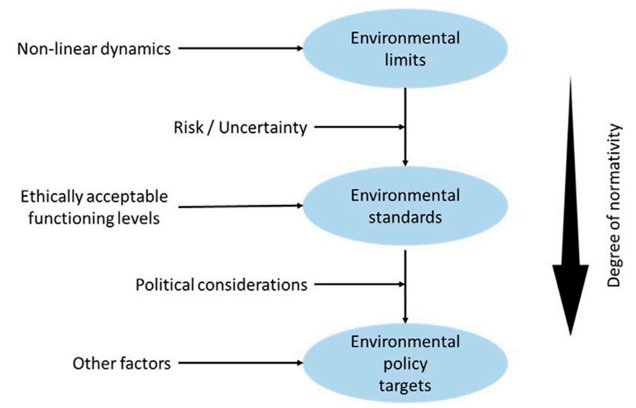

FIGURE 1 | Relationship between environmental limits, standards and policy targets.

An *environmental limit* represents a point beyond which non-linear dynamics significantly change the functions and/or structure of an ecosystem. Non-linear dynamics describe the process by which a small pressure change leads to a disproportionate ecological response (Capon et al., 2015), which sometimes can result in a regime shift (Biggs et al., 2018). Examples of regime shifts include the collapse of fisheries (Bavington 2010), algae blooms in lake ecosystems (Carpenter et al., 2007), transitions from forest to savannah (Lovejoy and Nobre 2018), and many more. In this context, it is worth noting that not all ecosystems are subject to such behavior (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, and the assessment of the risks associated with transgressing them. Environmental sustainability reference values 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 (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, such as the type of pressure or receptor, or the resilience of the system itself (UBA 2004; Scheffer 2009; Bobbink and Hettelingh 2011).

Environmental standards, which partially overlap with science-based targets (Andersen et al., 2020), 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. 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 (Steinberger and Roberts 2010; Di Giulio and Fuchs 2014), projections of future demand (Tilman et al., 2011; IRP 2019), health concerns (WHO 2000, 2005) 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. Likewise, the definition of some environmental standards also requires social norms such as "leave no one behind" or "protect the vulnerable" when dealing with issues such as access or impacts on humans.

Environmental policy targets often deviate science-based environmental standards, as defined above, 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. As a result, targets can become less stringent than environmental standards (Svancara et al., 2005; Doherty et al., 2018). Targets are derived mainly from policy documents and reflect people's desires to the extent to which policies are aligned with social preferences.

Figure 1 summarizes the relationship between environmental limits, standards and policy targets.

Uncertainties in the identification of critical environmental functions are closely linked to the selection of environmental sustainability reference values. It can be argued that the life support and sink functions that are responsible for the regulation of the Earth System are among those that should be prioritized. These are the type of functions addressed by Rockström et al. (2009) and Steffen et al. (2015) when assessing global environmental sustainability. However, the environmental sustainability concept used here is broader, for it also covers environmental sustainability at lower scales and incorporates economic and social aspects when these are associated with the exploitation of natural capital. Thus, environmental limits fall short from representing all the relevant functions of natural capital. Environmental standards, on the other hand, are more appropriate for such a task, although they also have limitations, e.g., a higher degree of normative judgement. Environmental policy targets are also inadequate as a general rule. For environmental standards to become targets policy endorsement is needed, which is not always the case, as environmental targets usually represent a compromise between science, economic costs, social consequences, and other relevant factors.

For life support, sink and human health-related functions, and renewable resources, reference values can be derived from natural and health 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 considerations. 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. Such judgments are inevitably embedded in the environmental standards proposed by international institutions or scientists and therefore reflect their attitudes to risk.

3.6 Strong Environmental Sustainability Indices

The ESGAP framework comprises three main metrics that provide complementary information on different aspects of environmental sustainability: the Strong Environmental Sustainability Index (SESI), the Strong Environmental Sustainability Progress Index (SESPI) and the monetary environmental sustainability gap. Beneath these three metrics, other composite indicators can be constructed, according to the typology of functions, or the principles of environmental sustainability set out above.

SESI provides a snapshot of a country's absolute performance against environmental standards that are linked to different environmental and resource areas (Usubiaga-Liaño and Ekins 2021). The indicators on which the index is based are intended to capture whether the capacity of natural capital to function is compromised over the long term. Each of the indicators is assigned a score between 0 and 100 based on a normalization method, where 0 and 100 represent failure and compliance with the environmental standard respectively. In order to compute the final index, the normalized scores of the underlying indicators are aggregated across different layers, including the sustainability principles and the four types of functions presented above. A score of 100 indicates that the environmental standards of all the indicators are met. The difference between 100 and the index score would yield the "physical sustainability gap," the index previously proposed by Ekins and Simon (1999).

SESI provides a static perspective on environmental sustainability. For this reason, Ekins and Simon (2001) proposed "years to sustainability" as a second metric aimed at providing a general sense of whether a country was moving in the right direction. Based on linear trends, "years to sustainability" showed the time it would take a country to meet all the environmental standards, which, although subject to strong assumptions, provided a clear and easy-to-understand message to policy makers. Nonetheless, this metric cannot be easily aggregated because negative trends in the individual indicators yield a score of infinity for "years to sustainability." As an alternative, we propose SESPI. SESPI shares the structure and underlying indicators of SESI. In order to capture the temporal dimension, two data points are used for each indicator to compute compound annual growth rates (CAGR), similar to what Eurostat uses to measure progress towards the SDGs (Eurostat 2019). CAGR values are compared to the ones that would be theoretically required to achieve the environmental standards at a given point in time, thereby giving a sense of whether enough progress is being made towards environmental sustainability.

Last but not least, the monetary environmental sustainability gap represents an aggregated monetary value of the maintenance costs (i.e., abatement, avoidance, restoration and protection costs) required to close the physical sustainability gap (i.e., the gap between sustainability conditions and SESI) for the relevant elements of natural capital, assuming previous losses are reversible. When divided by GDP, the resulting ratio is indicative of the "unsustainability intensity" of the economy (Ekins 2001).

3.7 Differences Between the Sustainability Gap Approach and the Environmental Sustainability Gap Framework

All knowledge builds on previous knowledge. As such, the renewed ESGAP framework shares several elements with the original SGAP approach. At the core, both ESGAP and SGAP rely on the concepts of strong sustainability, critical natural capital, environmental functions, and science-based environmental standards. The first three concepts remain largely unaltered in the renewed ESGAP framework. The fourth concept, science-based environmental standards, has been made much more specific in previous sections with relevant conceptual clarifications in relation to its meaning and the differences with related terms such as environmental limits and environmental policy targets.

The indices to be calculated as part of the framework have also changed. In the original work of Ekins, environmental sustainability performance was measured through an index representing the "physical sustainability gap", Progress towards environmental sustainability, on the other hand, was calculated through "years to sustainability", In the ESGAP framework, both indices have been replaced by SESI and SESPI. A third composite indicator—the monetary environmental sustainability gap—remains unaltered.

The effects of these changes are most notable in the implementation of the framework. Ekins and Simon (2001) estimated the physical sustainability gap for seven environmental topics. For each of the topics, they calculated the difference between the situation in a given year and the environmental standard. One of the limitations was that it mainly used environmental policy targets as sustainability reference values, rather than science-based environmental standards. Thus, in practice, the authors measured a policy rather than a sustainability gap. A second limitation of the study was that the physical sustainability gap index lacked a coherent structure that could be linked to the theoretical framework. The study computed an index consisting of seven indicators that were not linked explicitly to the environmental functions and sustainability principles described in the approach adopted in this paper. Likewise, the authors aggregated the indicator scores without any reflections on how the choices made during the construction of the index were related to the theoretical underpinnings of the index.

These issues have been addressed in this paper, and in a more empirical paper (Usubiaga-Liaño and Ekins 2021) in which the renewed ESGAP framework was implemented. In that paper, SESI was structured around the environmental functions and sustainability principles in **Table 3**, and all the indicators used had a science-based environmental standard, largely based on the overview in the next section. Likewise, the choices made in the construction of SESI were aligned with the theoretical aspects of the ESGAP framework, although as with any other index, the indicator selection and other methodological choices can embed the developer's bias (Greco et al., 2019). Thus, ESGAP has been designed with the intention to facilitate the implementation of the original SGAP approach.

4 OVERVIEW OF NATIONAL ENVIRONMENTAL STANDARDS

The literature on environmental standards at the national level is very scattered. As a result, there is no readily available set of environmental standards that can be used to operationalize the environmental sustainability principles presented in **Table 3**, although the recent review of approaches by Vea et al. (2020) is worth noting. This section presents a brief overview of environmental standards structured around the functions and sustainability principles described above. The focus is set on Europe, since the first exercise to operationalize the ESGAP framework has focused on European countries (Usubiaga-Liaño and Ekins 2021).

4.1 Source functions

Source functions can be split into renewable and non-renewable resources. In general, the environmental standards for resources take the form of exploitation rates that are deemed environmentally sustainable.

In the case of renewable resources, sustainable exploitation rates are based on the regenerative capacity of the resource. This is the case, for instance, for forest utilization rates (EEA 2017), water exploitation rates for surface water and groundwater (Raskin et al., 1997; EC 2009) or concepts such as maximum sustainable yield for fish (Meltzer 2009). In the case of fish, the main methods used in Europe to define overexploitation are based on criteria on stock abundance, population age and size distribution, and reproductive capacity, although the specific standards and reference values differ (EC 2010; FAO 2011).

For non-renewable resources, scarcity is key and thereby sustainable exploitation rates are defined considering the exploitation potential of the resources over a given timeframe. For soils, tolerable soil erosion rates based on the formation rate of soils are used as environmental standards (Verheijen et al., 2009). Other factors such as the content of organic matter, salinization and sealing are also linked to the functioning of soils, but lack a credible environmental standard (Loveland and Webb 2003; Huber et al., 2008). Regarding the extraction of abiotic raw materials such as metal ores, non-metallic minerals and fossil energy carriers, the environmental standard could take the form of a reserves-to-production ratio that indicates the time the extraction of a given material could be sustained under projected extraction rates. Nonetheless, to the knowledge of the authors, such standards have not been proposed or scientifically justified. Standards related to the consumption of raw materials exist (Schmidt-Bleek 1993; Bringezu 2009, 2011, 2015), but consumption of raw materials is commonly used as a proxy for environmental pressures (Steinmann et al., 2017) and is therefore not representative of the source functions of natural capital.

4.2 Sink functions

Sink functions refer to the capacity of natural capital to absorb, disperse or dilute wastes to reduce potential harms. They are split into two main groups. The first one addresses emissions affecting global processes, while the second addresses waste flows that lead to regional or local environmental degradation. In the case of global processes such as global warming and the depletion of the ozone layer, environmental standards can take the form of changes to mean global temperature increases (Schellnhuber et al., 2016) and thickness of the ozone layer respectively (Rockström et al., 2009). However, to be applicable at the national level, these global standards need to be translated to country emissions of greenhouse gases and ozone-depleting substances. Different approaches exist to do so (Höhne et al., 2014), but lead to different results (van den Berg et al., 2019). Nonetheless, given past and current trends, it seems reasonable to state that country emissions of greenhouse gases and consumption of ozone-depleting substances will have to fall to close to zero, or even negative values as is already the case for the latter.

The second group of indicators in the sink function addresses waste flows that lead to regional or local environmental degradation. Environmental standards for individual pollutants take the form of critical levels and critical loads in ecosystems. Ecosystem-specific critical levels and loads of substances leading to acidification, eutrophication, ground level ozone pollution and heavy metal pollution have been reported in different sources (Karlsson et al., 2003; Karlsson et al., 2007; Mills et al., 2007; Hettelingh et al., 2015; CLRTAP 2017; Hettelingh et al., 2017). In the case of freshwater ecosystems, environmental standards for surface waters and groundwater can be found in the relevant European legislation (European Parliament and European Council 2008; EC 2009). The same applies for marine waters (EC 2017).

4.3 Life support Functions

Environmental standards of life support functions are intended to depict the status of the elements of natural capital that underpin life on Earth. Standards have been proposed for the status of biodiversity, since this is an important predictor of the functioning and stability of ecosystems (Cardinale et al., 2012), and for the extent and condition of ecosystems.

For biodiversity, proposed standards have taken the form of global species extinction rates and species abundance (Steffen et al., 2015), although other aspects of biodiversity need further research (Mace et al., 2014). With biodiversity conservation as a central goal, environmental standards for limiting agricultural land use have also been proposed (Rockström et al., 2009; Bringezu et al., 2012; Usubiaga-Liaño et al., 2019).

Defining the quality of ecosystems, as in ecosystem condition standards, requires meeting different criteria. For terrestrial ecosystems, parameters on range, area, structure and function are used to define good quality (Röschel et al., 2020). The condition of freshwater and marine ecosystems, on the other hand, is determined based on a wide range of biological, physicochemical and other parameters outlined in the relevant EU legislation (EC 2003, 2017).

4.4 Human health and Other Welfare Functions

The functions in this group are linked to human health and other aspects of well-being such as recreation, culture, spirituality, etc. In relation to human health, environmental standards are formulated as maximum concentrations of air pollutants in indoor and outdoor environments (WHO 2005), in drinking water (European Council 1998) or bathing sites (EC 2002). All these standards are based on the health impacts of different pollutants on humans. In the case of other welfare functions, standards are lacking for most of the non-use values of natural capital. Access to green areas (Poelman 2018) and the condition of natural and mixed World Heritage sites (Osipova et al., 2014) could be considered exceptions.

5 DISCUSSION

There are hundreds of metrics intended to reflect various aspects of the environmental dimension of sustainable development. They cover such diverse phenomena as environmental pressures and states, features of production and consumption systems, aspects of environmental policies and related mechanisms, links between humans and nature, etc. Nonetheless, despite the growing volume of information being generated, environmental degradation continues to grow (IPBES 2019; UN Environment 2019).

Ekins and Simon (1999) argued two decades ago that nations lacked metrics that allowed them to assess environmental sustainability from a strong sustainability perspective. Since then, relevant progress has been made on several fronts. First, advances in the conceptualization (Díaz et al., 2018; Haines-Young and Potschin 2018; Fairbrass et al., 2020), accounting (Millennium Ecosystem Assessment 2005; IPBES 2019; Brandon et al., 2021) and valuation (Obst et al., 2016; Ling et al., 2018) of natural capital and ecosystem services have led to the inclusion of ecosystems in the System of Environmental-Economic Accounting (UNDESA 2021). In this context, the increase in the use of satellite imagery (e.g., Pettorelli et al. (2014)), citizen science (e.g., Conrad and Hilchey (2011)), machine learning (e.g., Willcock et al. (2018)) and artificial intelligence (e.g., Villa et al. (2014)) offer promising prospects for natural and ecosystem service accounting (UN Environment 2019). Second, in the last two decades, metrics such as the Environmental Performance Index and the Ecological Footprint have gained significant traction in monitoring the environmental performance of countries and some have even gained media attention (Morse 2016). At the same time, the framework provided by the SDGs and the underlying targets and indicators represents a unique political consensus on how to implement and monitor the global development agenda. Through those metrics and others, the characterization of environmental phenomena has changed and now many environmental metrics provide very much needed context by measuring progress towards targets or some type of reference values instead of just providing information that could be hard to interpret on its own.

In this paper we have argued that measuring environmental sustainability requires indicators that are linked to the functions provided by natural capital and that use science-based reference values to contextualize performance. While indicators related to the functioning of natural capital are abundant in many sets of indicators and indices, the necessary science-based reference values are still insufficiently present in many relevant metrics such as the various SDG indicator sets, the Environmental Performance Index, the EEA environmental indicators and the Transition Performance Index. Science-based reference values gained significant attention after the publication of the Planetary Boundaries framework. Since then, the use of science-based reference values is increasingly being used at different scales. At the product level it is emerging in fields such as life cycle assessment (Bjørn et al., 2016; Bjørn et al., 2020), at company level science-based targets are increasingly being adopted (Walenta 2020) and at the national and regional level the Planetary Boundaries framework has been adapted several times (Nykvist et al., 2013; Cole et al., 2014; Hoff et al., 2014; Dao et al., 2015; Lucas and Wilting 2018).

While achieving environmental sustainability will require transformations at every scale, current systems of environmental governance are largely driven by processes and legislation at the national level. And at this level, the Planetary Boundaries framework has had limited impact (Li et al., 2021), partly because the downscaling of global boundaries for some issues remains problematic (Häyhä et al., 2016). For example, the availability of freshwater (one of the nine identified Planetary Boundaries) is far more a local and regional, than planetary, issue, and differs dramatically within and between regions. Thus, after more than 20 years and despite all the progress made on the data and metrics front, this paper shows that the metric gap identified by Ekins and Simon (1999) remains.

The updated ESGAP framework provides the theoretical basis to bridge that gap. It builds on the original SGAP approach published two decades ago by combining the key elements that have stood the test of time, refining others and proposing new composite indicators that make the renewed ESGAP framework easier to implement as proven in recent work (Usubiaga-Liaño and Ekins 2021). ESGAP puts the concepts of strong sustainability, critical natural capital, environmental functions, and science-based reference values at the center of a consistent and theoretically sound framework that can be used as the basis to develop a set of policy-relevant metrics of environmental sustainability at the national level. In contrast to most sustainability metrics, which tend to either describe the current state or trends (Kwatra et al., 2020), the ESGAP metrics proposed here, when combined, can provide information on both the static and dynamic aspects of national environmental sustainability across a range of relevant environmental and resource issues, as well as the monetary gap required to bridge the gap between the current and the sustainable situation.

One of the key contributions of the ESGAP framework is the role played by science-based standards in the measurement of environmental sustainability. As argued before, environmental standards differ from environmental policy targets in that they are intended to reflect the scientific understanding of the conditions under which relevant functions of natural capital can be maintained over the long term. Policy targets, in contrast, are more normative, since they are formulated through a process in which, besides scientific considerations, various economic, social and other factors are taken into account. To date, there are no composite indicators or indicator sets focused on the national level in which science-based environmental standards provide the essential reference.

In this context, there is a scattered literature on environmental standards, which has been summarized in **section 4**. The standards mentioned here have either been taken from the scientific literature or from relevant environmental legislation informed by expert input. It is important to bear in mind that environmental standards do not have a homogeneous meaning in that they can variously refer to acceptable health risks, acceptable environmental impacts, precautionary expert guesses, or judgements about safe distance from tipping points. Thus, the level of consensus around environmental standards differs considerably. In all cases though, their transgression flags a potential problem that requires further policy attention. As the knowledge base improves, existing environmental standards might change, or new ones might be formulated. This would impact the indicators chosen to characterize environmental sustainability and the results obtained therefrom.

6 CONCLUSION

Metrics fulfil a variety of functions. From awareness-raising to monitoring progress, metrics have become a key part of environmental governance. Nonetheless, although the evidence of the seriousness of environmental degradation provided by global environmental assessments is unequivocal, the urgency they communicate is not matched by the measures adopted by countries to tackle environmental degradation. The little weight given to scientific evidence in certain decisions has led to an increasing number of calls from scientists (Ripple et al., 2017; Ripple et al., 2020; Wiedmann et al., 2020; Albert et al., 2021) and from the civil society such as the Fridays for Future movement for decision makers to better integrate scientific evidence into the decision-making process.

This paper has proposed specific criteria to assess whether existing environmental and sustainable development metrics are fit for purpose to monitor environmental sustainability at the national level. In contrast to previous attempts, we have provided a more analytical and structured review, based on which we have concluded that a measurement gap exists. Addressing this gap is critical to adequately monitor and communicate environmental sustainability performance and trends to decision makers and other relevant agents.

Against this background, the ESGAP framework provides the theoretical underpinning for developing policy-relevant indices of environmental sustainability that can help bridge this measurement gap. It does so by using or adapting well established concepts in ecological economics and environmental science so that they can be embedded in environmental sustainability metrics. The framework is gaining interest for its potential for implementation. Work in implementing the framework for European countries is ongoing (Usubiaga-Liaño and Ekins 2021), with pilot studies being carried out in countries as varied as New Caledonia, Vietnam, Kenya, Japan, China and the Bahamas.

Beyond the theoretical soundness, the ESGAP metrics can contribute to better decision making by more accurately representing environmental sustainability. In the absence of accurate representation, we risk providing misleading information, which can ultimately delay or hamper the adoption of environmental policies. On a broader level, ESGAP has the potential to embed strong sustainability thinking and science-based reference values in nations in which these concepts are not sufficiently reflected in policies, to better communicate environmental urgency to decision makers and other agents, and to complement GDP in its (mis) use as a headline indicator of development.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AU-L designed the study and wrote the first draft. PE contributed to writing the study and supervised the PhD on which the work is based.

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SUPPLEMENTARY MATERIAL

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