Composite environmental indices – A case of rickety rankings

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Composite indices have been widely used to rank the environmental performance of nations. Such environmental indices can be useful in communicating complex information as a single value and have the potential to generate political and media awareness of environmental issues. However, poorly constructed, or poorly communicated indices can hinder efforts to identify environmental failings. The current issue in the field is that there are considerable differences in rank among existing environmental indices. Here, we provide a review of the conceptual frameworks and methodological choices used for existing environmental indices to enhance our understanding of their accuracy and applicability. In the present study, we review existing global indices according to their conceptual framework (objectives of the index and set of indicators included) and methodological choices made in their construction (e.g., weighting and aggregation). We examine how differences in conceptual frameworks and methodology may yield a more, or less, optimistic view of a country's environment. Our results indicate that (1) multidimensional environmental indices with indicators related to human health and socioeconomics are positively correlated; (2) environment-only indices that exclude such indicators are also positively correlated with each other; (3) multidimensional indices and environment-only indices are negatively correlated with each other or are not correlated at all. This indicates that the conceptual frameworks and indicators included may influence a country's rank among different environmental indices. Our results highlight that, when choosing an existing environmental index – or developing a new one – it is important to assess whether the conceptual framework (and associated indicators) and methodological choices are appropriate for the phenomenon being measured and reported on. This is important because the inclusion of confounding indicators in environmental indices may provide a misleading view of a country's environment.

1 **Composite Environmental Indices – A Case of Rickety Rankings**

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19 **Abstract**

20 Composite indices have been widely used to rank the environmental performance of nations.
21 Such environmental indices can be useful in communicating complex information as a single
22 value and have the potential to generate political and media awareness of environmental
23 issues. However, poorly constructed, or poorly communicated indices can hinder efforts to
24 identify environmental failings. There are considerable differences in rank among existing
25 environmental indices. Here, we provide a review of the conceptual frameworks and
26 methodological choices used for existing environmental indices to enhance our understanding
27 of their accuracy and applicability. In the present study, we review existing global indices
28 according to their conceptual framework (objectives of the index and set of indicators included)
29 and methodological choices made in their construction (e.g., weighting and aggregation). We
30 examine how differences in conceptual frameworks and methodology may yield a more, or less,
31 optimistic view of a country's environment. Our results indicate that (1) multidimensional
32 environmental indices with indicators related to human health and welfare or policy are
33 positively correlated; (2) environment-only indices that exclude such indicators are also
34 positively correlated with each other; (3) multidimensional indices and environment-only indices
35 are negatively correlated with each other or are not correlated at all. This indicates that the
36 conceptual frameworks and indicators included may influence a country's rank among different
37 environmental indices. Our results highlight that, when choosing an existing environmental
38 index – or developing a new one – it is important to assess whether the conceptual framework
39 (and associated indicators) and methodological choices are appropriate for the phenomenon
40 being measured and reported on. This is important because the inclusion of confounding
41 indicators in environmental indices may provide a misleading view of a country's environment.

42 **1   Introduction**
43 Composite environmental indices attempt to communicate complex information by combining
44 multiple indicators into a single score. They provide an overall snapshot of some features of

45 environmental systems and allow for comparisons between environmental systems (Oţoiu &
46 Grădinaru, 2018). Environmental indices can be useful tools to measure stability and change
47 over time (improvement or decline), easily communicate information to the general public and
48 policymakers, drive accountability between countries, encourage accountability of a nation's
49 government to its citizens, and facilitate public engagement (Dobbie & Dail, 2012; Nardo et al.,
50 2005). Environmental indices can also help inform and support policy decisions, as well as
51 generate political and media awareness of environmental issues (Haberland, 2008). However, if
52 indices are poorly constructed or communicated, they can hinder efforts to identify and address
53 environmental failings and may mislead policy messages and decisions (Alberti & Parker,
54 1991).

55 The popularity of environmental indices has grown in recent years. Environmental indices have
56 been used to measure and compare results for individual nations in global analyses (Bradshaw
57 et al., 2010; Wackernagel et al., 2019; Wendling et al., 2020), for clusters of nations (Cook et
58 al., 2017; Halkos & Zisiadou, 2018), for regions within a nation (Mukherjee & Kathuria, 2006;
59 Universiti Teknologi, 2018), and to measure the state of specific ecosystems (Blumetto et al.,
60 2019). Most commonly, however, environmental indices are used in global studies to compare
61 results across nations, because national policy formulation and implementation are centred at
62 the national level (Roberts, 2011; Usubiaga-Liaño & Ekins, 2021). Therefore, in this review, the
63 geographic scale is for individual nations within global analyses.

64 There is a diverse range of available environmental indices, but country rankings differ
65 considerably in these different indices. To illustrate, national rankings vary by an average of 45
66 places between the 2018 versions of the Environmental Performance Index (EPI) and
67 Ecological Footprint (EF) (ranks normalized 0-100, Supplementary File 1). Such large rank
68 variations, particularly for low income and high income countries, have led to questions about
69 the legitimacy and validity of rankings (Morse & Fraser, 2005; Press Information Bureau
70 Government of India, 2022). Some environmental indices include indicators such as access to
71 clean drinking water and sanitation, mortality, and per capita income for which high income
72 nations will score well and low income countries will score poorly. The inclusion of such
73 indicators may provide a more or less optimistic view of the environment of a nation, depending
74 on its development status (e.g., Global North, Global South) (Bradshaw et al., 2010; Haberland,
75 2008; T).

76 There is extensive literature examining metrics for sustainable development and environmental
77 sustainability (Alberti & Parker, 1991; Böhringer & Jochem, 2007; Bradshaw et al., 2010; Dobbie
78 & Dail, 2012; Ebert & Welsch, 2004; Kwatra et al., 2020; Mallett, 1999; Oţoiu & Grădinaru, 2018;
79 Siche et al., 2008). However, past work has largely focused on the need for credible
80 environmental metrics (Alberti & Parker, 1991; Hák et al., 2016), principles for constructing
81 composite indices (Dobbie & Dail, 2012; Floridi et al., 2011; Nardo et al., 2005), and weighting,
82 aggregation, and uncertainty analysis methods (Burgass et al., 2017; Gan et al., 2017; Greco et
83 al., 2019; Morse & Fraser, 2005; Tripathi & Singal, 2019). Research into rank differences
84 between existing environmental indices is relatively sparse. Research into rank variations in
85 other fields, such as university rankings and sports leagues, is also limited and has largely
86 concentrated on construction methods and policy implications (Garcia-Zorita et al., 2018;
87 Saisana et al., 2011).

88   The aim of this review are to answer the following questions: (1) Which conceptual framework(s)
89   or indicators inform the development of the country rankings? What effect do different
90   conceptual frameworks (and indicators included have on global rankings? To what extent do the
91   different environmental indices adequately capture environmental issues in low income and high
92   income countries? In doing so, this review provides insights into how environmental indices are
93   constructed and provide recommendations for best practices. In the present study, we have
94   identified ten environmental indices for which country rankings can be compared to improve our
95   knowledge of how conceptual frameworks and methodological choices (e.g., weighting and
96   aggregation methods) may influence rank variation. This paper provides a novel contribution to
97   the development and use of composite environmental indices. This review is intended for
98   environmental scientists interested in environmental assessment and protection, conservation
99   executors, environmental analysts, and policymakers at both the national and international
100 levels.

101 The paper is organized as follows. First, we discuss how different understandings of sustainable
102 development, environmental sustainability, and natural capital have informed environmental
103 indices. Second, we discuss differences in the conceptual frameworks and methodological
104 choices used to develop environmental indices. Third, we summarize existing environmental
105 indices and the conceptual frameworks and construction choices behind them. Fourth, we
106 examine correlations between ranks in global environmental indices. Fifth, we examine ranks for
107 two high income countries (Germany and New Zealand) and two low income nations (Mongolia
108 and Niger) and identify potential reasons for wide differences in rank for low and high income
109 nations generally. Finally, we discuss our key findings and outline how conceptual framework
110 and methodological choices may affect the ranking of nations in environmental indices.

111 *2*   **Review of Global Environmental Indices**
112 The Brundtland Commission (1987) defined sustainable development as 'development that
113 meets the needs of the present without compromising the ability of future generations to meet
114 their own needs'. The three pillars (or dimensions) of sustainability are economy, environment,
115 and society (see Fig 1). The aim of sustainable development is to use economic development to
116 promote fairer societies within the ecological carrying capacity of the planet (Baker, 2016;
117 Strange & Baley, 2008).

118 **Figure 1: Diagram depicting the three pillars of sustainable development, adapted from**
119 **Purvis et al. (2018).**

120 There are complex connections and trade-offs between economic growth, improvements in
121 social state, and environmental quality (Strange & Baley, 2008). The Environmental Kuznets
122 Curve (EKC) hypothesises that environmental degradation initially increases with income, then
123 declines (Stern et al. 1996). However, critics have highlighted that the EKC model is
124 debateable, particularly when considering different indicators of environmental degradation. For
125 example, biodiversity may not improve with rising income (Mills & Waite, 2009). Several studies
126 have demonstrated that economic growth has a strong positive effect on carbon dioxide, sulphur
127 dioxide, and industrial greenhouse gas (GHG) emissions, but weaker effects on particulate
128 matter (PM) and non-industrial GHG emissions (Holtz-Eakin & Seldon, 1995; Stern, 2017). The
129 constructors of the pENV investigated relationships between per capita wealth and
130 environmental impact and found that EKC predictions were not supported (Bradshaw et al.

131   2010). The EPI team, however found a positive correlation between EPI scores and country
132   wealth - indicating that rising GDP per capita is associated with higher EPI scores (Wolf et al.
133   2022).

134   While complex interactions exist between the three pillars of sustainability, environmental
135   sustainability can be distinguished from social sustainability and economic sustainability
136   (Goodland, 1995; Usubiaga-Liaño & Ekins). Several different definitions for environmental
137   sustainability exist (Table 1). A common theme in these definitions is the need for some
138   qualities or functions of natural capital to be sustained for future generations. Natural capital (the
139   natural environment) is comprised of natural resource stocks (e.g., water, forests, soil, wetlands,
140   atmosphere), which provide a flow of goods and services. Goods and services can be
141   renewable and non-renewable with and without marketed value (Ekins et al., 2003; Helm, 2015;
142   OECD, n.d.). Indicators representing the qualities or functions of natural capital can be linked to
143   environmental pressures, states, and impacts, as well as social states where their functions are
144   associated with human health and welfare (Ekins et al., 2003; Usubiaga-Liaño & Ekins, 2021).

145   **Table 1. Definitions of Environmental Sustainability, adapted from Usubiaga-Liaño &**
146   **Ekins (2021).**

147   Environmental metrics represent the environmental dimension of sustainable development and
148   use a variety of indicators related to the qualities or aspects of natural capital (Usubiaga-Liaño &
149   Ekins, 2021). For the purposes of this review, we categorize environmental indices into two
150   broad categories. Environment-only indices focus exclusively on aspects of natural capital that
151   represent pressures, states, or impacts and exclude indicators related to environmental policies
152   or human health and welfare. Thus, environment-only indices only include indicators that fall
153   under the environmental pillar of sustainable development (Fig. 1). In line with research by
154   Bradshaw et al. (2010), multidimensional indices use indicators that represent aspects of
155   natural capital linked to environmental pressures, states, impacts as well as indicators related to
156   environmental policies or human health and welfare. Human health and welfare functions
157   provide services to humans which maintain health and contribute to human wellbeing in other
158   ways – both economic and noneconomic (Usubiaga-Liaño & Ekins, 2021). Multidimensional
159   indices typically incorporate (either directly or as calculation components) indicators such as
160   human access to safe sanitation and drinking water, exposure to pollutants, and per capita
161   income. Unlike environment-only indices, multidimensional indices include indicators that fall
162   under all three pillars of sustainable development (Fig 1).

163   ***2.1   Considerations for constructing environmental indices***
164   Composite environmental indices are typically developed using the same basic steps
165   (development of a conceptual framework, data selection, imputation of missing data, weighting
166   and aggregating, uncertainty and sensitivity analysis) (Table 2). Some indices, however, may
167   not use all the steps, or the conceptual framework and methodological choices may not be
168   adequately described. This is concerning because results are often presented in the media
169   without sufficient information regarding the conceptual framework or methods used to construct
170   a given index (Conrad & Cassar, 2018). Additionally, misleading rankings can be misused by
171   politicians and industry organizations (Hsu, 2013; New Zealand Parliament, 2011; Rowarth,
172   2020, 2021). For example, the director of two industry organizations representing dairy farmers
173   in New Zealand has used the country's high ranking in the Legatum Prosperity Index (LPI) to

174 argue that New Zealand's agricultural industry has a lower environmental impact than other
175 countries (Rowarth, 2021), despite decades of scientific research suggesting otherwise
176 (Duncan, 2014; Howard-Williams et al. 2013; Joy, 2015). Thus, it is worthwhile to investigate
177 how the conceptual frameworks and construction choices used in existing indices may influence
178 rankings. In the case of the Natural Environment Pillar of the LPI (hereafter referred to as LPI-
179 NE), the aim is to measure aspects of the physical environment that have a direct effect on
180 people. Nevertheless, this index includes indicators that do not measure the physical
181 environment, such as disability-adjusted life year (DALY) as a measure of disease burden and
182 survey responses (e.g., are you satisfied or dissatisfied with the quality of water?). This example
183 illustrates the importance choosing indicators that are consistent with the environmental
184 phenomenon it aims to measure.

185 **Table 2. Standard principles for constructing composite indices, adapted from Dobbie**
186 **and Dail (2012) and Nardo et al. (2005)**

187 Several issues should be considered when assessing the adequacy of an environmental index
188 and whether it is fit for purpose (Bradshaw et al., 2010; Colling & Flynn, 2015). Firstly,
189 environmental indices differ according to the conceptual frameworks that inform them. Some
190 environmental indices such as the EPI and Environmental State and Sustainability Index (ESSI)
191 aim to measure how close nations are to established environmental policy targets (Oţoiu &
192 Grădinaru, 2018; Wolf, 2022), while others focus on the supply and demand of nature (the
193 Ecological Footprint) (Wackernagel et al., 2019), the health of ecosystems (Environmental
194 Wellbeing Index (EWI) (Prescott-Allen, 2001), or environmental impacts (absolute ENV (aENV)
195 and proportional ENV (pENV)) (Bradshaw et al., 2010). A conceptual framework should define
196 the objectives of the index and provide a clear outline of what is being measured (i.e., what is
197 the environmental phenomenon being measured?) (Dobbie & Dail, 2012; Nardo et al., 2005).
198 However, if the conceptual framework for a given index lacks clear objectives and definitions of
199 terms, and if selection criteria for indicators do not reflect the conceptual framework, this can
200 lead to debate and confusion (Haberland, 2008; Ihobe, 2013).

201 Secondly, indicators should be relevant to the phenomenon being measured and data selection
202 processes should be carefully considered to avoid introducing inappropriate or poor-quality
203 indicators (or excluding key indicators). It is worth noting that there is often a compromise
204 between scientific precision and information available—what scientists would like to measure
205 does not always correspond with what can practically be measured at a given point in time
206 (Nardo et al., 2005). However, if the available data sets are inadequate it can lead to questions
207 about whether national ranks are meaningful (Browning, 2011; Haberland, 2008; Ihobe, 2013;
208 Press Information Bureau Government of India, 2022). This was the case for the water quality
209 index included in the 2010 EPI (Emerson et al., 2010). In New Zealand, freshwater scientists
210 revealed flaws in the water quality index used and challenged the prime minister at the time
211 about his misuse of New Zealand's rank for freshwater in the EPI (Browning, 2011; New
212 Zealand Parliament, 2011). Subsequently the EPI team reviewed the indicator and it was
213 removed from later versions of the index (Hsu, 2013). Another example of issues with data
214 quality and coverage is the inclusion of renewable water resources and freshwater withdrawal in
215 the LPI-NE (Legatum Institute, 2020). Because data is limited for large parts of the world,
216 modelled data from the Food and Agriculture Organization (FAO) AQUASTAT database is used

217   instead. The FAO itself raised the need for caution when using the dataset: "the problems of
218   insufficient data and dubious accuracy paint a picture that, if interpreted as a final product, lead
219   to incorrect assumptions" (41, Challenges section, para. 5). The FAO highlighted issues with
220   data coverage for North America, Europe, Japan, Australia, and New Zealand—all of which rank
221   highly in the LPI-NE (FAO, 2021b). Failure to assess the impact of imputed values can impact
222   on the quality of an index.

223   Another issue to consider is that data from different time periods may be used by the developers
224   of environmental indices. A given index may include data for a particular point in time or
225   averages for a set number of years. For example, the aENV and pENV use the most recent
226   three-year average for annual fertilizer consumption and the most recent ten-year average for
227   CO_2 emissions (Bradshaw et al., 2010). Others may include data for a particular point in time,
228   trends over a certain time period, or future projections. For example, in the EPI forest loss is
229   measured over a five-year period and compared to a reference year, GHG emissions are
230   predicted for the year 2050, and human exposure to heavy metals is calculated for a 30-year
231   period (Wolf et al., 2022; Wolf, 2022). While the appropriateness of timeframes may vary
232   according to the indicator, it is crucial to clearly communicate the periods used so that potential
233   users of the index can evaluate the decisions made by the constructors. However, timeframes
234   for data collection and decision-making are not clearly communicated for some indices. For
235   example, timeframes for the dataset used for the CIEP are not provided (García-Sánchez et al.,
236   2015), which adds another level of complexity when interpreting the index.

237   Finally, there are issues with the statistical methods used for some environmental indices.
238   Different procedures may be used for normalization, weighting, aggregation, and uncertainty
239   and sensitivity analysis. Weighting techniques are particularly important as they can lead to
240   different rankings (Chakrabartty, 2018; Dobbie & Dail, 2012; Morse & Fraser, 2005). There are
241   three common methods for weighting indicators: (1) expert-opinion based weighting, which uses
242   subjective judgements in an open discussion with experts (e.g., EPI), (2) equal weighting where
243   all indicators are given the same weighting (e.g., Environmental Vulnerability Index (EVI)), and
244   (3) statistics-based weighting (e.g., ESSI, aENV and pENV). Indices that use equal and expert
245   opinion-based weighting methods have been criticized for failing to consider the interlinkages
246   and dynamic interrelations of the various components (Agliardi et al., 2014; Morse & Fraser,
247   2005; Paulvannan Kanmani et al., 2020). Indices such as the aENV, pENV and ESSI use
248   multivariate analysis to explore the nature of datasets and determine weights (Bradshaw et al.,
249   2010; Oţoiu & Grădinaru, 2018). A recent study used stochastic dominance theory to investigate
250   how sensitive EPI scores are to alternative weight choices (Pinar, 2022). By using alternative
251   weights, 67 countries would have seen a rank change of at least 30 places, while 37 would have
252   seen a rank change of at least 50 places. This example illustrates the importance of
253   incorporating uncertainty and sensitivity analyses into the development of environmental
254   indices, as well as communicating the statistical methods employed explicitly and transparently.
255   It is important to highlight that statistical methods also have a drawback in that they cannot be
256   easily communicated, which may reduce public trust in the index.

257   In summary, environmental indices vary widely in terms of conceptual framework (what
258   environmental phenomena is being measured, terminology used, selection criteria for
259   indicators) and methodological choices (data choices, normalization, weighting and aggregation

260 techniques, uncertainty and sensitivity analysis). The quality of the data included in different
261 indices also varies (e.g., gaps in temporal and spatial coverage). The following section presents
262 a brief characterization of ten global environmental indices.

263 ***2.2   Summary of ten national-level indices***
264 *Search Method*
265 An exhaustive search was performed to identify potential worldwide environmental indices
266 (conducted by the first author). Two public search engines (Google and Bing) were used as well
267 as academic databases (Scopus, JSTOR, Science Direct). The following search strategy was
268 used: (Environmental AND (index OR indices OR composite)) AND (nation OR national OR
269 countries OR performance OR quality OR health). Our characterization is restricted to ten
270 national level indices that have sufficient published information to determine their properties. Of
271 the ten indices, only the EPI, LPI-NE, Ef pc and EF tot are ongoing projects and have recent
272 versions available. We have included the remaining six indices as they provide valuable
273 information on the strengths and weaknesses of environmental indices. Indices were included in
274 our analysis if they included at least 100 countries, if the weighting and aggregation methods
275 were clear, and if there was sufficient information about the indicators included (e.g., data
276 sources were transparent, and indicators clearly defined). To avoid researcher bias, the first and
277 second authors evaluated each of the ten potential national-level environmental indices
278 separately.

279 Four indices (the CIEP, EPI, ESSI, and LPI-NE) are multidimensional indices, while the
280 remaining indices (EFpc, EFtot, EVI, EWI, aENV, pENV) are environment-only indices. The
281 weighting and aggregation methods used for multidimensional and environment-only indices are
282 mixed (Tables 3 and 4). To illustrate, the four multidimensional indices use three different
283 methods. The CIEP and ESSI use statistics-based weighting, the EPI uses expert opinion-
284 based weighting, and the LPI-NE uses a combination of two methods where weights are
285 primarily determined by expert opinion and academic literature, and to a lesser extent by
286 statistical significance to the economic and social wellbeing of a country. Environment-only
287 indices also use a mix of different methods. The aENV and pENV use statistics-based
288 weighting, the EFpc and EFtot use expert opinion-based weighting, and the EVI and EWI use
289 equal weighting.

290 Information for each index is summarised in overview tables, including (1) a brief
291 characterization of each index, (2) what each index aims to measure—and whether this it does
292 so adequately or not, (3) the methods used to construct each index (according to the steps
293 outlined in table 2), and (4) their strengths and weaknesses.

294 **Table 3. Summary of four multidimensional indices, including conceptual framework,**
295 **weighting and aggregation choices, strengths and weaknesses.**

296 **Table 4. Summary information for six environment-only indices including conceptual**
297 **frameworks, weighting and aggregation choices, strengths and weaknesses.**

298 **3   Rank Correlations in Global Environmental Indices**
299 There are considerable differences in rank among existing environmental indices. Here, we
300 compare country ranks for each of the indices identified in section 2.2, and explore potential
301 explanations for differences in ranking, such as conceptual framework and construction choices.

302 ***3.1 Methods***

303 First, we examined rank correlations for global environmental indices. Data for the EPI (2020),
304 LPI-NE (2021), EF per capita (EF pc) and EF total (EFtot) (2018) was sourced from official
305 websites (Global Footprint Network, 2022; Legatum Institute, 2021; Yale Center for
306 Environmental Law and Policy, n.d.). Data for ESSI (2018), EVI (1999), aENV and pENV (2010)
307 was obtained from academic publications (Bradshaw et al., 2010; Kaly et al., 2004; Oţoiu &
308 Grădinaru, 2018). Data for the CIEP (2015) was obtained directly from Dr Thiago Almeida
309 (Campina Grande Federal University, Brazil), one of the developers of the CIEP (Almeida,
310 2015a).

311 Ranks were compiled for each of the following indices: CIEP, EPI, ESSI, LPI-NE, aENV, pENV,
312 EFpc and EFtot, EVI, EWI. Countries were only included if there was a value for each index,
313 resulting in a total of 114 countries. Original rankings were normalized using the following
314 formula:

315
$$z_i = \frac{(x_i - \min(x))}{(\max(x) - \min(x))} * 100$$

316 Where z_i is the ith normalised value in the set, x_i is the ith value in the dataset, $\min(x)$ is the
317 minimum value in the dataset, and $\max(x)$ is the maximum value in the dataset.

318 To determine the degree of agreement between ranks we used Kendall's τ coefficient, which is
319 a commonly used measure of rank correlation (Field, 2018). Because several ranks were tied,
320 we chose Kendall's τ coefficient over Spearman's rank correlation because it is considered
321 more appropriate in the case of tied ranks in the data set (Field, 2018). Kendall's τ was
322 calculated using IBM SPSS Statistics (Statistical Package for Social Sciences) for Windows,
323 Version 28. If these distinct environmental indices assess similar measurable aspects of
324 environmental features of countries, moderate-to-high positive correlations are to be expected.

325 Second, we investigated rank correlations for indices that were published in the same year.
326 Original ranks were normalized using the method outlined previously and Kendall's τ coefficient
327 was used to determine the degree of agreement between ranks for: the pENV and EPI (2010),
328 the aENV and EPI (2010), the EFpc and EPI (2018), EFtot and EPI (2018).

329 Third, we examined rank correlations for pillars within the EPI. For the 2010 version of the EPI,
330 the environmental health and ecosystem vitality pillars could be tested for correlations because
331 the environmental health pillar consists exclusively of human health and welfare indicators,
332 while the ecosystem vitality pillar consists exclusively of indicators of ecosystem pressures,
333 states, and impacts. For the most recent versions of the EPI, human health and welfare
334 indicators are no longer the sole components of the environmental health pillar. Thus, a simple
335 correlation analysis for the pillars is not possible.

336 Finally, we compiled rank summaries for four countries to investigate rank patterns for low and
337 high income countries. Germany and New Zealand represent high income countries in the
338 Europe and Pacific regions, respectively. The countries of Mongolia and Niger represent low
339 income countries in Asia and Africa, respectively. The four countries face a range of different
340 environmental issues. Germany has a high emissions profile and faces issues with air and water
341 pollution as well as biodiversity loss (European Environment Agency, 2015; OECD, 2023).

342 Environmental issues in New Zealand include water pollution, soil degradation, biodiversity loss,
343 and a high emissions profile (OECD, 2017, New Zealand Ministry for Environment, 2022). In
344 Niger, environmental issues include land degradation and desertification, pressure on natural
345 resources from population growth, and pollution from mining (Larsen & Mamossa, 2013, The
346 World Bank, 2021). Environmental issues in Mongolia include habitat and biodiversity loss, and
347 pollution from mining (Rossabi, 2021).

348 ***3.2   Results***
349 If these distinct environmental indices assess similar measurable aspects of environmental
350 features of countries, moderate-to-high positive correlations are to be expected. However, we
351 found positive correlations between multidimensional indices, positive or no correlations
352 between environment-only indices, and negative or no correlations between multidimensional
353 and environment-only indices.

354 *Rank correlations for ten national level indices*

355 Correlations ranged from moderate negative to strong positive (Tables 3a and 3b). The highest
356 positive correlation was between the EPI and ESSI, which indicates that the increase in a
357 country's EPI rank was associated with an increase in ESSI rank. There were moderate positive
358 correlations between the EPI and LPI-NE, EPI and CIEP, CIEP and ESSI, CIEP and LPI-NE,
359 ESSI and LPI-NE, aENV and EFtot, pENV and EVI, EVI and EWI. There were also weak
360 positive correlations between the EFpc and EWI, EFtot and EWI, aENV and pENV, EWI and
361 pENV.

362 **Table 5a. Degree of Correlation.**

363 **Table 5b. Correlation Matrix for EPI (2020), ESSI (2018), CIEP (2015), LPI-NE (2021), EVI**
364 **(1999), EWI (2001), EFtot (2018), EFpp (2018), aENV (2010), pENV (2010).**

365 There was a moderate negative correlation between the EPI and EFpc. This negative
366 correlation indicates there was an inverse relationship between the two indices, i.e., the
367 increase in a country's rank in the EFpc was associated with a decrease in rank in the EPI (or
368 vice versa). There were also weak negative correlations between the EFpc and ESSI, Efpc and
369 CIEP, aENV and EPI, EWI and EPI, EFpc and LPI-NE, EWI and ESSI, EVI and ESSI, EWI and
370 CIEP, and EVI and EPI.

371 *Rank correlations for indices published in the same year*

372 There was a moderate negative correlation between the 2018 versions of the EFpc and the EPI
373 (Kendall τ = -0.483, P < 0.01). Ranks varied up to 92 places (normalized 0-100). There was no
374 correlation between country ranks for the 2018 versions of the EFtot and the EPI (Kendall τ = -
375 0.109, P < 0.05) and country ranks varied by up to 93 places (normalized 0-100)
376 (Supplementary File 1).

377 There was no correlation between country ranks for the 2010 versions of the aENV and EPI
378 (Kendall τ = -0.072, P < 0.05) and country ranks varied up to 86 places (normalized 0-100).
379 There was also no correlation between ranks for the 2010 versions of the pENV and EPI
380 (Kendall τ = -0.156, P < 0.01) and country ranks varied up to 99 places (normalized 0-100)
381 (Supplementary File 1).

382 *Rank correlations for pillars within EPI (2010)*

383 There was a weak negative correlation between the Ecosystem Vitality and Environmental
384 Health pillars of the 2010 version of the EPI (Kendall τ = -0.219, P < 0.01). This indicates that an
385 increase in a country's environmental health ranking was associated with a decrease in its
386 ecosystem vitality ranking (or vice versa) (Supplementary File 1).

387 *Summary of Rankings for Germany, New Zealand, Mongolia and Niger*

388 When normalized 0-100, Germany's rank varied by 79 places (Fig 2a), and New Zealand's rank
389 varied by 88.6 places (Fig 2b). Germany and New Zealand achieved the highest scores in
390 multidimensional indices, and the lowest scores in environment-only indices. Mongolia's rank
391 varied by up to 80.3 places (Fig 2a), while Niger's rank varied up to 94 places when normalized
392 0-100 (Fig 2b). Mongolia and Niger achieved the highest scores in environment-only indices,
393 and the lowest scores in multidimensional indices.

394 Of note, when considering weighting methods there was no clear pattern across the different
395 indices. For example, rankings for New Zealand and Niger were quite disparate in the ESSI and
396 pENV (20.9 and 90.4; 95.7 and 2.3 respectively), even though both indices use statistics-based
397 weighting procedures. However, when considering Germany, New Zealand, Mongolia, and
398 Niger's rankings across multidimensional and environment-only indices patterns emerge.
399 Mongolia and Niger scored well in environment-only indices, while New Zealand and Germany
400 scored well in multidimensional indices.

401 **Figure 2a: Relation between Germany and Mongolia's ranks, relationship break down by**
402 **category of environmental index.**

403 **Figure 2b: Relation between New Zealand and Niger's ranks, relationship break down by**
404 **category of environmental index.**

405 **4   Discussion**
406 Composite indices have been widely used to rank the environmental performance of nations.
407 Despite their benefits, environmental indices can have numerous drawbacks; poorly constructed
408 or communicated indices can undermine efforts to identify and address environmental failings
409 and misguide policy messages and decisions (Böhringer & Jochem, 2007; Bradshaw et al.,
410 2010; Haberland, 2008; Morse & Fraser, 2005). This review sought to answer three questions.
411 The first question asked: which conceptual framework(s) or indicators inform the development of
412 country rankings in environmental indices? We split environmental indices into two broad
413 categories according to their conceptual frameworks and the indicators included.
414 Multidimensional indices measure environmental performance in relation to human health and
415 welfare functions, and typically incorporate indicators such as human access to safe sanitation,
416 exposure to pollutants, and per capita income. Environment-only indices, on the other hand,
417 focus exclusively on functions of natural capital that represent pressures, states, or impacts and
418 explicitly exclude indicators related to human health and welfare. Both multidimensional and
419 environment-only indices use a range of weighting and aggregation methods.

420 Second, we sought to understand the impact of different conceptual frameworks (and indicators)
421 on global rankings. We examined rank correlation for ten national level environmental indices,
422 and where possible, we investigated rank correlations for indices published in the same year.

423   While previous research has demonstrated the sensitivity of rankings to different weighting
424   methods, in our analysis we did not observe any clear patterns across the indices. Our results
425   indicate the following patterns: (1) multidimensional indices (CIEP, EPI, ESSI, LPI-NE) were
426   positively correlated with one another, (2) environment-only indices (EFpc, EFtot, aENV, pENV,
427   EVI, EWI) were positively correlated with one another, or there is no correlation, and (3)
428   multidimensional indices were either negatively correlated with environment-only indices, or
429   there is no correlation. Researchers have used a range of weighting methods. The
430   multidimensional indices included in this study showed much stronger positive correlations with
431   each other, than do environment-only indices. This may be due to similarities in the indicators
432   and datasets used. The ESSI, for example, was developed to guide revisions of the EPI and
433   uses similar indicators but with a statistics-based weighting system to account for relationships
434   between them. However, the general pattern of correlations observed for multidimensional and
435   environment-only indices indicate that conceptual framework and indicator choice may influence
436   a country's rank among different indices.

437   As a complement to our analysis of rank variation for existing national-level indices, we
438   examined rank correlations within the EPI's pillars. The ecosystem vitality pillar includes
439   indicators that fall under the environmental pillar of sustainable development, whereas the
440   environmental health pillar includes indicators that fall under the social and economic pillars of
441   sustainability. The negative correlation between the environmental health and ecosystem vitality
442   pillars of the 2010 version indicates that an increase in a country's environmental health rank is
443   associated with a decrease in the ecosystem vitality ranking. Our findings support previous
444   research (Bradshaw et al. 2010) and demonstrates that environmental sustainability can be
445   distinguished from social and economic sustainability. This highlights how the inclusion of
446   human health and welfare indicators may influence a country's overall rank with the potential to
447   misrepresent the environmental sustainability of different countries. The environmental health
448   pillar of most recent version of the EPI includes indicators relating to waste management as well
449   as human health and welfare indicators. Thus, it is not straightforward to compare ranks for the
450   environmental health and ecosystem vitality pillars. While it is beyond the scope of this article to
451   disaggregate and re-weight the indicators and issue categories of the most recent version of the
452   EPI, this could be explored in future research.

453   One limitation in our correlation study is that the release dates for the indices range over several
454   years. Unfortunately, some indices only have one iteration, and it was therefore not possible to
455   conduct a year-on-year comparison for every index. While this is an important limitation,
456   analyses of indices such as the EPI have confirmed strong positive correlations between ranks
457   over multiple iterations (Supplementary File 2). This indicates that country ranks within the same
458   index do not vary markedly over time and provides some assurance in the results reported here.
459   In particular, the EPI (and other indices such as the LPI-NE) could be constructed without
460   indicators related to human health and welfare and ranks compared to those in existing
461   environment-only indices, such as the Ecological Footprint. As the EPI uses expert opinion-
462   based weighting, different weighting procedures (e.g., multivariate analysis) could also be
463   considered along with sensitivity analysis. Additionally, subsets of data for the same years could
464   be analysed for a more direct comparison.

465 Thirdly, we sought to understand the extent to which the different environmental indices capture
466 environmental indices in low and high income countries. We have used the examples of
467 Germany, New Zealand, Mongolia, and Niger to illustrate the complexities involved when
468 interpreting ranks among different indices. Low income countries, such as Mongolia and Niger,
469 often score poorly in multidimensional indices and well in environment-only indices. In Niger
470 42.9% of the population live in extreme poverty (The World Bank., 2021) and only 13% of the
471 population has access to basic sanitation services (UNICEF, 2020). In Mongolia, 28% of the
472 population lives in poverty (The World Bank, 2023) and only 27% of the population has access
473 to sanitation (UNICEF, 2017). Thus, the inclusion of indicators such as access to sanitation and
474 GDP in multidimensional indices complicates interpretation, and ultimately leads to a less
475 optimistic view of Mongolia and Niger's environments when compared to high income nations.
476 By contrast Germany and New Zealand both score well in multidimensional indices. Germany
477 and New Zealand are classified as a high income nations and this is reflected in indicators such
478 as access to clean drinking water and sanitation (UNDESA, 2021; World Bank, n.d.). The
479 inclusion of such indicators provides a more optimistic view of German and New Zealand's
480 environments when compared to lower income nations. Because interactions between
481 economic growth, improvements in human health and welfare, and environmental quality are
482 complex, it is important to treat multidimensional indices with caution – multidimensional indices
483 require more layers of interpretation than environment-only indices.

484 Research looking at rank differences between environmental indices and socio-economic has
485 largely focussed on relationships between the EPI and GDP per capita, human development
486 (Lai & Chen, 2020; Tektüfekçi & Kutay, 2016; Wolf et al. 2022; Wurie & Pillai, 2014). While the
487 scope of this article was concentrated on examining correlations in environmental indices, the
488 dataset collated for the present research could be utilised to extend research into correlations
489 between multidimensional and environment-only indices and other composite indices or
490 indicators of human health and welfare such as GDP. These may include sustainability and
491 climate indices such as the HDI, Global Sustainability Index (GSI), Sustainable Development
492 Index (SDI), and Global Social Mobility Index.

493 Our paper provides insight into the benefits and challenges of constructing environmental
494 indices, which can help inform the future design of (improved) indices. It is important to assess
495 whether the conceptual framework and indicators included are appropriate. If an index is
496 intended to measure the qualities or functions of natural capital linked to environmental as well
497 as human health and welfare or policy processes, then it may be appropriate to include
498 indicators such as access to sanitation, indoor air pollution, and per capita income. If the index
499 is intended to measure the environment-only, then functions linked to human health and
500 welfare, or policy should be excluded. If such indicators are included, the actual state of natural
501 environments may not be accurately represented.

502 In this article we have: (1) examined existing environmental indices and quantified rank
503 variations, (2) identified patterns across multidimensional and environment-only indices, and (3)
504 examined how conceptual frameworks and methodological choices influence global rankings.
505 Our findings highlight wide variations in country ranks among existing environmental indices.
506 Specifically, our results suggest that conceptual framework and indicator choice can affect
507 ranking and produce a more, or less, optimistic view of a country's environment. While

508 weighting procedures and sensitivity analysis may have some impact on overall ranking, it is
509 likely that conceptual framework and indicator choice have a larger effect.

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820

Figure 1

Diagram depicting the three dimensions of sustainability, adapted from Purvis et al. (2018).

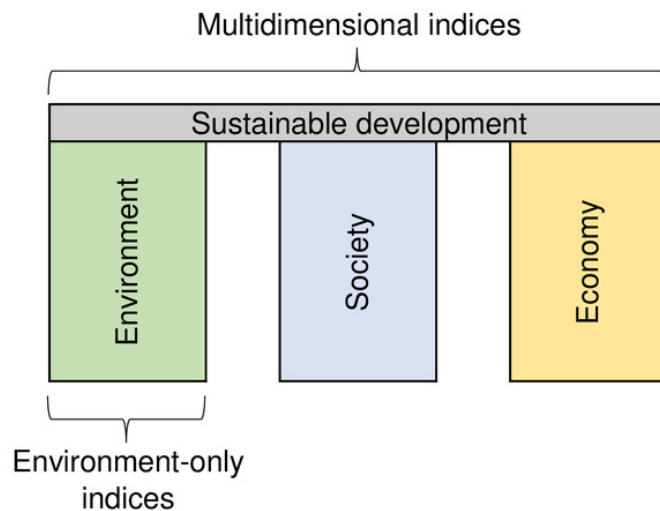
Note. Multidimensional indices include indicators that fall under the environment, society, and economy pillars. Environment-only indices include indicators that fall under the environment pillar.

Note. Multidimensional indices include indicators that fall under the environment, society, and economy pillars. Environment-only indices include indicators that fall under the environment pillar.

Figure 2

Relation between: (a) ranks for New Zealand and Niger, (b) ranks for Germany and Mongolia (relationship break down by category of environmental index).

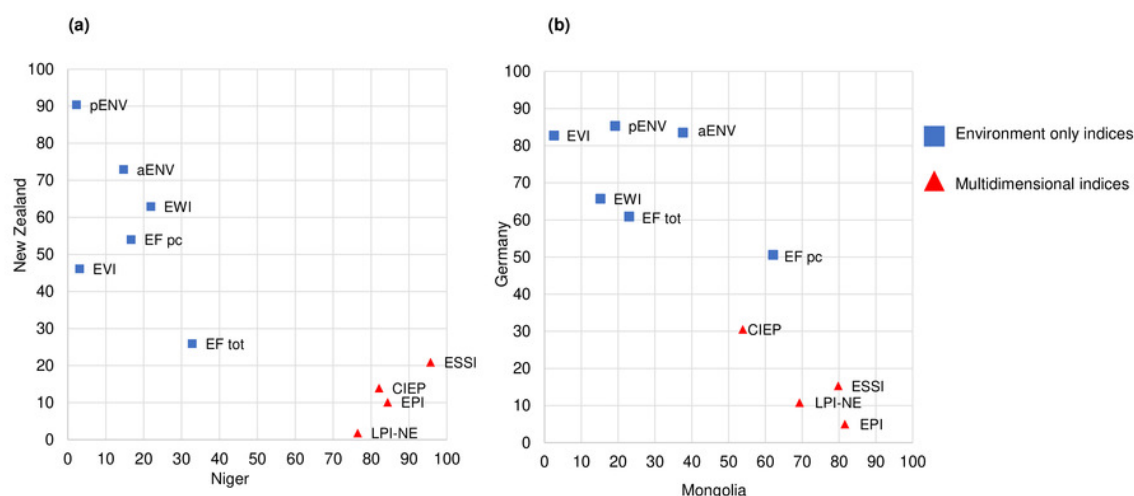
Note. Abbreviations: Composite Index of Environmental Performance (CIEP); Ecosystem Wellbeing Index (EWI); Ecological Footprint tot al (EF tot); Ecological Footprint per capita (EF pc); Environmental Performance Index (EPI); Environmental State & Sustainability and Index (ESSI); E nvi ronmental Vulnerability Index (EVI); Legatum Prosperity Index Natural Environment Pillar (LPI NE).

Note. Abbreviations: Composite Index of Environmental Performance (CIEP); Ecosystem Wellbeing Index (EWI); Ecological Footprint total (EF tot); Ecological Footprint per capita (EF pc); Environmental Performance Index (EPI); Environmental State & Sustainability and Index (ESSI); Environmental Vulnerability Index (EVI); Legatum Prosperity Index - Natural Environment Pillar (LPI-NE).

Table 1. Definitions of Environmental Sustainability, adapted from Usubiaga-Liaño & Ekins (2021) .

1 **Table 1. Definitions of Environmental Sustainability, adapted from Usubiaga-**
2 **Liaño & Ekins (2021).**

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

Table 2. Standard principles for constructing composite indices, adapted from Dobbie and Dail (2012) and Nardo et al. (2005)

1 **Table 2. Standard principles for constructing composite indices, adapted from Dobbie**
2 **and Dail (2012) and Nardo et al. (2005)**

Step & reasoning
1. *Establishment of a conceptual framework*
• Provides criteria for the selection and combination of indicators under a fitness-for-purpose principle.
2. *Data selection*
• Based on analytical soundness, measurability, regional coverage, and relevance of the indicators to the phenomenon being measured and their relationship to each other.
• Quality of indicators should be checked.
3. *Imputation of missing data*
• Required to provide a complete data set (e.g., by means of single or multiple imputations).
• Missing variables may be estimated.
4. *Multivariate analysis*
• Used to study the overall structure of the dataset, assess the suitability, and guide subsequent methodological choices (e.g., weighting and aggregation).
5. *Normalisation*
• Carried out to render the variables comparable.
6. *Weighting and Aggregation*
• Performed to select appropriate weighting and aggregation procedures.
• Compensability among indicators should be allowed.
7. *Uncertainty and sensitivity analysis*
• A multi-modeling approach may be used to build the index, and alternative conceptual scenarios for the selection of underlying indicators considered.
8. *Return to the data*
• Required to reveal the main drivers for an overall good or bad performance.
• Transparency for good analysis and policymaking.
9. *Links to other indicators*
• To correlate the composite indicator (or its dimensions) with existing (simple or composite) indicators as well as to identify linkages through regressions
10. *Visualization of results*
• Visualization can influence or help to enhance interpretability.

Table 3. Summary of four multidimensional indices, including conceptual framework, weighting and aggregation choices, strengths and weaknesses.

Note. Accounting based = A, Equal weighting = E, Expert opinion-based = Ex, Statistics based = S Abbreviations: Composite Index of Environmental Performance (CIEP); Environmental Performance Index (EPI); Environmental State & Sustainability and Index (ESSI); Legatum Prosperity Index Natural Environment Pillar (LPI-NE).

1 **Table 3. Summary of four multidimensional indices, including conceptual framework, weighting and aggregation choices,**
2 **strengths and weaknesses.**

Index	Countries	Indicators	Weighting and aggregation choices	Conceptual Framework	First published in
EPI	180	32	Ex	Environmental performance – proximity to established international environmental policy goals and targets	Esty et al. 2006
ESSI	163	22	S	Environmental state and sustainability	Oţoiu & Grădinaru, 2018
CEP	152	19	S	Assessment of environmental performance in relation to human health	Almeida, 2015
LPI-NE	167		Ex & S	Evaluation of physical environment in relation to human prosperity	Legatum Institute, 2017

Summary of indices

EPI

- The EPI was preceded by the Environmental Sustainability Index (ESI) which was first published in 2000. The EPI has been published from 2006 onwards and aims to have a narrower scope than its predecessor, focusing on key environmental policy outcomes. Despite the change in name and focus, the difference between the ESI and EPI is questionable. We performed a Kendall's τ investigation of rank correlations across the different versions of the ESI and EPI and results indicate that ranks for the countries have remained similar over time (Supplementary File 2).
- Issue categories are organized under three broad policy objectives (or pillars): climate change, ecosystem vitality, and environmental health.
- The environmental health objective considered a misnomer by some because it deals with human health as it is affected by the environment (Hermele, 2009). Together, all human health indicators receive 18% of total weight (Wolf et al. 2022). Thus, high income countries that fare well on human health indicators, such as clean drinking water, will score more highly than low income countries.
- The EPI developing team have highlighted problems with data gaps and the need for better data collection, reporting and verification (Wendling et al. 2018, Wendling et al. 2020).
- The choice of variables has been criticized because variables do not adequately capture specific dimensions of typical environmental problems in high income countries (e.g., water pollution from agriculture and soil management (Atici, 2009; Haberland, 2008)).
- A Joint Research Commission (JCR) analysis of the 2014 EPI found that changes in the policy objectives' weights and aggregation function led to significant variation for several countries. JCR reviews suggest that the EPI should move from expert-based weighting and aggregation methods to include multivariate analysis, uncertainty and sensitivity analysis.

ESSI

- Designed to build upon and guide future versions of the EPI.
- Includes human health indicators, such as life expectancy at birth, that do not reflect the aim of measuring the state of the environment.
- In contrast to the EPI, the ESSI uses factor analysis rather than expert opinion and judgement for indicator weighting.
- Country ranks generally comparable with the EPI, however, there are large differences for several countries.

CIEP

- Uses the Driving-Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework and aims to link health, environmental, and economic development issues.
- As the CIEP is designed to link environmental problems with human health, indicators such as access to drinking water, sanitation, child mortality, and per capita income are included.
- Constructed using statistical techniques: data is transformed using Yeo-Johnson transformation, weighting and aggregation are performed according to CRITITC (Criteria Importance Through Intercriteria Correlation), and aggregation is linear in two steps.
- The theoretical framework and statistical methods are clear and transparent. However, the name of the index is inconsistent with the constructors' goal of linking environmental problems with human health.
- The CIEP may be useful for decision makers seeking to reduce the impacts of environmental problems on human health, however, it is less useful as an indicator of the quality of natural systems.

LPI-NE

- The LPI-NE is part of the wider Legatum Prosperity Index that uses 12 pillars of prosperity (safety and security, personal freedom, governance, social capital, investment environment, enterprise conditions, market access and infrastructure, economic quality, living conditions, health, education, and natural environment).
- Includes 6 elements: preservation efforts, oceans, forest, soil, exposure to air pollution, and emissions.
- Human health measures (e.g., exposure to fine particulate matter) are included in the LPI-NE; this does not fit with the aim of evaluating aspects of the physical environment, and these indicators might be better placed under the health pillar of the wider LPI.
- Uses population-weighted scores to capture effects on individuals rather than countries. Weights are determined by two factors: (1) the relevance and significance of the indicator to prosperity (informed by academic literature and expert opinion), and (2) the statistical significance of the indicator to economic and social wellbeing of a country.

3   *Note.* Accounting based = A, Equal weighting = E, Expert opinion-based = Ex, Statistics based = S

4   Abbreviations: Composite Index of Environmental Performance (CIEP); Environmental Performance Index (EPI); Environmental
5   State & Sustainability and Index (ESSI); Legatum Prosperity Index Natural Environment Pillar (LPI-NE).

Table 4. Summary information for six environment-only indices including conceptual frameworks, weighting and aggregation choices, strengths and weaknesses.

Note. Accounting based = A, Equal weighting = E, Expert opinion-based = Ex, Statistics based = S Abbreviations: Ecosystem Wellbeing Index (EWI); Ecological Footprint total (EF tot); Ecological Footprint per capita (EF pc); Environmental Vulnerability Index (EVI).

1 **Table 4. Summary information for six environment-only indices including conceptual frameworks, weighting and**
2 **aggregation choices, strengths and weaknesses.**

Index	Countries	Indicators	Weighting and aggregation choices	Conceptual Framework	First published in
EVI	192	50	E	Environmental vulnerability	Kaly et al. 1999
EWI	180	52	E	Environmental quality – proximity to goal (low level of ecosystem stress)	Prescott-Allen, 2001
EF tot	178	16	A	Ecological deficit/ecological reserves (total)	Rees, 1992
Ef pc				Ecological deficit/ecological reserves (per capital)	
aENV	178	12	S	Environmental impact – performance with respect to absolute (total) global impact	Bradshaw et al. 2010
pENV				Environmental impact – performance with respect to total resources available per country	

Summary of indices

EVI

- Intended to be used alongside separate economic and social vulnerability indices and designed to provide insight into the processes that can negatively influence sustainable development.
- Considers both natural and human induced changes (e.g., habitat fragmentation, overfishing, earthquakes).
- Human health and socioeconomic indicators are explicitly excluded from the EVI. Using independent environmental, economic, and social vulnerability indices allows relationships between the three pillars of sustainability to be identified.
- Could be improved upon if statistical measures were used for weighting and aggregation rather than simply using unweighted averages.

EWI

- Measures progress towards the goal of a high level of ecosystem wellbeing and was developed to be used alongside the Human Wellbeing Index (HWI). The EWI and HWI are used to compare human conditions with the state of the environment.
- Explicitly excludes human health indicators and indicators of environmental policies and practices. This allows trade-offs between the different pillars of sustainability to be identified.
- Uses unweighted averages to build separate indices for land, water, air, species and genes, and resource use. The separate indices are then aggregated to form the EWI.
- The inclusion of statistical methods would improve the reliability of the EWI, rather than reliance on unweighted averages.

EF tot and EF pc

- EF accounting focusses on the supply and demand of nature. On the supply side, biological capacity is the ability of an ecosystem to produce useful biological materials and absorb CO_2. On the demand side, the EF measures the ecological assets a population requires to produce the resources it consumes and to absorb its waste.
- Designed to raise awareness about the impact of humans on natural systems, with the aim to guide sustainability policy.
- The Global Footprint Network have openly recognized limitations to the EF. The EF is not a full metric of environmental sustainability because some key environmental impacts are not captured. For example, the EF uses the size of fishing grounds, but does not take into account the quality of these resources (a polluted fishing ground will be less productive than a health well-managed fishing ground).
- The EF overestimates biocapacity because it does not distinguish between sustainable and unsustainable land use.
- The EF has been criticized because of its fixed weighting scheme where some categories receive identical weights. When identical weights are assigned the potential interlinkages of the various components are ignored. Ideally, multivariate analysis should be used to explore the nature of datasets and assess the contribution of the different variables.

- Despite its limitations, footprint accounting can be a powerful tool to visualize human exploitation of resources in a single dimension (the land and water area required to support human use). For example, one international study (covering Australia, Canada, United States, United Kingdom, Mexico, France, Italy, Germany, Brazil, and the Netherlands) surveyed individual users on their experience and perceptions of the EF calculator. 91% of the 4245 participants considered the EF to be a valuable tool for knowledge generation, and 78% found it useful to motivate actions (Collins et al. 2020). This indicates that the EF has been useful in terms of raising awareness about the impacts of humans on natural systems.

aENV and pENV

- Environmental impact variables include natural forest loss, habitat conversion, marine captures, fertilizer use, water pollution, carbon emissions, and biodiversity threat.
- The constructors acknowledge that they could not include all major indicators of environmental degradation (e.g., bush meat harvest, coral reef habitat quality, freshwater degradation) because data was not available at the global scale.
- The conceptual framework clearly states what the index is measuring (environmental impact) and explicitly excludes confounding human health and socioeconomic factors to provide the most accurate assessment of impact for natural environments.
- The ENV uses multivariate statistical analysis to account for interlinkages of the various components and to determine component weights.

- Of the two versions, the aENV is considered a better reflection of a country's contribution to the global environmental state.

3   *Note.* Accounting based = A, Equal weighting = E, Expert opinion-based = Ex, Statistics based = S

4   Abbreviations: Ecosystem Wellbeing Index (EWI); Ecological Footprint total (EF tot); Ecological Footprint per capita (EF pc);

5   Environmental Vulnerability Index (EVI).

Table 5a. Degree of Correlation. Table 5b. Correlation Matrix for EPI (2020), ESSI (2018), CIEP (2015), LPI-NE (2021), EVI (1999), EWI (2001), EF tot (2018), EF pp (2018), aENV (2010), pENV (2010).

Note. *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). Abbreviations: Composite Index of Environmental Performance (CIEP); Ecosystem Wellbeing Index (EWI); Ecological Footprint total (EF tot); Ecological Footprint per capita (EF pc); Environmental Performance Index (EPI); Environmental State & Sustainability and Index (ESSI); Environmental Vulnerability Index (EVI); Legatum Prosperity Index - Natural Environment Pillar (LPI-NE).

Table 5a. Degree of Correlation.

moderate negative	weak negative	very weak negative	very weak positive	weak positive	moderate positive	strong positive
-0.59 to -0.40	-0.39 to -0.20	-0.19 to -0.01	0.00 to 0.19	0.20 to 0.39	0.40 to 0.59	0.60 to 0.79

2   **Table 5b. Correlation Matrix for EPI (2020), ESSI (2018), CIEP (2015), LPI-NE (2021), EVI (1999), EWI (2001), EF tot (2018), EF**
3   **pp (2018), aENV (2010), pENV (2010).**

	EPI	ESSI	CIEP	LPI-NE	EVI	EWI	EF tot	EF pc	aENV
ESSI	0.683**								
CIEP	0.573**	0.574**							
LPI-NE	0.491**	0.451**	0.448**						
EVI	-0.259*	-0.262**	-0.121	-0.058					
EWI	-0.399**	-0.355**	-0.260**	-0.095	0.403**				
EF tot	-0.113*	-0.112	0.037	-0.034	0.190**	0.256**			
EF pp	-0.444**	-0.343**	-0.377**	-0.276**	0.163*	0.346**	0.197**		
aENV	-0.037	-0.067	0.110	-0.089	0.079	0.171**	0.427**	-0.011	
pENV	-0.085	-0.136*	-0.034	-0.050	0.438**	0.262**	0.165**	-0.006	0.274**

Multidimensional indices (ESSI, CIEP, LPI-NE); *Environment-only indices* (EVI, EWI, EF tot, EF pp, aENV, pENV)

Multidimensional indices (EPI, ESSI, CIEP, LPI-NE)   Environment-only indices (EVI, EWI, EF tot, EF pc, aENV)

5   Note. *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

6   Abbreviations: Composite Index of Environmental Performance (CIEP); Ecosystem Wellbeing Index (EWI); Ecological Footprint total
7   (EF tot); Ecological Footprint per capita (EF pc); Environmental Performance Index (EPI); Environmental State & Sustainability and
8   Index (ESSI); Environmental Vulnerability Index (EVI); Legatum Prosperity Index - Natural Environment Pillar (LPI-NE).