The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits

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Abstract

The Sustainable Development Goals (SDGs) provide targets for humanity to achieve sustainable development by 2030. A monitoring framework of 248 environmental, social, and economic indicators, reported nationally by 193 UN Member States, tracks progress. The framework includes 92 environmental indicators, most of which refer to environmental policies. The SDG monitoring framework provides data to assess whether, across countries, environmental policies are: 1. Addressing environmental pressures, 2. Linked to environmental improvements, and 3. Linked with societal benefits delivered by healthy environments. We use statistical analysis and a generalized linear modeling approach to test for correlations between SDG indicators related to environmental policies, environmental pressures, the state of the environment, and social impacts delivered by healthy environments. Our results show that environmental policies, particularly protected areas and sustainable forest certification, are linked with environmental improvements, mainly in forest and water ecosystems. However, we find no evidence that environmental improvements are linked with positive social impacts. Finally, environmental pressures, including freshwater withdrawal, domestic material consumption, and tourism, are linked with environmental degradation. Environmental policy responses are generally increasing across countries. Despite this, the state of the environment globally continues to decline. Governments must focus on understanding why environmental policies have not been sufficient to reverse environmental decline, particularly concerning the pressures that continue to degrade the environment. To better track progress towards sustainable development, we recommend that the SDG monitoring framework is supplemented with additional indicators on the state of the environment.

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The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits

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Key Points:

- The state of the environment globally continues to decline despite increasing environmental policy responses.
- The SDG indicators provide no evidence that environmental policies are delivering secondary social benefits.
- Protected areas and sustainable forest certification are linked with environmental improvements mainly in forest and water ecosystems.

Abstract

The Sustainable Development Goals (SDGs) provide targets for humanity to achieve sustainable development by 2030. A monitoring framework of 248 environmental, social, and economic indicators, reported nationally by 193 UN Member States, tracks progress. The framework includes 92 environmental indicators, most of which refer to environmental policies. The SDG monitoring framework provides data to assess whether, across countries, environmental policies are: 1. Addressing environmental pressures, 2. Linked to environmental improvements, and 3. Linked with societal benefits delivered by healthy environments. We use statistical analysis and a generalized linear modeling approach to test for correlations between SDG indicators related to environmental policies, environmental pressures, the state of the environment, and social impacts delivered by healthy environments. Our results show that environmental policies, particularly protected areas and sustainable forest certification, are linked with environmental improvements, mainly in forest and water ecosystems. However, we find no evidence that environmental improvements are linked with positive social impacts. Finally, environmental pressures, including freshwater withdrawal, domestic material consumption, and tourism, are linked with environmental degradation. Environmental policy responses are generally increasing across countries. Despite this, the state of the environment globally continues to decline. Governments must focus on understanding why environmental policies have not been sufficient to reverse environmental decline, particularly concerning the pressures that continue to degrade the environment. To better track progress towards sustainable development, we recommend that the SDG monitoring framework is supplemented with additional indicators on the state of the environment.

Plain Language Summary

Governments implement environmental policies to reduce ecological degradation and sustain environmental benefits to humans, such as food and clean water. The Sustainable Development Goals (SDGs) call for all countries to commit to pathways that lead to sustainable development. Progress towards achieving the Goals is reported by governments using 231 indicators. The SDG indicators track the implementation of environmental policies, the state of the environment, and environmental benefits such as food security and drinking water access. Using the data underlying the SDG indicators reported by governments to date, we investigate whether the

implementation of environmental policies correlates with improvements in the environment and the provision of environmental benefits to humans. Results show that most environmental policies are not associated with environmental improvements; worse, we find no evidence that environmental policies lead to more human benefits. However, we see two types of environmental policies, protected areas and sustainable forest certification, that lead to increasing the size of forest and water ecosystems which are essential for sustaining the lives of plants, animals, and humans that rely on them. Our findings highlight that governments must improve their use of environmental policies to achieve environmental improvements and the benefits humans derive from the environment.

1. Introduction

In September 2015, the United Nations Sustainable Development Summit adopted an international framework to guide development efforts, entitled Transforming our World: the 2030 Agenda for Sustainable Development (United Nations, 2015). The Agenda is built around 17 Sustainable Development Goals (SDGs), divided into 169 targets, which are a call to action from all countries to move the world onto a sustainable development trajectory. An underlying monitoring framework composed of 231 unique indicators (a further thirteen are repeated under different targets) tracks progress toward the goals and targets. The environmental dimension of the SDG monitoring framework is composed of 92 indicators (UNEP, 2021). These indicators encompass a range of topics, such as sustainable consumption, ocean acidification, and environmental education, and a range of environments, such as marine, freshwater, and mountain ecosystems. A dataset underlies the SDG monitoring framework and is composed of indicators reported to the UN by the Member States or derived by the UN from global datasets when nationally produced indicators are unavailable. However, some indicators still need more data, as discussed further below.

Environmental policies are intended to reduce environmental damage, incentivise positive environmental behaviour, and guide practices toward a more sustainable future (Schwartz & Goubran, 2020). The umbrella term 'environmental policy' encapsulates various environmental policy types, including regulatory instruments, market-based instruments, voluntary agreements, and information provision (Jordan et al., 2003). In addition, innovation policy may also be used to improve the environment (OECD, 2011). Most recently, a class of policy instruments called

'Nature-based solutions' has been defined as 'actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham et al., 2016).

The SDG monitoring framework uses SDG indicators to track the national use of environmental policy instruments. For example, indicator 15.8.1 covers legislation about invasive alien species (a regulatory instrument), indicator 15.4.1 covers the protection of mountain biodiversity (a Nature-based Solution), and indicator 12.1.1 covers sustainable consumption policies (the indicator does not specify instrument type).

If the aim of environmental policies is 'to prevent or reduce harmful effects of human activities on ecosystems' (Bueren, 2019) and to 'address societal challenges…by providing human well-being benefits' (Cohen-Shacham et al., 2016), we should expect that environmental improvements would follow the use of environmental policies. In addition, environmental improvements would also benefit human society via ecosystem services. Indeed, the natural environment provides various services that benefit humans, such as providing food and fibre, mitigating the effects of extreme weather events, and cultural connections to nature (Millennium Ecosystem Assessment, 2005). In this study, we use the SDG monitoring framework data to investigate, at the national scale, the relationships between the use of environmental policies, the state of the environment, and the provision of environmental benefits to society.

The DPSIR indicator framework describes the interactions between society and the environment (Kristensen, 2004; UN Environment, 2019). The framework provides a structure to understand the causal links between 'driving forces' [D] (economic sectors, human activities), 'pressures' [P] (emissions, waste, resource use), environmental 'states' [S] (physical, chemical, and biological), 'impacts' [I] (on ecosystems, human health, and functions), and political 'responses' [R] (policies, and other actions at different levels). In this study, we investigate whether the SDG monitoring framework's data provides evidence for relationships, at a national level, between political 'responses,' the 'state' of the environment, and the 'impacts' of the environment on society. In addition, we investigate relationships between environmental 'pressures' (UN Environment, 2019) and environmental 'state' indicators to highlight which environmental pressures require increased policy attention to reduce their harmful impacts. Finally, this investigation allows us to leverage the SDG monitoring framework data to investigate whether national environmental policies are delivering their primary objective of improving the state of the environment and their secondary objective of reducing the negative impacts of environmental degradation on people.

Several assessments of interactions between the SDGs already exist (Breuer et al., 2019; Scharlemann et al., 2020). Such assessments have focused on interactions at Goal (Breuer et al., 2019) or Target level (Fuso Nerini et al., 2018), specific Goals or Targets (International Council for Science (ICSU), 2017), actors (PwC, 2016), or countries (Weitz et al., 2019). They have used a range of quantitative and qualitative methods. Only a single study (Pradhan et al., 2017) has investigated SDG interactions at the indicator level, considering the entire SDG monitoring framework. (Pradhan et al., 2017) assessed correlations between pairs of SDG indicators using Spearman's rank for all indicators and countries where time-series data was available. The work presented here advances the Pradhan et al. study in two important ways. Firstly, rather than investigating all possible combinations of indicators, we take an evidence-based approach to identify pairs of indicators for which there is prior evidence of a relationship between political 'responses,' environmental ‘pressures,’ environmental 'states,' and social 'impacts'. This evidence-based approach provides hypotheses for selecting indicator pairs to investigate and aids the interpretation of results. It also strengthens the likelihood that any correlations discovered have at least some causal elements. Secondly, in practice, the links between indicators are context-specific and may depend on many factors, such as geography, demographics, or the socio-economic situation (Breuer et al., 2019). Here, we use a modelling framework to investigate the correlation between indicator pairs while controlling for potentially confounding factors, including the population, GDP, and geographic region of each country included in the analysis. Therefore, this study uses the SDG monitoring framework data to investigate whether national environmental policies deliver their intended primary environmental and secondary social benefits and identify which environmental pressures require increased political attention. First, we apply the DPSIR framework to identify SDG indicators representing environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts.' Secondly, we identify plausible relationships between indicators of environmental pressures, environmental policy responses, the state of the environment, and secondary societal impacts. Finally, we use statistical tests and multivariate analysis to test relationships between SDG indicators while controlling for confounding factors of countries' development and geographic status. Leveraging the dataset underlying the SDG monitoring framework, our approach allows us to ask the questions:

Are environmental policies correlated with improvements in the state of the environment? These results will suggest where political efforts have the desired impact on the environment.

Are improvements in the state of the environment correlated with reductions in the impacts of poor environmental quality on society? These results will highlight where environmental policies can deliver additional societal benefits.

Is there evidence of negative impacts from environmental pressures on the state of the environment? These results will highlight where additional efforts need to focus.

2. Materials and Methods

2.1. Classifying SDG indicators and assessing data availability

We classified the 231 unique SDG indicators and their underlying sub-indicators into one of four groups (Table 1). Some SDG indicators are composed of a single indicator, and others are disaggregated into sub-indicators. For example, SDG indicator 2.5.1 'Secure genetic resources for food' is produced by aggregating two underlying sub-indicators: 1. The number of local breeds for which sufficient genetic resources are stored for reconstitution, and 2. Plant breeds for which sufficient genetic resources are stored. In contrast, SDG 6.6.1 includes sub-indicators related to water body extent, wetland extent, and mangrove extent, which are used without aggregation. In addition to our classification, Table 1 shows the smaller number of indicators with sufficient data to carry out our analysis.

Table 1. Classification and data availability of the SDG indicators and sub-indicators

Class	**Number of unique indicators (and sub-indicators)**	**Number of unique indicators (and sub-indicators) with sufficient data to include in the analysis**
Environmental policy responses	50 (85)	22 (38)
Environmental states	11 (36)	5 (9)
Social impacts	16 (44)	11 (31)
Environmental pressures	20 (41)	18 (38)

Data collection efforts to support the SDG monitoring framework vary significantly across the Targets and Indicators (UNEP, 2019). Several SDG indicators do not have a method of data collection (classified as Tier 3), or data is not produced regularly by countries (classified as Tier 2) (IAEG-SDGs, 2020). In addition, a large proportion of the environmental SDG indicators lack methods of data collection and underlying datasets (UNEP, 2019). Therefore, we assessed the availability of data underlying each indicator and sub-indicator in terms of the number of UN Member States that have reported data for at least two time points since 2000. We included only those indicators with data for at least twenty countries (Table 1). We extracted data from the Global SDG Indicators Database between January and June 2020. Additional updated SDG indicator data that were not publicly available were sourced from UNEP and added to the analysis on 21 July 2020.

2.1.1 Group 1: Environmental policy responses

There are 50 unique SDG indicators from 14 Goals related to environmental policies that cover issues such as sustainable agricultural management, renewable energy use, and action plans for sustainability. In addition, the SDG monitoring framework contains sufficient data to include 22 environmental policy indicators in this analysis.

2.1.2 Group 2: Environmental states

There are 11 SDG indicators from five Goals that relate to the state of the environment. These indicators measure the quality and quantity of water resources, marine eutrophication, plastic concentration and acidity, fish stocks, forest cover, land degradation, green land cover in mountain ecosystems, and extinction risk of wild and domesticated species. The SDG monitoring framework contains sufficient data to include five environmental state indicators in this analysis.

2.1.3 Group 3: Social impacts

There are 16 SDG indicators from seven Goals that relate to the social impacts of the environment. These indicators include the human and economic impacts of natural disasters, food, and water access, and mortality attributed to air pollution. The SDG monitoring framework contains sufficient data to include 11 social impact indicators in this analysis.

2.1.4 Group 4: Environmental pressures

There are 20 SDG indicators from seven Goals related to environmental pressures. These indicators include water stress, domestic material consumption (DMC), tourism, and infrastructure development. The DMC indicator comprises numerous material-specific sub-indicators including, but not limited to, DMC of wood, minerals, fossil fuels, crops, wild catch, and harvested materials. The SDG monitoring framework contains sufficient data to include 18 environmental pressure indicators in this analysis.

2.2. Identifying potential synergies between indicator pairs

The IPBES Global Assessment (Watson et al., 2019) provides a global evidence review of the environmental and social effects of environmental pressures and policy responses; for example, the direct environmental impacts of sustainability certification schemes on forest ecosystems and the secondary social impacts on access to non-timber forest products (Shanley, 2002). For the indicators with sufficient data to include in our analysis (Table 1), we identify potential relationships between pairs of SDG indicators and their sub-indicators using this evidence base. To investigate the relationship between environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts' we identify 618 potential relationships between SDG indicators and their underlying sub-indicators. We detail these potential relationships in the Supplementary Information.

We supplemented the evidence presented in IPBES Global Assessment through consultation with experts from various environmental and social stakeholder groups. This consultation on selecting SDG indicator relationships took the form of an online meeting held on 21-22 April 2020 and an online survey held from 29 May to 13 June 2020. We provide the minutes of this meeting and an overview of the responses received from experts to the online survey in the Supplementary Information.

2.3. Determining how to interpret SDG indicators to identify improvements in environmental and social conditions

A good indicator has a clear relationship to the situation about which it is reporting. Of the environmental state and social impact indicators that we include in this investigation, we identify when they are showing improvements in the state of the environment and the social impacts of the environment (Figure 1). In terms of improving environmental and social conditions, some indicators would increase (e.g., forest area and schools with drinking water access), and other indicators would decrease (e.g., air pollution and food insecurity). Different correlation directions indicate desirable relationships between environmental pressure, environmental policy, environmental state, and social impact indicators. Environmental state indicators that show improvement when they increase should show a **positive correlation** with environmental policy indicators, e.g., an *increase* in forest areas should correlate positively with *increasing* the protection of forest ecosystems. Conversely, environmental indicators that show improvement when they decrease should show a **negative correlation** with environmental policy indicators, e.g., *decreasing* domestic species extinction risk should correlate negatively with *increasing* conservation of domestic species' genetic resources.

Environmental state indicators will tend to be negatively affected by environmental pressures, with the direction of the correlation depending on whether improvement in each indicator is represented by an increase or a decline.

Finally, the desirable correlation between an environmental state and a social impact indicator would suggest that social impacts are improving alongside improvements in the state of the environment. Again, the desirable direction of the correlation depends on whether improvement is associated with increasing or decreasing values of each indicator.

SDG Indicators		What we want to see	Direction of correlation in response to: Increasing environmental policies	Direction of correlation in response to: Decreasing environmental pressures
State of the environment				
2.5.2	Local breeds extinction	*Decreasing* proportion of local breeds classified as being at risk of extinction	−	+
6.6.1	Water ecosystems	*Increasing* extent of water-related ecosystems	+	−
11.6.2	Air pollution	*Decreasing* levels of fine particular (e.g. PM2.5 and PM10) matter in cities	−	+
15.1.1	Forest area	*Increasing* forest area	+	−
15.5.1	Species at risk	*Increasing* Red List Index indicates decreasing species extinction risk	+	−

SDG Indicators		What we want to see	Direction of correlation in response to an environmental state indicator that shows improvement when values are: Increasing	Direction of correlation in response to an environmental state indicator that shows improvement when values are: Decreasing
Social impact				
1.5.1	Disasters: human impacts	*Decreasing* human impacts of disasters	−	+
1.5.2	Disasters: economic impacts	*Decreasing* economic impacts of disasters	−	+
2.1.1	Undernourishment	*Decreasing* prevalence of undernourishment	−	+
2.1.2	Food insecurity	*Decreasing* prevalence of moderate or severe food insecurity	−	+
2.2.2	Children wasted	*Decreasing* prevalence of children wasted	−	+
2.2.2	Children overweight	*Decreasing* prevalence of children overweight	−	+
4.a.1	Schools drinking water access	*Increasing* proportion of schools offering access to drinking water	+	−

Figure 1. The desirable direction of correlation between indicators (plus sign indicates a positive correlation, minus sign indicates a negative correlation) that show improvement in the state of the environment in response to increasing environmental policies and decreasing environmental pressures (upper table) and the social impacts of the state of the environment (lower table).

2.4. Investigating relationships between indicator pairs

Investigating the correlation between a pair of SDG indicators determines whether there is evidence of a statistically significant relationship between them. We used a generalized linear regression modelling (GLRM) approach to investigate whether there is evidence for a relationship between pairs of indicators while controlling for some confounding factors. The sign (positive or negative) of the correlation coefficients produced by the GLRM indicates the direction of the relationship between a pair of indicators. While the correlation coefficient helps identify associations between indicators, confounding factors can influence the observed relationship. For example, a country that has experienced significant GDP growth may simultaneously observe improvements in two indicators. There appears to be a correlation between the two unrelated variables, but GDP influences both. To mitigate the influence of this phenomenon, we developed the GLRM to estimate the relationship between the indicator pairs, which also included variables to capture changes in population and GDP. In addition, we include a fixed effect to account in the model for regional factors.

There are several essential aspects to note regarding our approach. Firstly, the relationship measured by the correlation coefficient is assumed to be linear. If there is a non-linear association between two indicators, this approach will not be able to capture it adequately. Secondly, given the extreme differences between some countries, many indicators were highly skewed and varied widely across the sample. As this can distort the correlation coefficient, a log transformation of the indicator measurements was applied before analysis to mitigate data skewness. The estimated values lend themselves well to this transformation, as they are generally positive, such as percentages, square kilometres, and hectares. The values also have a significant variance in scale, which this transformation helps compress, reducing the impact of outliers. Thirdly, as we were investigating relationships between pairs of indicators over time, our investigation was limited to those indicators with at least two data points. Finally, the analysis compares two indicators across the number of countries over the time that matching data is available. Therefore, for each relationship we investigated, the sample size is limited to the indicator reported by the smallest number of countries.

2.4.1 Generalised linear regression model (GLRM)

The complete model formulation is as follows:

$$\log(Y) = \beta_1 \log(X) + \beta_2 \log(pop) + \beta_3 \log(GDP) + I_{region}$$

Where:

Y: environmental state indicator OR social impact indicator

X: environmental pressure OR environmental policy OR environmental state indicator pop and GDP: country population and GDP at the observed year, the potential confounding variables

I_{region}: fixed effect estimate for each geographical region

β_1, β_2, and β_3: model coefficients estimated by the maximum likelihood that measures the relationship between each variable and the dependent variable Y.

Hypothesis testing was conducted on the coefficient of interest (β_1) to assess whether, after having accounted for the influence of the potential confounder variables, there is still sufficient evidence for a relationship between two indicators with the significance level of $\alpha = 0.05$ used. Additionally, the model framework allows the calculation of the R^2 value, which measures how good a fit the model provides and how much of the variance in the dependent variable the model captures. We used an R^2 threshold of 0.2 to ensure the minimum goodness of fit of the model. All statistical analysis was conducted using the R software (R Core Team, 2021).

3. Results

We identified significant correlations between the indicators on the state of the environment, with the indicators on environmental policies and pressures—some correlations aligned with our hypotheses, and others contrasted with our hypotheses. However, we identified no significant correlations between the indicators on the state of the environment and the social impacts of the environment. Therefore, the Results section presents only the findings of the analysis of the environmental policy, pressure, and state indicators, and no findings on the social impact indicators, as we found no significant relationships with these indicators.

3.1. Relationships between environmental policies, the state of the environment

Table 2. The environmental policy indicators that correlate significantly with the environmental state indicators. Correlations that show environmental improvement are presented in the upper half of the table. Correlations that show environmental degradation are presented in the lower half of the table. The middle column describes the causal relationship between environmental policies and environmental improvements based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental policy indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental policy, leading to environmental improvements**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
7.2.1 Renewable	11.6.2 Outdoor	Greater reliance on clean fuels leads to less	(IEA et al.,	*Increasing* renewable

Environmental policy indicator	Environmental state indicator	Hypothesised outcomes of environmental policy, leading to environmental improvements	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
energy	air pollution in cities	combustion of dirty fuels, which reduces the amount of air pollutants produced and leads to improvements in air quality	2022, p. 7)	energy use correlates with *decreasing* levels of fine particulate matter in cities
7.2.1 Renewable energy	15.1.1 Forest area	Greater reliance on clean fuels reduces reliance on wood resources for energy which leads to less deforestation and a greater extent of forest ecosystems	(IEA et al., 2022, p. 7)	*Increasing* renewable energy use correlates with *increasing* forest area
15.1.2 Protection of Key Biodiversity Areas (KBAs)	6.6.1 Water ecosystems	Protection of KBAs reduces the abstraction of water from protected water ecosystems and leads to an increase in water ecosystem extent	(Chan et al., 2006; IUCN, 2012)	*Increasing* protection of KBAs is correlated with *increasing* water ecosystem extent
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.1.1 Forest area	Protection of KBAs reduces deforestation in protected forest ecosystems and leads to an increase in forest area	(Carranza et al., 2014; Geldmann et al., 2013)	*Increasing* protection of KBAs is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.1.1 Forest area	Sustainable forest certification reduces unsustainable deforestation, which increases forest area	(Auld et al., 2008; Damette & Delacote, 2011; Potapov et al., 2017; Rametsteiner & Simula, 2003)	*Increasing* sustainable forest certification is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.5.1 Species at risk	Sustainable forest certification reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Burivalova et al., 2017; Kalonga et al., 2016; van Kuijk et al., 2009)	*Increasing* sustainable forest certification is correlated with *increasing* Red List Index, which indicates *decreasing* species extinction risk
15.2.1 Protected forest area	15.1.1 Forest area	Protection of forest ecosystems reduces unsustainable deforestation, which increases forest area	(Carranza et al., 2014; Eklund et al., 2016)	*Increasing* the protection of forests correlates with *increasing* forest area
2.5.1 Secure genetic resources for food	2.5.2 Local breeds extinction	Conservation of genetic resources reduces the extinction risk of domesticated species	(*Coping with Climate Change*, 2015; Enjalbert et al., 2011)	*Increasing* conservation of genetic resources for food correlates with an *increasing* proportion of local breeds at risk of extinction
6.a.1 Investment in water and sanitation	6.6.1 Water ecosystems	Investment catalyses improved water resource management which reduces demand for, and abstraction of, water from water ecosystems and leads to an increase in water ecosystem extent	(Turral et al., 2010)	*Increasing* investment in water and sanitation correlates with *decreasing* water ecosystem extent
7.1.2 Primary reliance on clean fuels	11.6.2 Air pollution	Greater reliance on clean fuels and technologies leads to less non-renewable resource combustion, which reduces the amount of air pollutants produced and leads to improvements in air quality	(IEA et al., 2022, p. 7)	*Increasing* reliance on clean fuels correlates with *increasing* levels of fine particulate matter in cities
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.5.1 Species at risk	Protection of KBAs reduces human disturbance of biodiversity, which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al.,	*Increasing* protection of KBAs is correlated with *decreasing* Red List Index, which indicates an *increasing* species extinction risk

Environmental policy indicator	Environmental state indicator	Hypothesised outcomes of environmental policy, leading to environmental improvements	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
			2016)	
15.2.1 Sustainable forest long-term management	15.5.1 Species at risk	Sustainable forest management reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Burivalova et al., 2017)	*Increasing* the forests under sustainable long-term management correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.2.1 Protected forest area	15.5.1 Species at risk	Protection of forest ecosystems reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al., 2016)	*Increasing* protection of forests correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.4.1 Mountain protected areas	15.5.1 Species at risk	Protection of mountain ecosystems reduces human disturbance of biodiversity in mountain ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Gray et al., 2016)	*Increasing* protection of mountain ecosystems correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.8.1 Invasive alien species	15.5.1 Species at risk	National legislation and adequate resourcing for the prevention or control of invasive alien species leads to a reduction in the negative impacts of invasive alien species on biodiversity and a reduction in the number of species threatened with extinction	(Butchart et al., 2006)	*Increasing* prevention and management of alien invasive species correlates with *decreasing* Red List Index, which indicates *increasing* species extinction risk.

3.1.1 Extinction risk of local breeds (2.5.2)

The extinction risk of local breeds was positively correlated with policies to secure genetic resources for food (2.5.1) (Table 2), suggesting that despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is going up.

3.1.2 Water ecosystem extent (6.6.1)

We found a positive correlation between the protection of important sites for terrestrial and freshwater biodiversity (15.1.2) and the extent of water ecosystems (Table 2). On the other hand, we found a negative correlation between water ecosystem extent and the value of development assistance for water supply and sanitation (6.a.1), suggesting that increased spending on water and sanitation is related to decreasing water ecosystem extent. Furthermore, there was no significant relationship between water ecosystem extent and water use efficiency (6.4.1).

3.1.3 Air pollution (11.6.2)

Air pollution, measured as levels of outdoor fine particulate matter in cities, was positively correlated with the proportion of the population with primary reliance on clean fuels and technology (7.1.2) (Table 2). This result suggests that despite the increasing use of clean fuels and technologies, urban air pollution levels continue to increase. Conversely, air pollution was negatively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1), suggesting that there may be a link between renewable energy use and air pollution in cities.

3.1.4 Forest ecosystem extent (15.1.1)

The extent of forest ecosystems was positively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1) (Table 2). This result suggests a relationship between increasing renewable energy use and increasing forest area, perhaps due to decreasing deforestation linked to the use of timber for energy production. We found no significant correlation between forest ecosystem extent and population with primary reliance on clean fuels and technology (7.1.2). However, forest ecosystem extent was positively correlated with the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of forests certified under an independently verified certification scheme (15.2.1), and the area of forest that is protected (15.2.1). These results suggest that protected area policies and forest certification schemes are related to increasing forest ecosystem extent.

3.1.5 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental policy indicators (Table 2), including the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of protected forest ecosystems (15.2.1), the extent of protection of mountain ecosystems (15.4.1), implementation of long-term forest management plans (15.2.1), and the prevention or control of Invasive Alien Species (15.8.1). These results suggest that despite implementing these environmental policies, several of which have the primary objective of conserving biodiversity, the number of species at risk of extinction continues to increase. Only the extent of forests certified under an independently verified certification scheme (15.2.1) correlated positively with decreased species extinction risk. There was no significant relationship between species extinction risk and the protection of marine ecosystems (14.5.1). We must highlight that SDG indicator 15.5.1, based on the IUCNs Red List

Index, does not include marine species. Therefore the link between this indicator and marine protected areas (indicator 14.5.1) is tenuous.

3.2.Relationships between environmental pressures and the state of the environment

Table 3. The environmental pressure indicators that correlate significantly with the environmental state indicators. Correlations that show environmental degradation are presented in the upper half of table. Correlations that show environmental improvements are presented in the lower half of table. The middle column describes the causal relationship between the environment and society based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental pressure indicator	Environmental state indicator	Hypothesised outcomes of environmental pressures, leading to environmental degradation	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
6.4.2 Water stress	6.6.1 Water ecosystems	More significant water stress increases demand for, and abstraction of, water from water ecosystems and leads to a decrease in water ecosystem extent	(Arroita et al., 2017; Pekel et al., 2016; Rosen et al., 2000)	*Increasing* water stress correlates with *decreasing* water ecosystem extent
8.4.2 DMC of crops	15.5.1 Species at risk	Greater consumption of crops promotes increased agricultural production, which increases human disturbance of natural ecosystems and biodiversity, which pushes more species toward extinction	(Foley et al., 2005; Lambertini, 2020)	*Increasing* consumption of domestically produced crops correlates with *increased* species extinction risk
8.4.2 DMC of fossil fuels	11.6.2 Air pollution	Greater consumption of fossil fuels involves the combustion of fossil fuels which produces air-borne pollutants which reduce air quality	(De Longueville et al., 2014)	*Increasing* consumption of domestically produced fossil fuels correlates with *increased* air pollution in cities
8.4.2 DMC of wild catch and harvest	15.5.1 Species at risk	Increased exploitation and consumption of wildlife reduces the population sizes of species and pushes more species toward extinction	(Bradshaw et al., 2009; Butchart et al., 2006; Fa et al., 2003; Nasi et al., 2011; Vliet et al., 2007)	*Increasing* consumption of wild-caught and harvested species correlates with *increased* species extinction risk
8.9.1 Tourism	6.6.1 Water ecosystems	Increased tourism increases demand for, and abstraction of, water from water ecosystems and lead to a decrease in water ecosystem extent	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* water ecosystem extent
8.9.1 Tourism	15.1.1 Forest area	Increased tourism promotes deforestation through the development of tourism infrastructure	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* forest area
8.9.1 Tourism	15.5.1 Species at risk	Increased tourism leads to land use change to develop tourism infrastructure, which disrupts ecosystems. Furthermore, it leads to more significant numbers of people visiting areas of high biodiversity value, which increases biodiversity disturbance and pushes more species toward extinction. Alternatively, nature-based tourism can promote biodiversity conservation.	(Bookbinder et al., 1998; Gössling, 2002)	*Increasing* tourism correlates with *increasing* species extinction risk
8.4.2 DMC of crops	15.1.1 Forest area	Greater consumption of crops promotes increased agricultural production, which increases demand for land, which drives	(Foley et al., 2005; Geist & Lambin,	*Increasing* consumption of domestically produced crops correlates with

Environmental pressure indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental pressures, leading to environmental degradation**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
		deforestation and decreases forest area	2002; Gibbs et al., 2010; Potapov et al., 2017)	*increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	6.6.1 Water ecosystems	Mining uses large quantities of freshwater. Therefore an increase in the DMC of minerals extracted by mining will decrease the extent of water ecosystems.	(Palmer et al., 2010)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* water ecosystem extent
8.4.2 DMC of metal ores and non-metallic minerals	15.1.1 Forest area	Mining drives deforestation. Therefore an increase in the DMC of minerals extracted by mining will decrease forest area.	(Potapov et al., 2017; Schueler et al., 2011; Sonter et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	15.5.1 Species at risk	Mining has a negative local effect on biodiversity due to habitat destruction and pollution. Therefore an increase in the DMC of minerals extracted by mining will increase the number of species at risk of extinction.	(Deikumah et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *decreasing* species extinction risk
8.4.2 DMC of wood	15.1.1 Forest area	Greater consumption of wood resources promotes deforestation, which reduces forest area. Conversely, greater wood consumption promotes the conversion of non-forested land to timber plantations which increases forest area	(Geist & Lambin, 2002; Payn et al., 2015; Potapov et al., 2017)	*Increasing* consumption of domestically produced wood correlates with *increasing* forest area
9.a.1 Infrastructure support	6.6.1 Water ecosystems	Support for dam infrastructure will increase the water ecosystem extent due to the creation of reservoirs associated with dams. Alternatively, support for, and construction of, other forms of infrastructure, such as urban development, degrades natural ecosystems and reduces water ecosystems' extent.	(Davis & Froend, 1999; Lehner et al., 2011; Wang et al., 2008; Žganec, 2012; Zhang, 2009)	*Increasing* financial support for infrastructure correlates with *increasing* water ecosystem extent.

3.2.1 Water ecosystem extent

The extent of water ecosystems was negatively correlated with water stress (6.4.2) (Table 3), measured as the proportion of freshwater withdrawals to available freshwater resources, and with tourism (8.9.1), measured as the proportion of tourism GDP in a country's total GDP. This result suggests that the extent of water ecosystems declines as freshwater withdrawals and tourism activities increase. On the other hand, the extent of water ecosystems was positively correlated with domestic material consumption (DMC) of crops (8.4.2), DMC of metal ores and non-metallic minerals, and international financial support for infrastructure (9.a.1). This result suggests that the extent of water ecosystems increases as consumption of domestically produced crops increases, perhaps due to increased area used for irrigation, with increasing consumption of domestically produced metal ores and non-metallic minerals, and with increasing financial support for infrastructure, perhaps due to the construction of dams and the reservoirs created by them.

3.2.2 Air pollution (11.6.2)

We found a positive correlation between air pollution levels and DMC of fossil fuels (8.4.2) (Table 3), suggesting that air quality in cities declines as consumption of domestically produced fossil fuels increases.

3.2.3 Forest ecosystem extent (15.1.1)

Forest ecosystem extent correlated positively with DMC of crops, wood, and metal ores and non-metallic minerals (8.4.2) (Table 3), suggesting that forest extent increases as consumption of these domestically produced materials increases. Conversely, forest ecosystem extent correlated negatively with tourism (8.9.1), suggesting that forest extent decreases as a country's economic reliance on tourism increases, potentially due to deforestation associated with the tourism industry. There was no significant relationship between forest extent and infrastructure support (9.a.1).

3.2.4 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental pressures (Table 3), including DMC of crops (8.4.2), DMC of wild catch and harvest materials (8.4.2), and tourism (8.9.1). This result suggests that the number of species at risk of extinction increases as consumption of domestically produced crops increases, as the amount of wild materials extracted from a country's territory increases, and as tourism increases. Conversely, there was a positive correlation between species extinction risk and consumption of domestically produced metal ores and non-metallic minerals. Finally, there was no significant relationship between species extinction risk and water stress (6.4.2).

4. Discussion

In this study, we use the dataset underlying the SDG monitoring framework to investigate the relationship, across countries, between environmental policies, the state of the environment, the impact of the environment on society, and the pressures that continue to impact the environment. We used a correlation analysis combined with a statistical modelling approach to investigate the correlations between pairs of SDG indicators that we hypothesised to have a relationship based on evidence in the scientific literature and expert opinion. Where the results of the statistical analyses agreed with the scientific rationale, we inferred that this is evidence of a causative relationship between the indicator pairs. Our results highlight where environmental policies may be achieving their intended goals. For example, protecting Key Biodiversity Areas is linked with the increasing extent of forest and water ecosystems. Our results suggest that more effort is required to increase the positive environmental impacts of policies, such as conserving genetic resources to decrease the extinction risk of domesticated species. Surprisingly, our results provide no evidence for the social impacts of the state of the environment, potentially due to the complexity of ecosystems and the difficulty of detecting relationships between the non-market benefits humans derive from the environment and the state of ecosystems. Finally, our results suggest that environmental pressures, including freshwater withdrawals, tourism, and domestic material consumption of crops, fossil fuels, and wild catch and harvest, continue negatively impacting the environment.

This study gives us a flavour of the relationships, across countries, between governmental approaches to tackling environmental degradation and the state of the environment to understand where environmental responses may be achieving their intended aims and where they are falling short. For example, a policy response that appears to be working for conserving forest and water ecosystems is protecting important sites for terrestrial and freshwater biodiversity. Indeed there is convincing evidence that protected areas reduce deforestation (Geldmann et al., 2013; Joppa & Pfaff, 2011). However, the impact of protecting freshwater ecosystems is more challenging to understand than in forest ecosystems and there is less evidence of the benefits of protecting freshwater ecosystems (Adams et al., 2015). Our results offer new evidence about the benefits of protected areas on the extent of freshwater ecosystems.

Our results also highlight policies that may not be having their desired impact. For example, despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is increasing. This result suggests that policymakers must do more to conserve domesticated species from the threat of extinction. Indeed the latest reports from the FAO on this topic highlight numerous shortcomings in the state of genetic resource conservation, including missing risk status assessments for the majority of breeds and a lack of early warning systems for genetic erosion (Scherf et al., 2015). In addition, SDG indicators 2.5.1 and 2.5.2 need more data for many countries (Gil et al., 2019). Ultimately, conservation efforts, and the indicators used to monitor them, must be improved to mitigate and monitor the genetic extinction risk of economically and socially valuable species (Gandini & Hiemstra, 2021).

Our results regarding the relationship between species extinction risk and environmental responses were sobering yet not unexpected. Only a single environmental response (forest certification) correlated in a direction that suggests that extinction risk is declining in response to an environmental policy, which aligns with empirical evidence that forest certification contributes positively to biodiversity conservation (Lehtonen et al., 2021). However, the extent of protected areas of forest ecosystems, mountain ecosystems, and Key Biodiversity Areas all correlated with an *increase* in species extinction risk, which aligns with the criticisms that protected areas have fallen short of their conservation goals over the past decade (Maxwell et al., 2020). Regarding the environmental pressures that drive biodiversity loss, our results agree with the contemporary evidence that agricultural land use change and direct exploitation of wildlife remain the main drivers of terrestrial biodiversity declines (Balvanera et al., 2019; Jaureguiberry et al., 2022). Our results highlight that countries need to do more to holistically tackle the multiple drivers of biodiversity loss using environmental policies that are socially just and align with countries' climate change ambitions. At the 15th Conference of Parties to the UN Convention on Biological Diversity, UN Member States agreed to a new set of Goals and Targets to address biodiversity loss and restore natural ecosystems (CBD, 2022a), progress towards which will be tracked by an underlying monitoring framework of indicators (CBD, 2022b). Adopting the monitoring framework is a significant achievement as it is the first time an officially agreed monitoring framework has accompanied the CBD's international biodiversity agreements. A rigorous mechanism for tracking countries' progress on biodiversity will push governments to prioritise the effective design and implementation of environmental policies that bend the curve of biodiversity decline.

We investigated the environment's social impacts, including the human and economic impacts of natural disasters, food insecurity, health impacts of food access, and drinking water access. We found no evidence for relationships between the state of the environment and its impacts on society. Although alarming, this is somewhat not surprising, considering the complexity of ecosystems and their relationships with the goods and benefits that humans derive from the environment. Ecosystems are characterised by 'feedback loops, non-linearities, and alternative states' (Mace, 2019), which makes it challenging to delineate simple relationships between the state of the environment, the ecological functions that support ecosystem services, and the final environmental goods and benefits that society enjoys. It may also be harder to detect a direct link between humans and environmental goods and benefits at a national scale, (the scale of our analysis in this study), because less people now directly depend on the goods and benefits produced by their local ecosystems. Most people now live in cities(UNDESA, 2019) and consume food and materials that are produced by ecosystems outside their local area, and often far outside their national jurisdictions(Folke et al., 1997). There has also been less research on the social impacts of some types of environmental policies than on their environmental impacts (Johnson et al., 2022). Finally, the methods that are used to produce national statistics can be inappropriate for surveying the population groups that do directly depend on their local ecosystems for food and water such as indigenous communities(Walter & Andersen, 2016).

We also investigated environmental pressures, and our results suggest that the human activities that cause environmental degradation, including freshwater withdrawals, tourism, consumption of domestically produced crops, mined minerals, fossil fuels, and wild materials, continue to degrade the environment. Indeed, our findings align with the IPBES global assessment which details freshwater withdrawals, harvesting of materials from nature, mining of fossil fuels, agricultural land-use change, and tourism as direct drivers of environmental change that continue to threaten the state of nature globally (Balvanera et al., 2019). To improve environmental outcomes, countries will need to continue to mitigate these human activities' negative environmental impacts.

Policy responses and environmental pressures continue to increase while the state of the environment continues to decline (Lambertini, 2020; UN Environment, 2019), which illustrates that, to improve the environment, national governments need to do more. Existing policies need to do more to achieve their intended goals and require greater stringency or redesign (UN Environment, 2019). Others may need to be implemented correctly or enforced adequately. Moreover, policies must tackle the underlying drivers of environmental change, such as values, technology, demography, the economy, and governance, which often subvert well-meaning environmental policies. Environmental policies need to engage sufficiently with land and sea use policies, including agriculture, fisheries, renewable energy, and transport (European Habitats Forum, 2019). In addition, countries must respond holistically to environmental declines by integrating environmental policies into agriculture, fisheries, and energy policies that drive environmental change.

We make some recommendations for future improvements to the SDG monitoring framework. First, indicators on policy responses dominate the environmental dimension of the SDG monitoring framework (50 out of 92 indicators), while only 11 measure the state of the environment (Campbell et al., 2020). We recommend that the framework be supplemented with additional environmental state indicators to better track whether policy responses lead to environmental improvements. Secondly, we recommend that indicator 15.5.1, the Red List Index on wild species extinction risk, is disaggregated into multiple sub-indicators of terrestrial, freshwater, and marine species. Currently, indicator 15.5.1 only includes terrestrial species, so it is unsuitable for assessing the success of indicator 14.5.1 on marine protected areas and sub-indicator 15.1.2 on the protection of freshwater Key Biodiversity Areas. The Red List Index for marine species (see, for example, (Nieto et al., 2015)) and a sub-indicator for freshwater species would be more suitable for monitoring the success of marine and freshwater conservation interventions than indicator 15.5.1 in its current form. Finally, national environmental monitoring agencies should adopt science-based standards for the environmental state indicators to provide clear targets for achievement (Usubiaga-Liaño & Ekins, 2022). Standards for some indicators will be uniform across all countries, such as the WHO's safe air pollution levels (World Health Organization & WHO European Centre for Environment, 2021). The standards of other indicators will need to be country-specific and defined through scientific investigation of environmental thresholds in the unique environmental context of each country.

The SDG monitoring framework's data is a valuable resource of indicators for tracking countries' progress toward environmental sustainability. By testing the relationships between indicators of countries' responses to environmental pressures, the state of the environment, and the impacts of the environment on society, we show that governments are making some progress toward sustainable development in some areas, but there are many areas for improvement. If governments wish to maintain nature's contributions to people into perpetuity, they need to improve their policy responses to environmental pressures.

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Open Research

The SDG indicators data used for the study is available in both a private FigShare repository (https://figshare.com/s/83dc27cba88c5c7d91e3) and publicly available on the SDG Indicator Database (www.unstat.un.org/sdgs/dataportal/database). The R software used for the statistical analysis is available at https://www.r-project.org/ (R Core Team, 2021) and the R code used to conduct the statictial analysis will be made publically available on a GitHub repository on publication.

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