Are we on the right path? Measuring progress towards environmental sustainability in European countries

Authors

Arkaitz Usubiaga-Liaño [a, b] (*)

Paul Ekins [a]

[a]: Institute for Sustainable Resources, University College London, 14 Upper Woburn Place, WC1H 0NN, London (United Kingdom)

[b]: Basque Centre for Climate Change, Scientific Campus of the University of the Basque Country, 48940, Leioa (Spain)

(*): Corresponding author: arkaitz.usubiaga@bc3research.org

Keywords

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

Abstract

Current environmental and sustainable development metrics fail to capture environmental sustainability from a strong sustainability perspective, which can lead to misleading messages around the urgency to reduce environmental degradation. The Environmental Sustainability Gap (ESGAP) framework addresses this measurement gap with metrics that reflect whether the functions of natural capital can be sustained in the long term. To date, the framework has been implemented through the Strong Environmental Sustainability

Index (SESI), which provides a 'snapshot' perspective on whether countries meet science-based environmental standards for a wide range of environmental and resource topics at a given point in time. However, SESI does not show whether countries are moving towards or away from environmental sustainability. This is a perspective often overlooked in many environmental and sustainable development metrics.

In order to address this research gap, this paper presents the Strong Environmental Sustainability Progress Index (SESPI). SESPI comprises 19 indicators. For each of these indicators, it measures whether under current trends, standards of environmental sustainability will be reached in 2030. The resulting information is normalised, weighted and aggregated into a single index that has been computed for 28 European countries. The results show mixed progress for Europe with notable differences between countries and indicators, but generally speaking, it can be concluded that Europe is not on a sustainable path.

All in all, SESPI can answer the question of whether we are making progress towards environmental sustainability and make the main messages more digestible to decision makers and the general public.

1. Introduction

Good governance requires a good information base, which in turn requires appropriate metrics that translate data into useful information. One of the key purposes of metrics – used here as a broad concept that comprises individual indicators, sets of indicators and composite indicators – is to capture and simplify a complex reality (EEA 2003). Being at the core of modern politics, sustainable development is one of those complex concepts that analysts have tried to operationalise through metrics. How multidimensional concepts are translated into indicators depends on factors such as data availability, indicator selection criteria and the interpretation of the concept itself. The latter is particularly relevant for sustainable development because its elusiveness has allowed different stakeholders to adapt it to their own context (Greco et al. 2019). A common feature in the different understandings of sustainable development is the substitution capacity between the functions humans obtain from different types of capitals (Neumayer 2003), namely, manufactured, human, social and natural (Ekins 1992). This determines, for instance, the conditions that need to be met for development to be considered environmentally sustainable.

Theoretical aspects aside, global indicator-based environmental assessments leave no doubt as to the unsustainability of the current development path (IPCC 2014; IPBES 2019; UN Environment 2019). However, because of their comprehensiveness and the effort required to coordinate and update the evidence base, these assessments are only published every few years. A more targeted and timelier overview can be arranged around a limited number of indicators or a composite indicator that require less resources to be updated. This type of approach is often taken to monitor environmental policies or international environmental agreements, where a manageable number of indicators is often used to monitor progress towards goals. Given that most policies intended to tackle environmental degradation are adopted at the national level, the question remains as to whether countries have adequate metrics in place. In this context, Usubiaga-Liaño and Ekins (2021a) argued that countries lack robust and resonant monitoring systems if environmental sustainability is to be understood in the context of strong sustainability. Under this perspective, environmental sustainability requires the maintenance of the environmental functions of natural capital in the long term. As the authors explain, any indicator trying to represent environmental sustainability conditions needs to be related to the functions of natural capital and to have a science-based reference value – hereinafter environmental standard – against which performance can be measured. While the use of reference values to contextualise indicator performance has increased in recent years, the most well-known environmental metrics, which include the different SDG indicator sets (Lafortune et al. 2018; IAEG-SDGs 2019; OECD 2019; Eurostat 2020) and the Environmental Performance Index (Wendling et al. 2020), do not consistently use environmental standards, but rather a mix of policy targets, best-performing countries and environmental standards. Given that policy targets are usually not aligned with science-based environmental standards (Kutlar Joss et al. 2017; Doherty et al. 2018; UNEP 2020) and the performance of frontrunners does not necessarily reflect environmental sustainability conditions, such practice cannot be used to monitor environmental sustainability, as it can provide a false sense of success. The Planetary Boundaries (Steffen et al. 2015) framework, on the other hand, is based on environmental standards, but their use at the national scale remains problematic (Häyhä et al. 2016). This leaves a measurement gap when it comes to monitoring environmental sustainability at the national level.

The Environmental Sustainability Gap (ESGAP) framework, which builds on the concepts of strong sustainability, critical natural capital, environmental functions and science-based environmental standards, was developed to address this measurement gap (Usubiaga-Liaño and Ekins 2021a). While implementing the ESGAP framework, Usubiaga-Liaño and Ekins (2021b) computed the Strong Environmental Sustainability Index (SESI) for European countries as a first step towards measuring the environmental sustainability of nations. SESI aggregated 21 indicators addressing a wide range of environmental and resource topics, each of which had its corresponding environmental standard, into a single index of national environmental sustainability performance. Nonetheless, SESI only provides a snapshot view of environmental sustainability, and therefore is not able to capture progress over time. This temporal perspective is often overlooked in sustainable development and environmental metrics (Hametner and Kostetckaia 2020) and deserves more attention in the context of environmental sustainability. Thus, countries still lack a metric that can show whether they are moving towards environmental sustainability from a strong sustainability perspective.

Against this background, this paper presents and computes the Strong Environmental Sustainability Progress Index (SESPI) for European countries. The index not only reflects whether countries are moving towards or away from environmental sustainability, but also captures whether, if current trends are maintained, environmental standards will be reached at a predefined point in time (in this case by 2030). Thus, SESPI contributes to the measurement of environmental sustainability by adding the often-overlooked temporal dimension. In this context, section 2 provides an overview of metrics that consider the time dimension. Section 3 describes the methodology and data sources used to construct and compute SESPI, while section 4 presents the main results for the 27 European Member States and the UK (hereinafter European countries for readability purposes, or Europe or European block when referred to as a single entity). European countries are chosen as a case study because of data availability. Section 5 discusses the main findings, while section 6 concludes.

2. The temporal dimension in sustainable development and environmental metrics

Historically, most environmental and sustainable development metrics have reflected country performance at a given point in time (Hametner and Kostetckaia 2020). When time series were available for most indicators, progress was monitored by comparing the results of the latest year with those of previous years. Given that in most cases the metrics employed measured relative performance (i.e. the performance of countries against frontrunners), they failed to show systematically whether countries were making enough progress towards specific goals such as environmental policy targets or environmental standards. A few notable exceptions include the work of Sicherl (1973) and Ekins and Simon (2001).

In the early 1970s, Sicherl (1973) proposed the time-distance approach as a way to complement the snapshot overview often presented by data users. The approach relies on two metrics: 'S-time-distance', which measures the time difference it takes a country to achieve a given level of a variable of interest reached by another country, and 'S-time-step', which shows the number of years needed in the past to increase one unit of a variable of interest (Sicherl 2011). In the context of the Sustainability Gap approach, Ekins and Simon (2001) proposed 'years to sustainability' (Y2S) in order to provide an easy-to-understand message about progress towards or away from environmental sustainability. Y2S represents the years required to reach a given environmental standard by linearly extrapolating current trends, thereby giving a general indication of whether countries are in the right track to achieve relevant environmental standards. Although easy to understand, the index presented a number of problems, the main one being the impossibility of aggregating the values when an indicator was showing negative trends and its Y2S value was infinite.

More recently, the emergence of the Sustainable Development Goals (SDGs) triggered new metrics intended to measure progress towards them, although most SDG indices still reflect country performance at a given point in time (see Hametner and Kostetckaia (2020) for some examples). In this context, Eurostat (2014) provided an overview of methods that could be used to measure progress over time depending on the type of data available, which laid the foundation for different assessments (Allen et al. 2020; Eurostat 2020; Hametner and Kostetckaia 2020; Simsek et al. 2020). Of special interest in the context of this paper is the method that compares observed trends with desired trends to evaluate not only whether countries are headed in the right direction, but also whether, if maintained, observed trends would lead to reaching a given target at a given point in time. When a target value is available, Eurostat (2020) and Sachs et al. (2020) use this method to measure progress towards the SDGs. Nonetheless, there are different ways of calculating observed and desired trends. In the case of Eurostat, observed trends are assumed to follow an exponential function, while Sachs et al. (2020), on the other hand, use a linear function. The results of these assessments are presented in a variety of ways, most of which require normalising the data on trends to make it comparable across indicators. In the different publications, progress or lack thereof is commonly presented through the use a limited set of icons or colours to represent progress or lack thereof (Sachs et al. 2020), through a score-based system (Hametner and Kostetckaia 2020) or a combination of the two (Allen et al. 2020; Eurostat 2020). Depending on the context, the comparison between observed and desired trends is interpreted at the level of individual indicators or at the level of indicator groups. The latter requires applying a normalisation, weighting and aggregation process to the results as with composite indicators.

Alternatives to this approach also exist in indicator-based assessments. The most notable one in Europe is the more qualitative perspective provided in the State and Outlook of the Environment Report (SOER) published by the European Environment Agency every five years (EEA 2019b). SOER incorporates the temporal perspective by combining data on trends, modelling results and expert input. Arguably, SOER-type assessments of trends are more comprehensive, but also demand a more complex process and require more resources to be implemented.

3. Methodology

The construction of SESPI follows the most comprehensive manual on composite indicators (OECD and JRC 2008; JRC 2019). The following subsections describe the methodology in more detail.

3.1. Theoretical framework

SESPI is based on the ESGAP framework and as such, key methodological aspects of the index are aligned with the conceptual foundations of the framework. The most relevant elements of ESGAP are described in Table 1 in order to ease the understanding of the decisions taken in the next sections. The framework is described in more detail in Usubiaga-Liaño and Ekins (2021a).

Table 1: Key features of the ESGAP framework

Concept	Description
Human well-being	It is generated through processes that depend on the combination of natural, manufactured, human and social capital.
Natural capital	It represents the elements of nature that directly and indirectly produce value or benefits to people.
Strong sustainability	There is limited substitution capacity between the functions of natural capital and other types of capital.
Critical natural capital	Natural capital that has unique functions that cannot be replaced.
Environmental functions	Subset of the physical, chemical or biological interactions between the components and processes of natural capital that define its capacity to provide goods and services. We distinguish four broad kinds: source (provision of resources), sink (regulation of waste), life support (maintenance of ecosystem health and biodiversity), and human health and welfare (other services to humans).

Environmental sustainability	It requires the functions of natural capital to be sustained over time.
Sustainability principles	They describe general requirements for the maintenance of environmental functions. They further divide environmental functions as follows: • Source: 'Renew renewable resources' and 'Use non-renewables prudently' • Sink: 'Prevent global warming and ozone depletion' and 'Respect critical levels and critical loads for ecosystems' • Life support: 'Maintain biodiversity and ecosystem health' • Human health and other welfare: 'Respect environmental standards for human health' and 'Conserve landscape and amenity'
Science-based environmental standards	They reflect environmental sustainability conditions.

Based on Usubiaga-Liaño and Ekins (2021a) and key references therein.

Based on the concepts above, the ESGAP framework argues that critical functions of natural capital need to be maintained. These environmental functions can be classified in the following broad categories: source, sink, life support, and human health and welfare. Source functions are linked to the provision of resources, sink functions to the absorption of waste, life support functions to the maintenance of biodiversity and ecosystem health, and human health and welfare to human health and other intangibles such as amenity, landscape quality, etc. In practice, it is impossible to identify all the functions that need to be maintained in various social and geographical contexts. Thus, ESGAP proposes a set of principles that can be used to define the conditions that describe environmental sustainability. The sustainability principles, which are described in Table S3 in the supplementary material, further split the source and sink functions into biotic and abiotic resources, and global- and regional-scale pollution processes respectively. The human health and welfare functions are also split to distinguish processes related to the maintenance of human health, and those related to other aspects that are relevant to human welfare.

3.2. Indicator selection

The indicators used to compute SESPI (hereinafter SESP indicators) have been selected based on three criteria: relevance, methodological soundness and data quality. The relevance criterion requires the indicators to be representative of environmental sustainability. As argued above, environmental sustainability requires the functions of natural capital to be sustained over time. Thus, for indicators to be relevant, they need to be related to the functions of natural capital, to have science-based environmental standards against which performance can be measured and to be meaningful at the national level. The methodological soundness criterion considers the readiness and maintenance of statistical production, accessibility and transparency, and compliance with existing methodological standards. Lastly, the data quality criterion covers aspects related to the frequency of dissemination, timeliness, time and geographical coverage and data comparability. The supplementary material describes how the initial list of 30 potential indicators was reduced to the 19 indicators that form SESPI, building on the criteria described here.

The selected 19 indicators are arranged around environmental functions, sustainability principles, and environmental topics in line with the ESGAP framework as shown in Figure S1 in the supplementary material. The list of indicators and the category of environmental function they have been allocated to are shown in Table 2. The data used to populate the index has been obtained primarily from European institutions such as the European Environment Agency, the European Commission's Joint Research Centre, non-governmental organisations or from other well-established centres. The data points used in each indicator are also shown in Table 2. More information can be found in Table 3 in the Appendix, while information about the indicators and the environmental standards used is given in the supplementary material.

Table 2: List of SESP indicators

Function	Indicator [Unit]	Year 0	Year 1
Source	Forest utilization rate [%] *	2010	2015
	Freshwater bodies not under water stress [%]	2010	2015
	Groundwater bodies in good quantitative status [%]	2009	2015
	Area with tolerable soil erosion [%]	2010	2016
Sink	CO_2 emissions [tonnes per capita] *	2013	2018
	Consumption of ozone-depleting substances [kg per capita] *	2014	2019
	Cropland and forest area exposed to safe ozone levels [%]	2012	2017
	Terrestrial ecosystems not exceeding the critical loads of eutrophication and acidification [%]	2005	2017
	Surface water bodies in good chemical status [%]	2009	2015
	Groundwater bodies in good chemical status [%]	2009	2015
	Coastal water bodies in good chemical status [%]	2009	2015
Life support	Terrestrial habitats in favourable conservation status [%]	2012	2018
	Surface water bodies in good ecological status [%]	2009	2015
	Coastal water bodies in good ecological status [%]	2009	2015
Human health and welfare	Population exposed to safe levels of outdoor air pollutants [%]	2012	2017
	Population using clean fuels and technologies for cooking [%]	2013	2018
	Samples that meet the drinking water criteria [%]	2011	2013
	Recreational water bodies in excellent status [%]	2014	2019

	Natural and mixed world heritage sites in good conservation outlook [%]	2017	2020

Note: the three indicators marked * are either not a percentage or not necessarily bounded in the 0-100% range, and are therefore subject to a different normalisation treatment, as discussed further below.

3.3. Data treatment

The indicators above show whether at a given point in time environmental standards are met across a range of environmental and resource issues. Since the goal of SESPI is to show current trends in respect of sustainability, SESPI requires normalisation of the ratio between observed trends and desired trends as in Eurostat (2020), where the latter are defined as trends that would lead to meeting an environmental standard at a defined point in the future. The main difference between the method used here is that it considers linear instead of exponential trends in order to increase the understandability of the method. The formulation of observed trends ($trend_{obs}$) for a period going from t_0 (base year) to t_1 (most recent year) is given below. The years used as t_0 and t_1 are shown above in Table 2. In Equation 1, I represents the value of each indicator.

Equation 1

$$trend_{obs} = \frac{I_{t_1} - I_{t_0}}{t_1 - t_0}$$

On the other hand, desired trends are calculated as follows:

Equation 2

$$trend_{des} = \frac{x_{t_r} - I_{t_1}}{t_r - t_1}$$

where x is the environmental standard (100 in most indicators) and t_r is the target year, in this case, 2030 in order to align it with the time horizon of the SDGs.

The ratio between observed and desired trends ($R_{o\text{-}d}$) compares a linear extrapolation of the past with the linear trend required in the future to achieve an environmental standard, thereby providing an intuitive metric of whether enough progress is being made in each individual indicator.

Equation 3

$$R_{o-d} = \frac{trend_{obs}}{trend_{des}}$$

Negative scores for $R_{o\text{-}d}$ indicate that country performance is worsening and therefore it will be impossible to reach the environmental standard unless those trends are reversed. Values higher than 100% suggest that under current trends the environmental standard will be met before the target year, while values between 0% and 100% are indicative of an improving trend that is still insufficient to meet the environmental standard by the target year.

3.4. Normalisation

Normalised country scores depend on the difference between the observed and desired trajectory. Thus, indicators in which observed trends are close to those considered sustainable will get high normalised scores, while indicators in which observed trends are not aligned with desired trends will get low normalised scores. In order to formalise the mathematical formulation of the statement above, we use the goalpost normalisation method. In the goalpost method, the user defines upper and lower goalposts aligned with sustainable and unsustainable conditions, which are then assigned a normalised score of 100 and zero respectively.

We use two slightly different approaches depending on the characteristics of the SESP indicators. For indicators that represent an environmental or social state bound in the 0-

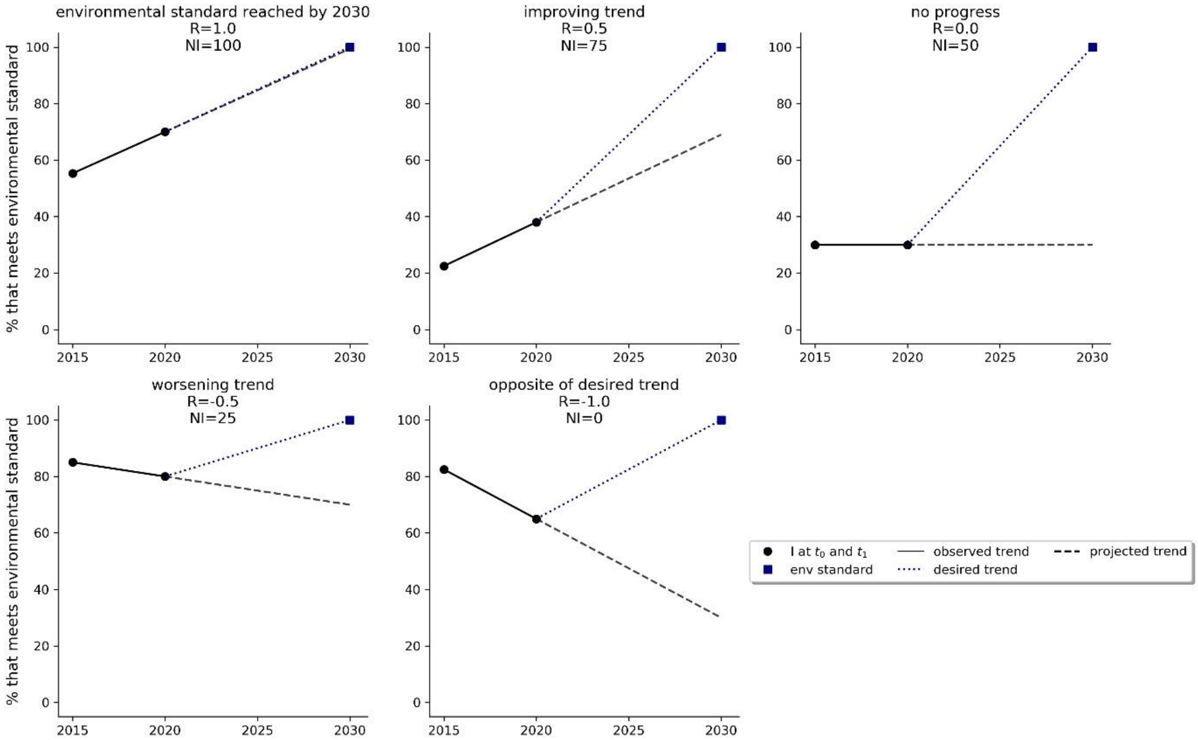
100% range (16 out of 19 indicators, see Table 2), we use the following normalisation method based on R_{o-d} values. In Equation 4, the normalised score (NI) is a function of the ratio between observed and desired change (R_{o-d}). Normalised scores lower than zero and higher than 100 are assigned zero and 100 values.

Equation 4

$$NI = 50 + 50R_{o-d}$$

In practice, normalised scores can be interpreted as follows. R_{o-d} values ≥1 show that if current trends are maintained, the environmental standard will be met in 2030 or earlier. Thus, based on Equation 4 they get a normalised score of 100. When no change occurred and therefore R_{o-d} equals zero, a normalised score of 50 is obtained. In between, improving trends that are insufficient to meet the environmental standard (R_{o-d} in the 0-1 range) are assigned a normalised score between 50 and 100. On the negative side, a trend that is the opposite of the desired trend (R_{o-d} = -1) is assigned a normalised score of zero. In between, scores between zero and 50 are indicative of less intense worsening trends. This is visually represented in Figure 1, where the values of a fictional indicator are shown for five fictional countries (see the note at the bottom of the figure).

Figure 1: Interpretation of the normalised scores for a fictional indicator in different fictional countries



In the first country (top left), observed and desired trends are equal and therefore, the environmental standard will be reached in 2030 under current trends ($R_{o\text{-}d}$=1), which gives a normalised score of 100. In the second country (top centre), the observed trend shows a change in the right direction ($R_{o\text{-}d}$=0.5), but this will be insufficient to meet the environmental standard by 2030. In the third country (top right), there is no progress ($R_{o\text{-}d}$=0), which leads to a normalised score of 50. In the fourth country (bottom left), change occurs in the wrong direction ($R_{o\text{-}d}$=-0.5), which leads to a normalised score of 25. Finally, in the last country (bottom centre), observed change is the opposite of what it should be to meet the environmental standard ($R_{o\text{-}d}$=-1). This is equivalent to a normalised score of zero.

The second approach applies to the remaining indicators (three out of 19: forest utilization rate, CO_2 emissions, consumption of ozone-depleting substances, marked with a * in Table 2). Their values are not bound in the 0-100 range and therefore can go from zero to infinite, and in some cases from minus infinite to infinite. Since in most cases the environmental standard has not been met in t_1, Equation 4 is commonly used. In very specific circumstances (when the environmental standard was already met in t_1) a different formulation applies as explained in the supplementary material. This different formulation has been designed to capture the possibilities of meeting or not meeting the environmental standard in 2030 with worsening trends in cases in which the environmental standard was already met in t_1 (e.g. with worsening trends 0.3 tonnes CO_2 per capita in 2018 could evolve to 0.4 tonnes per capita or 0.6 tonnes per capita in 2030, where only the last case fails to meet the environmental standard of 0.5 tonnes per capita). The interpretation of the normalised scores remains the same.

3.5. Weighting and aggregation

Weights are intended to capture the relative importance of the phenomena represented in indicators, although this does not reflect their impact in the final index score (Becker et al. 2017). Arguably, the different environmental functions represented in SESPI would warrant different weights depending on their importance. Likewise, diverging national endowments would justify the use of country-specific weights for indicators. Nonetheless, there is no agreed method to do so, so equal weights have been used for simplicity.

The aggregation method used represents whether an index reflects weak or strong sustainability conditions. By excluding the economic and social dimensions of sustainability in SESPI, we implicitly embed the limited substitution capacity between natural capital and other capitals in line with strong sustainability. Within the index, a geometric mean has been used in order to represent the limited substitutability between the functions of natural capital. As in other indices, zeros and small values are treated to avoid the problems arising from their presence when aggregating with the geometric mean. Thus, a minimum score of five is assigned to all the normalised values before aggregation (see supplementary material).

All in all, SESPI can be interpreted as follows. A value of 100 indicates that all the indicators describe trends that are aligned with meeting their respective environmental standards in 2030. A score of zero, indicates that all the indicators are going in the wrong direction and, therefore, in 2030 the environmental sustainability performance of countries will have deteriorated considerably. In between, low scores suggest that (at least) a few indicators are going in the wrong direction, and therefore several environmental functions will be threatened in the future. High scores reflect the opposite.

A geographical aggregation has also been carried out to represent the results at European level, rather than at country level, which is the level at which the data has been compiled originally. In order to represent the results for the European block, the data of each indicator has been aggregated with a weighted mean, thereby considering the differences in population, ecosystem area, length of rivers, etc. as required in each indicator.

3.6. Uncertainty analysis

It has been established that different normalisation, weighting and aggregation choices significantly affect the results of a related, but snapshot, environmental sustainability index (Usubiaga-Liaño and Ekins 2021b), which highlights the importance of aligning the choices made during the construction of an index with its theoretical framework so that the index properly captures the phenomenon it intends to represents. Here we tested the effects of choosing different base years to calculate observed trends. To that end, equations 1-4 were recalculated using 1,000 different t_0 combinations (keeping t_1 constant) selected through a Montecarlo analysis, which were then used to compute index and function scores.

4. Results

4.1. Main results

Figure 2 shows the SESPI scores of the 28 European countries covered in this paper. Most countries score between 40 and 60 points, which suggests that under current trends they will not reach all the environmental standards in 2030, the closing year of the SDGs. In the top, the Czech Republic, Luxembourg and Latvia are slightly above the 60-point line. This can be interpreted as most indicators moving in the right direction, with only a few showing no progress or going in the wrong direction (it should be remembered that using the geometric mean of the indicators for aggregation gives greater weight to the lower indicator scores, to reflect the non-substitutability characteristic of strong sustainability). In this context, it is important to bear in mind that, for individual SESP indicators, a normalised score of 100 indicates that under current trends an indicator will achieve the environmental standard in 2030 or sooner, or it has already achieved it. A score of 50 shows that no progress has been reported, while a score of zero shows that current trends are exactly the opposite of what is needed to meet the environmental standard in 2030. At the bottom, Italy and Portugal have less than 34 points, and Croatia gets a score of 26. These countries will not only miss the environmental standards but are also going in the wrong direction in many instances. The European block scores 42 points. The reader should note that in exceptional cases, data gaps result in the scores of some countries being computed with slightly fewer indicators. This is shown in the supplementary Excel file.

Figure 2: SESPI score for the 27 European Member States and the UK

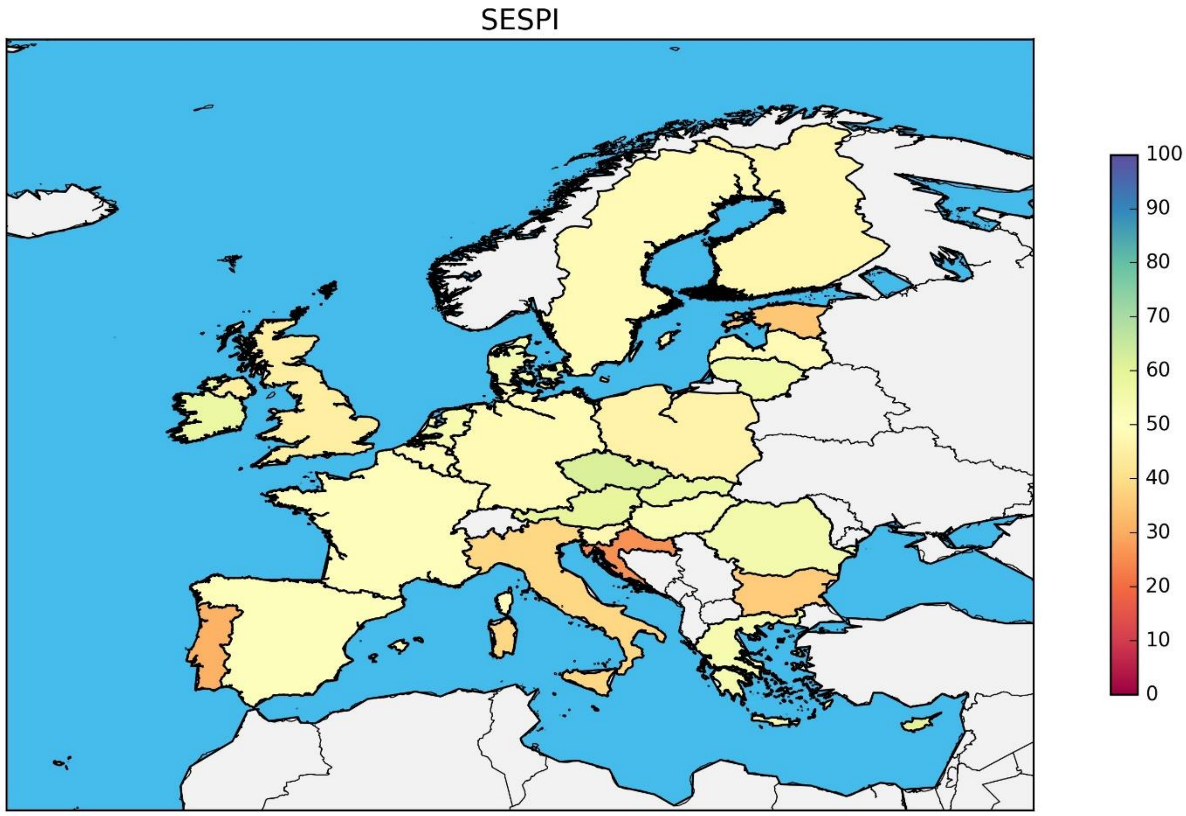


Figure 3 represents the SESPI scores at the level of environmental function (see Figure S2 in the supplementary material for the results at the level of the sustainability principles). Countries perform worse in the source function, which considers the provision of biotic and abiotic resources. In this function, scores range from 71 in Lithuania to 16 in Portugal, with 22 countries scoring less than 50 points. The European block scores 24 points. The overall score of the source functions is driven down mainly by the low performance of two indicators of renewable resources: forest resources and freshwater resources. In the former, although many Northern and Central-West European countries experienced an increase in the net annual increment of forest resources between 2010 and 2015, fellings increased at a higher rate, which led to higher exploitation rates and therefore a worsening trend (Forest Europe 2020). In South-East Europe, available resources barely changed in the same period, but fellings increased, thereby resulting in higher exploitation rates as well. In Central-Eastern European countries exploitation rates decreased. With regard to freshwater resources, the river basin areas suffering from water stress in at least one quarter of the year increased between 2010 and 2015. This is partly the result of lower available freshwater resources in 2015 due to a significant decrease in net precipitation (Eurostat 2021). Performance in groundwater scarcity is generally much better. Between 2009 and 2015, the area of European groundwater bodies in good quantitative status increased from 87% to 90%, which results in a normalised score of 100. This follows a continued decrease in groundwater abstraction in Europe since 1990 (EEA 2019b). At the country level, trends are generally good with more than half of the countries headed towards achieving the environmental standards by 2030. In the case of soil erosion, at the European level there has been barely any change in the area that is subject to tolerable soil erosion rates. This is partly because erosion rates in arable lands tend to be much higher than the environmental standard, and therefore, even when erosion rates are reduced, the percentage of land area that meets the environmental standard might not increase. Nonetheless, Panagos et al. (2020) report positive signs as a result of conservation practices in countries such as Austria, Denmark, Germany, Estonia, France and Portugal. On the other end, they mention Bulgaria as a laggard in the implementation of management practices intended to reduce soil erosion. Perhaps most worrying, the performance of some Mediterranean countries that suffer from high erosion rates has worsened between 2010 and 2016.

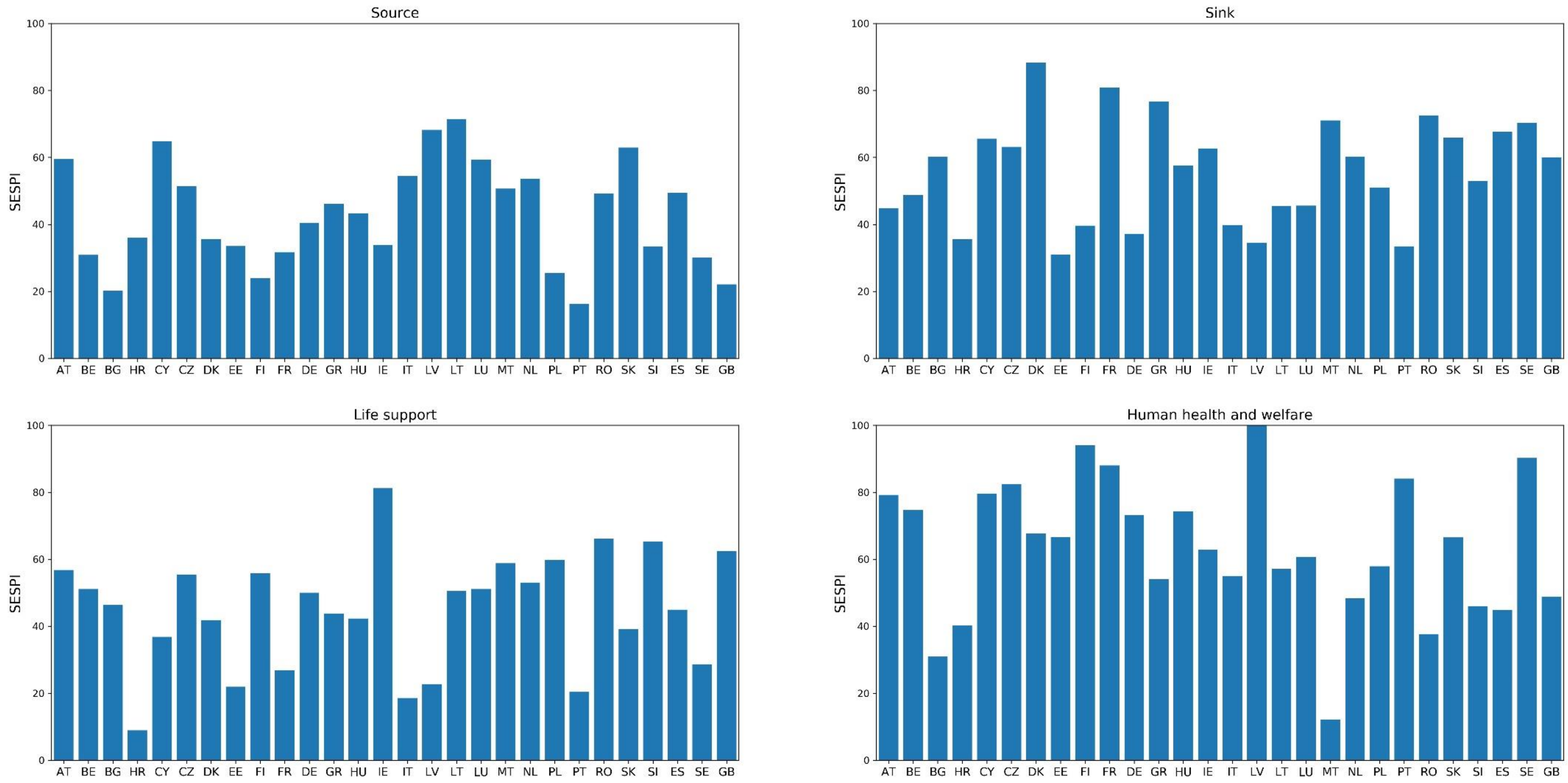
The European block reports scores between 48 and 55 in the remaining functions with relevant differences in the underlying principles. In the sink functions, scores tend to be higher for Earth System processes with all the countries scoring 100 in consumption of ozone-depleting substances (where the standard has already been met) and many countries reporting progress in reducing CO_2 emissions. In this vein, although 18 European countries reported average annual per-capita CO_2 emission reductions in the range of 0-11% between 2013 and 2018, these are in most cases not sufficient to meet the environmental standard in 2030. As a result, most normalised scores range between 50 and 90. The remaining 10 countries reported increases in emissions between 0-3%.

Regarding chemical pollution in ecosystems, country performance is much more uneven with France, Denmark and Romania generally moving in the right direction, and 15 countries obtaining scores below 40. The European block shows improving trends in the chemical status of terrestrial ecosystems (stronger in relation to ozone pollution compared to eutrophication and acidification). In contrast, small progress was reported in the chemical status of groundwater, while the situation of surface and coastal water systems worsened. The reader should note that the latter statement needs qualifications on two grounds. First, although the percentage of surface and coastal water bodies in good chemical status decreased between 2009 and 2015, significant progress has been made in reducing the concentration of some pollutants such as pesticides or some heavy metals (EEA 2018a). Nonetheless, the presence of other substances such as mercury leads to failure to meet good chemical status in numerous freshwater bodies (EEA 2018a). Second, caution is advised when comparing the country performance over time, as the results are affected by the methods used to collect data, which might differ.

In the life support functions, Ireland, Romania and Slovakia are at the top, while 14 countries score less than 50 points. At the European level, progress is similar across the three broad ecosystem categories considered (terrestrial, freshwater and coastal) with scores that range between 44 and 52. In terrestrial ecosystems, the percentage of habitats classified as having a good conservation status decreased slightly between 2012 and 2018. Trends differ considerably depending on the country and terrestrial habitat type (EEA 2020a). Freshwater and coastal ecosystems describe a relatively stable situation with a very small change between 2009 and 2015 at European level, with high variation between countries (EEA 2018a). As in the previous paragraph, the trends reported should be interpreted carefully because of the methods used to assess the ecological status of freshwater ecosystems. Beyond comparability issues, it seems clear that under these trends, terrestrial, freshwater and coastal ecosystems will not meet the environmental standards by 2030. This is specially worrying in the case of terrestrial and freshwater ecosystems, where only 16% and 36% of the ecosystems met the standard in the last year for which data was available.

Lastly, most European countries report progress in the human health and other welfare functions with 14 countries scoring more than 75 points, three of which with a normalised score of 100. The European block scores 52 points. The country distribution of the scores in indicators of human health, on the one hand, and other welfare aspects, on the other, is similar, although countries with high scores in one of the principles do not necessarily have high scores in the other. When it comes to indicators related to human health, Europe shows mixed progress. While the percentage of population exposed to outdoor air pollution levels below the WHO guideline values more than doubled from 11 to 26 between 2012 and 2017 (score 76), the population with access to clean cooking fuels declined slightly (score 14), although most of the population meets the environmental standard. In the drinking water indicator, the European block obtained a score of 100. With regard to other welfare functions, the number of European bathing sites reporting excellent water quality increased from 86% to 88% between 2014 and 2019. At this pace, the environmental standard would not be reached by 2030. At the national scale, ten countries reported progress compatible with meeting the environmental standard in the near future, while nine others reported some progress, although insufficient. Last, there have barely been any changes in the conservation status of natural and mixed World Heritage sites between 2017 and 2020. Accordingly, most countries obtain a score of 50, while the European block scores 52 points.

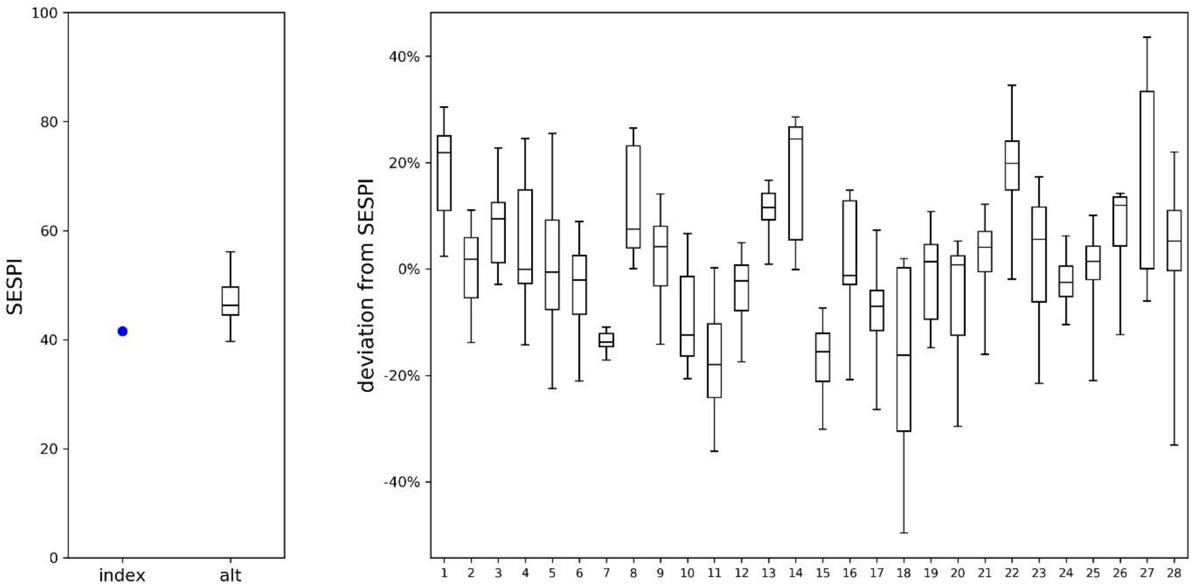
Figure 3: SESPI scores by environmental function



4.2. Uncertainty analysis

When using the years shown in Table S4 to calculate observed and desired trends, the score for the European block is 42. Using different data points as t_0 (with t_1 kept constant) generally leads to higher index scores (median 46) as shown in the left side of Figure 4. At the country level, in most cases changes in index scores range from ±20%, although exceptions apply.

Figure 4: Uncertainty associated with time at index level. (a) Index score for Europe with the default and alternative base years. (b) Distribution of differences between the country index scores obtained using different time points.

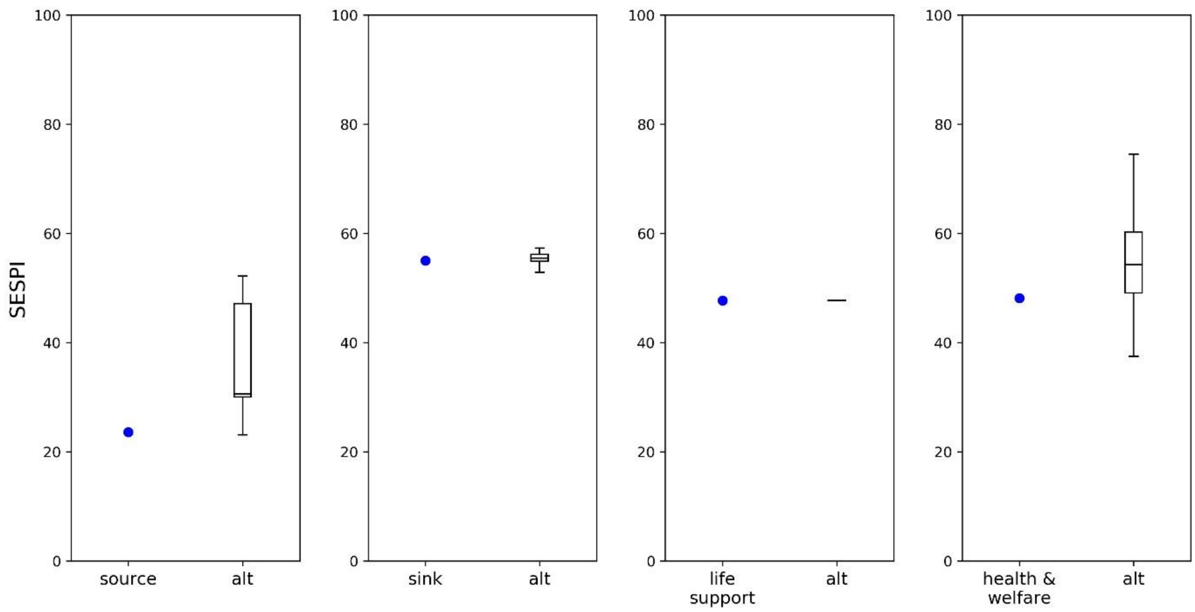


The x axis in figure a shows the default and the alternative values generated using different data points as t_0. alt: alternative. The x axis in figure b represents the 28 European countries in the same order as in Figure 3.

The upper and lower edges of the rectangle in the boxplot represent the 75th and 25th percentiles, while the top and bottom markers represent the maximum and minimum values.

The differences by broad function category differ considerably for the European block as shown in Figure 5. Source and human health and other welfare are the most affected functions. The score for the source functions tends to be higher (24 with the default method, median of 31 with alternative) with virtually all the runs leading to a higher score. In the case of human health and other welfare functions, the median score obtained in the Montecarlo analysis is similar to the default score (54 and 52 respectively), although much higher and lower scores are obtained depending on the run. The default and alternative methods in the sink and life support functions yield very similar results. In the case of life support functions, the same score is obtained in every run. The reason is that the indicators in this category only have two data points, so no real alternative could be tested. Something similar occurs in the sink functions, where four out of seven indicators only have two data points. The rest show relatively constant changes irrespective of the time point used as t_0. The results by indicator are shown in Figure S4.

Figure 5: Uncertainty associated with time at function level. Index score for Europe with the default and alternative baseline years for (a) source, (b) sink, (c) life support and (d) human health and other welfare functions



The x axis in the figures shows the default and the alternative values generated using different data points as t_0. alt: alternative.

The upper and lower edges of the rectangle in the boxplot represent the 75th and 25th percentiles, while the top and bottom markers represent the maximum and minimum values.

5. Discussion

5.1. Measuring progress towards environmental sustainability

Environmental and sustainable development metrics have historically provided a snapshot perspective, thereby informing about country performance at a given point in time. Although metrics intended to capture temporal trends have been around for a long time (e.g. Sicherl (1973); Ekins and Simon (2001)), recently this dimension has gained more importance through the SDGs (Eurostat 2020; Sachs et al. 2020).

Beyond assessing whether the functions of natural capital are threatened, the need to provide insights on whether countries are moving in the right direction has been a key aspect of the ESGAP framework since its inception (Ekins et al. 2003). In order to address this aspect and to complement the snapshot perspective given by SESI (Usubiaga-Liaño and Ekins 2021b), SESPI intends to shed light on whether countries are making progress towards or away from environmental sustainability. To that end, it shares the same structure as SESI and mirrors, to the extent possible, its set of indicators, but instead of reflecting whether environmental standards are met in a given year, the data is used to compare observed trends with those required to meet the environmental standards sometime in the future (in this case 2030). The data produced for this comparison is then normalised and aggregated, following the weighting of the indicators, into a single score, where an index value of 100 indicates that, if sustained, the trends reported for each indicator would lead to meeting all the environmental standards by 2030. Conversely, a score of zero indicates that for every indicator the change needed to achieve environmentally sustainability is occurring in the wrong direction. In between, high scores represent improving trends for most indicators, while low scores indicate the opposite. While interpreting the results, it is important to bear in mind that the index cannot be considered a forecast of the future, since it does not indicate whether those trends will actually be sustained and does not embed wider considerations such as innovations, political pressures and other factors that can affect the evolution of its indicators.

On a more general note, it is important to understand that metrics such as SESPI capture the 'big picture' of multidimensional concepts by aggregating relevant indicators into a single index (OECD and JRC 2008). Of course, this has advantages and disadvantages (Saisana et al. 2005).

5.2. Is Europe making progress towards environmental sustainability?

European countries show mixed progress towards environmental sustainability. Europe as a block scores 42 points with relevant differences between environmental functions and indicators. The highest score in an environmental function is 55, far from the scores that would indicate substantial progress towards meeting the environmental standards in the near future.

Europe is making little progress in the management of natural resources with very uneven performance depending on the resource under consideration. On the negative side, increased exploitation rates of forest resources and freshwater resources in some parts of Europe drive the score down. On the opposite end, the indicator showing groundwater bodies in good quantitative status is increasing as a result of a decrease in water abstraction (EEA 2019b), while there has been barely any change in the land area with tolerable soil erosion rates. The remaining environmental functions also show mixed progress with scores that range between 48 and 55.

In the sink function, there are relevant differences between global and regional processes. In the global processes, progress is being made in the right direction. On the one hand, the commitments under the Montreal Protocol and its amendments resulted in Europe meeting the environmental standard already in the past and set it in a sustainable trajectory for the future. When it comes to climate change, Europe reduced its per-capita CO_2 emissions at a rate of 1.5% per year between 2013 and 2018 (Eurostat 2019), which, although positive, is far from the reduction rates required. In this vein, Europe has committed to be climate neutral by 2050 – 20 years later than the reference year used in SESPI –, yet the current trajectory is not enough to even reach existing policy targets (a 55% reduction in greenhouse gas emissions compared to 1990) (EEA 2019b). In the case of regional processes, the progress made in cutting chemical pollution is also quite uneven depending on the ecosystem type. In terrestrial ecosystems, Europe has made considerable progress in cutting ozone pollution, with more limited progress with regard to eutrophication. In this context, the implementation of existing policies are expected to be insufficient as well (Amann et al. 2018). In freshwater systems, the general situation has worsened in surface waters, although some progress has been made in reducing the concentration of some metals and pesticides in surface water bodies (EEA 2018a). The presence of some ubiquitous, persistent, bioaccumulative and toxic substances such as mercury and brominated diphenyl ethers in many water bodies explains the failure to meet the environmental standard (EEA 2018a). In groundwater systems, there has been little change, partly because the area of groundwater bodies in which nitrate concentration – the most relevant pollutant in Europe – has increased, has been compensated by the area in which it has decreased (EEA 2020b). In coastal systems, the trends are headed in the wrong direction despite some progress has been reported in addressing some pollutants.

Europe scores 48 points in life support functions. In terrestrial ecosystems, the slight reduction in the percentage of habitats in good status occurred despite the constant increase in the terrestrial area protected as part of the Natura 2000 network, which suggests that the designation of protected areas does not guarantee effective ecosystem protection (EEA 2019b). In freshwater ecosystems, there was barely any change in the length of rivers in good ecological status, while there was a slight worsening in the case of coastal waters. In both cases, performance is far from the 100% target for all freshwater bodies (including coastal) defined in the Water Framework Directive (European Parliament and European Council 2000), which was meant to be achieved already in 2015.

Uneven progress can be seen in the indicators related to the human health and welfare functions, where Europe scores 52 points. Considerable progress has been made in recent years in improving outdoor air quality, although this is not sufficient to get to 100% of the population below the environmental standard by 2030. The full implementation of current policies around 87% of the population is expected to meet the environmental standard in 2030 (Amann et al. 2018). Indoor air pollution describes a different picture. While compliance with the environmental standard is much higher (94%), there has barely been any change in recent years. Arguably, these areas deserve less attention except in very specific contexts (e.g. in Eastern Europe, where the use of solid fuels for cooking is more common than in other parts of Europe).

As for other welfare indicators, Europe is making some progress in the quality of bathing sites. Although in the right direction, under this trend, not all the bathing sites would meet the environmental standards in 2030. In the case of natural and mixed World Heritage sites, the percentage of sites in good status rose only slightly between 2017 and 2020 (Osipova et al. 2020). This trend is far from the one needed to move all the sites to good quality status.

The results above show that the progress made towards environmental sustainability differs considerably depending on the topic addressed. If we consider the categories in Figure S3, there are three indicators (16%) that are on a sustainable trajectory, zero that describe good progress, four (21%) that report some progress, six that remained almost constant (32%) and six (32%) that are clearly on an unsustainable path. All in all, it cannot be said that Europe is on an environmentally sustainable trajectory.

The trends presented here are largely consistent with those described in the last European State and Outlook of the Environment Report (SOER) (EEA 2019b). This is hardly surprising, as there is some overlap between SESP indicators and those used in SOER to map the status of environment and human health, and therefore, much of the data used for SESPI has also been used in SOER. In this context, it is important to bear in mind that SOER not only contains a much more comprehensive assessment of trends and outlook, which combines data on trends, modelling results and expert input, but also covers many more indicators. While doing so, SOER reports progress towards policy targets.

While the European SOER represents a more comprehensive assessment of trends and outlook, SESPI brings value added in three aspects. First, SESPI has the potential to simplify the communication of indicator trends for non-specialists who lack the time to read long reports such as SOER or who want to easily identify the areas in which a country performs best or worst. Second, one of the insights provided by the European SOER is whether Europe is on track to meet environmental policy targets. However, policy targets and science-based standards often differ (Kutlar Joss et al.

2017; Doherty et al. 2018; UNEP 2020) and therefore, SESPI provides a complementary and necessary perspective on progress towards environmentally sustainability. Without it, countries risk falling short from implementing the actions needed to tackle environmental degradation. Third, not every country has the capacity and expertise to produce a comprehensive SOER report. In those countries, SESPI represents an easy to implement index that can capture the main trends across those indicators related to the functioning of natural capital.

In this vein, it is relevant to note that the paragraphs above discuss the trends in Europe as a whole. Nevertheless, each country has its own story, which SESPI can help narrate.

5.3. Uncertainty, limitations and further work

Because the normalised score of SESP indicators depends on indicator trends, understanding the uncertainty introduced by the selection of the base year is critical to properly interpret the index and indicator scores. As shown in Figure S4, several indicator scores are quite sensitive to the base year chosen, although, except in limited cases, the score consistently captures the direction in which progress is being made. These effects propagate to the function and index scores differently. The lack of longer time series for some indicators prevents reaching more solid conclusions. The uncertainty analysis presented is not only relevant for the interpretation of SESPI scores. The results suggest that similar uncertainty analysis could be relevant for other indices that use similar methods to SESPI (e.g. (Allen et al. 2020); Eurostat (2020); Hametner and Kostetckaia (2020)), since these do not test the influence of the baseline year chosen in their results. Likewise, the choice of 2030 as target year has been based on its policy relevance, yet while we move closer to that year, its relevance might decrease. Alternatively, SESPI could be computed for a period of ten years from the present in order to avoid being associated with a specific year.

A second aspect that deserves attention is the difference in data availability between indicators. In principle, the same time gap should be used to compute trends, and ideally, data availability should permit a distinction between short- and long-term trends. Because the data for SESP indicators is updated at different intervals, it was not possible to use the same time gap for all the indicators. There are also some comparability issues with other indicators such as those reported as part of the Water Framework Directive, which also requires the results to be interpreted carefully.

For these reasons, the SESPI calculations in this paper should be seen as a proof of concept. Compared to other metrics that measure trends towards the SDGs (Eurostat 2020; Hametner and Kostetckaia 2020; Sachs et al. 2020), SESPI suffers from some limitations in the data availability and comparability aspects. Especially data availability issues are more evident in SESPI because it contains considerably fewer indicators than other sustainable development metrics. In this first version of SESPI, this is a necessary trade-off between relevance and data quality when selecting indicators to populate the index. Reducing the update gap of some indicators, using nowcasting methods or using expert input to produce outlooks such as in the case of SOER help mitigate the impact of data availability.

6. Conclusions

Most environmental and sustainable development metrics show country performance in a given year. Except for a few exceptions in the past, only recently different metrics have emerged specifically intended to measure progress over time, thereby addressing a commonly overlooked aspect in indicator-based sustainability assessments. All these metrics compare current trends with those required theoretically to achieve the SDG targets and therefore fail to represent environmental sustainability when the SDG targets are not aligned with science-based environmental standards. Thus, countries still lack metrics that can answer a simple question: “are we making progress towards environmental sustainability?”.

SESPI addresses this gap by incorporating the temporal dimension into the environmental sustainability assessment of countries, thereby complementing the snapshot perspective given by SESI. At the indicator level, SESPI shows progress (or lack thereof) towards science-based environmental standards by comparing current trends with those needed to meet the environmental standards by a certain date. This information is then aggregated through a five-level structure that considers indicators, topics, sustainability principles and environmental functions in order to generate index scores at higher levels that can be used to provide a simple message around the question above.

The results suggest that the progress made at European level is mixed with noteworthy differences between countries and indicators. In general terms, considerable progress is being made in areas such as outdoor air quality, ozone depleting substances and groundwater abstraction, while trends in other areas such as the exploitation of forest and surface water resources are more worrying. SESPI can be a complement to the more complex picture shown in more comprehensive reports such as SOER, and can be a useful tool to highlight to decision makers and the general public those environmental issues most in need of attention.

Acknowledgements

The authors wish to thank Thomas Scheusnar (Umweltbundesamt), Panos Panagos (European Commission) and Nihat Zal (European Environment Agency) for sending additional data that was not available online at the time. The authors would also like to thank the staff from the JRC's Competence Centre on Composite Indicators and Scoreboards for providing feedback on earlier versions of the index through the COIN open days.

Funding

This research is supported by María de Maeztu excellence accreditation 2018-2022 (Ref. MDM-2017-0714), funded by MCIN/AEI/10.13039/501100011033/; and by the Basque Government through the BERC 2022-2025 program.

Appendix

Table 3: List of SESP indicators and data sources

Function	Principle	Topic	SES indicator [Unit]	Data
Source	Renew renewable resources	Biomass	Forest utilization rate [%]	Forest Europe et al. (2015); Forest Europe (2020)
		Freshwater	Freshwater bodies not under water stress [%]	EEA (2018b)
			Groundwater bodies in good quantitative status [%]	EEA (2018a)
	Use non-renewables prudently	Soil	Area with tolerable soil erosion [%]	Panagos et al. (2015); Panagos et al. (2020)
Sink	Prevent global warming, ozone depletion	Earth system	CO_2 emissions [tonnes per capita]	Eurostat (2019)
			Consumption of ozone-depleting substances [kg per capita]	Ozone Secretariat United Nations Environment Programme (2019)
		Terrestrial ecosystems	Cropland and forest area exposed to safe ozone levels [%]	Horálek et al. (2019); Horálek et al. (2020)

	Respect critical levels and loads for ecosystems		Ecosystems not exceeding the critical loads of eutrophication and acidification [%]	Tsyro et al. (2020)
		Freshwater ecosystems	Surface water bodies in good chemical status [%]	EEA (2018a)
			Groundwater bodies in good chemical status [%]	EEA (2018a)
		Marine ecosystems	Coastal water bodies in good chemical status [%]	EEA (2018a)
Life support	Maintain biodiversity and ecosystem health	Terrestrial ecosystems	Terrestrial habitats in favourable conservation status [%]	EEA (2020c)
		Freshwater ecosystems	Surface water bodies in good ecological status [%]	EEA (2018a)
		Marine ecosystems	Coastal water bodies in good ecological status [%]	EEA (2018a)
Human health and welfare	Respect standards for human health	Human health	Population exposed to safe levels of outdoor air pollutants [%]	Horálek et al. (2019); Horálek et al. (2020)
			Population using clean fuels and technologies for cooking [%]	WHO (2020)
			Samples that meet the drinking water criteria [%]	EC (2016)
		Other welfare	Recreational water bodies in excellent status [%]	EEA (2019a)

	Conserve landscape and amenity		Natural and mixed world heritage sites in good conservation outlook [%]	Osipova et al. (2017); Osipova et al. (2020)

References

Allen, C., M. Reid, J. Thwaites, R. Glover, and T. Kestin. 2020. Assessing national progress and priorities for the Sustainable Development Goals (SDGs): experience from Australia. *Sustainability Science* 15(2): 521-538.

Amann, M., M. Anderl, J. Borken-Kleefeld, J. Cofala, C. Heyes, L. Höglund-Isaksson, G. Kiesewetter, Z. Klimont, L. Moosmann, P. Rafaj, R. Sander, W. Schöpp, M. Tista, F. Wagner, and W. Winiwarter. 2018. *Progress towards the achievement of the EU's air quality and emissions objectives*. Laxembourg: International institute for Applied Systems Analysis.

Becker, W., M. Saisana, P. Paruolo, and I. Vandecasteele. 2017. Weights and importance in composite indicators: Closing the gap. *Ecological Indicators* 80: 12-22.

Doherty, T. S., L. M. Bland, B. A. Bryan, T. Neale, E. Nicholson, E. G. Ritchie, and D. A. Driscoll. 2018. Expanding the Role of Targets in Conservation Policy. *Trends in Ecology & Evolution* 33(11): 809-812.

EC. 2016. *Synthesis Report on the Quality of Drinking Water in the Union examining Member States' reports for the 2011-2013 period, foreseen under Article 13(5) of Directive 98/83/EC*. COM(2016) 666 final. Brussels.

EEA. 2003. *Environmental Indicators: Typology and Use in Reporting*. Copenhagen: European Environment Agency. EEA internal working paper.

EEA. 2018a. *European waters. Assessment of status and pressures 2018*. No 7/2018. Copenhagen: European Environment Agency. EEA Report.

EEA. 2018b. *Use of freshwater resources*. Copenhagen: European Environment Agency.

EEA. 2019a. *Country reports 2018 bathing season*. Copenhagen: European Environment Agency.

EEA. 2019b. *The European environment — state and outlook 2020. Knowledge for transition to a sustainable Europe*. Copenhagen: European Environment Agency.

EEA. 2020a. *State of nature in the EU. Results from reporting under the nature directives 2013-2018*. EEA Report No 10/2020. Copenhagen: European Environment Agency.

EEA. 2020b. *Nutrients in freshwater in Europe*. Copenhagen: European Environment Agency.

EEA. 2020c. *National summary dashboards - Habitats Directive – Art.17*. Copenhagen: European Environment Agency.

Ekins, P. 1992. A Four-Capital Model of Wealth Creation. In *Real-Life Economics: Understanding Wealth-Creation*, edited by P. Ekins and M. Max-Neef. London: Routledge.

Ekins, P. and S. Simon. 2001. Estimating sustainability gaps: methods and preliminary applications for the UK and the Netherlands. *Ecological Economics* 37(1): 5-22.

Ekins, P., S. Simon, L. Deutsch, C. Folke, and R. De Groot. 2003. A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological Economics* 44(2-3): 165-185.

European Parliament and European Council. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

Eurostat. 2014. *Getting messages across using indicators. A handbook based on experiences from assessing Sustainable Development Indicators*. Luxembourg: Eurostat.

Eurostat. 2019. *Greenhouse gas emissions by source sector*. Luxembourg: Eurostat.

Eurostat. 2020. *Sustainable development in the European Union. Monitoring report on progress towards the SDGs in an EU context*. Luxembourg: Eurostat.

Eurostat. 2021. Renewable freshwater resources (env_wat_res).

Forest Europe. 2020. *State of Europe's Forests 2020*. Bratislava: Ministerial Conference on the Protection of Forests in Europe.

Forest Europe, UNECE, and FAO. 2015. *State of Europe's Forests 2015*. Madrid: Ministerial Conference on the Protection of Forests in Europe.

Greco, S., A. Ishizaka, M. Tasiou, and G. Torrisi. 2019. On the Methodological Framework of Composite Indices: A Review of the Issues of Weighting, Aggregation, and Robustness. *Social Indicators Research* 141(1): 61-94.

Hametner, M. and M. Kostetckaia. 2020. Frontrunners and laggards: How fast are the EU member states progressing towards the sustainable development goals? *Ecological Economics* 177: 106775.

Häyhä, T., P. L. Lucas, D. P. van Vuuren, S. E. Cornell, and H. Hoff. 2016. From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged? *Global Environmental Change* 40: 60-72.

Horálek, J., M. Schreiberová, F. d. Leeuw, P. Kurfürst, P. d. Smet, and J. Schovánková. 2019. *European air quality maps for 2016: PM10, PM2.5, Ozone, NO2 and NOx spatial estimates and their uncertainties*. ETC/ACM 2018/8. Bilthoven: European Topic Centre on Air Pollution and Climate Change Mitigation.

Horálek, J., M. Schreiberová, P. Schneider, P. Kurfürst, J. Schovánková, and J. Ďoubalová. 2020. *European air quality maps for 2017: PM10, PM2.5, Ozone, NO2 and NOx spatial estimates and their uncertainties*. ETC/ATNI 2019/9. Kjeller: t. European Topic Centre on Air pollution, noise and industrial pollution,.

IAEG-SDGs. 2019. IAEG-SDGs Tier Classification for Global SDG Indicators. https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/. Accessed.

IPBES. 2019. *Global assessment report on biodiversity and ecosystem services*. Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

IPCC. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: The Intergovernmental Panel on Climate Change.

JRC. 2019. *Your 10-Step Pocket Guideto Composite Indicators & Scoreboards*. Ispra: Joint Research Centre.

Kutlar Joss, M., M. Eeftens, E. Gintowt, R. Kappeler, and N. Künzli. 2017. Time to harmonize national ambient air quality standards. *International Journal of Public Health* 62(4): 453-462.

Lafortune, G., G. Fuller, J. Moreno, G. Schmidt-Traub, and C. Kroll. 2018. *SDG Index and Dashboards. Detailed Methodological paper*. New York: Bertelsmann Stiftung and the Sustainable Development Solutions Network (SDSN).

Neumayer, E. 2003. *Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Cheltenham: Edward Elgar.

OECD. 2019. *Measuring Distance to the SDG Targets 2019: An Assessment of Where OECD Countries Stand*. Paris: organisation for Economic Co-operation and Development.

OECD and JRC. 2008. *Handbook on Constructing Composite Indicators: Mehodology and User Guide*. Paris: Organisation for Economic Co-operation and Development.

Osipova, E., M. Emslie-Smith, M. Osti, M. Murai, U. Åberg, and P. Shadie. 2020. *IUCN World Heritage Outlook 3: A conservation assessment of all natural World Heritage sites*. Gland: International Union for the Conservation of Nature.

Osipova, E., P. Shadie, C. Zwahlen, M. Osti, Y. Shi, C. Kormos, B. Bertzky, M. Murai, R. Van Merm, and T. Badman. 2017. *IUCN World Heritage Outlook 2: A conservation assessment of all natural World Heritage sites*. Gland: International Union for the Conservation of Nature.

Ozone Secretariat United Nations Environment Programme. 2019. *Data centre*. Secretariat for The Vienna Convention for the Protection of the Ozone Layer & The Montreal Protocol on Substances that Deplete the Ozone Layer.

Panagos, P., C. Ballabio, J. Poesen, E. Lugato, S. Scarpa, L. Montanarella, and P. Borrelli. 2020. A Soil Erosion Indicator for Supporting Agricultural, Environmental and Climate Policies in the European Union. 12(9): 1365.

Panagos, P., P. Borrelli, J. Poesen, C. Ballabio, E. Lugato, K. Meusburger, L. Montanarella, and C. Alewell. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy* 54: 438-447.

Sachs, J., G. Schmidt-Traub, C. Kroll, G. Lafortune, G. Fuller, and F. Woelm. 2020. *The Sustainable Development Goals and COVID-19. Sustainable Development Report 2020*. Cambridge: Cambridge University Press.

Saisana, M., A. Saltelli, and S. Tarantola. 2005. Uncertainty and sensitivity analysis techniques as tools for the quality assessment of composite indicators. *Journal of the Royal Statistical Society: Series A (Statistics in Society)* 168(2): 307-323.

Sicherl, P. 1973. TIME-DISTANCE AS A DYNAMIC MEASURE OF DISPARITIES IN SOCIAL AND ECONOMIC DEVELOPMENT*. *Kyklos* 26(3): 559-575.

Sicherl, P. 2011. *New Understanding and Insights from Time-Series Data Based on Two Generic Measures: S-Time-Distance and S-Time-Step*. Working Paper No 44. Paris: Organisation for Economic Co-operation and Development. OECD Statistics Working Papers.

Simsek, Y., W. G. Santika, M. Anisuzzaman, T. Urmee, P. A. Bahri, and R. Escobar. 2020. An analysis of additional energy requirement to meet the sustainable development goals. *Journal of Cleaner Production* 272: 122646.

Steffen, W., K. Richardson, J. Rockstrom, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, S. R. Carpenter, W. de Vries, C. A. de Wit, C. Folke, D. Gerten, J. Heinke, G. M. Mace, L. M. Persson, V. Ramanathan, B. Reyers, and S. Sorlin. 2015. Planetary boundaries: guiding human development on a changing planet. *Science* 347(6223): 1259855.

Tsyro, S., W. Aas, S. Solberg, A. Benedictow, H. Fagerli, and T. Scheuschner. 2020. Status of transboundary air pollution in 2018. In *Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components*, edited by H. Fagerli, et al. Oslo: Norwegian Meteorological Institute,.

UN Environment. 2019. *Global Environment Outlook – GEO-6: Healthy Planet, Healthy People*. Nairobi.

UNEP. 2020. *Emissions Gap Report 2020*. Nairobi: United Nations Environment Programme.

Usubiaga-Liaño, A. and P. Ekins. 2021a. Time for science-based national targets for environmental sustainability: An assessment of existing metrics and the ESGAP framework. *Frontiers in Environmental Science* 9(524).

Usubiaga-Liaño, A. and P. Ekins. 2021b. Monitoring the environmental sustainability of countries through the strong environmental sustainability index. *Ecological Indicators* 132: 108281.

Wendling, Z. A., J. W. Emerson, A. de Sherbinin, D. C. Esty, and e. al. 2020. *2020 Environmental Performance Index*. New Haven: Yale Center for Environmental Law & Policy.

WHO. 2020. *Percentage of the population using clean and polluting fuels and technologies for cooking*. Geneva: World Health Organisation.