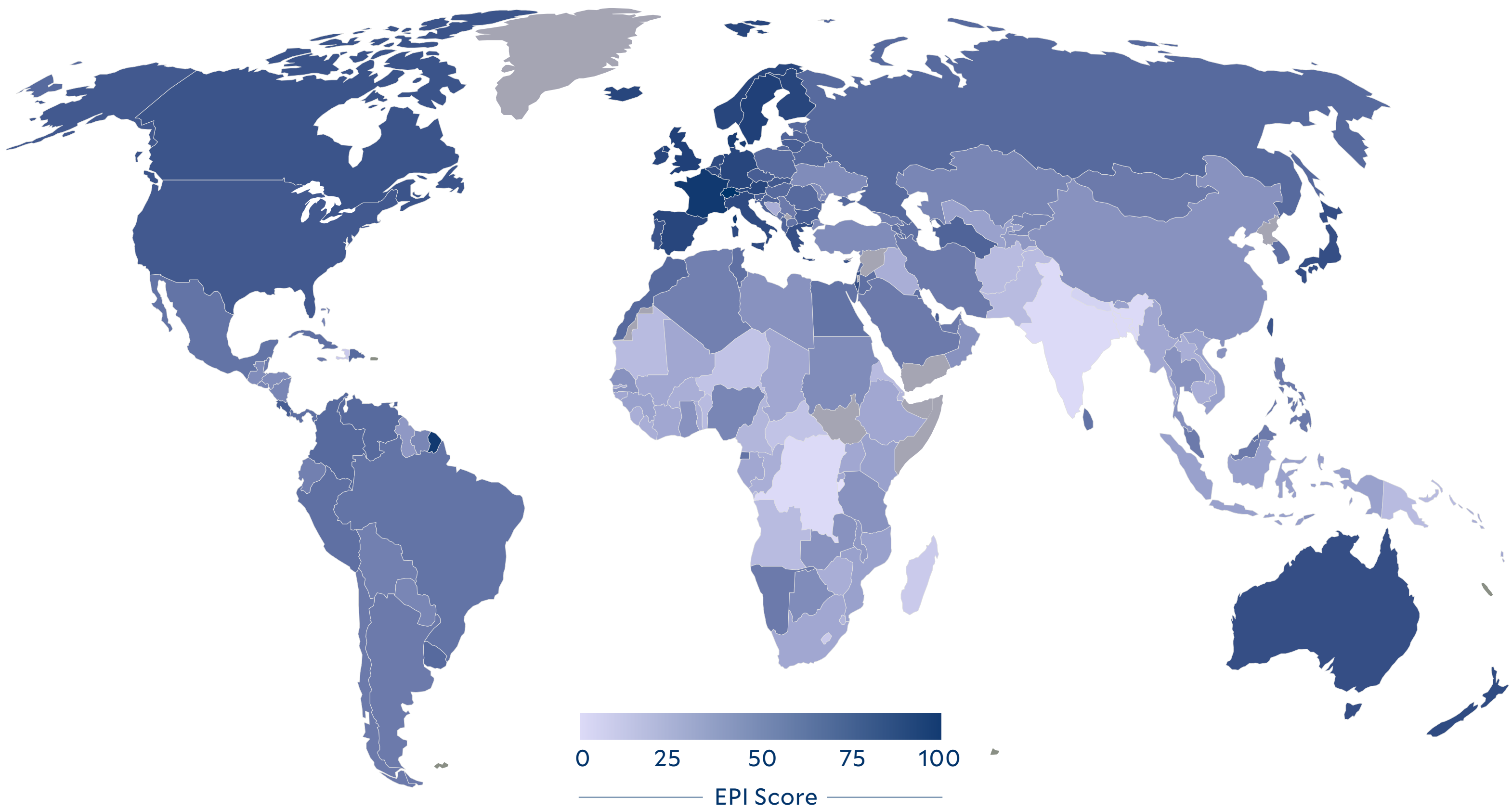
2018 ENVIRONMENTAL PERFORMANCE INDEX

GLOBAL METRICS FOR THE ENVIRONMENT:
RANKING COUNTRY PERFORMANCE
ON HIGH-PRIORITY ENVIRONMENTAL ISSUES



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Environmental Performance Index

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2018 ENVIRONMENTAL PERFORMANCE INDEX

Careful measurement of environmental trends and progress provides a foundation for effective policymaking. The 2018 Environmental Performance Index (EPI) ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. These metrics provide a gauge at a national scale of how close countries are to established environmental policy goals. The EPI thus offers a scorecard that highlights leaders and laggards in environmental performance, gives insight on best practices, and provides guidance for countries that aspire to be leaders in sustainability.

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EXECUTIVE SUMMARY

Careful measurement of environmental trends and progress provides a foundation for effective policymaking. The 2018 Environmental Performance Index (EPI) ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. These metrics provide a gauge on a national scale of how close countries are to meeting established environmental policy goals. The EPI thus offers a scorecard that highlights leaders and laggards in environmental performance, gives insight on best practices, and provides guidance for countries that aspire to be leaders in sustainability.

Innovations in the 2018 EPI data and methodology have generated new rankings founded on the latest advances in environmental science and analysis. Results are shown in Figure ES-1. Switzerland leads the world based on strong performance across most issues, especially air quality and climate protection. In general, high scorers exhibit longstanding commitments to protecting public health, preserving natural resources, and decoupling greenhouse gas (GHG) emissions from economic activity.

India and Bangladesh come in near the bottom of the rankings. Low scores on the EPI suggest the need for national sustainability efforts on a number of fronts, especially cleaning up air quality, protecting biodiversity, and reducing GHG emissions. Some of the laggards face broader challenges, such as civil unrest, but the low scores for others can be attributed to weak governance. The EPI draws attention to the issues on which policymakers must take further action.

While the EPI provides a framework for greater analytic rigor in environmental policymaking, it also reveals a number of severe data gaps. As the EPI project has highlighted for two decades, better data collection, reporting, and verification across a range of environmental issues are urgently needed. The existing gaps are especially pronounced in the areas of sustainable agriculture, water resources, waste management, and threats to biodiversity. Supporting stronger global data systems thus emerges as essential to better management of sustainable development challenges.

LOGIC OF ENVIRONMENTAL METRICS

The world has entered a new era of data-driven environmental policymaking. With the UN's 2015 Sustainable Development Goals, governments are increasingly being asked to explain their performance on a range of pollution control and natural resource management challenges with reference to quantitative metrics. A more data-driven and empirical approach to environmental protection promises to make it easier to spot problems, track trends, highlight policy successes and failures, identify best practices, and optimize the gains from investments in environmental protection.

The overall EPI rankings indicate which countries are doing best against the array of environmental pressures that every nation faces. From a policy perspective, greater value derives from drilling down into the data to analyze performance by specific issue, policy category, peer group, and country. Such an analysis can assist in refining policy choices, understanding the determinants of environmental progress, and maximizing the return on governmental investments.

KEY FINDINGS

- Air quality remains the leading environmental threat to public health. In 2016 the Institute for Health Metrics and Evaluation estimated that diseases related to airborne pollutants contributed to two-thirds of all life-years lost to environmentally related deaths and disabilities. Air pollution issues are especially acute in rapidly urbanizing and industrializing nations such as India and China.

- The world has made great stride in protecting marine and terrestrial biomes, exceeding the international goal for marine protection in 2014. Additional indicators measuring terrestrial protected areas suggest, however, that more work needs to be done to ensure the presence of high-quality habitats free from human pressures.

- Most countries improved their GHG emission intensity over the past ten years, reducing their emissions per unit of output. Three-fifths of countries in the EPI have declining CO_2 intensities, while 85–90% of countries have declining intensities for methane, nitrous oxide, and black carbon. These trends are promising yet must be accelerated to meet the ambitious targets of the 2015 Paris Climate Agreement.

- With 20 years of experience, the EPI reveals a tension between two fundamental dimensions of sustainable development: (1) environmental health, which improves with economic growth and prosperity, and (2) ecosystem vitality, which comes under strain from industrialization and expanded economic activity. Good governance emerges as the critical means of balancing these distinct dimensions of sustainability.

FIGURE ES-1 THE 2018 EPI RANKINGS Rank, EPI Score, and Regional Standing (REG, shown in color) for 180 countries

RANK	COUNTRY	SCORE	REG
1	Switzerland	87.42	1
2	France	83.95	2
3	Denmark	81.60	3
4	Malta	80.90	4
5	Sweden	80.51	5
6	United Kingdom	79.89	6
7	Luxembourg	79.12	7
8	Austria	78.97	8
9	Ireland	78.77	9
10	Finland	78.64	10
11	Iceland	78.57	11
12	Spain	78.39	12
13	Germany	78.37	13
14	Norway	77.49	14
15	Belgium	77.38	15
16	Italy	76.96	16
17	New Zealand	75.96	1
18	Netherlands	75.46	17
19	Israel	75.01	1
20	Japan	74.69	1
21	Australia	74.12	2
22	Greece	73.60	18
23	Taiwan	72.84	2
24	Cyprus	72.60	19
25	Canada	72.18	20
26	Portugal	71.91	21
27	United States of America	71.19	22
28	Slovakia	70.60	1
29	Lithuania	69.33	2
30	Bulgaria	67.85	3
30	Costa Rica	67.85	1
32	Qatar	67.80	2
33	Czech Republic	67.68	4
34	Slovenia	67.57	5
35	Trinidad and Tobago	67.36	1
36	St. Vincent & Grenadines	66.48	2
37	Latvia	66.12	6
38	Turkmenistan	66.10	7
39	Seychelles	66.02	1
40	Albania	65.46	8
41	Croatia	65.45	9
42	Colombia	65.22	2
43	Hungary	65.01	10
44	Belarus	64.98	11
45	Romania	64.78	12
46	Dominican Republic	64.71	3
47	Uruguay	64.65	3
48	Estonia	64.31	13
49	Singapore	64.23	3
50	Poland	64.11	14
51	Venezuela	63.89	4
52	Russia	63.79	15
53	Brunei Darussalam	63.57	4
54	Morocco	63.47	3
55	Cuba	63.42	4
56	Panama	62.71	5
57	Tonga	62.49	3
58	Tunisia	62.35	4
59	Azerbaijan	62.33	16
60	South Korea	62.30	5
61	Kuwait	62.28	5
62	Jordan	62.20	6
63	Armenia	62.07	17
64	Peru	61.92	6
65	Montenegro	61.33	18
66	Egypt	61.21	7
67	Lebanon	61.08	8
68	Macedonia	61.06	19
69	Brazil	60.70	7
70	Sri Lanka	60.61	6
71	Equatorial Guinea	60.40	2
72	Mexico	59.69	8
73	Dominica	59.38	5
74	Argentina	59.30	9
75	Malaysia	59.22	7
76	Antigua and Barbuda	59.18	6
77	United Arab Emirates	58.90	9
78	Jamaica	58.58	7
79	Namibia	58.46	3
80	Iran	58.16	10
81	Belize	57.79	10
82	Philippines	57.65	8
83	Mongolia	57.51	9
84	Serbia	57.49	20
84	Chile	57.49	11
86	Saudi Arabia	57.47	11
87	Ecuador	57.42	12
88	Algeria	57.18	12
89	Cabo Verde	56.94	4
90	Mauritius	56.63	5
91	Saint Lucia	56.18	8
92	Bolivia	55.98	13
93	Barbados	55.76	9
94	Georgia	55.69	21
95	Kiribati	55.26	4
96	Bahrain	55.15	13
97	Nicaragua	55.04	14
98	Bahamas	54.99	10
99	Kyrgyzstan	54.86	22
100	Nigeria	54.76	6
101	Kazakhstan	54.56	23
102	Samoa	54.50	5
103	Suriname	54.20	15
104	São Tomé and Príncipe	54.01	7
105	Paraguay	53.93	16
106	El Salvador	53.91	17
107	Fiji	53.09	6
108	Turkey	52.96	24
109	Ukraine	52.87	25
110	Guatemala	52.33	18
111	Maldives	52.14	10
112	Moldova	51.97	26
113	Botswana	51.70	8
114	Honduras	51.51	19
115	Sudan	51.49	14
116	Oman	51.32	15
117	Zambia	50.97	9
118	Grenada	50.93	11
119	Tanzania	50.83	10
120	China	50.74	11
121	Thailand	49.88	12
122	Micronesia	49.80	13
123	Libya	49.79	16
124	Ghana	49.66	11
125	Timor-Leste	49.54	14
126	Senegal	49.52	12
127	Malawi	49.21	13
128	Guyana	47.93	20
129	Tajikistan	47.85	27
130	Kenya	47.25	14
131	Bhutan	47.22	15
132	Viet Nam	46.96	16
133	Indonesia	46.92	17
134	Guinea	46.62	15
135	Mozambique	46.37	16
136	Uzbekistan	45.88	28
137	Chad	45.34	17
138	Myanmar	45.32	18
139	Côte d'Ivoire	45.25	18
140	Gabon	45.05	19
141	Ethiopia	44.78	20
142	South Africa	44.73	21
143	Guinea-Bissau	44.67	22
144	Vanuatu	44.55	7
145	Uganda	44.28	23
146	Comoros	44.24	24
147	Mali	43.71	25
148	Rwanda	43.68	26
149	Zimbabwe	43.41	27
150	Cambodia	43.23	19
151	Solomon Islands	43.22	8
152	Iraq	43.20	17
153	Laos	42.94	20
154	Burkina Faso	42.83	28
155	Sierra Leone	42.54	29
156	Gambia	42.42	30
157	Republic of Congo	42.39	31
158	Bosnia and Herzegovina	41.84	29
159	Togo	41.78	32
160	Liberia	41.62	33
161	Cameroon	40.81	34
162	Swaziland	40.32	35
163	Djibouti	40.04	36
164	Papua New Guinea	39.35	21
165	Eritrea	39.34	37
166	Mauritania	39.24	38
167	Benin	38.17	39
168	Afghanistan	37.74	22
169	Pakistan	37.50	23
170	Angola	37.44	40
171	Central African Republic	36.42	41
172	Niger	35.74	42
173	Lesotho	33.78	43
174	Haiti	33.74	12
175	Madagascar	33.73	44
176	Nepal	31.44	24
177	India	30.57	25
178	Dem. Rep. Congo	30.41	45
179	Bangladesh	29.56	26
180	Burundi	27.43	46

ASIA · CARIBBEAN · EASTERN EUROPE & EURASIA · EUROPE & NORTH AMERICA · LATIN AMERICA · MIDEAST & NORTH AFRICA · PACIFIC · SUB-SAHARAN AFRICA

1

INTRODUCTION

THE LOGIC OF ENVIRONMENTAL METRICS

Sustainable development has entered a new era of data-driven environmental policymaking. To meet the ambitious targets outlined in the United Nations 2015 Sustainable Development Goals (SDGs) and the Paris Climate Agreement, countries must integrate environmental performance metrics across a range of pollution control and natural resources policies. Data provide additional tools and abilities to policymakers, enabling success by gauging progress or backsliding, identifying best practices, and revealing insights into sustainability challenges that would otherwise remain hidden.

The 2018 Environmental Performance Index (EPI) scores 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. These metrics provide a gauge at a national scale of how close countries are to established environmental policy goals. Now in its 11th iteration, policymakers, scholars, non-governmental organizations, and the media have relied upon the biennial release of the EPI for policy insights and tracking of trends in sustainability. The EPI turns the latest advances in environmental science with worldwide datasets to form into a powerful summary of the state of sustainability around the world.

Data must be carefully organized and communicated to have a meaningful impact on the policy process. Debates about environmental challenges are often hampered by lack of problem definition, uncertainty about the nature of these challenges, and ill-defined solutions. Gathering data into the EPI helps to resolve these difficulties. The EPI serves as a communication tool for translating complex ideas into simpler, more useful forms. The single, 0–100 score for each country serves as a starting point for deeper discussions. We invite government officials, non-governmental organizations, and citizens all over the world to analyze the sub-scores of the EPI to discern which issues are holding back sustainability. Country scores on the EPI are translated into rankings. The EPI rankings are intended to inspire countries to engage in healthy competition, vying to rise to the top of their peer groups. Backcasting EPI scores from historic data allows countries to track their progress over time. In these ways, the EPI offers several insights that are useful for identifying best practices, informing policy agendas, and setting priorities in environmental governance.

THE 2018 ENVIRONMENTAL PERFORMANCE INDEX

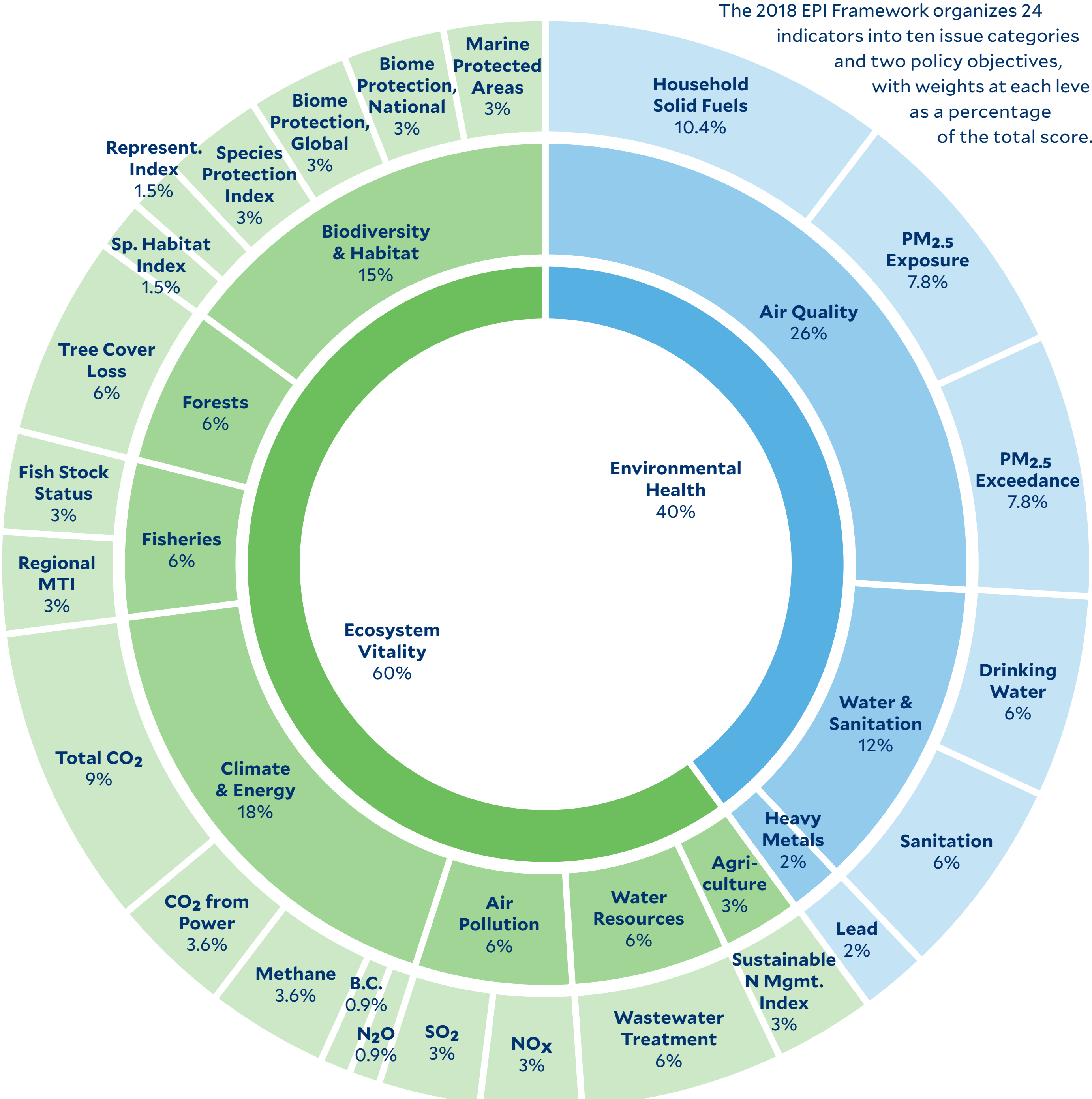
The 2018 EPI represents a composite index. We begin by gathering data on 24 individual metrics of environmental performance, as shown in Figure 1-1. These metrics are aggregated into a hierarchy beginning with ten issue categories: Air Quality, Water & Sanitation, Heavy Metals, Biodiversity & Habitat, Forests, Fisheries, Climate & Energy, Air Pollution, Water Resources, and Agriculture. These issue categories are then combined into two policy objectives—Environmental Health and Ecosystem Vitality—and then finally consolidated into the overall EPI. To allow for meaningful comparisons, we construct scores for each of the 24 indicators, placing them onto a common scale where 0 indicates worst performance and 100 indicates best performance. How far a country is from achieving international targets of sustainability determines its placement on this scale. The indicator scores are then multiplied by weights, shown in Figure 1-1, and added together to produce scores at the levels of the issue categories, policy objectives, and the final EPI. These scores serve as the basis for country ranks. Indicators are constructed from the most recently available data for each of the 24 metrics of environmental performance. To track changes over time, we also apply the same methods to historic data in order to show what the EPI score for each country would be in a baseline year, generally ten years prior to the current report. We take the performance of every country and aggregate those data into measurements of global performance. We score these global aggregates on the same 0–100 scale as individual countries, showing the state of the world on each indicator. The results of the 2018 EPI—the scores, rankings, trends, and global aggregates—translate environmental data into terms that are comprehensive and comprehendible.

REPORT ORGANIZATION

This report provides comprehensive coverage of the 2018 Environmental Performance Index. It proceeds in several sections. Chapter 2 discusses the methodology of the 2018 EPI. Chapter 3 summarizes the results, highlighting key findings of the EPI, global performance, country performance, and trends among peer groups. Chapter 4 is a retrospective on the 20-year history of the EPI, offering lessons learned from producing a composite index of environmental performance and noting our impact. Chapters 5–14 give background information on each of the issue categories in greater detail, explanations of the indicators, and discussions of the results. Further details about the 2018 EPI are available on our website, epi.yale.edu, including data downloads, country profiles, and the Technical Appendix.

FIGURE 1-1 THE 2018 EPI FRAMEWORK

The 2018 EPI Framework organizes 24 indicators into ten issue categories and two policy objectives, with weights at each level as a percentage of the total score.



2

METHODOLOGY

Environmental Performance Index

METHODOLOGY

This chapter briefly describes the methodology for the 2018 Environmental Performance Index. For a more general and authoritative explanation of composite indexing, we refer the reader to the Organization for Economic Co-operation and Development (OECD) handbook on the subject (Nardo et al., 2008). Hsu et al. (2013) explain the general process of constructing the EPI. Further details about the data and calculations are in the online Technical Appendix.

INDICATOR FRAMEWORK

Measuring a complex construct like environmental performance requires an organizing structure for the component metrics. The EPI uses a hierarchical framework that groups indicators within issue categories, issue categories within policy objectives, and policy objectives within the overall index; see Figure 2-1. The EPI has long been based on two policy objectives: Environmental Health, which measures threats to human health, and Ecosystem Vitality, which measures natural resources and ecosystem services. These objectives reflect the dominant policy domains within which policymakers and their constituents generally deal with environmental problems. Many governments have departments or ministries devoted to public health and natural resources whose portfolios correspond to the EPI policy objectives.

Likewise, the issue categories are organized along the lines most familiar to stakeholders within environmental policy. In the 2018 EPI, 24 indicators are grouped within ten issue categories:

- Air Quality
- Water & Sanitation
- Heavy Metals
- Biodiversity & Habitat
- Forests
- Fisheries
- Climate & Energy
- Air Pollution
- Water Resources
- Agriculture

A country's EPI score can be disaggregated to levels of the policy objectives or the issue categories, allowing performance to be tracked at different levels; see Figure 2-1.

DATA SELECTION

Every version of the EPI strives to identify the best available data based on the latest scientific advances in order to produce useful and credible scores for the global community.

DATA SOURCES

Data for the 2018 EPI come from international organizations, research institutions, academia, and government agencies. These sources use a variety of techniques, including:

- Remote sensing data collected and analyzed by research partners;
- Observations from monitoring stations;
- Surveys and questionnaires;
- Academic research;
- Estimates derived from both on-the-ground measurements and statistical models;
- Industry reports; and
- Government statistics, reported either individually or through international organizations, that may or may not be independently verified.

INCLUSION CRITERIA

While more data are available today than ever before, not all environmental data are applicable to the EPI. In order to be useful for measuring environmental performance, we judge candidate datasets according to several criteria for inclusion. Ideal datasets would satisfy each of the following.

RELEVANCE. Data should measure something about the environment that is applicable to most countries in most circumstances.

PERFORMANCE ORIENTATION. Data should measure environmental issues that are amenable to policy intervention. Countries should not be penalized for environmental or resource endowments beyond their control. Indicators should also measure on-the-ground outcomes from policies rather than policy inputs. If direct measurement of outcomes is not possible, proxy measurements that are causally related to those outcomes may be acceptable substitutes.

ESTABLISHED METHODOLOGY. Different governments, researchers, or stakeholders may attempt to measure the same thing in different ways, resulting in data that are not comparable across countries or time. To be included in the EPI, data must be measured using an established methodology, peer-reviewed by the scientific community, or endorsed by an international organization.

VERIFICATION. The most credible data are either verified by a third party or produced as a result of a data collection process that is open to scrutiny so that a third party could audit the results.

COMPLETENESS. Datasets are complete if they cover two dimensions. First, a dataset is spatially complete if it covers a sufficient number of countries. Many studies are conducted at the regional level or, for example, only for OECD countries, and so could not provide information on the entire world. Second, a dataset is temporally complete if it provides measurements across time. Some studies are one-off measurements that provide a snapshot. Such snapshots do provide information about environmental performance, but they may not be recent and cannot show trends. It is also important that the producers of datasets demonstrate a commitment to continued production of data into the future.

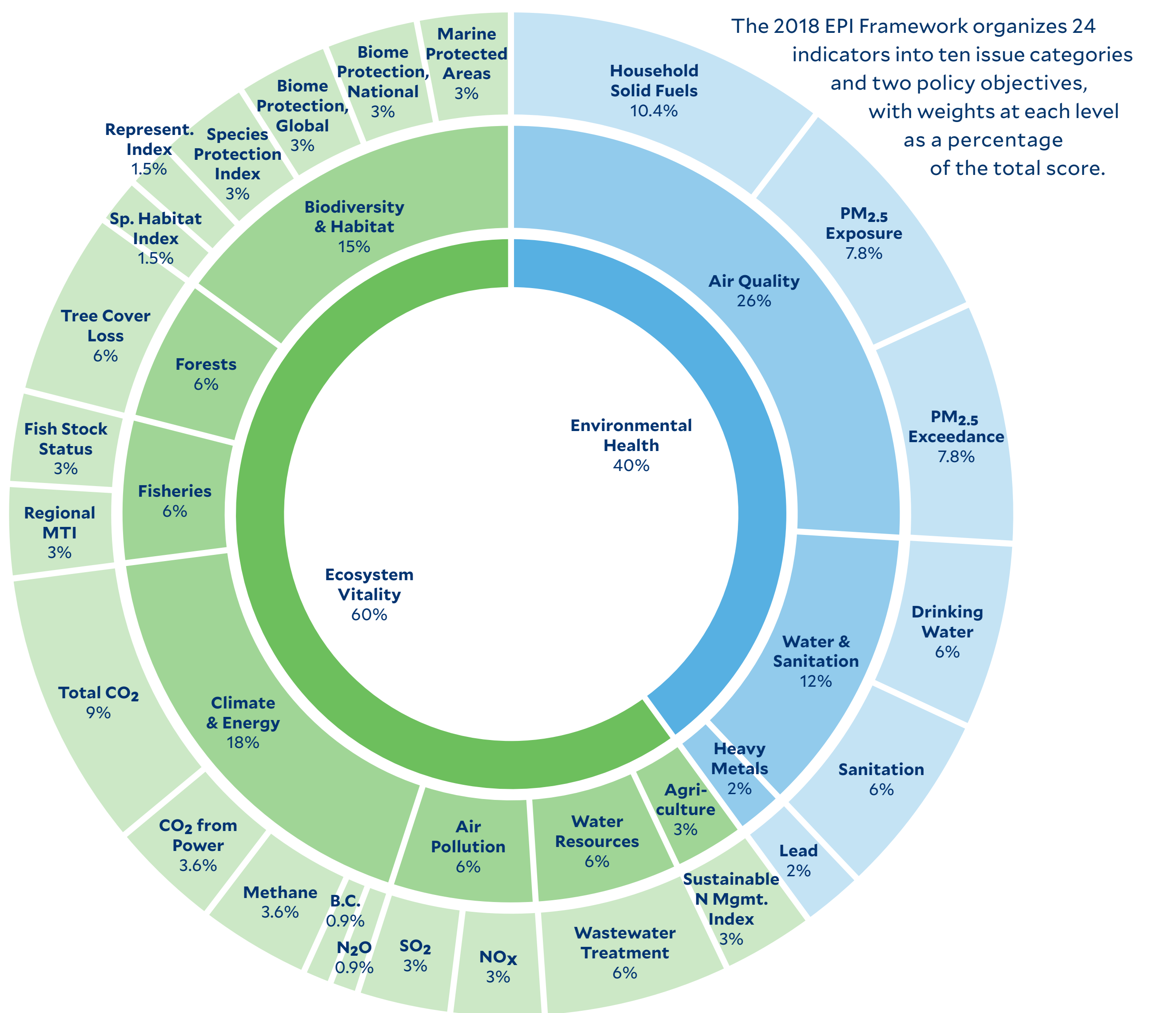
QUALITY. High-quality data are accurate, reliable, and valid. The best measurements come from direct observation rather than estimation by statistical models.

SELECTION PROCESS

Selection of data for the EPI follows three basic approaches. First, we examine our existing indicators. The previous iteration is a good starting point for each new EPI, and we look to improve on weaknesses and incorporate updates to this set of indicators. Second, the EPI responds to the needs of policymakers and the priorities of the international community, as described by international agreements. The 2015 Sustainable Development Goals (SDGs) outline the general areas of concern, and the Inter-Agency and Expert Group on SDG Indicators lists 232 potential indicators to track progress on SDG targets (IAEG-SDGs, 2018). Third, the EPI casts a wide net to find potential candidate metrics for the EPI. Sources include international organizations, the scientific literature, government agencies, and experts among the issue categories. The EPI strives to use the best available metrics that rely on the latest advances in global data systems. The EPI team judges each potential indicator by how well it satisfies the EPI inclusion criteria outlined above.

Ideally, each metric should satisfy all of the EPI criteria. The EPI occasionally uses a dataset that falls short in some respect, however. Reasons for inclusion of such a dataset are twofold. First, an issue category may be so critically important to environmental performance that it is necessary to use some metric rather than no metric. As long as an indicator provides some useful signal to policymakers and stake-

FIGURE 2-1 THE 2018 EPI FRAMEWORK



holders about the state of the environment — when no better datasets are available — we may include the imperfect dataset. In the 2018 EPI, for example, we rely on estimates of disability-adjusted life-years (DALYs) lost due to lead exposure even though such estimates come from sparse data sources. Second, in issue categories where global data systems are still emerging, the EPI may rely on pilot or nascent metrics. We use the recently proposed Sustainable Nitrogen Management Index as an indicator within the Agriculture issue category, for example (Zhang & Davidson, 2016). These metrics can draw greater attention to these efforts and the need for international support. Even less-than-ideal indicators contribute to the overall usefulness of the EPI as a composite index, building a foundation for evidence-based policy-making.

A complete description of the data used to construct the 2018 EPI indicators can be found in the online Technical Appendix. In the interest of transparency, the EPI has always been candid about the limitations of the datasets used. Each EPI seeks to improve on past iterations by correcting previous mistakes and testing innovations. Throughout the report, we note limitations of the datasets and feature promising new metrics that may be incorporated into future versions of the EPI.

INDICATOR CONSTRUCTION

Once the data for the EPI have been identified, indicator construction proceeds along several steps. First, the data must be cleaned and prepared for further analysis. We note in the Technical Appendix for each dataset the country coverage and the years included. Second, some variables must be standardized in order to be comparable across countries and over years. Greenhouse gas (GHG) emissions, for example, must be divided by the size of each country's economy, as measured by GDP, to calculate carbon intensity. Other normalizations include dividing by units of area or population, calculating percent changes, developing trends over time, or taking weighted averages of several variables. The Technical Appendix describes these normalizations for relevant indicators in greater detail.

The third step is to scrutinize metrics for skewness. Skewed datasets have most countries clustered at one end of the distribution with few countries spread across the rest of the range of scores. In such cases we usually rely on logarithmic transformations, which improve the interpretation of results. Most importantly, the logarithmic transformation takes the crowd of countries bunched together in raw data units and spreads them out. This spread allows us to better differentiate between countries whose relative performances would otherwise be obscured. With raw data, only the countries at the extremes of the measurement spectrum can easily be compared; making important distinctions between the leaders is difficult without a suitable transformation.

One of our metrics, $PM_{2.5}$ exposure, illustrates the usefulness of transforming the data. Consider the four countries in Figure 2-2. In the upper panel, the leaders, Iceland and Kazakhstan, are separated by the same difference in $PM_{2.5}$ concentrations as the laggards, China and Pakistan — about 10 μg/m^3. Iceland is an order of magnitude better than Kazakhstan, while China and Pakistan differ by much less in percentage terms. The effects of these ambient concentrations of $PM_{2.5}$, however, are substantively different. If Iceland were to move to the level of Kazakhstan, this deterioration would be more notable than if Pakistan were to move to the level of China. The lower panel, with the transformed data, illustrates that the important differences in performance aren't between leaders and laggards but within the leaders. Kazakhstan has much to gain by marginally improving $PM_{2.5}$ exposure, but the laggards can make major improvements only through substantial efforts at reducing this environmental risk. Logarithmic transformation aids in making appropriate comparison based on percentage differences that are often far more important than absolute differences. Transforming the data also improves the interpretation of differences between countries where relative performance depends on the end of the spectrum into which they fall. The final step is to rescale the data into a 0–100 score. This process puts all indicators on a common scale that can be compared and aggregated into the composite index. The EPI uses the distance-to-target technique for indicator construction, which situates each country relative to targets for worst and best performance — discussed in more detail below — corresponding to scores of zero and 100, respectively. The generic formula for calculating the indicator is: Where x is a country's value,

$$\text{Indicator Score} = \frac{x - \underline{x}}{\overline{x} - \underline{x}} \times 100$$

$\overline{x}$ is the target for best performance, and

$\underline{x}$ is the target for worst performance.

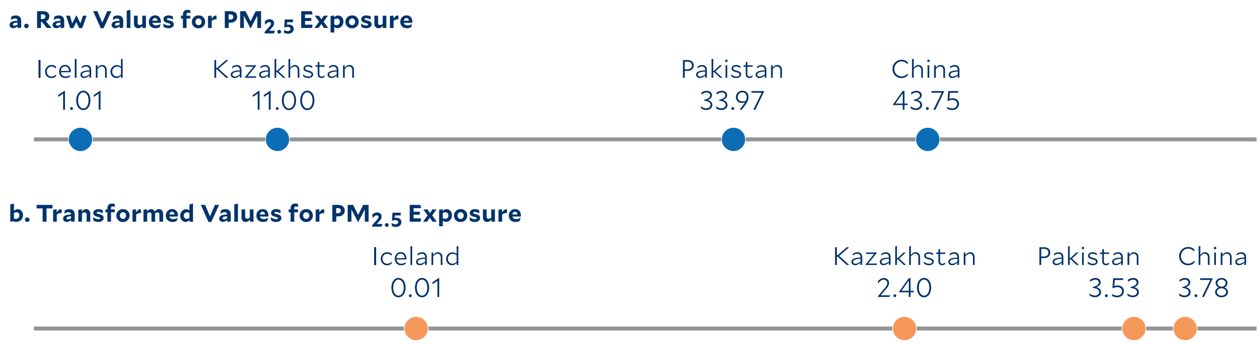
If a country's value is greater than $\overline{x}$, we cap its indicator score at 100. Likewise, if a country's value is less than $\underline{x}$, we set its indicator score to 0.

The EPI employs targets to identify the best and worst performance for each indicator. Targets may be set by a number of criteria. The EPI selected targets for best performance according to the following hierarchy:

1. Good performance is set forth in international agreements, treaties, or institutions, such as the World Health Organization. If there are no such targets,

FIGURE 2-2 TRANSFORMING SKEWED DATA

Four countries in the *$PM_{2.5}$ exposure* metric illustrate the usefulness of logarithmic transformation.



2. Good performance is based on the recommendation of expert judgment. If no such recommendations are available,

3. Good performance is set at either the 95th- or 99th-percentile, depending on the distribution of the underlying data.

Setting the target for worst performance follows a similar logic, though the first two criteria are rarely available. We usually set the worst performance target at the 1st- or 5th-percentile, depending on the distribution of the underlying data. For the 2018 EPI, we calculate percentiles using the complete time series of all available data for each indicator, not just using data from the most recent year. Trimming off the tails of the underlying distribution is helpful because it prevents outliers from having undue influence on the resulting scores. Complete details about the targets are in the online Technical Appendix.

WEIGHTING AND AGGREGATION

Once all indicators have been constructed on the 0–100 point scale, we aggregate them at each level of the framework hierarchy. Indicator scores are aggregated into issue category scores, issue category scores into policy objective scores, and policy objective scores into final EPI scores. In the field of composite indices, there are various methods for weighting and aggregation (Munda, 2012; Munda & Nardo, 2009; Nardo et al., 2008, pp. 33ff). The EPI sacrifices sophistication in favor of transparency; at each level of the aggregation we calculate a simple weighted arithmetic average. The weights used to calculate EPI scores (Figure 2-1) represent just one possible structure, and we recognize that users of the EPI may favor different weights. Our data are available for download from epi.yale.edu for those interested in examining the results produced by alternative aggregations.

ENVIRONMENTAL HEALTH

Within the Environmental Health policy objective, we assigned weights based on the distribution of global disability-adjusted life-years (DALYs) lost to the environmental health risks in the 2018 EPI (see Blanc, Friot, Margni, & Jolliet, 2008). In 2016, the most recent year for which estimates are available, approximately 65% of DALYs were attributable to air quality, 30% to water and sanitation, and 5% to lead exposure. For air quality, 40% of DALYs were attributed to household use of solid fuels, and 60% were attributed to ambient $PM_{2.5}$ exposure, which we allocate equally between our two $PM_{2.5}$ indicators. For water quality, DALYs were approximately equally distributed between drinking water and sanitation, resulting in weights of 50% for each. Lead exposure is the only indicator for the Heavy Metals issue category, and therefore receives 100% of the weight.

ECOSYSTEM VITALITY

Whereas the policy objective of Environmental Health has an empirical basis for deriving weights, the selection of weights in Ecosystem Vitality, shown in Figure 2-1, is more subjective. We attempt to strike a balance between the relative gravity of each issue category and the quality of the underlying data. According to the Planetary Boundaries model (Rockström et al., 2009), the two leading threats to the environment are biodiversity loss and climate change. Biodiversity loss entails habitat-focused indicators, as in our Biodiversity & Habitat issue category (25%), as well as the indicators in Forests (10%) and Fisheries (10%). Within Climate Change (25%), the GHGs are roughly weighted according to their relative contributions to climate forcing. The balance of the weight within Ecosystem Vitality lies with Air Pollution (10%), Water Resources (10%), and Agriculture (5%). Although we are fully aware of the importance of these issue categories, the low weight given to them here is due mainly to the paucity of indicators. As new data become available for measuring these issue categories, different weights should emerge in future versions of the EPI.

POLICY OBJECTIVES

As in previous years, the relative weight given to each policy objective is informed by the variance of each. Environmental Health has a much wider spread ($\sigma = 20.8$) than Ecosystem Vitality ($\sigma = 11.2$). A simple 50-50 weighting would give too much influence to the Environmental Health policy objective, masking the meaningful variation within Ecosystem Vitality. Without adjustment, countries that perform well on Environmental Health would score well on the EPI, with less input from their performance on Ecosystem Vitality. In order to help account for this potential imbalance, the 2018 EPI gives a weight of 40% to Environmental Health and 60% to Ecosystem Vitality. These weights do not reflect a prioritization of "nature" over humans, and we believe that ecosystem services are just as vital to human well-being as clean air and water. Rather, our choice of weights is guided by the data and serves to produce a more balanced and useful final score.

MATERIALITY

Not every indicator is applicable to every country in the 2018 EPI. Countries differ in natural resource endowments, geography, and physical characteristics. For example, landlocked countries have no fisheries. In order to account for these differences, the 2018 EPI uses two materiality filters (Table 2-1). Countries meeting the criteria in these filters are not scored on the associated indicators and issue categories. In effect, we set the weight of these indicators and issue categories to zero for these countries and spread that weight across the other weights within the same level of aggregation.

TABLE 2-1 MATERIALITY FILTERS APPLIED TO THE 2018 EPI

MATERIALITY FILTER	CRITERIA	ISSUE CATEGORY	INDICATOR	NO. OF COUNTRIES
Forest	Total forested (≥ 30% canopy cover) area < 200 km^2	Forests	Tree Cover Loss	30
Sea	Landlocked *OR* Coastline : Land Area ratio < 0.01	Fisheries	Fish Stock Status Regional MTI	44
			Marine Protected Areas	

NOTE: Countries meeting the listed criteria are not scored on the associated indicators and issue categories.

MISSING DATA

Datasets that lack sufficient coverage of EPI countries are usually discarded, but in some cases the data are so useful that we included them and then have to account for missing values. In the 2018 EPI, these include the Species Protection Index, Species Habitat Index, fish stock status, Regional MTI, CO_2 emission intensity (power), wastewater treatment, and Sustainable Nitrogen Management Index. When an issue category relies on multiple indicators, we average around these missing values, redistributing the weight to non-missing scores. In other cases, we imputed missing values based on the performance of similar countries. We describe details on the imputation of missing values for fish stock status, wastewater treatment, and Sustainable Nitrogen Management Index in the online Technical Appendix.

BASELINE SCORES

The 2018 EPI methodology can also be applied to historic data to calculate EPI scores and sub-scores for each country. While we calculate the 2018 EPI based on the most recent year for each dataset, changes over time can be discerned by comparing these scores to a baseline score. For most datasets, our baseline uses data from approximately ten years prior to the most recent year. We offer these baseline scores as a more helpful point of comparison than full back-casted annual scores. Not all datasets lend themselves to straightforward longitudinal analysis, especially considering the variety of temporal coverage among the datasets on which the 2018 EPI is based. We describe further details about the baseline scores in the online Technical Appendix.

GLOBAL SCORECARD

The 2018 EPI also includes a global scorecard that illustrates how the world is doing in each issue category. Where feasible, country-level data on each indicator are aggregated to the global level. We then construct indicator scores based on these global values using the same procedure as in the Indicator Construction step. For most indicators, we are able to construct scores for both the most recent year and the baseline year. Unlike performance, which is most relevant in a country-level context because nations are the units that adopt environmental policies, the global scorecard is most useful for assessing the current state of the world.

CHANGES FROM THE 2016 EPI

Every iteration of the EPI requires changes to the methodology. Innovation allows the EPI to take advantage of the latest advances in environmental science and analysis. We introduce new datasets, better normalizations, expanded country coverage, and other updates to increase the sophistication and usefulness of the index. Not every innovation endures, however, and the 2018 EPI, like previous iterations, learns from and drops experiments that have proved problematic. In the interest of a more robust measurement tool, we welcome feedback on every version of the EPI and will work to continue making improvements.

Changes in methodology between versions of the EPI mean that historical EPI scores are not comparable. Differences in EPI scores across EPI iterations are largely due to additions and subtractions of indicators, new weighting schemes, and other aspects of the methodology — not necessarily to decreased or increased performance. We therefore urge users not to attempt such cross-version comparisons of EPI scores or sub-scores without careful qualifications. Attempting to assemble time series or panel data of EPI scores from current and past versions of the EPI is strictly inappropriate. True within-country changes in performance are better assessed by using the 2018 EPI baseline scores or inspecting the raw data.

ENVIRONMENTAL HEALTH

The 2018 EPI brings several changes to the Environmental Health policy objective. First, the 2016 EPI introduced an environmental risk exposure pilot indicator. While sophisticated, this indicator was methodologically opaque and difficult to interpret, and we exclude it from the 2018 EPI. Second, we have also dropped NO_2 as an indicator because the dataset on which it was based is no longer actively updated. This pollutant is also well correlated with $PM_{2.5}$. Third, we avail ourselves of the Institute for Health Metrics and Evaluation's (IHME) data on lead exposure to add a new issue category related to Heavy Metals. Fourth, we switch to exclusive use of the IHME indicators to measure several issue categories. The 2016 EPI used additional data sources for indicators in the Water & Sanitation issue category, but these indicators are highly correlated with IHME data, adding little distinct value to the EPI. Fifth, the units of measurement for IHME indicators switch to age-standardized disability-adjusted life-years (DALYs) lost due to environmental risks per 100,000 persons, also known as the DALY rate. We feel that these units provide better comparability across countries and over time while also measuring direct health outcomes. Sixth, as mentioned above in Weighting and Aggregation under Environmental Health, DALYs also provide the foundation for developing weights within this policy objective.

ECOSYSTEM VITALITY

We introduce changes in the 2018 EPI for almost every issue category in Ecosystem Vitality. In the Biodiversity & Habitat category, the Species Protection indicators are replaced by the similar Species Protection Index. We also add two new indicators: the Protected Area Representativeness Index and the Species Habitat Index. The indicator on tree cover loss changes from a 14-year average to a five-year moving average to better understand the responsiveness of trends in deforestation to policy decisions. The materiality filter for Forests in the 2016 EPI included a new criterion to exclude countries in which "less than 2 percent of total land area is covered with greater than 30% tree canopy" (Hsu et al., 2016, p. 31). While this was an attempt to focus only on countries with substantial forest resources, we now believe that countries in which forests are scarce ecosystems actually have a greater need to conserve them. The 2018 EPI uses the sole criterion described in Table 2-1 for the materiality filter for Forests. Recognizing the emerging role of ecosystem-based fisheries management, we add the new Regional Marine Trophic Index to the Fisheries issue category.

Within Climate & Energy, we add new indicators for three additional greenhouse gases (GHG): methane, nitrous oxide, and black carbon. The 2016 EPI made several important changes in how GHG emissions are normalized across countries. We retain most of these changes, though countries at or below the 5^{th}-percentile of emission intensity in the power sector are no longer automatically given top scores. Rather, across all emissions indicators, we use a new method for rewarding countries that have invested in emissions reductions to the point that current trends are flat. The 2016 EPI also included a materiality filter for least-developed countries and small-island developing states. After the 2015 Paris Climate Agreement, in which all countries regardless of size or development status are called to reduce emissions, such a filter no longer seems warranted; therefore, we drop the materiality filter from the 2018 EPI. The 2018 EPI reintroduces the issue category Air Pollution, last featured in the 2012 EPI, as confined to the consequences for ecosystems. Two pollutants are of particular global concern, SO_2 and NO_X, and we normalize these by the same method as used for GHG. Within Agriculture, we replace the two indicators used in the 2016 EPI by a new indicator to capture the effects of nitrogen fertilizer, the Sustainable Nitrogen Management Index, proposed by our data partners at the University of Maryland. Based on the most recent data, we also use new methods for imputing missing data, described in greater detail in the online Technical Appendix.

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3

RESULTS

Environmental Performance Index

The 2018 EPI provides a quantitative basis for comparing, analyzing, and understanding environmental performance for 180 countries.

We score and rank these countries on their environmental performance using the most recent year of data available as well as data from approximately a decade earlier. The state of the world is captured in the Global Scorecard. These results reveal current standings on a core set of environmental issues and identify where progress is or is not being made. The full results of the 2018 EPI, including country and indicator-level analysis, are available at epi.yale.edu. We highlight some of the most important results here in the report.

CHARACTERISTICS OF THE EPI

As in previous reports and studies, the 2018 EPI shows a positive correlation with country wealth, as measured by per capita GDP. Figure 3-1 illustrates the relationship between EPI scores and wealth. One of the consistent lessons of the EPI is that achieving sustainability goals requires the material prosperity to invest in the infrastructure necessary to protect human health and ecosystems. In a rapidly urbanizing world, it is important to build facilities that deliver improved sources of drinking water, manage wastewater, and mitigate pollution— as through smokestack scrubbers. The inherent tension of sustainable development is that income growth too often comes at the cost of the environment, especially through exploitation of natural resources and unchecked industrialization. The trade-offs between environmental performance and country wealth are also confounded by trade. So far, the spillover costs of trade are poorly captured in most metrics on the environment, though this is an area of active scholarship (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017). Our pilot metrics further explore current efforts to improve global accounting methods to achieve the Sustainable Development Goals (SDGs) and Targets.

Another enduring finding from the EPI is that the policy objectives constitute distinct dimensions of sustainability. Figure 3-2 illustrates the relationship between sub-scores for Environmental Health and Ecosystem Vitality in the 2018 EPI. While positively correlated, there is substantial variation in both dimensions. The figure suggests tension, as economic growth creates resources to invest in environmental protection while adding to pollution burdens and habitat stress.

COUNTRY PERFORMANCE

Individual country ranks and EPI scores are shown in Map 3-1 and Figure 3-3. At the top of the rankings, Switzerland leads the world in the 2018 EPI with a score of 87.42 in overall environmental performance. Switzerland's top ranking reflects strong performance across most issues, especially Climate & Energy and Air Pollution. Within Environmental Health, Switzerland also stands out in Water & Sanitation. While Switzerland's Biodiversity & Habitat score is 84.20, 62nd in the world, its protected areas have the top score on the *Protected Area Representativeness Index*.

France (83.95), Denmark (81.60), Malta (80.9), and Sweden (80.51)

FIGURE 3-1 THE RELATIONSHIP BETWEEN 2018 EPI SCORES AND GDP *PER CAPITA*

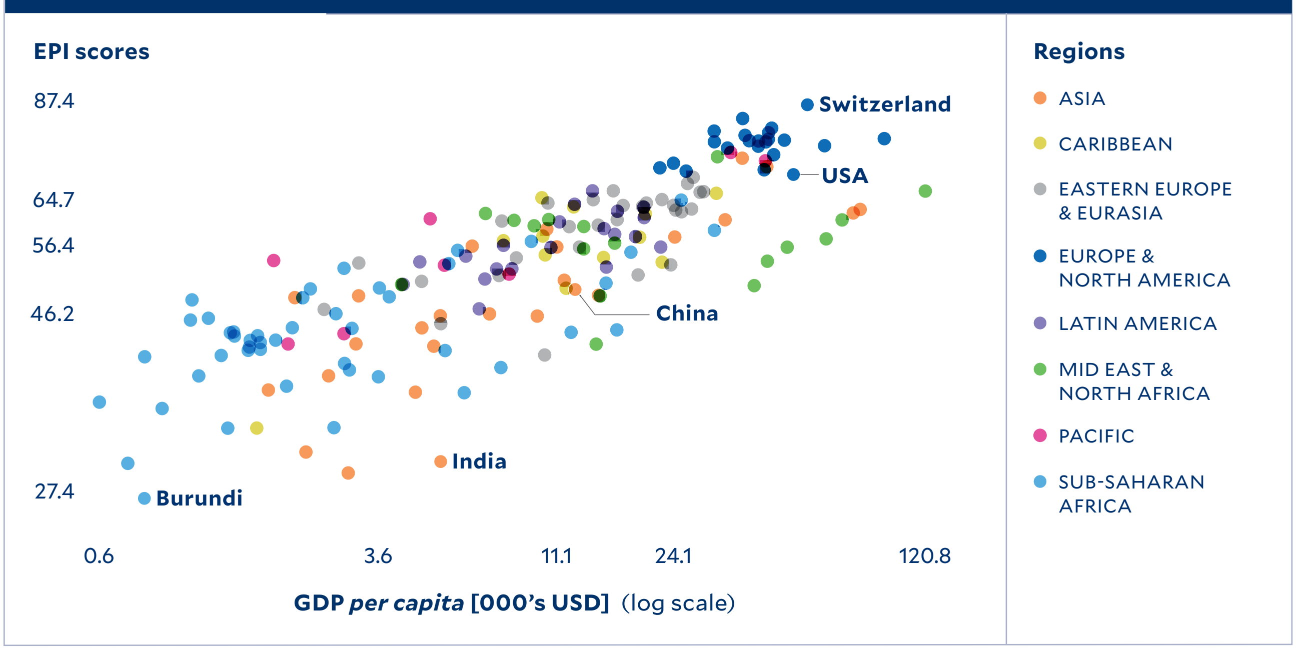
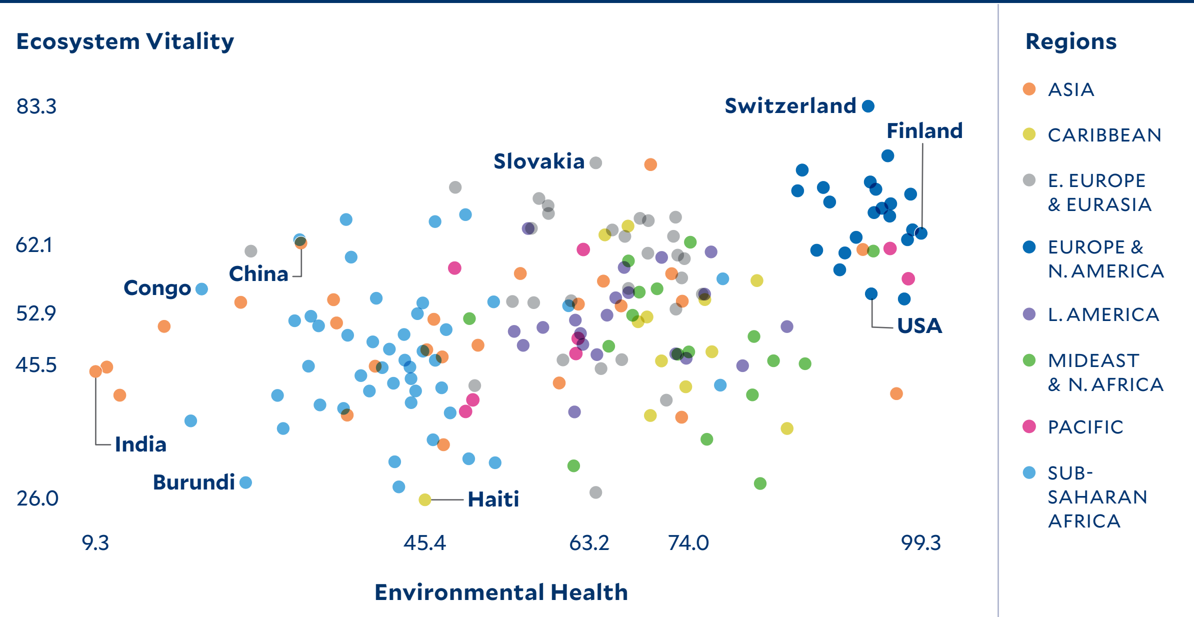
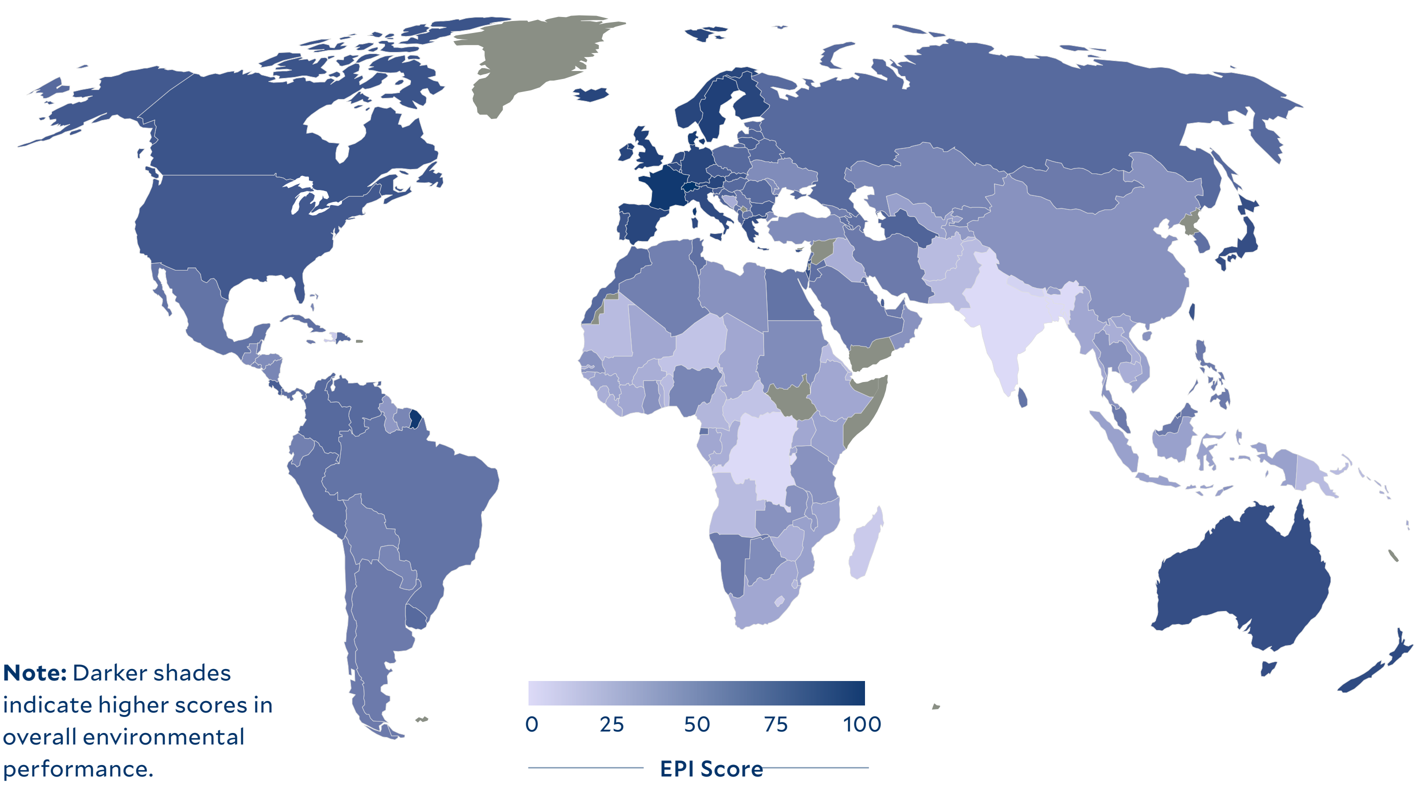


FIGURE 3-2 POLICY OBJECTIVES IN THE 2018 EPI



Note: The relationship between sub-scores on the two policy objectives for all 180 countries in the 2018 EPI illustrate that Environmental Health and Ecosystem Vitality are distinct dimensions of environmental performance.

MAP 3-1 2018 EPI SCORES BY COUNTRY



Note: Darker shades indicate higher scores in overall environmental performance.

FIGURE 3-3 THE 2018 EPI RANKINGS

Rank, EPI Score, and Regional Standing (REG, shown in color) for 180 countries

RANK	COUNTRY	SCORE	REG	RANK	COUNTRY	SCORE	REG	RANK	COUNTRY	SCORE	REG
1	Switzerland	87.42	1	61	Kuwait	62.28	5	121	Thailand	49.88	12
2	France	83.95	2	62	Jordan	62.20	6	122	Micronesia	49.80	13
3	Denmark	81.60	3	63	Armenia	62.07	17	123	Libya	49.79	16
4	Malta	80.90	4	64	Peru	61.92	6	124	Ghana	49.66	11
5	Sweden	80.51	5	65	Montenegro	61.33	18	125	Timor-Leste	49.54	14
6	United Kingdom	79.89	6	66	Egypt	61.21	7	126	Senegal	49.52	12
7	Luxembourg	79.12	7	67	Lebanon	61.08	8	127	Malawi	49.21	13
8	Austria	78.97	8	68	Macedonia	61.06	19	128	Guyana	47.93	20
9	Ireland	78.77	9	69	Brazil	60.70	7	129	Tajikistan	47.85	27
10	Finland	78.64	10	70	Sri Lanka	60.61	6	130	Kenya	47.25	14
11	Iceland	78.57	11	71	Equatorial Guinea	60.40	2	131	Bhutan	47.22	15
12	Spain	78.39	12	72	Mexico	59.69	8	132	Viet Nam	46.96	16
13	Germany	78.37	13	73	Dominica	59.38	5	133	Indonesia	46.92	17
14	Norway	77.49	14	74	Argentina	59.30	9	134	Guinea	46.62	15
15	Belgium	77.38	15	75	Malaysia	59.22	7	135	Mozambique	46.37	16
16	Italy	76.96	16	76	Antigua and Barbuda	59.18	6	136	Uzbekistan	45.88	28
17	New Zealand	75.96	1	77	United Arab Emirates	58.90	9	137	Chad	45.34	17
18	Netherlands	75.46	17	78	Jamaica	58.58	7	138	Myanmar	45.32	18
19	Israel	75.01	1	79	Namibia	58.46	3	139	Côte d'Ivoire	45.25	18
20	Japan	74.69	1	80	Iran	58.16	10	140	Gabon	45.05	19
21	Australia	74.12	2	81	Belize	57.79	10	141	Ethiopia	44.78	20
22	Greece	73.60	18	82	Philippines	57.65	8	142	South Africa	44.73	21
23	Taiwan	72.84	2	83	Mongolia	57.51	9	143	Guinea-Bissau	44.67	22
24	Cyprus	72.60	19	84	Serbia	57.49	20	144	Vanuatu	44.55	7
25	Canada	72.18	20	84	Chile	57.49	11	145	Uganda	44.28	23
26	Portugal	71.91	21	86	Saudi Arabia	57.47	11	146	Comoros	44.24	24
27	United States of America	71.19	22	87	Ecuador	57.42	12	147	Mali	43.71	25
28	Slovakia	70.60	1	88	Algeria	57.18	12	148	Rwanda	43.68	26
29	Lithuania	69.33	2	89	Cabo Verde	56.94	4	149	Zimbabwe	43.41	27
30	Bulgaria	67.85	3	90	Mauritius	56.63	5	150	Cambodia	43.23	19
30	Costa Rica	67.85	1	91	Saint Lucia	56.18	8	151	Solomon Islands	43.22	8
32	Qatar	67.80	2	92	Bolivia	55.98	13	152	Iraq	43.20	17
33	Czech Republic	67.68	4	93	Barbados	55.76	9	153	Laos	42.94	20
34	Slovenia	67.57	5	94	Georgia	55.69	21	154	Burkina Faso	42.83	28
35	Trinidad and Tobago	67.36	1	95	Kiribati	55.26	4	155	Sierra Leone	42.54	29
36	St. Vincent & Grenadines	66.48	2	96	Bahrain	55.15	13	156	Gambia	42.42	30
37	Latvia	66.12	6	97	Nicaragua	55.04	14	157	Republic of Congo	42.39	31
38	Turkmenistan	66.10	7	98	Bahamas	54.99	10	158	Bosnia and Herzegovina	41.84	29
39	Seychelles	66.02	1	99	Kyrgyzstan	54.86	22	159	Togo	41.78	32
40	Albania	65.46	8	100	Nigeria	54.76	6	160	Liberia	41.62	33
41	Croatia	65.45	9	101	Kazakhstan	54.56	23	161	Cameroon	40.81	34
42	Colombia	65.22	2	102	Samoa	54.50	5	162	Swaziland	40.32	35
43	Hungary	65.01	10	103	Suriname	54.20	15	163	Djibouti	40.04	36
44	Belarus	64.98	11	104	São Tomé and Príncipe	54.01	7	164	Papua New Guinea	39.35	21
45	Romania	64.78	12	105	Paraguay	53.93	16	165	Eritrea	39.34	37
46	Dominican Republic	64.71	3	106	El Salvador	53.91	17	166	Mauritania	39.24	38
47	Uruguay	64.65	3	107	Fiji	53.09	6	167	Benin	38.17	39
48	Estonia	64.31	13	108	Turkey	52.96	24	168	Afghanistan	37.74	22
49	Singapore	64.23	3	109	Ukraine	52.87	25	169	Pakistan	37.50	23
50	Poland	64.11	14	110	Guatemala	52.33	18	170	Angola	37.44	40
51	Venezuela	63.89	4	111	Maldives	52.14	10	171	Central African Republic	36.42	41
52	Russia	63.79	15	112	Moldova	51.97	26	172	Niger	35.74	42
53	Brunei Darussalam	63.57	4	113	Botswana	51.70	8	173	Lesotho	33.78	43
54	Morocco	63.47	3	114	Honduras	51.51	19	174	Haiti	33.74	12
55	Cuba	63.42	4	115	Sudan	51.49	14	175	Madagascar	33.73	44
56	Panama	62.71	5	116	Oman	51.32	15	176	Nepal	31.44	24
57	Tonga	62.49	3	117	Zambia	50.97	9	177	India	30.57	25
58	Tunisia	62.35	4	118	Grenada	50.93	11	178	Dem. Rep. Congo	30.41	45
59	Azerbaijan	62.33	16	119	Tanzania	50.83	10	179	Bangladesh	29.56	26
60	South Korea	62.30	5	120	China	50.74	11	180	Burundi	27.43	46

ASIA · CARIBBEAN · EASTERN EUROPE & EURASIA · EUROPE & NORTH AMERICA · LATIN AMERICA · MIDEAST & NORTH AFRICA · PACIFIC · SUB-SAHARAN AFRICA round out the top five countries in the 2018 EPI. Within Environmental Health, Denmark, Malta, and Sweden stand out for high scores in Air Quality. Additionally, Malta has the top rank in Water & Sanitation, and Sweden scores highest in *lead exposure*. On Ecosystem Vitality, France, Denmark, and Malta earn top scores in the issue category Biodiversity & Habitat. France and Denmark rank first in *marine protected areas*, and Malta joins them in first place in the protection of terrestrial biomes. Sweden places third in Climate & Energy, and France and Denmark excel in sustainable nitrogen management. In general, high scorers exhibit long-standing commitments to protecting public health, preserving natural resources, and decoupling GHG emissions from economic activity.

At the bottom of the 2018 EPI rankings are Nepal (31.44), India (30.57), the Democratic Republic of the Congo (30.41), Bangladesh (29.56), and Burundi (27.43). Low scores on the EPI are indicative of the need for national sustainability efforts on a number of fronts, especially cleaning up air quality, protecting biodiversity, and reducing GHG emissions. Some of the lowest-ranking nations face broader challenges, such as civil unrest, but the low scores for others can be attributed to weak governance. We draw special attention to the issue category Air Quality. As the dominant source of diseases and disability in our data, countries that score poorly in the 2018 EPI on Air Quality, such as India (Air Quality score of 5.75), China (14.39), and Pakistan (15.69), face a public health crisis that demands urgent attention.

TABLE 3-1 GLOBAL SCORES FOR THE EPI AND SUB-SCORES FOR POLICY OBJECTIVES, ISSUE CATEGORIES, AND INDICATORS

Current scores are based on most recent year of data available, and Baseline applies to data roughly one decade prior.

	CURRENT	BASELINE
ENVIRONMENTAL PERFORMANCE	**46.16**	**41.68**
ENVIRONMENTAL HEALTH	**31.50**	**28.16**
AIR QUALITY	**33.82**	**32.74**
Household Solid Fuels	22.10	14.77
$PM_{2.5}$ Exposure	33.24	36.73
$PM_{2.5}$ Exceedance	50.03	52.72
WATER & SANITATION	**25.19**	**17.24**
Drinking Water	25.51	17.75
Sanitation	24.87	16.72
HEAVY METALS / Lead Exposure	39.23	34.20
ECOSYSTEM VITALITY	**55.93**	**50.68**
BIODIVERSITY & HABITAT	**58.12**	**45.91**
Marine Protected Areas	100.00	47.90
Terrestrial Biome Protection	64.30	57.03
Species Protection Index	67.73	63.88
Protected Area Representativeness Index	37.04	26.57
Species Habitat Index	80.07	94.93
FORESTS / Tree Cover Loss	**94.04**	**99.41**
FISHERIES	**58.22**	**57.52**
Fish Stock Status	65.89	73.17
Regional Marine Trophic Index	50.54	41.87
CLIMATE & ENERGY	**42.68**	**37.64**
CO_2 Emissions Intensity (total)	31.34	25.47
CO_2 Emissions Intensity (power)	42.40	40.79
Methane Emissions Intensity	64.61	58.16
N_2O Emissions Intensity	58.29	52.60
Black Carbon Emissions Intensity	53.92	49.71
AIR POLLUTION	**47.74**	**38.06**
SO_2 Emissions Intensity	40.48	32.42
NO_X Emissions Intensity	54.99	43.70
WATER RESOURCES / Wastewater Treatment	**62.13**	**62.13**

The United States places 27th in the 2018 EPI, with strong scores on some issues, such as Water & Sanitation (90.92) and Air Quality (97.52), but weak performance on others, including deforestation (8.84) and GHG emissions (45.81). This ranking puts the United States near the back of the industrialized nations, behind the United Kingdom (6th), Germany (13th), Italy (16th), Japan (20th), Australia (21st), and Canada (25th).

Of the emerging economies, China and India rank 120th and 177th respectively, reflecting the strain rapid economic growth imposes on the environment. Brazil ranks 69th, suggesting that a concerted focus on sustainability as a policy priority will pay dividends — and that the level and pace of development is just one of many factors affecting environmental performance. South Africa ranks 142nd. Sustainability outcomes among emerging economies remain highly variable.

Seychelles ranks as the most-improved country over the past decade, rising from a baseline score of 47.05 to a 2018 EPI score of 66.02, equivalent to a jump of 86 places in the rankings. This improvement springs largely from its commitment to combating greenhouse gas emissions. São Tomé and Príncipe, Kuwait, and Timor-Leste also increased their scores due to several factors, including the establishment of areas protecting biodiversity and habitat. Burundi, Central African Republic, Madagascar, the Bahamas, and Latvia slipped significantly in environmental performance, largely due to sub-par performance on climate change. Countries at the top of the EPI rankings tend not to change very much over time. High scorers have little room for improvement, and the durability of good governance and investments in infrastructure make deterioration rare.

Another story of interest is Colombia. Following a peace deal between the government and the Revolutionary Armed Forces of Colombia (FARC), Colombia now has an opportunity to expand conservation efforts while promoting economic development in post-conflict regions (Palmer, 2017). The government plans to train 1,100 former FARC fighters to track and report illegal logging and promote sustainable farming and ecotourism (Moloney, 2017). Efforts to protect rainforest habitat are also expanding. The government has doubled the area of its national parks since 2010 and plans to expand protected areas in post-conflict regions in 2018 (Palmer, 2017). The country's modest gains in its EPI score could be a sign of promising environmental protections to come.

GLOBAL SCORECARD

The Global Scorecard shows the current state of the world and movement in trends since the baseline year. In Table 3-1, at the level of the overall environmental protection, we see that the world is still far from achieving international targets for the environment, with the equivalent of a score of 46.16. This is slightly better than the baseline score of 41.68. Just as we find at the country level, the overall global score is mostly pulled down by the policy objective of Environmental Health, which has a score of 31.50. Ecosystem Vitality, on the other hand, is more robust at 55.93 yet still shows much room for improvement. Since the baseline period, Ecosystem Vitality has increased by more than Environmental Health, perhaps indicating that gains from efforts to protect critical habitat and sustain natural resources have been more impactful than those that have sought to address dimensions of human and environmental health.

Trends over recent decades suggest that environmental quality is improving in a number of regards, indicating that the global community is moving closer to many of its development goals. The pace of progress, however, may not be fast enough to achieve the targets outlined in the Sustainable Development Goals and other international objectives. In the Ecosystem Vitality policy objective, Biodiversity and Habitat scores indicate the international community has achieved the Aichi Biodiversity Targets' 10% conservation goal for marine protected areas well before its 2020 target. However, we find countries must continue to increase the size of protected areas within national boarders at an accelerated rate if they are to achieve the 17% terrestrial conservation target.

REGIONAL TRENDS

European countries lead the EPI's top performers, occupying 17 the top 20 positions. While the United States (27th) scores among the top 30 nations worldwide, it ranks towards the bottom of its regional ranking. Many **European and North American nations** are members of the OECD. All are ranked highly on the United Nations Human Development Index, a measure of quality of life within a country. However, national trends and statistics often mask inequities and poor results at the sub-national level. The water crisis in Flint, Michigan, in the United States underscores the disproportionate environmental burdens that can exist within even the most developed countries and highlights key areas for improvement.

The spread in rankings among **Asian countries** is larger than for any other region. Japan (20th), Taiwan (23rd), and Singapore (49th) emerge as regional leaders, while Nepal (176th), India (177th), and Bangladesh (179th) are among the lowest-performing countries in both their region and the world. The spread in scores may be explained by the varying levels of economic development within Asia. Several countries in Asia have experienced rapid periods of economic growth within the last century. East Asian countries, like Japan and South Korea, witnessed considerable improvements in economic productivity post World War II. These improvements often translated into higher levels of human development and environmental performance. Conversely, many Asian countries in South and Southeast Asia are still in a state of transition. India's low scores are influenced by poor performance in the Environmental Health policy objective. Deaths attributed to $PM_{2.5}$ have risen over the past decade and are estimated at 1.6 million annually (Institute for Environmental Analytics, 2017). Despite government action, pollution from solid fuels, coal and crop residue burning, and emissions from motor vehicles continue to severely degrade the air quality for millions of Indians.

Latin American nations are broadly distributed over the middle half of the 2018 EPI rankings. Costa Rica leads Latin America in the 30th position with a score of 67.85. Guyana received the lowest score in the region, landing in the 128th position with a score of 47.93. Levels of development vary widely among Latin American countries, resulting in a broad range of effective governance and in turn the provision of services for human health and the protection of ecosystems. For example, the per capita GDP of Honduras was estimated to be $5,500 in 2017 (CIA, 2017b) while, in contrast, Chile's per capita GDP was estimated to be $24,600 (CIA, 2017a). Environmental performance is of critical interest as Latin America is home to over 40% of the Earth's biodiversity and more than 25% of its forests. The area also encompasses the Amazon rainforest, the world's most biodiverse region (UNEP, 2016).

While **Latin America** made uneven progress on the issue categories examined in the 2018 EPI, a few bright spots emerged from the results. In 2017 Mexico created four new marine protected areas (MPAs) (IUCN, 2017b). Mexico's MPA at Revillagigedo is now the largest no-fishing area in North America (IUCN, 2017a) and supports nearly 360 species of fish, coral colonies, and four species of sea turtle (Bello, 2017). The 2018 EPI also identified Peru as one of the world's leaders in the sustainable management of fisheries. Three Peruvian Fisheries Acts were enacted after 1995 and greatly improved the sustainability of the nation's anchovy fishery. The legislation served to regulate foreign involvement in the fishery, control fishing quotas, and establish fishing seasons (Arias Schreiber, 2012) .

Haiti (174th) falls far below other countries in its peer group and is the only country outside sub-Saharan Africa and Asia that falls in the bottom 20 overall rankings. While **Caribbean** countries face several development challenges, including a limited land area for development, deforestation, and reliance on imports for energy needs, Haiti, the 7th worst performer, has faced significant political, economic, and social setbacks throughout its history (UNEP, 2013). Haiti and the Dominican Republic (46th) share an island, but environmental conditions in the two countries are vastly different. Haiti had substantially weaker performance than the Dominican Republic in the issue categories Water & Sanitation and Biodiversity & Habitat, scoring 26.95 points and 72.67 points lower in each category, respectively. Both countries, however, score poorly in agriculture and forests, indicating that soil erosion and deforestation remain key concerns on the island.

Countries in the **Middle East and North Africa** (MENA) are dispersed throughout the middle of the 2018 global rankings, with Israel (19th), Qatar (32nd), and Morocco (54th) leading the regional rankings. Oman (116th), Libya (123rd), and Iraq (152nd) rank as the lowest performers within the region. Many MENA countries contain vast hydrocarbon reserves, which often adversely impact performance on key indicators for Air Quality and Climate & Energy. Oil refineries, hydrocarbon-generated power plants, and high fossil fuel subsidies may have impacted performance for several MENA countries. Underpricing of energy from fossil fuel subsidies in many countries has contributed to wasteful energy use and poor performance in the Climate & Energy issue category. For example, the United Arab Emirates, a country with large economic resources and high quality of life, ranks 166th. Other countries, such as Saudi Arabia and Kuwait, also score low in the Climate & Energy issue category, ranking 134th and 161st, respectively. Opportunities for improvements in environmental performance exist. The MENA region shows vast potential for renewable energy, and many nations have begun the process of diversifying their energy portfolios.

Scores for **Eastern Europe and Eurasia** range widely. Some exhibit effective environmental regulations, and 14 countries place within the top 50 globally. Russia, the most politically and economically influential country in this region, ranks 15th in the region and 52nd overall. Russia's score is boosted by high performance in the Water Resources issue categories. In the Forests category Russia scores poorly, despite having the most total tree cover of any country. Several countries in the region score very highly in the Forests category. Kyrgyzstan and Tajikistan have successfully prevented recent tree cover loss. These scores may be influenced by the relatively small tree cover in these countries (World Bank, 2017). Bosnia and Herzegovina has the lowest score in the region by far, ranking 158th overall. The country scores poorly in most categories and receives zero scores for water resources. According to the IMF, Bosnia and Herzegovina may be growing after decades of hardship. Attention to environmental policymaking and enforcement could boost the country's performance in future years (IMF, 2015).

Countries in the **Pacific region** exhibit a broad range of scores, with New Zealand (17th) and Australia (21st) at the top of the group, demonstrating strong overall environmental performance. This is not surprising considering both nations wield considerable political and economic influence throughout the region and globally. In contrast, a majority of the Pacific countries with lower rankings are small island developing states with limited economic resources and weak or insufficient environmental governance. Vanuatu (144th) and the Solomon Islands (151st) exhibit the weakest EPI scores in the region. Over the past decade, countries in the Pacific region have experienced significant amounts of deforestation, and forest management is a high priority concern for the region. Low scores in the Forests issue category reflects a need to establish strong sustainable forest management measures as soon as possible if these countries hope to maintain vital ecosystem services.

Developing countries, particularly in **sub-Saharan Africa,** have the greatest to gain from improvements in environmental performance. Sub-Saharan African countries score lower than any other region, occupying 30 of the bottom 44 positions. Investments in clean water, sanitation, and energy infrastructure could help these countries significantly boost their scores. Rising populations in sub-Saharan Africa continue to put substantial pressure on limited environmental resources. The UN estimates that about half of the population in sub-Saharan Africa is living on less than a dollar a day, making it the world's poorest and least developed region (United Nations, 2014). The number of people living in slums, often without access to basic services, is expected to double to approximately 400 million people by

2020, putting even more pressure on these resources (United Nations, 2014).

High performance in **sub-Saharan Africa** is still possible, with Seychelles and Namibia both making significant progress on certain issue categories. Seychelles scored 39th in the overall rankings and first in its regional group. Seychelles' rise stems largely from improvements in the Climate & Energy issue category as a result of new policy choices that place climate change at the center of its development strategy. Seychelles' score increased by 83.21 from a 10.04 baseline, and Seychelles is now a net sink for global GHGs (Republic of Seychelles, 2015, p. 1). Namibia (79th) improved its Biodiversity & Habitat score significantly over the past decade, ranking 11th in the issue category. Namibia's deep commitment to biodiversity and environmental protection is embedded in its history. Namibia was the first African country to incorporate the environment into its constitution. Following its independence in 1990, the government returned ownership of its wildlife to the people, employing a successful, community-based management system that gave its citizens the right to create conservancies (Conniff, 2011; WWF, 2011). Today, Namibia has 148 protected areas covering 37.89% of its terrestrial environment and 1.71% of its EEZ (UNEP-WCMC, 2018).

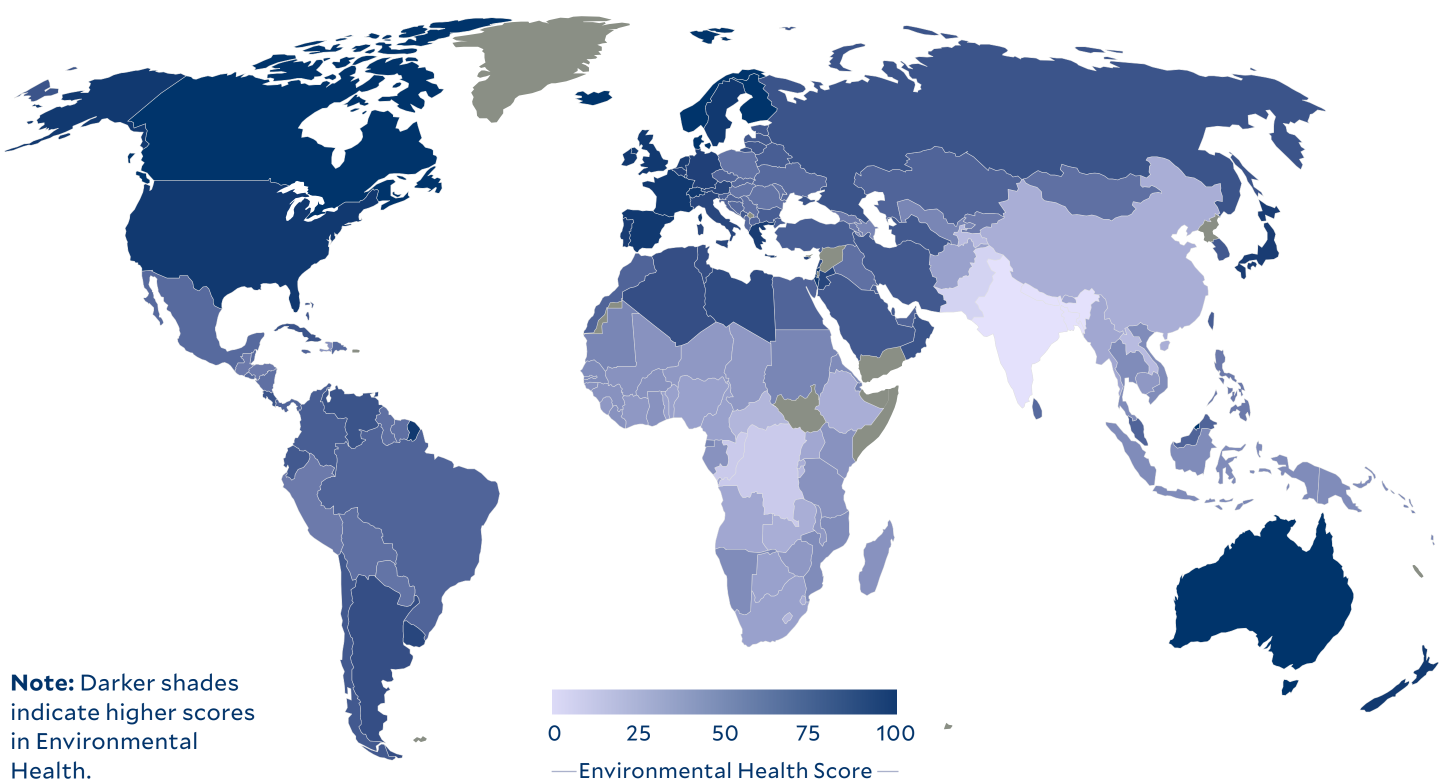
KEY FINDINGS

ENVIRONMENTAL HEALTH. Across the policy objective of Environmental Health, we find that environmental performance has increased only slightly over the past decade. Global scores have improved 3.34 points relative to a baseline of 28.16. Significant progress is still needed at the global level to protect public health and reach global international targets; see Map 3-2.

Air Quality remains the leading environmental threat to public health. In 2016 the Institute for Health Metrics and Evaluation estimated that diseases related to airborne pollutants contributed to two-thirds of all life-years lost to environmentally related deaths and disabilities. Pollution is particularly severe in places such as India and China, where greater levels of economic development contribute to higher pollution levels (WB & IHME, 2016). As countries develop, increased population growth in large cities, as well as increased industrial production and automotive transportation, continue to expose people to high levels of air pollution.

As nations industrialize, governments generally tighten regulations for **Water & Sanitation.** Investments in sanitation infrastructure mean fewer

MAP 3-2 EPI SCORES FOR THE ENVIRONMENTAL HEALTH POLICY OBJECTIVE BY COUNTRY



Note: Darker shades indicate higher scores in Environmental Health.

people are exposed to unsafe water, leading to fewer deaths from the associated risks. However, while global trends suggest a tightening of environmental regulations globally as nations industrialize, rapid growth in developing countries should remain a global priority. Countries should continue to develop capacity to ensure that growth in infrastructure keeps pace with population growth. Considerable action is still needed to ensure that safe drinking water and sanitation services are available worldwide.

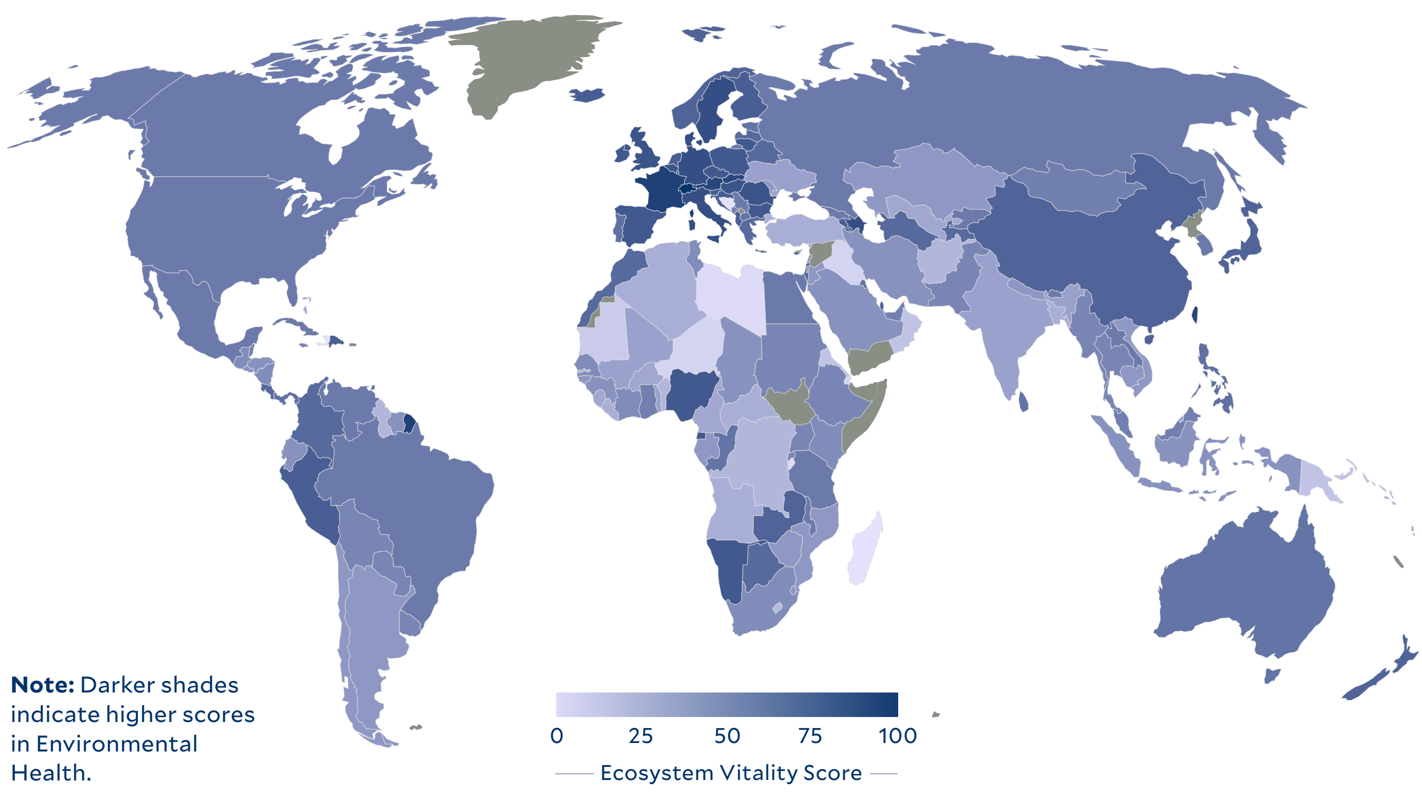
While exposure to **Heavy Metals** persists globally, many countries are managing to reduce lead poisoning despite a global increase in lead production. Regulations have proved effective in limiting exposure from sources including petrol, paint, and plumbing. Most notable is the phase-out of leaded gasoline in more than 175 countries (Landrigan et al., 2017, p.17). Problems persist in developing and urbanizing countries with high demand for lead batteries (Landrigan et al., 2017, p.16). Balancing economic development with pollution regulations will be key to minimizing the costly health impacts of lead exposure and continuing the encouraging global trend.

ECOSYSTEM VITALITY. Across the Ecosystem Vitality policy objective, we find that environmental performance has increased slightly. Global scores have increased 5.25 points relative to a baseline of 50.68. Despite this progress, the world is still far from achieving Ecosystem Vitality objectives; see Map 3-3. Key findings across the seven issue categories within the Ecosystem Vitality policy objective reveal areas of strong and weak performance in greater detail. These findings may be beneficial to policymakers, as they both characterize promising trends in environmental management and governance and identify areas in need of greater attention.

In **Biodiversity & Habitat,** the world has made great strides in protecting marine and terrestrial biomes, exceeding the international goal for marine protection in 2014. Additional indicators measuring terrestrial protected areas suggest, however, that more work needs to be done to ensure the presence of high-quality habitat free from human pressures.

For **Forests,** deforestation in a mall group of countries contributed substantially to increases in global tree cover loss. Fires, illegal logging, and land conversion for palm oil production and other agricultural purposes continue to threaten forest habitat in much of the world. Despite advances in remote sensing technologies, the lack of a universal definition for a forest and the absence

MAP 3-3 EPI SCORES FOR THE ECOSYSTEM VITALITY POLICY OBJECTIVE BY COUNTRY



Note: Darker shades indicate higher scores in Environmental Health.

of harmonized monitoring efforts limit the ability to assess the state of forests in a comprehensive manner.

Global trends in **Fisheries** scores indicate countries are increasingly harvesting fish from stocks that are overexploited or collapsed, while also targeting higher tropic-level species. A 7.28-point decline in fish stock status scores is of particular concern, as overfishing is the primary cause of decline in global fisheries. Formulation of new indicators that better characterize the impacts of fishing on marine ecosystems and expanded monitoring efforts that collect and report data in more detail will be essential to the preservation of global fish stocks, and the communities that rely on them.

In **Climate & Energy,** most countries improved GHG emission intensity over the past ten years. Three-fifths of countries in the EPI have declining CO_2 intensities, while 85-90% of countries have declining intensities for methane, nitrous oxide, and black carbon. These trends are promising yet must be accelerated to meet the ambitious targets of the 2015 Paris Climate Agreement.

Air Pollution scores for all countries have improved as global emissions intensities for both sulfur dioxide (SO_2) and nitrous oxides (NO_X) have fallen over a ten-year period. Despite progress at the global level, vast inequities between developed and developing countries persist. Countries with high coal consumption and large hydrocarbon reserves and refinery capacity continue to experience high levels of SO_2 and NO_X emissions relative to GDP.

In **Water Resources,** due to the limited availability of global wastewater treatment data, the global performance in wastewater treatment has not changed from the baseline. The spread in country performance is strongly related to economic development. Large amounts of missing data in global inventories indicate the difficulty of identifying wastewater treatment connection values in developing countries and underscore the need to ramp up infrastructure planning and data collection efforts to satisfy the targets in SDG 6 (water and sanitation).

In **Agriculture,** we find that much of the small improvement in nitrogen management over a ten-year period is the result of increased yields rather than increased efficiency. Mismanagement of nitrogen across the agricultural sector continues to threaten the health and sustainability of our natural resources. New indicators that better take into account regional variation in nitrogen use, country-specific benchmarks, and trade could improve global monitoring efforts.

With 20 years of experience, the EPI reveals a tension between two fundamental dimensions of sustainable development: (1) environmental health, which rises with economic growth and prosperity, and (2) ecosystem vitality, which comes under strain from industrialization and urbanization. Good governance emerges as the critical factor required to balance these distinct dimensions of sustainability.

OTHER FINDINGS. Better environmental measurement and indicators have great potential for guiding data-driven environmental policymaking. The 2018 EPI identifies areas for improvement in all areas. There have been some recent improvements, and technological progress in data collection has enabled better global monitoring of some environmental indicators. Data are still insufficient in some areas of high concern, preventing EPI from including measurements of issues such as freshwater quality, species loss, climate adaptation, and waste management when calculating each country's performance. Better data collection is needed to manage these resources for human and ecosystem health.

Actions that improve environmental performance often take place at the sub-national level. In large and diverse countries such as the United States, China, and Russia, performance on EPI indicators can vary regionally. As an example, due to differences in soil and unevenly distributed economic activity, the nitrogen use efficiency within each country will vary widely from region to region. National level measurements can therefore lose local relevance. Similarly, environmental impacts from pollution or resource extraction are not typically confined by political borders. Climate change highlights the fact that global environmental impacts are created by local activities. Using a country as the unit measure for environmental problems has advantages, but can obscure the realities of environmental performance.

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4

RETROSPECTIVE ON THE EPI

Environmental Performance Index

Two interconnected trends led to the launch of the Environmental Performance Index nearly twenty years ago: (1) dissatisfaction with the results of environmental policy efforts, and (2) recognition of the opportunity to make the environmental arena more data-driven and fact-based. Environmental policies based on anecdotal evidence, sensational events, hunches, and "gurus" drove too much of the policy agenda in the early days of the environmental movement, leading to misallocation of limited funds and less-than-stellar outcomes in many areas. The 20th-century laws and regulations began to reach diminishing marginal returns by the end of the 1990s. The pace of new efforts to control pollution and conserve natural resources slowed in the face of a backlash against environmental strategies perceived to be ineffective, costly, and out-of-touch (Glicksman, 2010).

At the same time, a second trend emerged, which offered a way to lift the green movement out of the doldrums. As data-driven approaches to decisionmaking revolutionized corporate performance and public management, the expansion of metrics, benchmarking, and better analytic foundations began to attract the attention of environmentalists. As early as the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, the logic of better metrics and data-driven decisionmaking emerged onto the global sustainability agenda. As Chapter 40 of Agenda 21 stated, "indicators of sustainable development need to be developed to provide solid bases for decisionmaking at all levels and to contribute to a self-regulating sustainability of integrating environmental and development systems" (UN, 1992). Following this declaration, environmental metrics and sustainable development indicators proliferated (Hampel, Issever Grochová, Janová, Kabát, & Střelec, 2016, p. 56; Wilson, Tyedmers, & Pelot, 2007, p. 299). The World Bank, the OECD, and the World Resources Institute all contributed, and the policy world followed suit with the world's major donor countries establishing the International Development Targets in 1996 (Levy, 2002, p. 12). Yet these diverse metrics lacked a unifying structure; unrelated and ungrouped, their impact on policymaking was muted. Three years after the Rio Conference, the world continued to lack the clarity that metrics had promised. Jonathan Lash, then president of the World Resources Institute, concluded, "there is no remotely similar number [to GDP] to indicate how the environment is fairing" (Hammond, Adriaanse, Rodenburg, Bryant, & Woodward, 1995, p. vii).

EMERGENCE OF THE EPI

The World Economic Forum (WEF) took up the cause of environmental metrics in 1999. Experience with data and metrics had already yielded fruitful products at WEF, as their global competitiveness rankings brought new insights into how countries compared in international commerce. Such experience inspired similar hope of a breakthrough for the environment. WEF founder and Chairman Klaus Schwab drew a dozen volunteers from ten countries out of the "Global Leaders for Tomorrow" program, the forerunner of the current WEF initiative, "Forum of Young Global Leaders." These leaders established an Environmental Task Force to bring sustainability to the attention of national policymakers and corporate executives, who gather for WEF's Annual Meetings in Davos, Switzerland. Capitalizing on the emerging environmental indicators, the task force sought to produce an Environmental Sustainability Index (ESI), analogous to WEF's competitiveness rankings. Condensing the unorganized array of metrics into a composite index would allow for ranking countries on their sustainability performance. These rankings would sharpen the focus of the global elite on the dimensions of sustainability and, in parallel, make environmental decisionmaking more data-driven and empirical. The task force commissioned one of its members, Yale professor Dan Esty, to develop a pilot ESI, with intellectual and financial support from WEF and its global partners.

Published in 2000, the Pilot ESI served as a proof-of-concept, demonstrating the feasibility and usefulness of a composite index for scoring and ranking countries on their sustainability performance (Esty, Levy, Granoff, & de Sherbinin, 2000). Subsequent versions of the ESI were released in Davos in 2001, 2002, and 2005 (Esty, 2001; Esty, Levy, Granoff, & de Sherbinin, 2002; Esty, Levy, Srebotnjak, & de Sherbinin, 2005) – each providing further evidence that the initial conclusions were correct and that there was an appetite among world policymakers for such an index.

As thinking about sustainability evolved, so too did the ESI. The year 2006 marked a significant shift in focus, with the publication of the Pilot Environmental Performance Index (EPI) (Esty et al., 2006). By changing from sustainability to performance, the EPI reframed the Yale-Columbia environmental metrics effort in three important ways (Esty & Emerson, 2018, pp. 96–97). First, the EPI sharpened its focus on issues that typically would fall under the purview of an environmental ministry rather than the broader — often too broad — sustainability agenda. Second, indicators from the ESI that measured endowments rather than performance, e.g., water availability, were dropped. The EPI would track matters over which policymakers had control, which helped to foster more productive discussions over environmental policy choices. Third and in a similar vein, the EPI was recast to focus on outcomes of environmental policy rather than drivers or policy inputs. New, improved versions of the EPI have been released biennially at Davos since the 2006 debut (Emerson et al., 2010, 2012; Esty et al., 2008; Hsu et al., 2014; Hsu, Esty, de Sherbinin, Levy, et al., 2016), with this 11th iteration in 2018 marking the 20th anniversary of the important work started by the WEF Environmental Task Force.

LESSONS FROM TWENTY YEARS

Over the course of two decades, several themes and lessons have emerged from the ESI and the EPI. First, the data and accompanying analyses reveal two distinct dimensions of the sustainability challenge. Environmental performance depends on both (1) investments in environmental infrastructure to manage waste and pollution, and (2) management of natural resources, which often come under strain as countries experience economic growth and industrialization. These divergent dimensions present policymakers with something of a dilemma: protecting environmental public health requires the prosperity that comes with economic growth, yet that same growth burdens ecosystem vitality as natural resources are consumed and pollution levels rise. Still, high performing countries — and those countries that have made substantial improvements in performance over time — demonstrate that this tension can be addressed if not fully resolved.

The second lesson from the ESI/EPI initiative is that rankings matter, i.e., countries respond to being graded on their environmental performance. Scorecards and leader lists grab the attention of policymakers in a way that an array of metrics — a dashboard of data — does not. Countries naturally compare themselves with their peers, whether based on geography, trade relationships, economic status, or other relevant criteria (Esty & Emerson, 2018, p.100). These comparisons show each country – issue-by-issue and at a variety of levels of aggregation — what kind of performance is possible. More importantly, such comparisons inspire competition for improvement in both high- and low-scoring countries.

Countries that score lower than policymakers expect typically progress through two stages of grief. First, they question the data and analysis used by the EPI team. But the EPI's commitments to transparency, openness, and constructive criticism often put any unfounded concerns to rest. Once satisfied about analytical rigor and accuracy, countries then move on to a second phase in which they engage with the data: trying to understand why they might have under-performed and how to do better in the future. Policymakers and other stakeholders may find that their expectations were confounded by a lack of attention on their most pressing environmental challenges. By relying on measure of outcomes rather than inputs, the EPI ensures that the discussions also focus on the effectiveness of policies. The EPI helps to ensure better environmental investments and more productive agendas in environmental policy.

IMPACTS ON COUNTRIES

By sparking curiosity and engaging policymakers with the data on environmental performance, the EPI affects countries at all levels of performance in concrete ways. Several countries have reached out to the EPI team over the years to better understand their scores, subsequently recasting their national approach to environmental policy, including Belgium, Mexico, South Korea, China, Malaysia, Norway, Turkey, Singapore, Chile, Costa Rica, Iraq, New Zealand, Slovakia, and the United Arab Emirates. In Belgium, for example, a ranking in 125th place out of 146 countries in the 2002 ESI shocked the policy community and media. Lagging so far behind peers like France, Germany, and the Netherlands, the data prompted a serious elevation of the environment on Belgium's policy agenda (Esty, 2018, p. 500).

Perhaps more dramatically, South Korea also ranked poorly on the 2002 ESI. With an overall rank of 136th—and 120th out of 122 countries on air quality—the government responded with the creation of the "136 Forum" in early 2003. A consortium of national ministries, municipal governments, nongovernmental organizations, and private sector companies, the 136 Forum sought to address several issues related to the environment and development (AIEES, 2012a, 2012b). Over the course of 40 regular meetings and 50 special project events, South Korea responded forcefully, with the creation of a national Air Quality Index based on increased air quality monitoring in Seoul and 27 other cities (AIEES, 2012a, 2012b). Concrete steps to reduce air pollution came in the form of more stringent standards, subsidies for low-emission technologies, new municipal transportation options, and investments in parks and other urban greenspaces (AIESS, 2012a). The ESI sounded a valuable wake-up call to a country that had neglected pressing environmental problems to its own peril.

Other countries have likewise been inspired by the ESI and EPI. In 2002, the United Arab Emirates ranked 141st on the ESI, prompting Abu Dhabi to launch the Global Environmental Data Initiative (AGEDI), a project dedicated to providing policymakers with, "actionable, timely information to inform and guide critical decisions," and to facilitate information sharing between the Abu Dhabi Environment Agency and the UN Environment Programme (PUC, 2017). Abu Dhabi made further efforts to track national progress toward environmental targets in July 2008, using the EPI methods to evaluate data (Fischer et al., 2009). Similarly, the 2010 EPI prompted the Department of Environment for Malaysia to develop two new tools, the Air Pollution Index and the River Water Quality Index, "aimed at providing valuable information to improve awareness and monitor change over time" (Bin Ahamed & Bahru, 2013, p. 13). EPI methods have been deployed at the state and provincial level in Mexico, China, India, Vietnam, the Basque Autonomous Community, and elsewhere (Esty et al., 2010; Hsu, 2018; Zomer & Hsu, 2015; Zuo, Hua, Dong, & Hao, 2017), demonstrating the usefulness of data-driven performance assessment at a variety of spatial scales. The process of using data to set priorities, frame agendas, and track progress has grown in popularity around the world.

METHODOLOGICAL SOPHISTICATION

The EPI evolves with each iteration, taking advantage of the latest advances in environmental science and reflecting the latest thinking on sustainability. Beyond the shift from the ESI to the EPI, other methodological lessons have emerged from two decades of experience. In constructing a composite index of environmental performance, several refinements prove to be important (Esty & Emerson, 2018, pp. 97–99).

- **Standardization.** Without considering important differences between countries, for examples, with respect to size, population, or level of economic development, raw data may not be comparable. Metrics need to be carefully standardized.

- **Targets.** By anchoring indicator scores to established goals or targets drawn from international agreements, policy guidelines, or scientific consensus, the EPI provides a gauge of global as well as national performance. The distance-to-target method allows analysts to distinguish between issues where national performance varies widely to ones where nearly everyone is doing poorly or well.

- **Scrutiny.** All datasets have anomalies and problems, so all data need to be carefully screened for outliers or potential errors that could lead to incorrect conclusions (e.g., Srebotnjak, 2007, p. 408). Carefully curating the data produces more accurate and high-impact metrics and rankings.

- **Winsorization.** Extreme values at either end of the scale can distort the overall distribution of scores. In these cases, trimming the tails is a useful corrective, ensuring a more meaningful array of metrics and scorecards.

- **Polarity.** Higher or lower raw values among variables may indicate better or worse outcomes for the environment depending on the context. Every metric needs to be scaled for a positive polarity, meaning higher scores signal better performance — an essential step for further aggregation.

- **Trends.** Longitudinal data are more powerful than snapshots, as trends help to reveal changes that may be just as or even more important than current status. Moreover, top-tier nations with declining performance need to focus on the negative trend rather than resting on their laurels on a static snapshot.

Further details about how these lessons apply to the 2018 EPI are described in Chapter 2, in the online Technical Appendix, and throughout the chapters describing indicators used in each issue category.

Of highest importance to producing sophisticated composite indices is the careful selection of which indicators to include in the EPI. Foremost among the inclusion criteria (see Chapter 2) is identifying indicators that are relevant to policymakers (Esty & Emerson, 2018, pp. 94–95; Srebotnjak, 2007, p. 413). When an issue category lacks indicators of outcomes, then proxy measures, i.e., indicators of some intermediate or correlated phenomenon, can still provide useful information. The EPI has long used protected areas, for example, to measure biodiversity performance, as habitat protection is strongly correlated with biodiversity preservation. When used, the EPI explains the logic behind the inclusion of such proxies so that the relevance to policymaking is clear.

Indeed, one of the hallmarks of the ESI and EPI has been a commitment to openness and transparency about data, methods, assumptions, and limitations. All the data used in the EPI is published online, as is documentation about the data sources and methodology. Such transparency is critical to establishing the credibility of the EPI. Exposing the analysis to scrutiny has the further benefit of soliciting constructive criticism. In humility, the EPI is a work in progress, and suggestions and critiques from policymakers, scientists, and advocates prompt many of the advances in EPI methods. Sensitivity analyses further test the assumptions behind the EPI, highlighting which steps in the computation might be driving results rather than the data. Where others may disagree on key assumptions, the online data allow critics to re-run the analysis themselves and create results that may be more useful for their policy questions. Such flexibility is essential to the evolution and continuous improvement of the EPI.

GLOBAL DATA SYSTEMS

Comprehensive data collection ensures that composite indices are most useful in identifying lagging indicators and directing attention toward pressing environmental problems. Even at the dawn of the interest in data-driven sustainability, the 1992 Rio Conference recognized gaps in data availability, poor data quality, and disparate levels of collection among countries (Srebotnjak, 2007, p. 408). These data problems hamper sustainability efforts to this day. The Inter-Agency and Expert Group on SDG Indicators classifies three-fifths of the 232 indicators under consideration to be lacking conceptual clarity, internationally established methodology and available standards, or regular collection by most countries (2018). The EPI consistently identifies gaps in several critical issue categories — areas of great importance to policymakers for which we have no good data or useful proxies. These areas include:

- **Sustainable agriculture and soil health**
- **Water quality** (sedimentation as well as organic and industrial pollutants)
- **Water quantity**
- **Invasive species**
- **Genetic biodiversity**
- **Wetlands and other freshwater ecosystems**
- **Municipal, hazardous, and nuclear waste management**

Data gaps persist for several reasons, including the difficulties in direct measurement; costs of data collection; lack of established, methodologically rigorous protocols; inconsistencies across time or jurisdictions; or lack of policy capacity (Emerson et al., 2010; Hsu, 2015; Srebotnjak, 2007, p. 408).

Yet new prospects for filling these gaps emerge every year. New advances in big data analytics, remote and distributed sensing, citizen science, and machine learning offer avenues to capture the kinds of data important to environmental policymaking. Scientists, governments, and researchers publish promising studies that can be characterized as pilot metrics, many of which are described throughout this report; see, e.g., Focus 4-1 on an attempt to gauge waste management. To be truly useful, though, these pilot metrics require institutional support, turning studies into global data systems with dedicated funding streams and established methodologies for data collection, reporting, and verification. As part of its mission of advancing data-driven environmental policymaking, the EPI team has consistently called attention to where greater global effort can make a difference in closing these gaps.

FOCUS 4-1 PILOT INDICATOR: MUNICIPAL SOLID WASTE

With rising populations and urbanization, waste generation is expected to increase around the world and create serious health and environmental problems (World Bank, 2017). These problems include the spread of diseases, greenhouse gas emissions, and hazardous soil and water contamination (2017). While global data currently do not meet the requirements for inclusion as an indicator in the EPI, governments should still focus attention on improving their municipal solid waste (MSW) management (Hoornweg & Bhada-Tata, 2012). Improving MSW management would address multiple sustainable development goals. By examining how countries handle their MSW, policymakers can pursue effective measures to minimize waste's adverse impacts.

Waste management is especially relevant to SDGs 11 and 12. These Goals are aimed at sustainable and resilient cities and responsible patterns of production and consumption (UN, 2015). In low-income countries, waste is often openly burned or sent to unregulated dumps, threatening the health and safety of nearby residents (World Bank, 2017). In places where wealth is increasing, so is material consumption and the amount of waste per capita that is generated (World Bank, 2012).

- **SDG GOAL 11.** Make cities inclusive, safe, resilient, and sustainable.
- **SDG GOAL 12.** Ensure sustainable consumption and production patterns.

Poorly managed waste has significant environmental impacts on local and global environments (Bhada-Tata & Hoornweg, 2016; OECD, 2008). For instance, solid waste is a major contributor to climate change, accounting for at least 3–5% of greenhouse gas emissions worldwide. The decomposition of organic waste alone accounts for 11% of global methane emissions. In addition to contributing to climate change, the emission of pollutants like black carbon from openly burning waste promotes respiratory illness (Bhada-Tata & Hoornweg, 2016). Lack of proper containment is another challenge, allowing harmful chemicals from landfills to contaminate soils as well as ground and surface water. Such open waste sites are also breeding grounds for disease vectors and, with flooding, can lead to water-borne outbreaks of infectious diseases. Finally, solid waste is one of the largest sources of pollution in the oceans. By 2050, the World Economic Forum predicts there will be more plastic (by mass) than fish in the oceans (Bhada-Tata & Hoornweg, 2016). The generation and disposal of waste must be properly managed to prevent these negative environmental and health impacts.

Assessing data on municipal solid waste is an important but challenging part of evaluating a country's performance on waste management. Incomplete or inconsistent national data on waste generation, collection, and disposal make comparing countries exceedingly difficult. Where data do exist, differences in units, methodologies, and sources exacerbate inaccuracies. Further limitations stem from confounding definitions and differing compositions of waste (Bhada-Tata & Hoornweg, 2016). To accurately assess waste management on a global scale, the reliability of MSW information must be strengthened. This is of particular concern in low- and middle-income countries where solid waste data is further compromised by the lack of financial resources and waste management infrastructure (Hoornweg & Bhada-Tata, 2012, p. 32).

Despite gaps in global data, efforts are underway to collect and analyze global MSW information. The United Nations University's (UNU) global e-waste research initiative, the Sustainable Cycles (SCYCLE) program, is building country capacity to develop e-waste legislation and management strategies, as well as collecting high-quality e-waste data (United Nations University, 2015). The UNU's report *Global E-waste Monitor 2014* is the basis for the UN Sustainable Development Solutions Network's e-waste indicator — a new addition to the SDG Index and Report for 2017 (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017). In January 2017, the UNU also released its inaugural region-specific report, *Regional E-waste Monitor: East and Southeast Asia*. The report highlights the rapid generation of e-waste in the region. In just five years, e-waste volumes increased by 63% (Honda, Sinha Khetriwal, & Ruediger, 2016). These research efforts and the pilot indicators they have produced are important foundations for the creation of a global data system on solid waste management. Additional attention and support are needed to develop truly comprehensive metrics that can be used to track environmental performance in the future.

As a pioneer in composite indices of sustainable development, the EPI now inhabits an ecosystem of related projects. Drawing inspiration, lessons, and data from the ESI and the EPI, researchers have produced many composite indices that play important roles in shaping global discussions on the environment as an essential element of human well-being across many domains. The list below samples the breadth and reach of these sustainable development indicators, and Focus 4-2 illustrates the emergence of new directions for understanding environmental progress.

Human Development Index, "a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable, and have a decent standard of living." UN Development Programme. http://hdr.undp.org/en/content/human-development-index-hdi

Happy Planet Index, "tells us how well nations are doing at achieving long, happy, sustainable lives." New Economics Foundation. https://happyplanetindex.org/

Living Planet Index, "a measure of the state of the world's biological diversity based on population trends of vertebrate species from terrestrial, freshwater, and marine habitats." Zoological Society of London and World Wildlife Fund for Nature. http://www.livingplanetindex.org/home/index

Social Progress Index, measures, "the capacity of a society to meet the basic human needs of its citizens, establish the building blocks that allow citizens and communities to enhance and sustain the quality of their lives, and create the conditions for all individuals to reach their full potential." Harvard Institute for Strategy & Competitiveness. https://www.isc.hbs.edu/research-areas/Pages/social-progress-index.aspx

Legatum Prosperity Index, "describes the conditions required for prosperity. We describe these conditions as the combination of nine pillars: Economic Quality, Business Environment, Governance, Personal Freedom, Social Capital, Safety and Security, Education, Health, and the Natural Environment." The Legatum Institute. https://www.prosperity.com/

Environmental Vulnerability Index, "designed to be used with economic and social vulnerability indices to provide insights into the processes that can negatively influence the sustainable development of countries." South Pacific Applied Geoscience Commission (SOPAC), the UN Environment Programme, et al. http://www.vulnerabilityindex.net/

Sustainable Society Index, measures the sustainability of a country by integrating indicators of human, environmental, and economic wellbeing. Sustainable Society Foundation. http://www.ssfindex.com/

Global Liveability Index, "quantifies the challenges that might be presented to an individual's lifestyle in 140 cities worldwide. Each city is assigned a score for over 30 qualitative and quantitative factors across five broad categories of Stability, Healthcare, Culture and environment, Education and Infrastructure." The Economist Intelligence Unit. https://www.eiu.com/topic/liveability

Sustainable Development Goal Index, "provides a report card for country performance on the historic Agenda 2030 and the Sustainable Development Goals." Sustainable Development Solutions Network. https://www.sdgindex.org/

Ocean Health Index, "a measure of ocean health across countries and high seas regions." http://www.oceanhealthindex.org/

Notre Dame Global Adaptation Index, "summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience." Notre Dame Global Adaptation Initiative. https://gain.nd.edu/our-work/country-index/

Good Country Index, "to measure what each country on earth contributes to the common good of humanity, and what it takes away, relative to its size." https://www.goodcountry.org

Resource Governance Index, "measures the quality of resource governance in 81 countries that together produce 82 percent of the world's oil, 78 percent of its gas and a significant proportion of minerals, including 72 percent of all copper." Natural Resource Governance Institute. https://resourcegovernanceindex.org/

Global Green Economy Index, "uses quantitative and qualitative indicators to measure how well each country performs on four key dimensions: leadership & climate change, efficiency sectors, markets & investment and the environment." Dual Citizen LLC. https://www.dualcitizeninc.com/global-green-economy-index/

Environmental Democracy Index, "measures the degree to which countries have enacted legally binding rules that provide for environmental information collection and disclosure, public participation across a range of environmental decisions, and fair, affordable, and independent avenues for seeking justice and challenging decisions that impact the environment." World Resources Institute. https://environmentaldemocracyindex.org/

Global Aquaculture Performance Index, "a tool to empower seafood industry leaders and policy makers to make informed decisions about the environmental costs and benefits of farmed marine finfish." Seafood Ecology Research Group at the University of Victoria. http://web.uvic.ca/~gapi/about.html

FOCUS 4-2 PROTECTING THE ENVIRONMENT: IMPLEMENTATION OF GLOBAL ENVIRONMENTAL CONVENTIONS

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Countries around the world have taken on international commitments to protect and preserve the environment. To safeguard species, ecosystems, and human health, governments have created international agreements that guide their national behavior to regulate pollution and manage conservation. Examples include the Stockholm Convention, which regulates persistent organic pollutants, and the Basel Convention, which regulates hazardous waste. Several conventions safeguard biodiversity by protecting specific ecosystems or by protecting species from specific problems, such as the Ramsar Convention on wetlands or the Convention on International Trade in Endangered Species (CITES).

Implementing obligations under conventions reflects the extent to which countries are committed to environmental protection and shows good governance. Globally, the level of implementation has not been empirically measured and is largely unknown. As a result, there is no baseline against which to assess performance, actions, or even expectations. Without empirical evidence, we risk erroneous conclusions. Importantly, in the absence of measurement of implementation, it is impossible to determine whether the conventions solve the problems they were created to address.

To bridge this gap, we developed the Environmental Conventions Index (ECI), an empirical tool to measure the implementation of global environmental conventions that enables self-assessment and comparison with peers. The quantitative analysis of the ECI is grounded in the national reports submitted by state parties to each convention from 2001 to 2015. At this point the analysis is performed for four agreements: The Basel Convention on the Transboundary Movement of Hazardous Waste (1989), the Stockholm Convention on Persistent Organic Pollutants (2001), the Ramsar Convention on Wetlands of International Importance (1971), and CITES (1973). The analysis can be expanded over time to include other agreements such as the Convention on Biological Diversity, the Convention on Migratory Species, the UN Framework Convention on Climate Change, the UN Convention to Combat Desertification, and the World Heritage Convention.

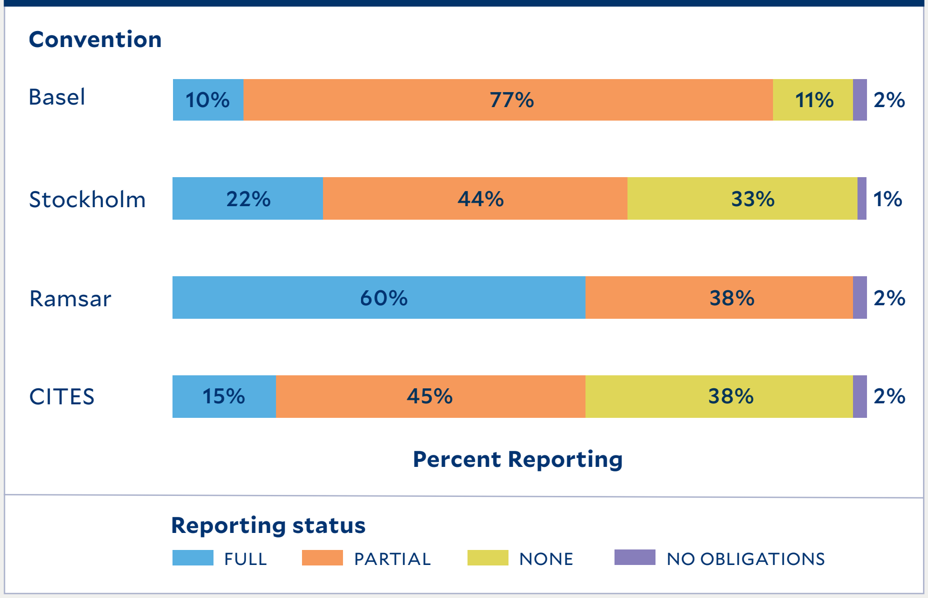
Environmental conventions introduce obligations for parties to report on their compliance with and implementation of the provisions established by each agreement. The parties to each treaty determine the type of information they want to collect through national reports, including the measures that they have taken, and establish the office or executive body to which the reports are to be submitted. National reports contain two types of information. First, they report on the legal, administrative, and policy measures that state parties adopt or intend to adopt to implement each agreement. Second, they report scientific data on the state of the environmental problem addressed by each convention at the national level.

Designing the ECI involved a multi-stage process to obtain information to assess implementation and develop a methodology that assures replicability across environmental conventions. We began by identifying the reporting obligations and commitments by state parties. To do this, we collected 2,754 national reports among the four agreements, reflecting responses to a total of 2,184 questions regarding implementation of the conventions. These data are categorized into indicators of obligations, including information, regulation, management, technical, and financial. Country reports are scored from 0–5 for each indicator, with 5 noting full implementation and 0 noting failure to report. These indicator scores are then aggregated to form a composite index for each country, though sub-scores by category are also feasible. Like the Environmental Performance Index (EPI), countries can be ranked by their ECI, both globally and regionally.

Reporting is a challenge in all conventions. As Figure 4-1 illustrates, the average reporting rates for all four conventions show that additional efforts are required. Reporting under the Ramsar Convention, however, is significantly higher than for any of the other conventions. Indeed, 60% of the parties to the Ramsar Convention have fully complied with all their reporting obligations since 2005. All parties to the convention have submitted at least one report during this period, including countries that joined after 2012, such as South Sudan, Swaziland, and Zimbabwe.

Implementation across the conventions varies. No one country shows the same performance across all conventions. Nevertheless, the findings reveal dynamics that demand further research and analysis and could offer

FIGURE 4-1 COMPLIANCE WITH NATIONAL REPORTING OBLIGATIONS BY CONVENTION



important case studies of best practices. Notably, several countries emerge as top performers. Higher level of development seems to be positively correlated with the implementation of the chemicals agreements — the Basel and Stockholm Conventions. In the biodiversity conventions, developing countries register high levels of implementation. Among the 12 countries with the top ten scores for the Ramsar Convention, nine are developing countries, and four of these — Mali, Uganda, Egypt, and Kenya — are in Africa. For CITES, countries such as the Philippines, Peru, Mozambique, and Nepal, rank among the top performers.

Ultimately, the ECI seeks to measure, explain, and improve the level of implementation across global environmental conventions with the hope of improving their effectiveness in resolving the global risks they were designed to address. To this end, it will be critical for national governments to engage with these findings and commit to improving performance.

In 2016, the research team carried out a project sponsored by the UN Environment Programme on assessing the implementation of global environmental conventions in ten countries around the world: Algeria, Argentina, Australia, Canada, Colombia, Czech Republic, Germany, Mozambique, the Republic of Korea, and Thailand. The project's results confirmed the relevance of the ECI as an innovative assessment tool. They showed that positive results correspond to the existence of governance instruments such as regulation and policy frameworks as well as specific initiatives. Relatedly, countries with lower scores face challenges with these same issues.

We also conducted a project, in partnership with the Yale Center for Environmental Law & Policy, to evaluate the relationship between the ECI scores and the EPI scores in selected East African countries. The ECI finds that Djibouti, Ethiopia, Kenya, Rwanda, Uganda, and Tanzania register different levels of progress toward fulfillment of their respective obligations under the environmental conventions. The ECI implementation results correlate with their environmental performance scores in the EPI. Countries that register progress in environmental performance regarding ecosystem vitality, such as Tanzania and Kenya, also have positive results in the implementation of the biodiversity conventions. Both countries are part of the top performers in the implementation of international commitments to protect wetlands, ranking 2nd and 4th in the region. Similarly, countries that are struggling with the implementation of the chemicals conventions register low levels of performance in terms of environmental health in the EPI.

Through engagement with the ECI, additional in-depth case studies could be developed to show the outcomes that individual countries attain and the impact on the state of the environment. In the context of the new United Nations 2030 Agenda for Sustainable Development, learning from the national implementation of the global environmental conventions would be critical to enhancing the ability to achieve the Sustainable Development Goals (SDGs). Countries can identify best practices and chart a course for the implementation of commitments under the SDGs that builds on the institutions already in place to ensure environmental protection under the global environmental conventions.

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LEGACY OF THE EPI

While the EPI continues to evolve as a robust and comprehensive tool for tracking environmental performance, twenty years of experience have already generated lasting contributions to the global approach to sustainable development. As environmental policy shifted away from its unsteady origins by the end of the 20th century, policymakers and other stakeholders became more interested in evidence-based decisions and demanded the data to support them. The EPI arose in response to these needs, emerging as the premier index of sustainability metrics. Combining data on environmental performance into composite scores and — more importantly — generating a global ranking of countries proved to be powerful developments in shaping policy agendas. Allowing countries to compare their EPI scores to their peers' grabs the attention of policymakers and inspires competition toward ever better performance. Several countries have used the EPI to guide national environmental agendas, to recast their approach to policymaking, and to develop better data frameworks for understanding the outcomes of those policies — including an enduring interest in subnational indices. The EPI has grown more methodologically sophisticated over the past twenty years, in the spirit of pulling the latest scientific advances into smarter governance. The global push for better environmental data systems brought about new datasets, broader issue coverage, and more consistent data collection and reporting. Still, the EPI recognizes the remaining data gaps and highlights areas where more attention from policymakers and scientists would bring about the greatest improvements in our understanding of the state of the environment and the outcomes of policy actions. The push for new and better data corresponds with a commitment by the world community to data-driven environmental policymaking. The 2015 Sustainable Development Goals illustrate this commitment, fixing metrics at the heart of the policy process, in both setting international targets and tracking progress toward them. Through rigorous, transparent data analytics, the EPI has led the way to environmental policymaking that is today more informed, focused, and effective.

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5

AIR QUALITY

Environmental Performance Index

Air Quality

SNAPSHOT

Air pollution affects individuals across all countries and socio-economic groups.

CATEGORY DESCRIPTION

Indoor and outdoor air pollution are leading threats to human health (WHO, 2006b, p. 87). Air pollution is produced by the natural or human-caused release of harmful contaminants into the atmosphere (WHO, 2014a). Air pollution is a global issue, affecting individuals across all countries and socioeconomic groups (WHO, 2016a). The EPI uses three indicators to measure air quality: **household solid fuels, $PM_{2.5}$ exposure,** and **$PM_{2.5}$ exceedance.**

Particulate matter (PM) exposure is associated with significant adverse health effects (Kloog, Ridgway, Koutrakis, Coull, & Schwartz, 2013; WHO, 2016a). These particulates can penetrate the human lung, leading to higher incidences of cardiovascular and respiratory disease (Goldberg, 2008). Recent research suggests that around 5 million people die prematurely every year due to air pollution, accounting for approximately one in every ten deaths annually (World Bank & IHME, 2016). Reducing air pollution levels globally can therefore improve human health today and in future generations.

INDICATORS INCLUDED

Household solid fuels. We measure household air pollution (HAP) as the health risk posed by the incomplete combustion of solid fuels, using the number of age-standardized disability-adjusted life-years (DALYs) lost per 100,000 persons due to this risk. **$PM_{2.5}$ exposure.** As a measure of chronic exposure, we use the population-weighted average ambient concentration of $PM_{2.5}$ in each country.

$PM_{2.5}$ exceedance. As a measure of acute exposure, we use the proportion of the population in each year that is exposed to ambient $PM_{2.5}$ concentrations that exceed World Health Organization (WHO) thresholds of 10, 15, 25, and 35 micrograms per meter cubed (µg/m^3) (2016a). These four proportions are averaged to produce a summary of the distribution of exposure levels in the country's population.

AIR QUALITY INDICATORS	
Household solid fuels	DALY rate
$PM_{2.5}$ exposure	µg/m^3
$PM_{2.5}$ exceedance	% population

CATEGORY OVERVIEW

Air pollution's widespread and substantial effects on human and environmental health make it an issue of global concern.

Exposure to airborne pollution is the fourth leading cause of premature death globally (World Bank & IHME, 2016, p.22). According to a recent study conducted by the World Bank and the Institute for Health Metrics and Evaluation (IHME), approximately 5.5 million people die prematurely from air pollution each year (2016, p. 22). Most of these deaths stem from respiratory diseases; even in small amounts, air pollution may reduce the quality of one's overall health (Goldemberg et al., 2000; World Bank & IHME, 2016; WHO, 2006b).

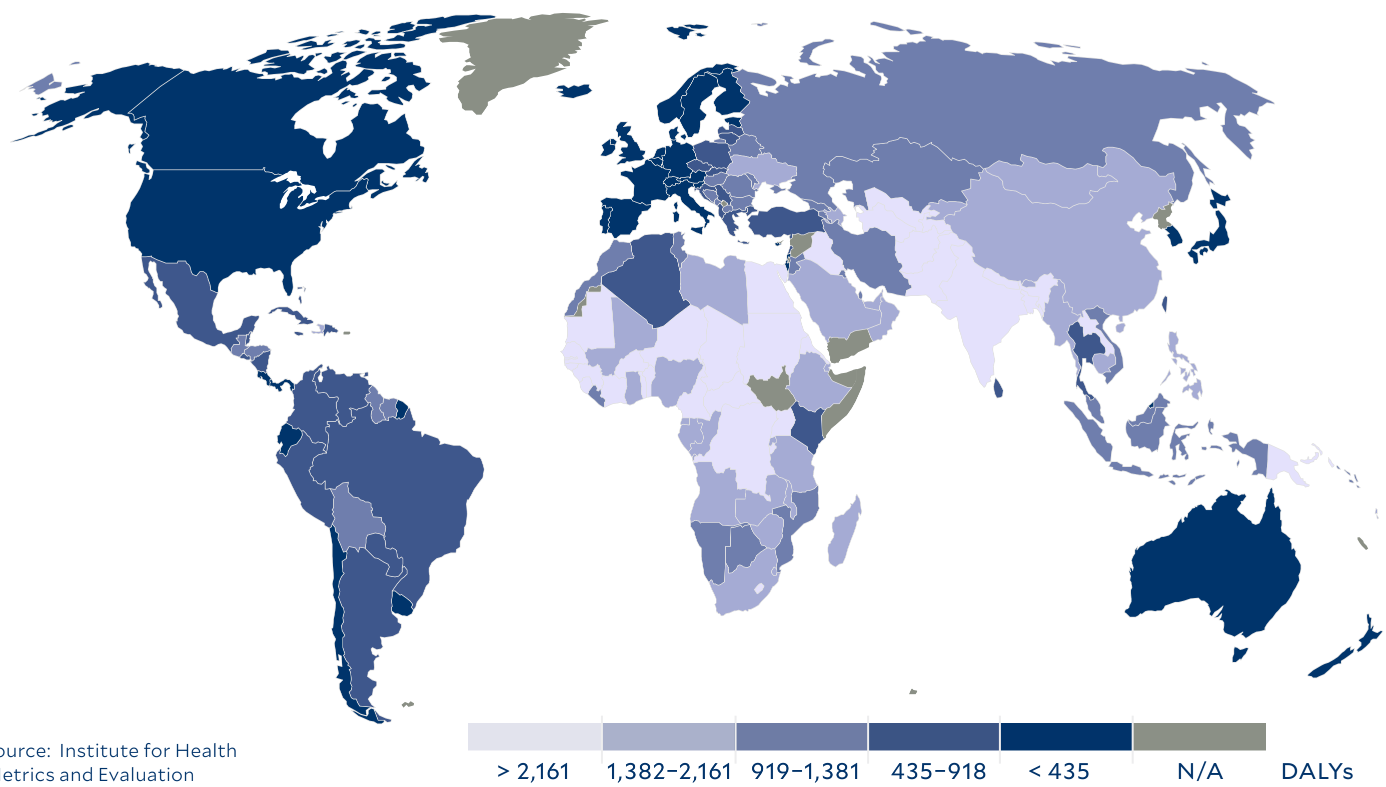
While air pollution consists of a mix of different pollutants, PM is among the of particulate emissions, which causes significant amounts of age-standardized DALYs worldwide, as seen in Map 5-2 (next page, bottom; Desai, Mehta, & Smith, 2004, pp. 8-10). The WHO estimates that incomplete combustion in these households can have fine particle concentrations up to 100 times higher than acceptable levels (2016a). Reducing air pollution in the home will bring substantial health and development benefits.

ENVIRONMENTAL. Air pollution harms the environment many ways. Pollutants can mix in the air or with rain and accumulate on plants, soils, and water. Examples of such impacts are discussed in Table 5-1.

SOCIAL. Impacts from air pollution have serious consequences for public health and well-being. Adverse health effects occur from exposure to pollutants even at lower concentrations (WHO, 2014a, p.1). In 2013, WHO's International Agency for Research on Cancer established that outdoor air pollution is carcinogenic to humans (WHO, 2013, p.1). In combination, $PM_{2.5}$, nitrous oxides (NO_X), and volatile organic compounds (VOCs) interact to form ground-level ozone, which is a highly toxic and reactive pollutant (WHO, 2014b). Sulfur dioxide (SO_2) and NO_X can transport far distances and react in the atmosphere to form very fine nitrate and sulfate particles (Lockwood, 2009). The burden of air pollution is thus a major challenge to sustainability.

ECONOMIC. Air pollution has significant costs for society by damaging people's health. According to a joint study conducted by the World Bank and the IHME, air pollution cost the global economy approximately US$225 billion in 2013 alone due to lost labor, and about US$5 trillion per year as a result of productivity losses and a degraded quality of life (World Bank & IHME, 2016, pp. 50, 52).

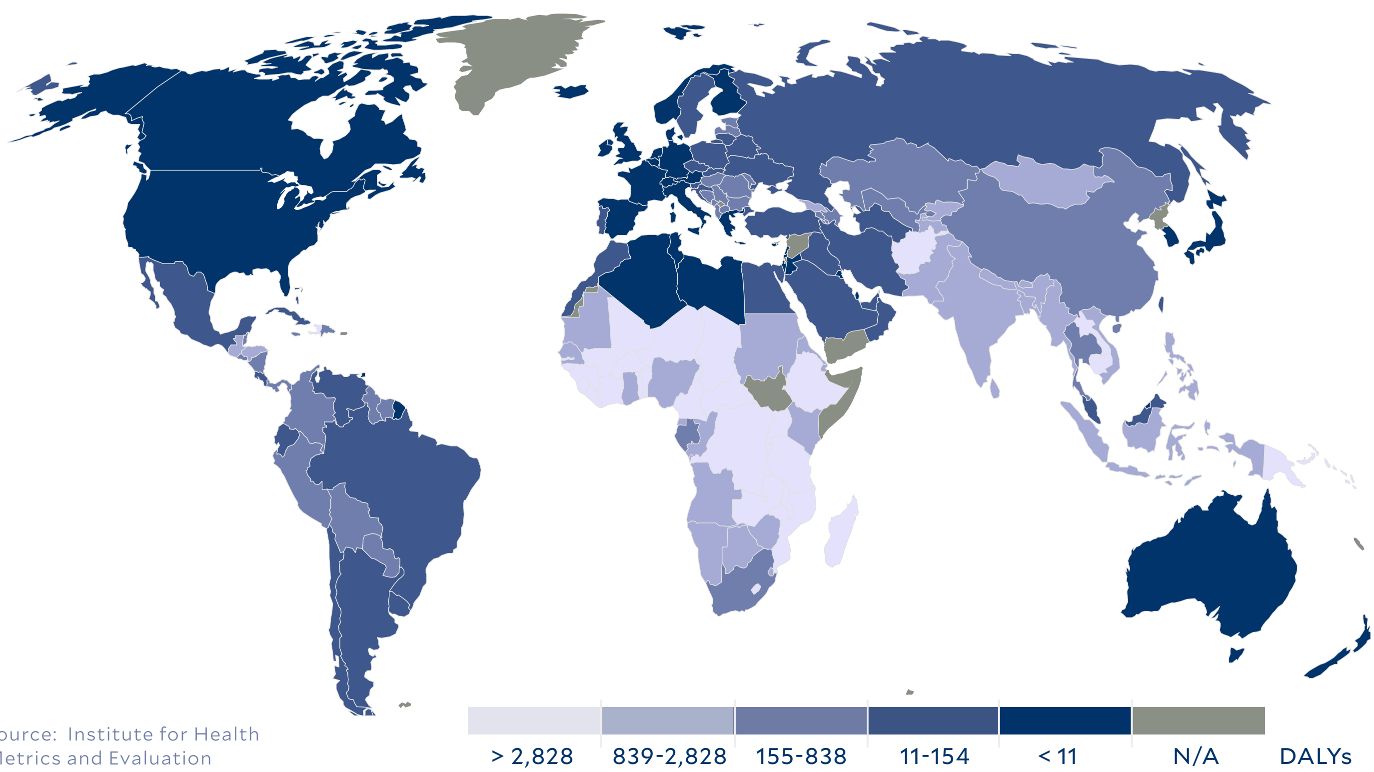
MAP 5-1 DISABILITY-ADJUSTED LIFE-YEARS (DALYs) LOST DUE TO $PM_{2.5}$ IN 2016



Source: Institute for Health Metrics and Evaluation

TABLE 5-1 ENVIRONMENTAL IMPACTS FROM AIR POLLUTION	
Acid rain	Acid rain is precipitation that contains significant amounts of nitric and sulfuric acids. These acids are formed through nitrogen oxides and sulfur oxides that are released into the air.
Eutrophication	Eutrophication is a process in which excess nutrients exacerbate blooms of algae in water. The increase in algae blooms has the potential to kill fish and cause a loss of plant life (Chislock, Doster, Zitomer, & Wilson, 2013).
Ground-level ozone	Ground-level ozone can lead to decreases in crop and tree productivity, abridged growth of trees, and a greater susceptibility of plants to disease and pests (Pope & Dockery, 2006).
Haze	Haze is caused when sunlight comes into contact with pollution particles in the air, reducing our visibility (EPA, 2006).

MAP 5-2 DISABILITY-ADJUSTED LIFE-YEARS (DALYs) LOST DUE HOUSEHOLD SOLID FUEL USE IN 2016



Source: Institute for Health Metrics and Evaluation

The pervasive social and environmental impacts of air pollution make it an important marker for sustainable development across all levels of economic development.

The drivers behind pollution differ by economic structure, however, and developing countries have different problems from developed countries. Air pollution is an important indicator for environmental quality and public health in developing regions, as economic expansion contributes to higher pollution levels (World Bank & IHME, 2016). Differences in the sources and severity of air pollution across country income groups require different solutions. Some nations, for example, should prioritize access to clean fuels, while others should concentrate efforts on emissions abatement in key sectors.

To improve public health and well-being, access to clean and affordable energy is necessary, especially for women and children in developing regions (Desai et al., 2004). Globally, almost 3 billion people continue to depend on solid fuels for cooking and heating (WHO, 2014a), including 90% of the rural sub-Saharan African population and 75% of the rural population in China and India (Pachauri, Rao, Nagai, & Riahi, 2012). Women and children experience the highest exposure levels from HAP due to their customary household roles (Pachauri & Rao, 2013; WHO, 2014a, p.1). Data further suggest that exposure to HAP during pregnancy increases the risk of stillbirth, early birth, lower birth weight, and stunting of children (WHO, 2017).

SUSTAINABLE DEVELOPMENT GOALS

GOAL 3 Ensure healthy lives and promote well-being for all at all ages.

TARGET 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.

GOAL 7 Ensure access to affordable, reliable, sustainable, and modern energy for all.

GOAL 9 Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

TARGET 9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.

GOAL 11 Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11.1 By 2030, ensure access for all to adequate, safe, and affordable housing and basic services, and upgrade slums.

TARGET 11.6 By 2030, reduce the adverse per capita environmental impact of cities, such as by paying special attention to air quality and municipal and other waste management.

GOAL 12 Ensure sustainable consumption and production patterns

TARGET 12.2 By 2030, achieve the sustainable management and efficient use of natural resources.

TARGET 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment.

TARGET 12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

INTERNATIONAL ORGANIZATIONS

Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). The CCAC was launched by the United Nations Environment Programme along with six countries to raise awareness and reduce short-lived climate pollutants in order to protect health, agriculture, and the environment. http://ccacoalition.org/en

Global Alliance for Clean Cookstoves (GACC). The GACC is a nonprofit organization operating under the UN to improve indoor air quality. One of the group's key objectives is for 100 million homes to adopt clean stoves and fuels by 2020. https://www.cleancookingalliance.org/

Sustainable Energy for All (SEforALL). SEforALL was launched by the UN and works to ensure universal access to modern energy services, double the global rate of improvement in energy efficiency, and double the share of renewable energy in the global energy mix by 2030. https://www.seforall.org

United Nations Environment Programme (UNEP). The UNEP is the agency within the UN to coördinate and implement environmental actions. As one of its many duties, the UNEP works to implement the SDGs. https://www.unenvironment.org

United Nations Children's Fund (UNICEF). UNICEF's environment team works in over 190 countries and territories to improve the lives of children globally. https://www.unicef.org/environment/

World Health Organization (WHO). The WHO is a specialized agency of the UN working on international health initiatives. One of WHO's health topics of focus is the public health impacts of air pollution. https://www.who.int/airpollution/en/

MULTILATERAL EFFORTS

Clean Cooking Forum 2017 (CCF). The UN Foundation's Global Alliance for Clean Cookstoves held its forum in New Delhi, India in October 2017. www.cleancooking2017.org

Global Platform on Air Quality and Health (Global Platform). The Global Platform is WHO's collaboration with organizations working to implement and monitor air pollution abatement strategies. The Global Platform convened in 2014 and 2015 to "systematically consolidate data on air quality and health by bringing together information on air pollution exposure from different sources." The final reports of these consultations are expected to be released soon. https://www.who.int/phe/health_topics/outdoorair/global_platform/en/

Global Strategy for Women's, Children's and Adolescents' Health, 2016-2030 (The Global Strategy). The Global Strategy is a collaboration led by the WHO working to put women, children and adolescents at the center of the SDGs. The Global Strategy focuses on improving access to clean sources of household energy. http://www.who.int/lifecourse/partners/global-strategy/global-strategy-2016-2030/en

WHA68.8: Health and the environment. Addressing the health impacts of air pollution: Delegates at the World Health Assembly adopted Resolution WHA68.8 to address the impacts of air pollution, identifying air pollution as the world's largest single environmental risk. apps.who.int/gb/ebwha/pdf_files/WHA68/A68_R8-en.pdf

The WHO and the United Nations Children's Fund's Global Action Plan for the Prevention and Control of Pneumonia and Diarrhea (GAPPD). The program's goal is to achieve universal access to drinking water in both health care facilities and homes by 2025. A core focus of the initiative is on improving indoor air quality (WHO, 2016a, p. 7). https://www.who.int/maternal_child_adolescent/documents/global_action_plan_pneumonia_diarrhoea/en/

One of the salient characteristics of air pollution is its spatial distribution.

Once emitted, air pollution is capable of traveling long distances. Pollution is often not confined to any one country. Harms to both people and nature, therefore, have the potential to occur far from where the pollutants are initially discharged (WHO, 2016a). Since the impacts from air pollution are widespread and broad, it would be helpful to obtain data connecting emissions, ambient concentrations, and consequent harms to human health.

Estimates of air pollution exposure vary by data collection technique. Air quality is measured by both satellite and ground-based methods (Engel-Cox, Kim Oanh, van Donkelaar, Martin, & Zell, 2013). Ground-based measurements are generally taken where a higher number of populations are exposed to $PM_{2.5}$, which provides accurate data for local planning purposes (Engel-Cox et al., 2013). Ground-level measurements, however, are not taken in much of the world, with especially few measurements in many low-income areas (Health Effects Institute, 2017, p. 5; Hsu, Reuben, Shindell, de Sherbinin, & Levy, 2013, p. 562). Satellite-based measurements provide estimates in areas where no ground-based measurements are obtainable (Engel-Cox et al., 2013, p. 585). Satellite monitoring can therefore provide a more complete air pollution picture globally. Synthesizing these two methods may environmental and public health practitioners with a more comprehensive measurement of air quality globally.

We focus on three indicators of exposure to air pollution, measuring $PM_{2.5}$ and HAP. These indicators capture a substantial portion of the global variation in health impacts due to air quality, either because of the direct threat posed by these pollutants or because they are correlated with threats posed by other pollutants (WHO, 2016a).

HOUSEHOLD SOLID FUELS

INDICATOR BACKGROUND. HAP use is a significant environmental risk factor. Incomplete combustion of solid fuels produces a substantial amount of particulate emissions (WHO, 2006b, 2017). Humans exposed to HAP at high concentrations often suffer significant, negative health effects (WHO, 2006a, pp. 62-66). Because exposure to HAP is often higher than other forms of air pollution, reducing the use of household solid fuels may improve human health to a greater degree than other air pollution abatement efforts (Goldemberg et al., 2000. The household solid fuel indicator is measured in DALYs lost due to HAP per 100,000 persons.

FOCUS 5-1 FALSE DATA AND REPORTING DISTORTS POLLUTION ESTIMATES

Despite the significant advances made in air quality monitoring technologies over the past 50 years (Engel-Cox et al., 2013), unreliable data continue to pose serious concerns for quality analysis. Without reliable data and information, environmental protection agencies will not have an appropriate gauge of local circumstances, cannot undertake appropriate pollution and emissions control benchmarking, and thus will not be positioned to make informed policy decisions.

Data reliability issues—problems with false reporting—are particularly acute in Russia and China. In June 2017, seven staffers of the Environmental Protection Department in China's Shaanxi Province were accused of tampering with air quality monitors and changing readings to show decreased levels of $PM_{2.5}$ and sentenced to over one year of prison (Connor, 2016; Shepherd, 2017). Major coal-dependent areas within China have admitted to falsifying data about their GDP, making trends about emission intensity difficult to interpret. For example, Inner Mongolia inflated data for, "added value of industrial enterprises of a certain scale," by 40% in 2016. Liaoning province revealed they faked data for five years, while Binhai included the commercial activities of companies only registered in the area for tax purposes in their GDP (Zhang, Pong, & Hornby, 2018). According to China's latest environmental protection law, which entered into force in 2015, anyone found guilty of altering air quality data will be held as accountable for the damages of the pollution they permit to occur (P.R.C. Ministry of Environmental Protection, 2016; Reuters Staff, 2016). China's leadership on improving data accuracy as a foundation for improved air quality shows that progress can be made — and that public health gains can be quickly achieved by addressing pollution problems more forthrightly.

DATA DESCRIPTION. The DALY rate from household solid fuel use comes from IHME's Global Burden of Disease study available at www.healthdata.org/gbd. Data are gathered through nationally reported household surveys that estimate the proportion of household solid fuel as the predominate fuel source in a country (Bonjour et al., 2013).

LIMITATIONS. Despite the strong relationship between the use of household solid fuels and health outcomes, our metric has multiple limitations. The limited knowledge regarding the size of the population exposed to various sources of air pollution, as well as imperfect data for the burden of air pollution-related diseases, are two of the primary reasons why multiple assumptions are necessary. Furthermore, standardization and double-counting issues, which emerge from the differing quality of data across countries, further complicate efforts to construct a global inventory or comparison of air pollution data. Finally, the type of predominant air pollution varies by regions. In urban areas, outdoor air pollution is the primary concern. Conversely, in rural regions, HAP is the more predominant issue.

$PM_{2.5}$ AVERAGE EXPOSURE AND $PM_{2.5}$ EXCEEDANCE

INDICATOR BACKGROUND. Both chronic and acute PM exposure are associated with significant adverse health effects (Kloog et al., 2013; WHO, 2016a). While chronic exposure is the biggest danger to mortality, exposure to high concentrations of $PM_{2.5}$ in short intervals can also aggravate both lung and heart conditions. These acute pollution events degrade human quality of life, increase hospital admissions, and cause premature death (WHO, 2006b).

We use two indicators for $PM_{2.5}$: exposure and exceedance. Exposure to ambient air pollution is represented by population-weighted annual average concentrations, which take into account the proportions of the population living with different levels of pollution.

1. $PM_{2.5}$ exposure. This indicator is a measure of the average amount of fine PM in micrograms per cubic meter. $PM_{2.5}$ exposure serves as a measure of the amount a person

FOCUS 5-2 INDIA'S LPG CONNECTION SCHEME

Over the last decade, approximately 800 million people have gained access to improved cookstoves, largely due to efforts in China and Brazil (Pachauri, Brew-Hammond, et al., 2012, p. 1419). These countries have been successful in transitioning to cleaner fuels because of strong government commitments to both the distribution and the improved affordability of stoves. The Chinese government, for example, has committed to providing all citizens with a basic standard for living, establishing local energy offices that provide training and installation support (Pachauri, Brew-Hammond, et al., 2012, p. 1437). Similarly, the Brazilian government has implemented policies that use targeted financial assistance to support access to liquefied petroleum gas (LPG) for low-income families (Lucon, Coelho, & Goldemberg, 2004).

Building on the efforts of China and Brazil's historic gains in access, the Government of India has made a concerted effort to expand access to modern cooking fuels. India has the world's largest population without access to modern energy services. Over 800 million people rely on traditional biomass for cooking (Bhojvaid et al., 2014). The Pradhan Mantra Uijwala Yojana (PMUY) is a welfare scheme launched by the Government of India to provide 50 million LPG connections and stoves to below-poverty line (BPL) women by the year 2019 (Jacob, 2017). The scheme, which entered the implementation stage in March 2016, operates through a direct benefits transfer. Eligible women can apply for a LPG connection by submitting an application along with proof of identity and a bank account. When an application is approved, the applicant receives a direct transfer of funds straight into her bank account, which she may then use to purchase her LPG connection (Government of India, 2016).

India is nearly half way to its 2019 target of 50 million stoves. As of May 2017, over 20 million families had signed up for LPG connections (Surabhi & Mishra, 2017). A survey undertaken in 12 districts in Uttar Pradesh after the program was implemented showed that PMUY has helped save women an average of one to two hours per day that was previously used to collect fuels for cooking and heating the household (Surabhi & Mishra, 2017). In implementing this policy, the Government of India has made a concerted attempt to address the needs of BPL households and women. If its goals are realized, PMUY has the potential to positively impact the lives of millions of BPL households by providing them with access to safe, affordable cooking technologies and fuels.

would be exposed to on a typical day in their country (Engel-Cox et al., 2013).

2. $PM_{2.5}$ exceedance. This indicator is a measure of the weighted average of the percentage of the population exposed to elevated levels of $PM_{2.5}$, by measuring instances when $PM_{2.5}$ concentrations exceeded 10, 15, 25, and 35 μg/m^3, which are the WHO's air quality guidelines and interim targets (WHO, 2016a). WHO Air Quality Guidelines provide a basis for global limits on air pollutants that pose significant human health risks. Guidelines are available for PM, ozone, nitrogen dioxide, and sulfur dioxide to help countries measure and monitor their progress over time. However, almost 90% of the world's population currently live in areas that exceed WHO thresholds for air pollution (World Bank & IHME, 2016).

TABLE 5-2
WHO $PM_{2.5}$ GUIDELINES

$PM_{2.5}$	10 μg/m^3 annual mean guideline
	15 μg/m^3 interim target 3
	25 μg/m^3 interim target 2
	35 μg/m^3 interim target 1

DATA DESCRIPTION. Data for population-weighted exposure estimates of $PM_{2.5}$ come from a synthesis of multiple datasets. The satellite-derived measurements were gathered by van Donkelaar et al. (2016) and based on data obtained from the Tropospheric Emissions Monitoring Internet Service (TEMIS). Population data were obtained by the Earth Observing System Data and Information System, Gridded Population of the World, v4 at the NASA Socioeconomic Data and Applications Center (SEDAC) hosted by the Center for International Earth Science Information Network (CIESIN) at Columbia University's Earth Institute (2016).

Data for these indicators are generated using satellite observations combined with ground-based measurements to correct for any potential bias. Using this method allows the $PM_{2.5}$ indicators to be generated across countries and on a global scale (de Sherbinin, 2015). Population-weighting allows regions with higher air pollution and more individuals nearby to signify higher overall averages (de Sherbinin, 2015). Values are available from 2008-2015 for 228 countries and territories.

Ideally, monitoring data for $PM_{2.5}$ would be collected throughout the year over numerous years. Most countries globally, however, do not operate robust systems of air quality monitoring stations, so other methods for measuring air quality are needed to provide a reliable view of pollution levels worldwide (Engel-Cox et al., 2013; Health Effects Institute, 2017, p. 5). For these areas, satellite measurements are used to estimate exposures to $PM_{2.5}$ (WHO, 2016a).

LIMITATIONS. Many factors make it hard to compare measurements of $PM_{2.5}$ across multiple countries, including the locations of measurement stations, differences in measurement methods, and differences in the duration of air pollution measurement records. For example, if measurements were only taken for a portion of the year, the reported data may differ from the actual annual averages (van Donkelaar et al., 2016). Further, measurement issues could arise if monitors are disproportionately affected by one source of pollution (Brauer et al., 2016).

RESULTS

GLOBAL TRENDS

Air quality remains a prominent risk to both public health and the environment. Countries can improve the overall health of their population by reducing exposure to air pollutants. Pollution is particularly severe in places such as India and China, where greater levels of economic development contribute to higher pollution levels (World Bank & IHME, 2016).

At the global scale, DALYs lost due to air pollution have declined over the last decade. Global trends, however, hide regional inequalities. Air pollution in many low-income and developing countries, however, is higher due to a greater use of household solid fuels for cooking and heating homes (Desai, Mehta, & Smith, 2004). Conversely, most high-income and developed countries see small effects from household solid fuels. Countries with continued high scores, such as Australia and Barbados, show long-term commitments to reducing the levels of air pollution. Large populations, however, still experience severe impacts stemming from poor air quality, notably in India, China, and Pakistan; see Table 5-5.

TABLE 5-3 GLOBAL TRENDS IN AIR QUALITY

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Household solid fuels	1906.35	1107.03	14.77	22.10
$PM_{2.5}$ exposure	25.70	27.07	36.73	33.24
$PM_{2.5}$ exceedance	41.11	43.45	52.72	50.03

NOTE: Metrics are in units of age-standardized DALYs lost due to each risk. CURRENT refers to the most recently available data, and BASELINE refers to historic data approximately ten years previous to CURRENT.

TABLE 5-4 LEADERS IN AIR QUALITY

RANK	COUNTRY	SCORE
1	Australia	100.00
1	Barbados	100.00
3	Jordan	99.61
4	Canada	99.28
5	Denmark	99.16
6	Finland	99.00
7	New Zealand	98.99
8	Brunei Darussalam	98.76
9	Iceland	98.55
10	United States	97.52

TABLE 5-5 LAGGARDS IN AIR QUALITY

RANK	COUNTRY	SCORE
171	Myanmar	36.57
172	Republic of Congo	23.84
173	Laos	23.37
174	Tajikistan	23.22
175	Dem. Rep. Congo	22.57
176	Pakistan	15.69
177	China	14.39
178	India	5.75
179	Bangladesh	4.12
180	Nepal	3.94

LEADERS & LAGGARDS

Changes in global air quality over the course of a decade reveal important regional trends. Our results find that most European, North American, and Latin American countries have comparably higher scores, that we may associate with lower pollution levels and lower DALY rates. Many Central and South American countries, for example, have implemented successful fuel switching campaigns aimed at reducing HAP. Smart subsidies and other forms of financial assistance are key components of policies on LPG access, including Brazil and Peru (Lucon et al., 2004).

Nearly all countries at the lower end of the global ranking are African or Asian nations. The most significant decrease in air quality and global air quality ranking over the past ten years has occurred in Singapore. Singapore's score dropped by almost 30 points, causing them to fall 111 spots in our ranking. While Singapore received high scores for household solid fuels both in 2016 and in 2005, their substantially lower scores for $PM_{2.5}$ exposure and exceedance account for significantly decreased air quality scores. In 2015, fires swept through Indonesia causing the most significant reason for Singapore's drop in ranking (Weisse & Goldman, 2017). The Ministry of the Environment and Water Resources has reported that, over the past two years, Singapore has not met its $PM_{2.5}$ target, PM_{10} target, and ozone target, and is not are not on track to meet WHO's air quality targets by 2020 (Othman, 2017). In speaking about Singapore's current trajectory, Masagos Zulkifli, Singapore's Minister of Environment and Water Resources, emphasized that Singapore is committed to finding ways to address air pollution. "Unfortunately if you look at our trajectory, we are not meeting our targets and therefore we need to do more to ensure that our air pollution issue is being addressed" (Othman, 2017).

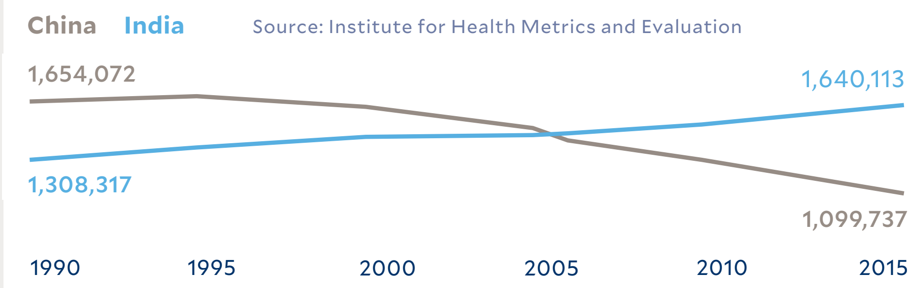
While neither leaders, nor laggards, countries in the Middle East, such as Bahrain, Iraq, Kuwait, Oman, Saudi Arabia, and United Arab Emirates, experienced the most substantial increases in their scores over the past decade due to decreasing levels of air pollution-related DALYs. Bahrain and Iraq improved their air quality and thus increased their scores most significantly, jumping up in the rankings by 47 and 46 places, respectively. Ritchie & Roser (2017) report that one reason DALY rates have sustantially improved are the effects of increased wealth and quality of life in the region.

Our findings illustrate the impacts of air pollution on human health globally. Increasing our knowledge on the links between air pollution and disease is fundamental to reduce the public health burden worldwide, and we can begin to lessen the effects of air pollution (Health Effects Institute, 2017, p.1).

FOCUS 5-3 AIR POLLUTION LEADS TO AS MANY PREMATURE DEATHS IN INDIA AS IN CHINA

Premature deaths from air pollution in China have begun to stabilize, while India has seen a steady rise in air pollution levels and $PM_{2.5}$-related deaths; see Figure 5-1. Both trends are significant. China and India combined made up approximately 52% of the 4.2 million deaths globally in 2015 (Health Effects Institute, 2017, p. 8). China has taken several steps over the past ten years to reduce the number of deaths related to air pollution. Among other policy initiatives, the country restricts traffic flow and construction activities during time periods with heavy pollution. One of the most heavily polluted cities in the world, Beijing, broadcasted a 'red alert' pollution warning level for the first time in 2015, which forced the government to implement policies to limit the human exposure to dangerous pollution levels. Due in part to government regulation, China has made substantial progress implement-ing effective policies that target air pollution.

FIGURE 5-1 ANNUAL DEATHS ATTRIBUTABLE TO $PM_{2.5}$



Meanwhile, India has made little progress reducing air pollution levels (Rowlatt, 2016). In November 2017, the government in Delhi declared a state of emergency. Particulate matter levels reached recorded highs of 969 ug/m3 (for real-time updates, the US embassy's air quality index can be accessed at aqicn.org/city/delhi/r.k.-puram). The WHO considers anything over 25 ug/m3 to be unsafe (WHO, 2006b). To put this into perspective, news sites were reporting that breathing the air in Delhi was "equivalent to smoking 44 cigarettes a day" (Wu, 2017). Arvind Kejriwal, Delhi's chief minister, even described the city as "a gas chamber" (2017). Blaming farmers who clear fields by burning crops, Kejriwal went on to say, "[e]very year this happens during this part of the year. We have to find a [solution] to crop burning in adjoining states" (2017).

Like Beijing, the government in Delhi has started to implement policies targeting their air pollution levels. These strategies include shutting down schools and suspending construction projects (Health Effects Institute, 2017; World Bank & IHME, 2016). If appropriate measures are enacted, India can learn from the success of the actions taken in China to decrease the levels of air pollution.

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6
WATER & SANITATION

Environmental Performance Index

Water & Sanitation

SNAPSHOT

Access to clean water is essential for human development, the environment, and the economy.

CATEGORY DESCRIPTION

More than 2 billion people, however, lack access to safe drinking water, sanitation, and hygiene (WHO & UNICEF, 2017, pp. 4–6). Poor water quality and inadequate sanitation affect all aspects of life. Inadequate access to clean water and sanitation sources hinders sustainable development efforts worldwide (WHO & UNICEF, 2017). The chapter Water and Sanitation uses two indicators to measure the health risks associated with unsafe *sanitation* and *drinking water* sources.

INDICATORS INCLUDED

- **Sanitation.** We measure *sanitation* as the proportion of a country's population exposed to health risks from their access to sanitation, defined by the primary toilet type used by households.

- **Drinking water.** We measure *drinking water* as the proportion of a country's population exposed to health risks from their access to drinking water, defined by the primary water source used by households and the household water treatment, or the treatment that happens at the point of water collection.

Both *sanitation* and *drinking water* are measured using the number of age-standardized disability-adjusted life-years (DALYs) lost per 100,000 persons. Minimizing the health risks posed from unsafe sanitation and drinking water is a vital step in evaluating a country's ability to maintain clean water systems and minimize contact with dangerous bacteria and viruses.

WATER & SANITATION INDICATORS	
Sanitation	DALY rate
Drinking water	DALY rate

Reliable sources of clean water and sanitation facilities are necessary for sustainable development, but more than two billion people worldwide lack access to safe drinking water, sanitation, and hygiene.
(WHO & UNICEF, 2017, pp. 4–6).

Polluted water and sanitation are associated with the spread of illnesses including diarrhea, typhoid fever, and cholera. Inadequate access to clean water and sanitation facilities hinders efforts to eradicate preventable diseases worldwide (WHO & UNICEF, 2017).

ENVIRONMENTAL

Adequate water quality is also vital for ecosystem health. Adverse environmental consequences from water pollution, such as increased toxicity, eutrophication, and salinization, pose great danger to our natural ecosystems. Humans introduce a number of harmful substances into the water cycle, such as pharmaceuticals and personal care products, which can disrupt aquatic environments. Large amounts of nutrients entering the water stream can cause eutrophication, or intense growth at the bottom of aquatic food chains. Eutrophication leads to oxygen depletion, die-offs of organisms, and reduced ecosystem services (United Nations Water, 2016, p.14). Major sources of nutrient pollution include agricultural runoff, domestic sewage, and industrial effluents (United Nations Water, 2016, p.12). Increased levels of salinity further causes declines in biodiversity and reductions in crop yields (Tilman, Cassman, Matson, Naylor, & Polasky, 2002, p. 672).

SOCIAL

Large access gaps in safe drinking water exist between developing and developed regions. As seen in Figures 6-1 and 6-2, developed regions have made substantial progress gaining access to safe drinking water and improving sanitation sources, but coverage remains ariable among developing countries. Further inequalities, such as rural-urban access gaps, exist on a more granular level. Data from the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) show that while 96% of people living in cities have access to drinking water sources that are protected from outside contamination, only 84% of the rural population obtains the same access to improved drinking water sources (WHO & UNICEF, 2015, p.4). Unsafe water and poor sanitation are leading causes of childhood mortality globally. More than 525,000 children under five years of age die every year from diarrheal diseases (WHO, 2017c), and 50% of child malnutrition is associated with these health risks (Prüss-Üstün, Bos, Gore, & Bartram, 2008, p.7). Eliminating the risks from unsafe water and poor sanitation help children both through better health and greater school attendance (Prüss-Üstün et al., 2008, p.17).

ECONOMIC

Inadequate water quality and poor sanitation also limit economic development (Cooley et al., 2013, p. 5). Illnesses associated with unsafe water, for example, increase the costs of healthcare (Prüss-Üstün et al., 2008, p. 21). Achieving levels of safe water quality globally, however, is not without its costs. The World Bank estimates that achieving universal basic water and sanitation will incur US$28.4 billion per year in global capital costs (Hutton & Varughese, 2016, p.7). Over the past three years, countries have collectively increased their budgets for water, sanitation, and hygiene measures by nearly 5% per year, but 80% of countries find their budgets for water and sanitation services are still inadequate to meet national targets (United Nations, 2017, p. 5).

Over the last 30 years, numerous international efforts have sought to address unsafe water, poor sanitation,

and the many issues that stem from them. The Millennium Development Goals (MDGs) aimed to reduce the amount of the global population without access to improved drinking water and sanitation by half between 1990 and 2015 (WHO & UNICEF, 2015). The international community reached its global MDG drinking water target in 2010. As of 2015, almost 90% of the population — about 6.5 billion people worldwide — use an improved drinking water source, which the WHO defines by the type of water treatment that happens at the point of water collection (WHO & UNICEF, 2017, p. 3). Improved access to clean drinking water is recognized as one of the most successful accomplishments of the MDGs. However, global sanitation outcomes were not as widespread. In 2015, the MDG sanitation target fell short of halving the proportion of the population without access to improved sanitation by about 700 million people (WHO & UNICEF, 2017, p.4). While much of the world has gained access to improved sanitation and drinking water sources, worldwide accomplishments conceal regional inequalities; see Figure 6-1 (Prüss-Üstün et al., 2008, p.1). The WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation (JMP) estimates that 884 million people lack access to improved drinking water sources, most of them located in sub-Saharan Africa and Oceania (WHO & UNICEF, 2017, pp. 3–4). Billions of people also lack access to basic sanitation services (WHO & UNICEF, 2017, pp. 3–4). As with water quality, regional disparities are often masked by the global trends. As seen in Figure 6-2, individuals in least developed countries still lack access to basic sanitary facilities (WHO & UNICEF, 2017, p. 3).

Recent studies in access further emphasize the scale of the water and sanitation access gap (WHO, 2017a, p. 24). Fifty-eight percent of the 159 million people who collected drinking water directly from surface water in 2015 lived in sub-Saharan Africa (WHO & UNICEF, 2017, p. 3). As seen in Figures 6-1 and 6-2, significant improvements in access to water and sanitation services still need to be made for several million people. A 2017 UN press release noted that countries must “radically” increase investments in water and sanitation services in order to protect their populations from water-related illnesses (WHO, 2017b).

FIGURE 6-1 PERCENT OF THE POPULATION WITH ACCESS TO DRINKING WATER

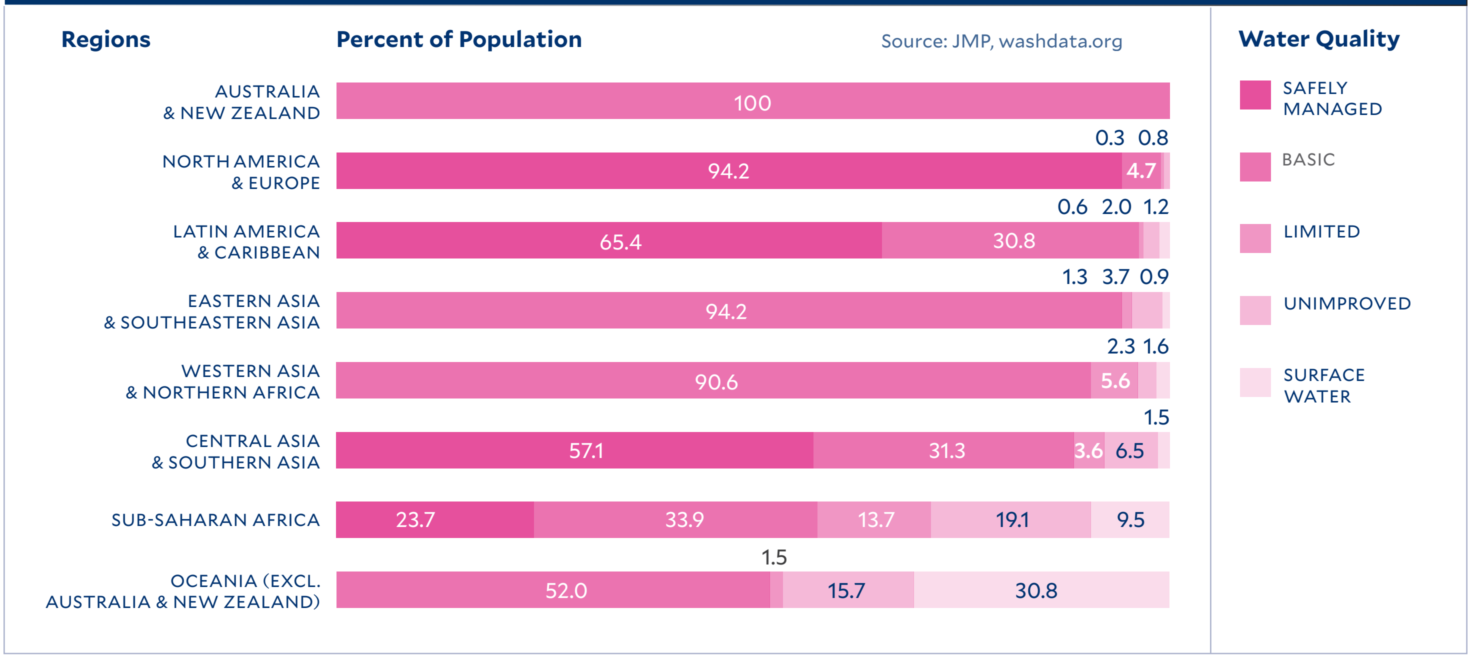
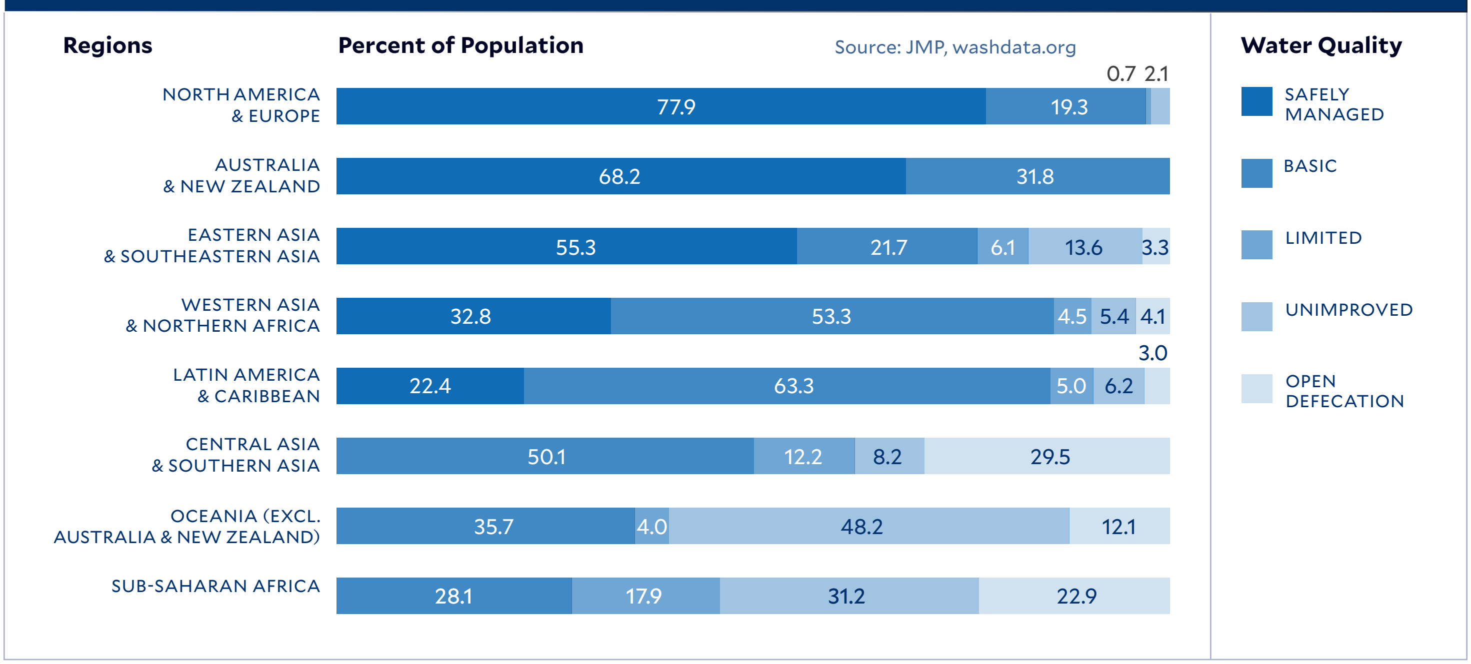


FIGURE 6-2 PERCENT OF THE POPULATION WITH ACCESS TO SANITATION SERVICES



SUSTAINABLE DEVELOPMENT GOALS

GOAL 3 Ensure healthy lives and promote well-being for all at all ages.

TARGET 3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases, and combat hepatitis, water-borne diseases, and other communicable diseases.

TARGET 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.

GOAL 6 Ensure availability and sustainable management of water and sanitation for all.

TARGET 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

TARGET 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

TARGET 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

TARGET 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary coöperation as appropriate.

TARGET 6.A By 2030, expand international coöperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

GOAL 11 Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11.5 By 2030, significantly reduce the number of deaths and the number of affected people, and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

In addition to the specific SDGs for water and sanitation, access to safe water and sanitation reinforces other SDGs. Clean water and sanitation are essential for many SDGs such as those related to health, gender equality, economic growth, and climate action (UNICEF, 2016, p. 4).

INTERNATIONAL ORGANIZATIONS

United Nations Water (UN-Water). UN-Water coördinates efforts of numerous groups working on issues relating to water and sanitation. http://www.unwater.org/

United Nations Children's Fund (UNICEF). UNICEF's water, sanitation, and hygiene team works all over the world on improving water and sanitation services to children and their families. https://www.unicef.org/wash/

World Bank. The World Bank is one of the largest investors in water quality globally, providing technical assistance and working with governments to improve access to water and sanitation services. http://www.worldbank.org/en/topic/water

World Health Organization (WHO). WHO's work on water, sanitation, and hygiene aims to address the burden of disease stemming from poor water quality and inadequate sanitation. http://www.who.int/water_sanitation_health/about/en/

WaterAid. WaterAid is an international nonprofit that was set up after the International Drinking Water & Sanitation Decade in 1981. https://www.wateraid.org/us/

MULTILATERAL EFFORTS

22nd Conference of the Parties. The UN climate change conference in Marrakech, Morocco, devoted a special day to highlight water as part of the climate change solution and as a way to help implement the Paris Climate Agreement. http://www.un.org/sustainabledevelopment/blog/2016/11/cop22-spotlights-water-as-part-of-the-climate-change-solution/

Call to Action on Sanitation. On World Water Day 2013 the WHO launched the Call to Action on Sanitation aiming to eliminate open defecation by 2025. https://www.who.int/water_sanitation_health/sanitation-waste/sanitation/sanitation-call-to-action/en/

General Comment No. 15. The Right to Water. In November 2002 the Committee on Economic, Social and Cultural Rights adopted General Comment No. 15, which states that "[t]he human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights." It also defined the right to water as the right of "everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses." http://www.refworld.org/pdfid/4538838d11.pdf

High Level Panel on Water (HLPW). The HLPW, formed in 2016 by the UN and the World Bank Group, works to provide leadership on ways to improve access to clean drinking water and sanitation facilities. https://sustainabledevelopment.un.org/

HLPWater. Human Rights Council Resolution. In September 2011 the UN adopted Resolution 18/1 that calls on Member States to ensure enough financing for sustainable delivery of water and sanitation services, further highlighting access to safe water and sanitation as a human right. http://www.un.org/es/comundocs/?symbol=A/HRC/RES/18/1&lang=E

International Conference on Water & the Environment and the Earth Summit. In 1992 both conferences had a focus on water, which helped people in developing countries gain access to safe drinking water sources. http://www.un.org/en/sections/issues-depth/water/

The human right to water and sanitation 64/292. In 2010 the UN declared for the first time that access to clean water and sanitation is a fundamental human right. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/64/292

The World Health Organization and the United Nations Children's Fund's Global Action Plan for the Prevention and Control of Pneumonia and Diarrhea (GAPPD): The GAPPD's goal is to achieve universal access to drinking water by 2025 (WHO, 2016, p. 7). http://www.who.int/maternal_child_adolescent/documents/global_action_plan_pneumonia_diarrhoea/en/

WASH4Work. The WASH4Work initiative was launched on World Water Day 2016 to mobilize businesses to improve workplace access to water, sanitation, and hygiene. https://wateractionhub.org/wash4work/

World Health Assembly Resolution. In May 2011 the WHO adopted this resolution asking states "to ensure that national health strategies contribute to the realization of water- and sanitation-related Millennium Development Goals while coming in support to the progressive realization of the human right to water and sanitation." http://apps.who.int/gb/ebwha/pdf_files/WHA64/A64_R24-en.pdf

World Toilet Day. On November 19 every year, World Toilet Day seeks to raise global awareness of access to sanitation facilities. Coördinated by UN-Water, World Toilet Day is part of a campaign to ensure global access to toilets by 2030. http://www.world-toiletday.info/

World Water Day. On March 22 every year, World Water Day focuses on actions that can be taken to work toward achieving universal access to safe drinking water. The new theme for this decade for action is, "Nature for Water." http://www.worldwaterday.org/.

Measuring water quality on a worldwide scale is critical for human health and well-being.

Srebotnjak et al. (2012) provide the most comprehensive description of a global data system monitoring access to clean water and sanitation. They specify several components of such a system, including indicators that measure the distribution of access, quantity, continuity, and reliability of safe drinking water and sanitation facilities. They find that an ideal water quality metric would be capable of being defined at both the local and national levels over multiple time periods in order for decisionmakers to allocate resources most effectively.

There is currently no standard global data collection approach for obtaining a comparable metric of country-specific water quality. Poor data quality and international coverage hinder global water quality measurement efforts. Water quality measurement, for example, is influenced by the level of background pollution at the monitoring location, the flow of the water, and the likely end use of the water (Srebotnjak et al., 2012).

There are two primary methods of collecting data: administrative reports and censuses and surveys. The JMP used the administrative reports to monitor the MDGs and often experienced problems with data collection, standardization, and reporting methods (WHO & UNICEF, 2015, p. 28). The JMP and Institute for Health Metrics and Evaluation (IHME) now use census and survey data to track water quality. This process has produced more comprehensive datasets. The JMP's *Access to Water* dataset, however, lacks information on whether water is priced affordably and whether the water is actually safe for consumption (Cooley et al., 2013). Further work is needed to improve current methods to attain the ideals laid out by Srebotnjak et al. (2012).

The 2018 EPI uses two indicators to measure the health risks from unsafe *sanitation* and *drinking water* globally: drinking water and sanitation. Data come from the IHME's Global Health Data Exchange database (http://ghdx.healthdata.org/) and measure the number of age-standardized disability-adjusted life-years (DALYs) lost per 100,000 persons — known as the DALY rate — from unsafe drinking water and sanitation.

SANITATION

INDICATOR BACKGROUND. We measure unsafe *sanitation* as the proportion of a country's population exposed to health risks from their access to sanitation, defined by the primary toilet type used by households (IHME, 2016, p. 52). Adequate sanitation facilities help to reduce and prevent fecal pollution from entering the environment and thereby reduce the transmission of diseases. Unsafe sanitation exposure is classified by the primary toilet type used by households (IHME, 2016, p. 52). Improved sanitation sources must meet specific requirements. An "improved" sanitation facility is one that hygienically separates human excreta from human contact (WHO & UNICEF, 2017, p. 50). "Improved" and "unimproved" sources are classified by the JMP and described in Table 6-1. The IHME data recognize that access to improved sanitation does not guarantee elimination of health risks. The Global Burden of Disease (GBD) project from IHME estimates the actual health outcomes from exposure to risks, and our indicator includes the health risks from all types of sanitation.

TABLE 6-1 CLASSIFICATION OF SANITATION SOURCES

"IMPROVED" SANITATION	"UNIMPROVED" SANITATION	NO FACILITIES
Networked sanitation • Flush and pour flush toilets connected to sewers • On-site sanitation • Flush and pour flush toilets or latrines connected to septic tanks or pits • Ventilated improved pit latrines • Pit latrines with slabs • Composting toilets, including twin pit latrines and container-based systems	On-site sanitation • Flush and pour flush toilets or latrines connected to septic tanks or pits • Ventilated improved pit latrines • Pit latrines with slabs • Composting toilets, including twin pit latrines and container-based systems	Open defecation

Source: WHO & Unicef, 2017, p. 50

FOCUS 6-1 MENSTRUAL HYGIENE MANAGEMENT IN INDIA

Menstrual hygiene management (MHM) is a critical issue, yet it remains a taboo subject in many cultures, often causing embarrassment. Inadequate MHM can affect one's health and education and is a particularly severe problem in developing regions (WHO, 2017a). It is estimated that poor menstrual hygiene causes approximately 70% of reproductive diseases in India (Venema, 2014). MHM may also jeopardize a girl's chance at an education. Girls in India miss on average five days of school per month, and 23% drop out of school once they start menstruating due to the lack of clean sanitary facilities (Sinhal, 2011). Clean water and sanitation facilities are thus essential to manage menstruation hygienically.

In 2015 the Government of India recognized the public health and sanitation problem associated with inadequate MHM and released the first National Guidelines on Menstrual Hygiene Management (Government of India, 2015). India's national guidelines are a first step to explicitly recognize the need for secure facilities for women and girls to wash and dispose of menstrual management materials safely. India has 113 million adolescent girls, but a survey in 2015 found that only about half of public schools have distinct bathrooms available for the girls to use (Government of India, 2015, p. 1). These measures are necessary both to improve self-worth among women and to allow them to remain in school (Government of India, 2015).

DRINKING WATER

INDICATOR BACKGROUND. Our drinking water indicator measures the proportion of a country's population exposed to health risks from their access to drinking water, defined by the primary water source used by households and the household water treatment, or the treatment that happens at the point of water collection. Due to an absence of national data on the safety of drinking water for many countries, drinking water is the best currently available proxy for monitoring improved access to safe drinking water. It also uses the JMP definitions of water sources, shown in Table 6-2. The JMP defines an "improved" drinking water source as a facility or delivery point that protects water from external contamination (WHO & UNICEF, 2017).

DATA DESCRIPTION. Data for the sanitation and drinking water indicators come from IHME's Global Burden of Disease (GBD) project. Data are available for years 2005–2016 for 195 countries (IHME, 2016, p. 52). Exposure by country was estimated from the Global Health Data Exchange databases of household surveys and census reports. The modeling shows both the prevalence of households with improved sanitation or improved drinking water sources and the proportion of households with a sewer connection or piped water.

LIMITATIONS. The GBD evaluates three adverse health outcomes from exposure to sanitation and drinking water: diarrheal diseases, typhoid fever, and paratyphoid fever. In conducting the GBD, IHME relies on the scientific

TABLE 6-2 CLASSIFICATION OF DRINKING WATER

"IMPROVED" SOURCES OF DRINKING WATER	"UNIMPROVED" SOURCES OF DRINKING WATER	NO FACILITIES
Piped supplies • Tap water in the dwelling, yard, or plot • Public standposts Non-piped supplies • Boreholes/tubewells • Protected wells and springs • Rainwater • Packaged water, including bottled water and sachet water • Delivered water, including tanker trucks and small carts	Non-piped supplies • Unprotected wells and springs	Surface water

Source: WHO & Unicef, 2017, p. 50

literature to provide key assumptions and data about health risks (IHME, 2016, p. 52). The epidemiological studies on diarrheal disease are much stronger than the studies on typhoid and paratyphoid. The gaps in the literature are an important source of uncertainty in GBD estimates.

Water quality assessments also rest on the assumption that "improved" water supplies are safe, but a significant number of water supplies that meet the definition of an "improved" source still do not meet WHO guidelines (Clasen et al., 2014, p. 889). Water supplied through pipes may be contaminated, and groundwater may also be contaminated by faulty latrines, or the treatment of the water is inadequate (Clasen et al., 2014; IHME, 2016).

FOCUS 6-2 SUCCESS STORY ELIMINATING OPEN DEFECATION IN THE NADIA DISTRICT OF WEST BENGAL

Lack of adequate sanitation facilities represents a critical public health issue in India. While open defecation rates globally are declining, over 500 million people living in India still defecate in public (WHO & UNICEF, 2015). Efforts to eliminate open defecation in Nadia, India's first open-defecation-free district, present an interesting case for how other areas might address the issue.

Nadia is a rural district in West Bengal with approximately 5.4 million people. In 2013 almost 40% of Nadia's population practiced open defecation (Express News Service, 2015). To address this, the government of Nadia developed a campaign to end open defecation in the district. The *Sabar Shouchagar* (Toilets for All) initiative was launched in October 2013. In addition to subsidizing toilet construction, the initiative also addressed social norms and emphasized behavioral changes (World Bank, 2015). Program implementation included mass awareness campaigns, partnerships with local organizations, and a 10% user fee to cover the cost of toilet construction (Ghosh, 2015). The localized ownership of the *Sabar Shouchagar* initiative within local government allowed for collaboration across almost all departments in the region (World Bank, 2015). Similar regions or countries struggling to end open defecation on a large-scale may benefit from studying the good practices and successes of the *Sabar Shouchagar* initiative.

GLOBAL TRENDS

Over the past decade, millions of people have obtained access to adequate drinking water and sanitation sources, and we find DALYs have decreased for both indicators. Global trends show an improvement in the proportion of a country's population exposed to health risks from their access to drinking water and sanitation. As a result, global *drinking water* and *sanitation* scores to increase by 7.76 and 8.15 points, respectively.

As the world population increases, the threat of deteriorating water quality remains an issue of global concern. Substantial improvements in access safe drinking water and sanitation services still need to be made in many regions and, as seen in Maps 6-1 and 6-2, geographic inequalities in access are evident. Developed regions have made significant progress gaining access to safe drinking water and improving sanitation sources, while coverage is variable among developing countries. Most regions saw a decrease in the total amount of people practicing open defecation. WHO and UNICEF report that sub-Saharan Africa and Oceania, however, saw an increase in open defecation rates from 204 to 220 million, and from one to 1.3 million, respectively (2017).

TABLE 6-3 GLOBAL TRENDS IN WATER & SANITATION

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Drinking water	1,313.7	749.0	17.75	25.51
Sanitation	1,108.6	581.7	16.72	24.87

Note: Metrics are in units of age-standardized disability-adjusted life-years lost due to each risk. Current refers to data from 2016, and Baseline refers to historic data from 2005.

TABLE 6-4 LEADERS IN WATER & SANITATION

RANK	COUNTRY	SCORE
1	Finland	100.00
1	Greece	100.00
1	Iceland	100.00
1	Ireland	100.00
1	Italy	100.00
1	Malta	100.00
1	Spain	100.00
1	United Kingdom	100.00
9	Switzerland	99.99
10	Norway	99.65

TABLE 6-5 LAGGARDS IN WATER & SANITATION

RANK	COUNTRY	SCORE
171	Liberia	4.79
172	Madagascar	4.04
173	Lesotho	2.86
174	Mali	2.69
175	Sierra Leone	2.50
176	Niger	2.44
177	Burundi	0.86
178	Kenya	0.63
179	Chad	0.32
180	Central African Republic	0.00

LEADERS & LAGGARDS

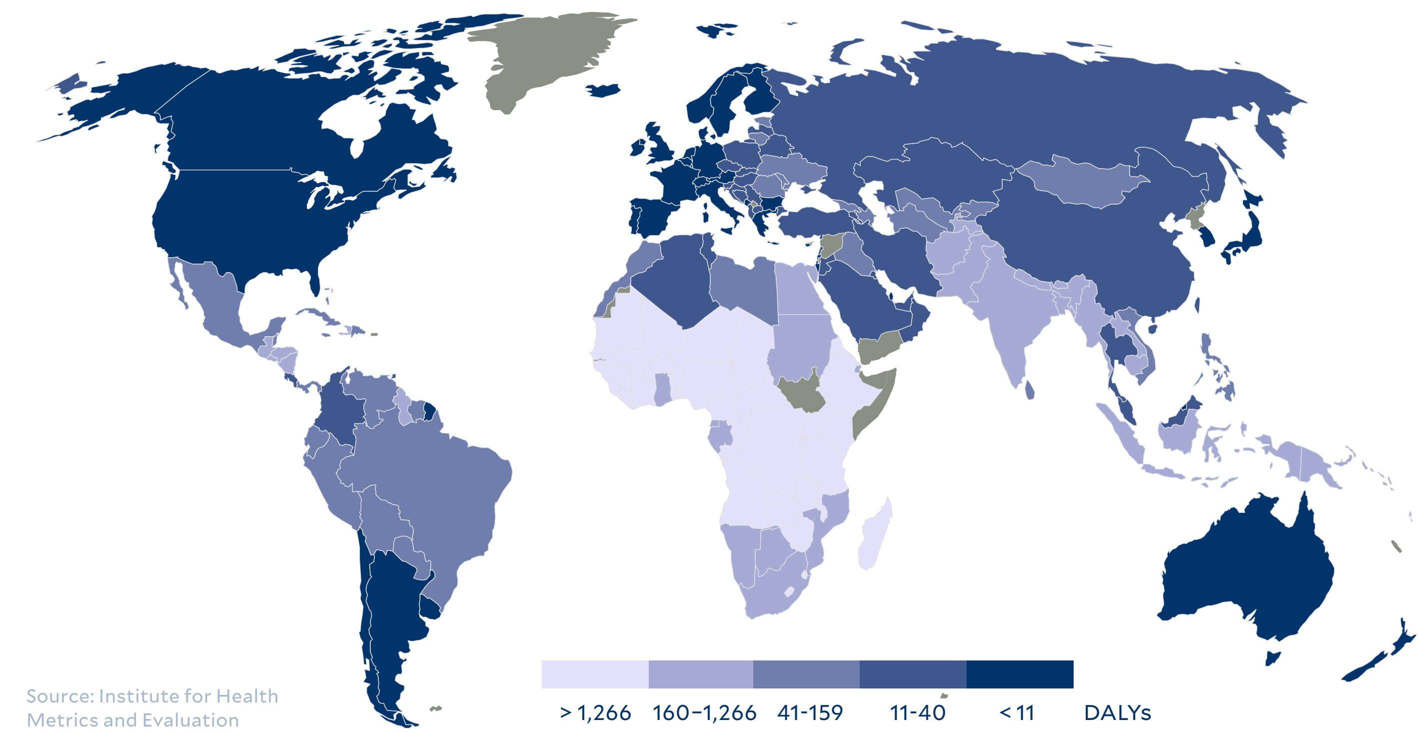
Results for Water & Sanitation indicate that European countries have remained dedicated to delivering clean water and sanitation services for the past decade. Greece, Iceland, Italy, Malta, and Spain all received scores of 100 in 2016 and in 2005. Other leaders in Water & Sanitation — Finland, Ireland, the United Kingdom, Switzerland, and Norway — also received scores of over 95 this year |and in previous iterations of the EPI. The European Union (EU) has implemented multiple policies spanning numerous decades that target water supply and sanitation. The Drinking Water Directive (98/83/EC), adopted in 1998, aims "to protect human health from adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean." The policies implemented in the EU, as well as policies in other countries at the top of the leaderboard, reflect sustained investment to clean drinking water and safe sanitation services (WHO & UNICEF, 2015).

All of the top ten laggards are located in sub-Saharan Africa, and the region is substantially behind the rest of the world in obtaining access to safe drinking water and adequate sanitation. Sub-Saharan Africa did not meet the MDG targets for both drinking water and sanitation. Over 300 million people still lack access to safe drinking water (WHO & UNICEF, 2015). In fact, the number of people without access to sanitation has actually increased to almost 700 million people since 1990 (WHO & UNICEF, 2015). The UN estimates that 115 people die every hour in Africa from diseases associated with contaminated drinking water and inadequate access to sanitation sources (United Nations, 2014). These numbers are of grave concern because of the health burden associated with a lack of access to drinking water and sanitation sources.

Population growth and poverty are the most important causal factors behind sub-Saharan Africa's water status (United Nations, 2014). Rising populations in sub-Saharan Africa are driving demand for water. The number of people living in slums, often without water or sanitation infrastructure, is expected to double to approximately 400 million people by 2020, putting even more pressure on water provisions.

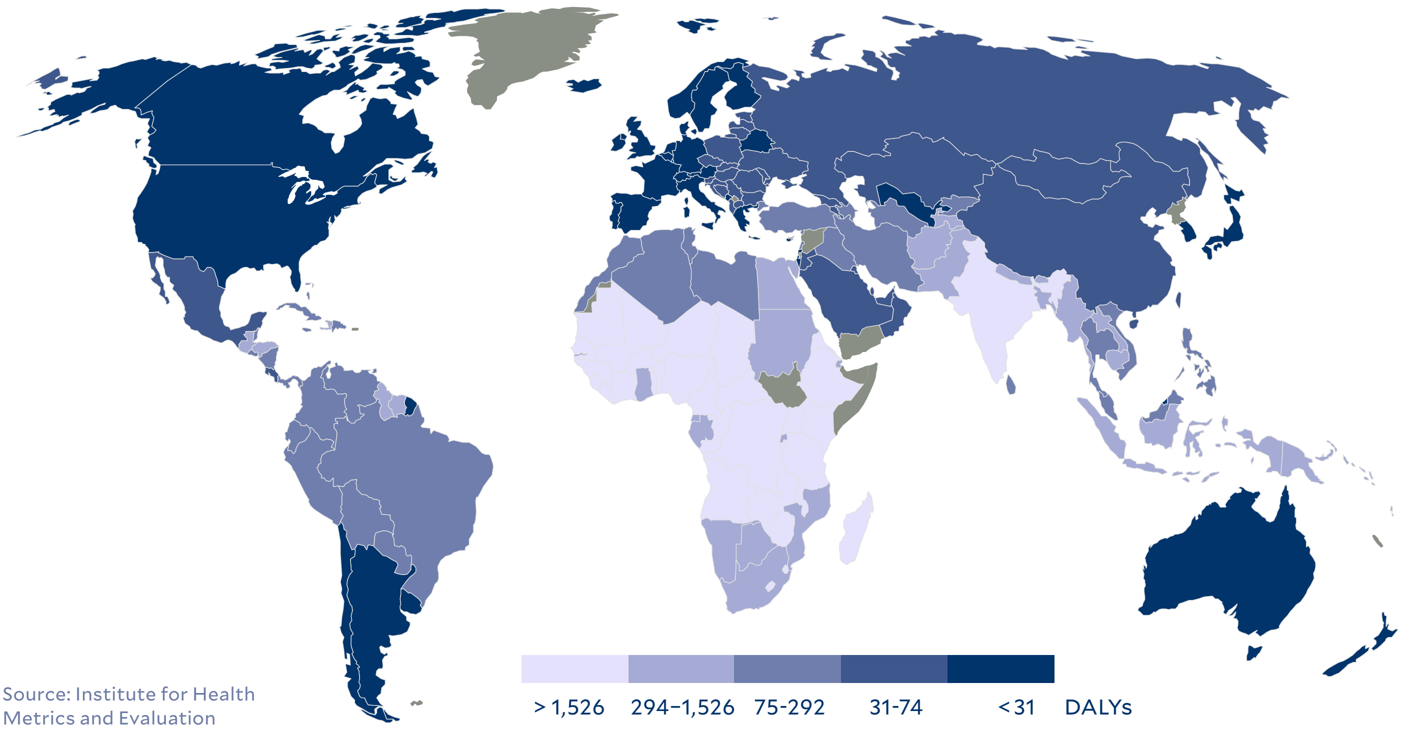
The UN further estimates that about half of the population in sub-Saharan Africa is living on less than a dollar a day, making it the world's poorest and least developed region (United Nations, 2014). Extensive poverty, along with rapid population growth, hinders efforts to provide safe and adequate drinking water and sanitation services in sub-Saharan Africa. Considerable action is still needed to ensure that safe drinking water and sanitation services are available worldwide.

MAP 6-1 DISABILITY-ADJUSTED LIFE-YEARS (DALYs) LOST DUE TO UNSAFE SANITATION IN 2016



Source: Institute for Health Metrics and Evaluation

MAP 6-2 DISABILITY-ADJUSTED LIFE-YEARS (DALYs) LOST DUE TO UNSAFE DRINKING WATER IN 2016



Source: Institute for Health Metrics and Evaluation

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7

HEAVY METALS

Environmental Performance Index

Heavy Metals

SNAPSHOT

Heavy metal exposure causes countless deaths and disabilities.

CATEGORY DESCRIPTION

The diverse range of sources and adverse health effects of heavy metals — including lead, arsenic, mercury, and cadmium — pose a complicated challenge for the world. We know that human activities are the primary driver of heavy metal production and pollution, contributing to disease and poverty on a global scale. Among heavy metals, lead is one of the most significant environmental health threats to children and pregnant women. The World Health Organization states that there is no known level of lead exposure that is considered safe, and lead poisoning in childhood is linked to cognitive impairment, violent crime in adulthood, and loss of economic productivity (Landrigan et al., 2017, p. 17).

Heavy metals have been used by humans for thousands of years. Their toxicity and tendency to accumulate in biological systems make them a significant health hazard. Some heavy metals such as copper and zinc have essential biological functions in miniscule amounts, but others — like lead, arsenic, mercury, and cadmium — can be life-threatening. Human exposure to toxic heavy metals persists globally, but the prevalence of heavy metal pollution is most notable in low- and middle-income countries (Järup, 2003, p. 167).

INDICATOR INCLUDED

LEAD EXPOSURE. Lead is a major environmental threat because of its severe human health effects, and because of its global prevalence in air, water, dust and soil, and various manmade products. We measure *lead exposure* using the number of age-standardized disability-adjusted life-years (DALYs) lost per 100,000 persons due to this risk.

HEAVY METALS INDICATOR	
Lead exposure	DALY rate

Despite the natural occurrence of heavy metals, human activities are the main driver of heavy metal pollution.

Even trace amounts can harm human health and the environment (Tchounwou, Yedjou, Patlolla, & Sutton, 2012). Adverse health effects and resistance to decay make heavy metals particularly hazardous pollutants. Although heavy metal toxicity is well documented, managing its exposure and related risks is a challenge around the world.

Sources of heavy metals vary, but human exposure is largely attributed to mining and industrial operations, including metal refineries, petrochemical production, power plants, and electronics manufacturing. Contamination can also occur from diffuse sources, such as aging metal pipes, food contamination, sewage discharge, and leaching from landfills (Caribbean Environment Programme, 2008). We see ongoing efforts to tackle the numerous sources of pollution, such as in large-scale mining. The 2016 meeting of the Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development concluded with its 62 member countries emphasizing the need for stronger legal frameworks that protect workers from mining-related pollution (Crawford, 2015). International efforts like this are helping establish stringent laws and testing requirements, but the countless sources of heavy metals and diverse pathways to human exposure make it difficult to effectively manage, much less eliminate, heavy metal pollution.

National and international heavy metal monitoring is not consistent. This reality emerges with particular force among developing countries where incidents of heavy metal exposure often go unnoticed or unreported, and public health laws are not properly enforced (Mamtani, Stern, Dawood, & Cheema, 2011). Confronted with a paucity of data to adequately capture the vast range of heavy metal occurrences, health threats, and environmental impacts, we chose lead as our proxy indicator to represent the impacts of heavy metal pollution on global sustainable development.

TABLE 7-1 MAJOR SOURCES OF CHILDREN'S EXPOSURE TO LEAD
Lead-based paints
Mining activities
Leaded fuels
Ceramic glazes
Drinking water systems with lead solder and pipes
Consumer products, e.g., traditional medicine, food cans, cosmetics, toys
Incineration of lead-containing waste
Electronic waste
Food, due to contaminated soil
Former industrial sites
Source: World Health Organization, 2010a, p.38

Lead and its negative health effects have been extensively studied by international bodies like the WHO. As a result there has been a steady reduction in contamination and disease burden, but occupational and community exposures to lead persist in many places around the world (Järup, 2003, p. 167; Landrigan et al., 2017, p. 17). According to the Institute for Health Metrics and Evaluation, in 2015 lead exposure accounted for nearly 0.5 million deaths and 9.3 million life years lost among adults 15 years and older, with the highest occurrence in developing regions (2017, p. 17).

Childhood exposure to lead is concerning because it causes permanent cognitive problems. WHO estimated in 2012 that lead was responsible for causing mild-to-moderate mental retardation of 0.6 million children annually (Landrigan et al., 2017, p. 17). Inhalation and ingestion are the primary ways in which lead enters the body. Once absorbed, lead can affect virtually every organ and reside in teeth and bones for decades (Meyer, Brown, & Falk, 2008). Children and the developing fetus of pregnant women are most susceptible to lead's negative effects. Children are able to absorb nearly four to five times more lead than adults, making lead a particularly dangerous heavy metal. (Meyer et al., 2008). Children who survive severe lead poisoning may suffer lifelong consequences, including behavioral disorders, physical disabilities, and learning impairments (WHO, 2017b). These symptoms can result in lower school performance, higher risks of drug abuse and incarceration, and decreased economic productivity (Landrigan et al., 2017). During pregnancy, lead stored in maternal bone can mobilize into the blood stream, and lead can be transferred from mother to child. In addition, high levels of lead can cause miscarriage, premature birth, and fetal malformations (WHO, 2017b). Prenatal and childhood exposures, as listed in Table 7-1, impose large and lasting costs, making prevention a priority for these vulnerable groups.

ENVIRONMENTAL

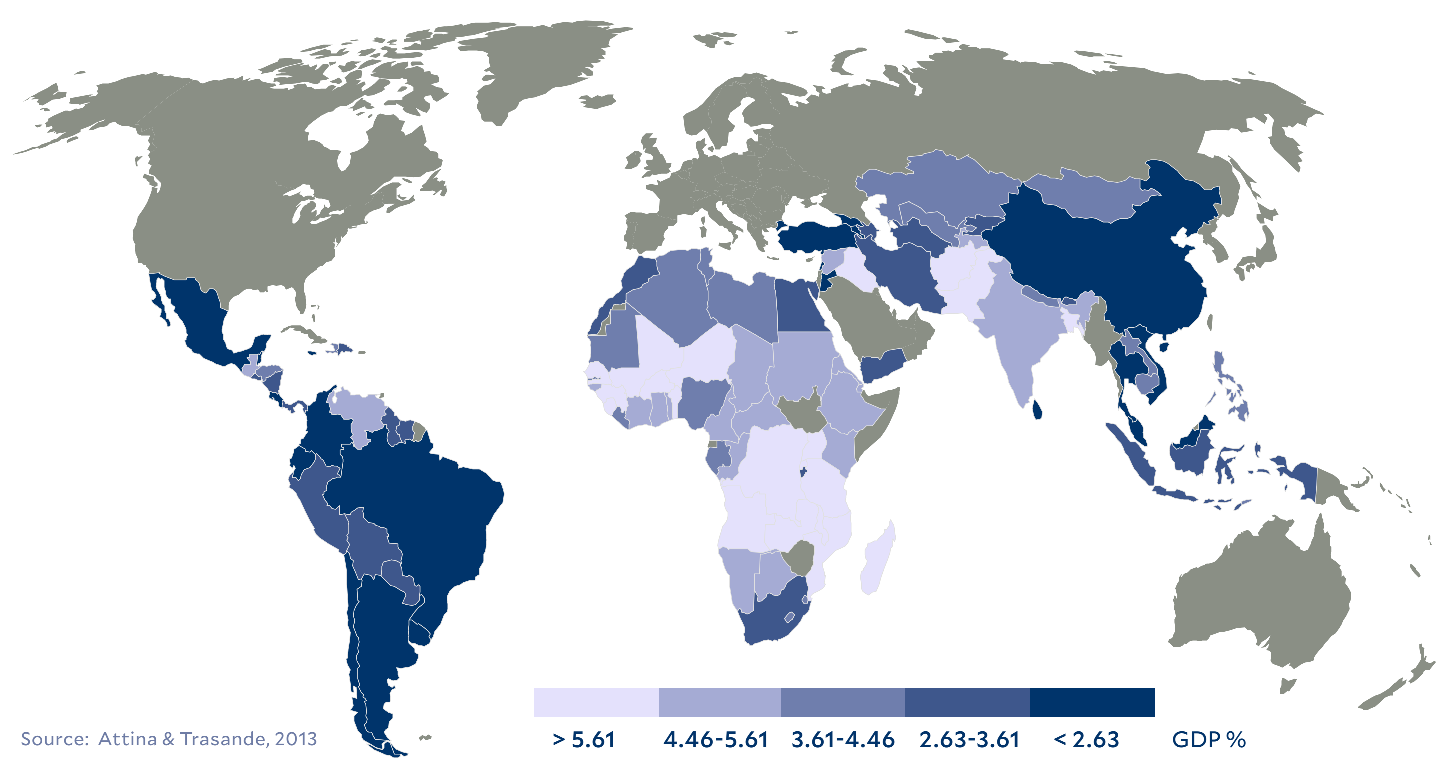
Lead can be found in the air, dust, soil, and water, as well as inside homes and various consumer goods. Natural levels of lead in soil range from 50 to 400 parts per million, but lead concentrations are much higher in some areas due to past use of leaded gasoline and past and present industrial emissions, notably from lead smelters (US EPA 2017). Lead can also get in the air, with concentrations peaking near metal-processing sites and waste incinerators. Atmospheric lead can be transported far from the emission source, settling on the ground and attaching to soil particles. It can then be re-suspended into the air, seep into the groundwater, or be absorbed by vegetation (US EPA, 2017). While lead amounts to only a small portion of the Earth's crust, humans mine and refine it easily, which increases the pervasive risks of lead exposure.

Plants are the foundation of our food chain, and given lead's acute toxicity and resistance to decay, even the smallest concentration of lead uptake is cause for concern. Food continues to be the major source of lead exposure despite lead's slow downward mobility in soil and low absorption rate by plant roots (D. Liu, Liu, Chen, Xu, & Ding, 2010). The lead content of plants is largely attributed to atmospheric deposition. Elevated lead concentrations have been recorded in plants near contaminated, industrially active sites (Alexander et al., 2010, p. 22). In the vicinities of ore deposits and factories that process and recycle lead, very high concentrations of lead are found even in the roots of vegetables (Alexander et al., 2010, p. 23). According to the European Food Safety Authority, cereal grains, vegetables, and tap water are the largest contributors to dietary lead exposure in the European population (Alexander et al., 2010, p. 30). There is significant variation in dietary lead content between and within countries. In Poland, vegetables, cereals, and meat products contributed the most to lead dietary exposure, whereas in Finland the majority of lead exposure was from beverages and dairy products (Alexander et al., 2010, p. 26). The various sources of lead, numerous contaminated food groups, and different lead accumulation factors make national and international exposure mitigation a particularly difficult task.

SOCIAL

Socioeconomic factors can be a telling predictor of lead-related threats. Ethnic minority groups and low-income communities often face greater risk from multiple sources including increased likelihood of occupational hazards, exploitative child labor, substandard housing, and residential proximity to polluting industries (WHO, 2010b, p. 35). A disproportionate burden of disease is placed on children, and an estimated 90% of children with elevated lead levels live in low-income regions (WHO, 2010b). For example, WHO reports that families in these communities are more likely to live in houses containing lead-based paint and to live on land located near lead-polluted industrial facilities (WHO, 2010b). In the most poverty-stricken countries, lead smelting factories employ the poorest populations, who lack the financial means to receive adequate medical treatment (WHO, 2010b). Marginalized communities are therefore most vulnerable and often disproportionately affected by lead poisoning. Cultural customs also contribute to lead exposure factors. Traditional crafts like lead-tainted

MAP 7-1 COST IN GDP OF CHILDHOOD EXPOSURE TO LEAD (PB)



Source: Attina & Trasande, 2013

ceramics, homemade cosmetics, and herbal medicine can be routes of exposure. With increased globalization, lead exposures may expand beyond countries of origin and into higher-income economies (WHO, 2010b).

ECONOMIC

Health impacts from lead exposure, including lifelong mental and physical impairments and direct medical treatment costs, place an overwhelming economic burden on society (WHO, 2010b, p. 34). As shown in Map 7-1, estimates suggest that the loss in lifetime economic productivity from childhood lead exposure amounts to roughly $977 billion annually in low- and middle-income countries (Attina & Trasande, 2013). These findings represent the substantial economic burden that can be avoided if policies to prevent lead exposures are implemented.

Successful lead mitigation can have significant economic benefits (Gould, 2009; Grosse, Matte, Schwartz, & Jackson, 2002). The removal of lead from gasoline in the United States illustrates the magnitude of these benefits (Landrigan et al., 2017, p.17). After the program was implemented in 1975, the average blood lead level of the U.S. population went down by over 90%, nearly eliminating childhood lead poisoning. Since 1980, cognitive ability in U.S. children has improved by 2–5 IQ points (2017, p.46). The 2017 Lancet Commission report suggests that the intelligence gains over the lifespans of children born since 1980 may be valued at over $6 trillion (2017, p.5). These benefits far outweigh the costs of phasing out lead as a fuel additive.

Global production of lead continues to rise.

Eighty-five percent of global lead demand is from the manufacture and recycling of lead-acid batteries, making this industry one of the primary sites of lead contamination (Attina & Trasande, 2013; WHO, 2017a, p.3). Despite continuing increases in global lead production, bans on the use of lead in petrol, paint, plumbing, and solder have produced substantial reductions in lead exposure. In 2002, lead was used in fuels in 82 countries, while only three countries continue to use leaded fuels today (WHO, 2017c). The international transition to unleaded petrol in the last few decades, coupled with lead control measures, has subsequently decreased blood lead levels in the general population and is considered a success story in heavy metal exposure mitigation (Landrigan et al., 2017).

Momentum has grown to establish lead paint laws globally. Each year, the international community promotes the phaseout of leaded paint during the International Lead Poisoning Prevention Week. Organized by the Global Alliance to Eliminate Lead Paint, in 2017 the weeklong initiative garnered participation from governments, academia, and civil society representing 42 countries to raise greater awareness of the issue (WHO, 2017c). Although progress is being made—in 2016, seven countries reported new policies to address lead in paint, raising the global total to 66 countries—only a third of countries have legally binding controls on lead paint, signifying the ongoing health liability of lead in paint (UNEP, 2017; WHO, 2017b).

Both developed and developing countries are working to manage the adverse effects of toxic heavy metals like lead (Tchounwou et al., 2012). Although the Minamata Convention on Mercury provides a potentially replicable international framework for regulating other heavy metals, no such global framework currently exists for lead. A multi-sector approach will be necessary to assess the expansive scope of lead exposure. Developing countries should focus their attention on strengthening public health laws and enforcement mechanisms to mitigate exposure (Mamtani et al., 2011).

SUSTAINABLE DEVELOPMENT GOALS

The safe and sustainable management of lead and other heavy metals plays an important role in achieving the Sustainable Development Goals (SDGs). Although lead is not explicitly mentioned, several SDGs address the mitigation of hazardous chemical exposure.

GOAL 3. Ensure healthy lives and promote well-being for all at all ages.

TARGET 3.9. By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.

GOAL 6. Ensure availability and sustainable management of water and sanitation for all.

TARGET 6.3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

GOAL 12. Ensure sustainable consumption and production patterns.

TARGET 12.2. By 2030, achieve the sustainable management and efficient use of natural resources.

TARGET 12.4. By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment.

TARGET 12.5. By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

INTERNATIONAL ORGANIZATIONS

International organizations are working to address the challenges of heavy metal pollution. The WHO has been a leader in evaluating the health effects and coördinating partnerships to advance pollution abatement policies (Landrigan et al., 2017, p.7).

Below is a list of some of the most relevant entities and regulations promoting chemical safety.

Many of the organizations' specific roles are detailed in the 2017 report from The Lancet Commission on Pollution and Health (2017, pp. 6–7): http://www.thelancet.com/commissions/pollution-and-health

International Programme on Chemical Safety (IPCS). The IPCS, established in 1980, is a joint venture of three organizations—the WHO, ILO, and UNEP—implementing chemical safety goals. The WHO is the executing agency in charge of setting the scientific basis for the safe use of chemicals and strengthening national capabilities for chemical safety. http://www.who.int/ipcs/en/

Global Alliance to Eliminate Lead Paint. The Global Alliance to Eliminate Lead Paint is a joint initiative led by the WHO and UNEP. Its objective is to prevent children's exposure to lead from paints and to minimize occupational exposures to it. Its goal is to eliminate lead paint internationally by 2020. http://www.who.int/ipcs/assessment/public_health/gaelp/en/

Inter-Organization Programme for the Sound Management of Chemicals (IOMC). The IOMC facilitates international action to achieve the sound management of chemicals through the collaboration of its nine member organizations: Food and Agriculture Organization, International Labour Organization, Organization for Economic Co-operation and Development, United Nations Environment Programme, United Nations Industrial Development Organization, United Nations Institute for Training and Research, World Health Organization, World Bank, and the United Nations Development Programme. http://www.who.int/iomc/en/

MULTILATERAL EFFORTS

Minamata Convention on Mercury. The Minamata Convention on Mercury is the first global, legally binding agreement designed to address contamination from a heavy metal. It was adopted in October 2013 and entered into force in August 2017. Major commitments include a ban on new mercury mines and phaseout of existing ones; the reduction of mercury use in several production processes; and controls on mercury release to land, water, and air. The first Conference of the Parties to the Minamata Convention took place in September 2017, and although some technical disagreements remain, the convention's eventual implementation will help protect human health and the environment from mercury poisoning (Wagner, 2017). http://www.mercuryconvention.org/

Strategic Approach to International Chemicals Management (SAICM). The UN Environment Programme is responsible for the oversight of SAICM, an international policy framework that aims to achieve the sound management of chemicals throughout their life cycles. SAICM's "2020 goal" is to produce and use all chemicals without significant adverse impacts on human health or the environment by the year 2020. http://www.saicm.org/

The Codex General Standard for Contaminants and Toxins in Food and Feed (Codex Stan 193-1995). The Codex Stan 193-1995, most recently amended in 2016, is part of the global collection of standards and guidelines adopted by the Codex Alimentarius Commission (CAC). The Codex Stan 193-1995 ensures food safety by setting maximum permissible levels of arsenic, cadmium, lead, mercury, and tin. CAC was established by FAO and WHO to protect consumer health and regulate the international food trade. http://www.fao.org/fao-who-codexalimentarius/en/

REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals). REACH is a regulation of the European Union, adopted in 2007 to improve the protection of human health and the environment from chemicals, while enhancing the competitiveness of the EU chemicals industry. http://ec.europa.eu/environment/chemicals/reach/reach_en.htm

Inter-Organization Programme for the Sound Management of Chemicals (IOCM). The IOMC facilitates international action to achieve the sound management of chemicals through the collaboration of its nine member organizations: Food and Agriculture Organization, International Labour Organization, Organization for Economic Coöperation and Development, United Nations Environment Programme, United Nations Industrial Development Organization, United Nations Institute for Training and Research, World Health Organization, World Bank, and the United Nations Development Programme. http://www.who.int/iomc/en/

Obstacles to measuring and ultimately eliminating lead pollution include the metal's widespread presence in the environment, its ability to travel long distances, and weak or unenforced control measures (WHO, 2011). Ideally, there would be standardized monitoring and data collection of lead contaminants in high risk zones, especially in low- and middle-income countries where significant exposure remains (Attina & Trasande, 2013). However, identifying these areas can be a challenge, and diagnosis can be difficult when exposure goes unnoticed and symptoms are relatively nonspecific (Haefliger, 2011).

To truly assess the global scale of lead exposure, greater oversight of both point and non-point sources is necessary. However, there is inadequate information on the impact of non-point sources. Non-point source pollution is increasingly difficult to monitor because the pollution stems from various sources including leaded aviation fuel, battery recycling, craft making, and electronic waste recovery (WHO, 2010a, p. 47).

Today, laboratories primarily assess lead exposure through the blood, measured as micrograms of lead per deciliter of blood.

Although lead poisoning can also be measured using hair, teeth, bone, and urine, measuring the blood lead level (BLL) is widely viewed as the most reliable tool (Haefliger, 2011, p. 1). This is particularly true for screening young children whose BLL can indicate recent, acute exposure (WHO, 2010a, p. 11). Less developed countries lack the resources to conduct comprehensive surveillance, which means lead poisoning's geographic and socioeconomic factors have yet to be fully understood (Meyer et al., 2008). Nonetheless, lead, compared to other heavy metals, is one of the most fully documented and researched pollutants. In light of the data available on lead globally, EPI has chosen to use lead exposure as a representative measure of the impact of heavy metal pollution worldwide.

LEAD EXPOSURE

INDICATOR BACKGROUND. *Lead exposure* is classified in two ways: acute and chronic lead poisoning. Acute toxicity is indicative of severe short-term exposure, whereas chronic toxicity describes repeated exposure, often at lower levels. Acute lead exposure is relevant to disease burden in children because their brain and nervous systems can absorb four to five times as much lead as adults (WHO, 2017b). This sensitivity is further exacerbated by children's innate exploratory behavior, resulting in greater ingestion of lead from soil, dust, paint, and other lead-contaminated objects (2017b). Chronic lead exposure is more pervasive in adults due to long-term occupational exposure and is manifested through increased blood pressure, kidney damage, and cardiovascular disease. Long-term exposure is not measured by BLL, and instead is measured as micrograms of lead per gram of bone. Lead that accumulates in the body over time is stored in bones, and the half-life of lead in blood is only about one month in adults (Payne et al., 2010). The consequences of lead exposure are measured in age-standardized disability-adjusted life-years lost per 100,000 persons, the DALY rate.

DATA DESCRIPTION. The 2018 EPI relies on the latest and best available estimates of lead-related DALY rates. The data on lead exposure DALY rates come from the Institute for Health Metrics and Evaluation's Global Burden of Disease Study (GBD), which is the most comprehensive worldwide epidemiological study of lead exposure to date. Publicly accessible at http://www.healthdata.org/gbd, this study examines mortality and morbidity trends from 1990 to 2016 based on major diseases, injuries, and risk factors from lead exposure. Data for the GBD are drawn from 332 different studies on blood and bone samples, spanning the years 1964 to 2013. In 2015 the spatial-temporal modeling methodology was improved to more accurately predict blood lead in country-years with insufficient data (Forouzanfar et al., 2016).

LIMITATIONS. While the GBD is the leading epidemiological study on environmental risks, several limitations in this indicator are worth noting. First, measuring lead exposure is a burdensome process, and the GBD must draw on sparse datasets of blood and bone samples. Interpolation of exposure levels introduces uncertainty into the final DALY rate estimates. Second, the collection of tissue samples faces a number of challenges, including unknown contaminants, lack of quality assurance, and the short half-life of lead in blood (Haefliger, 2011, p. 6; Payne et al., 2010). For adults exposed to long-term cumulative lead poisoning, the most valid method of assessment is noninvasive x-ray fluorescence measurement of bone lead concentration (Payne et al., 2010). Research is necessary to improve this technology, as this method is sensitive to slight movements and known to be difficult to use in practice. Finally, the GBD makes assumptions when linking lead exposure to actual health outcomes and the distribution of diseases and death across populations. The lead exposure indicator is the best available metric on this important environmental health risk, and future improvements will increase the accuracy of new estimates.

FOCUS 7-1 LEAD UNCOVERED: FLINT WATER CRISIS — DRINKING WATER IN THE UNITED STATES

In January 2016 the president of the United States declared a state of emergency in Flint, Michigan, due to severe lead contamination of the city's drinking water. In April 2014 the state government switched Flint's water source from Lake Huron to the Flint River. As more polluted and corrosive water ran through the city's aging lead service lines— the pipes connecting the water mains under the street to residences — lead began to leach into the drinking water at an unprecedented rate.

Flint is a majority African American city where 40% of residents live in poverty. The socioeconomically disadvantaged community was further stressed by drinking water with lead levels as high as 13,000 parts per billion (ppb) (Olson & Pullen Fedinick, 2016). Water with lead concentrations of 5,000 ppb is considered toxic waste by the U.S. Environmental Protection Agency (2016). Despite elevated lead concentrations, state officials dismissed citizens' concerns for over a year, and the EPA failed to act even after multiple tests called for federal intervention (2016). This crisis illustrates how even the most politically stable, economically powerful countries are not immune to lead exposure and its tendency to harm the most vulnerable communities.

Flint is not an isolated case of lead contamination. In the United States, over 18 million people in 2015 were served by water systems violating the Lead and Copper Rule (Map 7-2). Established in 1991, the Lead and Copper Rule regulates lead and copper concentrations in drinking water systems through corrosion control requirements (US EPA, 2008). This usually entails the addition of a corrosion inhibitor, such as orthophosphate, in the water. Violations continue to occur across the United States due to the regulation's weak implementation and enforcement, including the failure to properly test water quality, failure to report contamination, and failure to treat the water (Olson & Pullen Fedinick, 2016). In the case of Flint, officials switched water sources without implementing measures to protect residents from more corrosive water, causing a city-wide drinking water crisis.

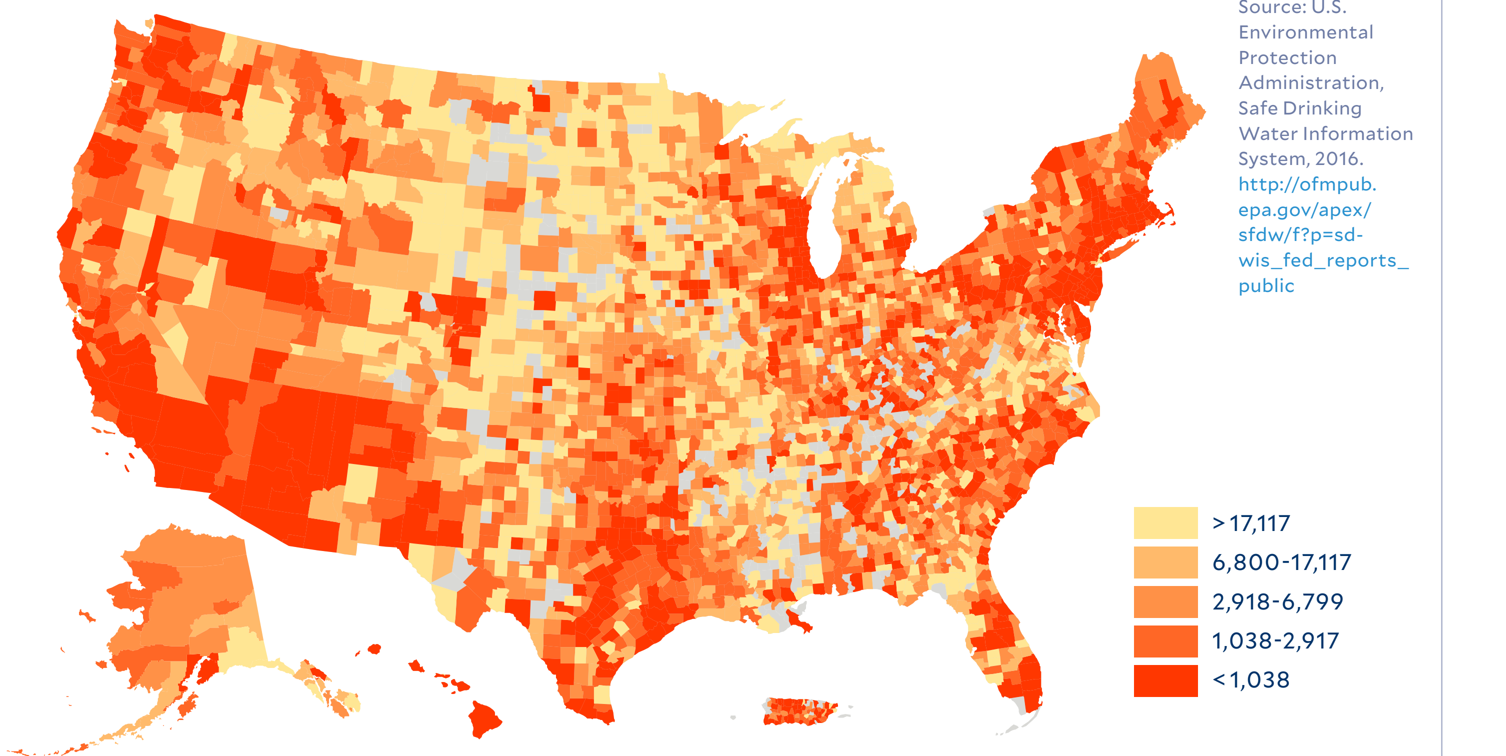
A comprehensive national inventory of lead service lines does not exist in the United States, but estimates range from 6 to 10 million lead service lines providing water to 15 to 22 million Americans (Olson & Pullen Fedinick, 2016). The geographic scope is enormous, and the problem is complicated by the variability of lead levels in tap water, even within the same water system. These conditions pose a significant challenge in identifying sites of contamination and enforcing the Lead and Copper Rule.

The current score for lead exposure has slightly improved compared to the baseline score,

indicating that countries have managed to reduce lead poisoning despite a global increase in lead production; see Table 7-2.

Global consumption of lead is increasing, driven mainly by the growing demand for lead batteries used in cars. Much of this new demand is in countries experiencing industrialization and urbanization (Landrigan et al., 2017, p.16). At the same time, the tightening of regulations regarding lead in petrol, paint, and plumbing has resulted in substantial reductions in lead exposure. Most notable is the phaseout of leaded gasoline in more than 175 countries (Landrigan et al., 2017, p.17). Although lead exposure has decreased, it remains a problem, especially for children in low- and middle-income countries (Attina & Trasande, 2013). Global trends reveal specific vulnerabilities, and children in particular continue to be at heightened risk of exposure from lead-based paint and lead pipes in drinking water systems (Attina & Trasande, 2013). Meanwhile, the informal recycling of lead-acid batteries continues with limited oversight and is a major cause of acute lead toxicity for both workers and nearby communities (Landrigan et al., 2017, p.17).

MAP 7-2 POPULATION OF AMERICANS SERVED BY WATER SYSTEMS WITH REPORTED VIOLATIONS OF THE LEAD AND COPPER RULE, 2015



Source: U.S. Environmental Protection Administration, Safe Drinking Water Information System, 2016. http://ofmpub.epa.gov/apex/sfdw/f?p=sdwis_fed_reports_public

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8
BIODIVERSITY & HABITAT

Environmental Performance Index

Biodiversity & Habitat

SNAPSHOT

Biodiversity underpins all ecosystem services that sustain our environment and power our economies.

CATEGORY DESCRIPTION

Natural habitats have witnessed considerable declines in biodiversity in recent decades. Today, many species are, however, at risk of extinction. The Biodiversity & Habitat issue category seeks to evaluate a country's performance in habitat conservation and species protection.

Each nation's Biodiversity & Habitat score reflects a composite of six underlying indicators. Our selected indicators are highlighted in the Convention on Biological Diversity's "Aichi Targets," a set of internationally agreed-upon goals for conservation and ecosystem management. The indicators in Biodiversity & Habitat are: *terrestrial biome protection (national weights), terrestrial biome protection (global weights), marine protected area, Species Protection Index, Protected Area Representativeness Index,* and *Species Habitat Index*.

INDICATORS INCLUDED

- **Terrestrial biome protection (national weights).** The percentage of biomes in protected areas, weighted by national composition of biomes.
- **Terrestrial biome protection (global weights).** The percentage of biomes in protected areas, weighted by global composition of biomes.
- **Marine protected areas.** The percentage of marine protected areas (MPAs) within a country's exclusive economic zone (EEZ).
- **Species Protection Index.** The average area of species' distributions in a country with protected areas.
- **Protected Area Representativeness Index.** The extent to which terrestrial protected areas are ecologically representative.
- **Species Habitat Index.** The proportion of habitat within a country remaining, relative to a baseline set in the year 2001.

We draw attention to the *Protected Area Representativeness* and *Species Habitat* indices, as these indicators represent new metrics within the 2018 EPI. These new indicators reflect international efforts to develop a common and more complete system for monitoring changes in biodiversity.

BIODIVERSITY & HABITAT INDICATORS	
Marine protected areas	% of EEZ
Terrestrial biome protection (national weights)	% of biomes (capped)
Terrestrial biome protection (global weights)	% of biomes (capped)
Species protection index	Unitless
Protected area representativeness index	Unitless
Species habitat index	Unitless

Biological diversity exists at multiple scales — at the ecosystem, species, and genetic levels.

Together, biological diversity forms the foundation of a resilient and sustainable planet. Habitat conservation is important not only for preserving key components of biological diversity, but for maintaining the associated ecosystem services which provide innumerable benefits and protections to humans, such as water provisioning, carbon sequestration, and flood prevention (UNEP-WCMC & IUCN, 2016a, p. 13).

Despite its importance, the planet continues to witness sharp declines in biodiversity. The Living Planet Index, which monitors abundance of over 14,000 populations of 3,706 vertebrate species, reveals an average 58% decrease among monitored species between 1970 and 2012 (WWF, 2016, p. 18). The World Wide Fund for Nature (WWF) finds the world may be entering the sixth mass extinction, noting that extinction rates are up to 100–1,000 extinctions per 10,000 species per 100 years (2016, p. 46).

Some ecosystems and species face more extreme extinction pressures than others. Three-quarters of coral reefs are threatened — a grim state of affairs given that reefs play an outsized role for biodiversity, providing critical habitat for a significant proportion of marine life despite covering only a small fraction of the oceans (Burke, 2011, p. 3). Similarly, the average risk of extinction for birds, mammals, and amphibians continues to increase, despite widespread gains in protected areas (PAs) and increasing recognition of the importance of biodiversity around the world (CBD & UNEP, 2014, p. 14). The extinction rate for amphibians may be between 25,039 and 45,474 times the background extinction rate (McCallum, 2007). Threatened by habitat degradation, unsustainable resource exploitation, pollution, invasive species, and climate change, the diversity of life on the planet is likely to continue to diminish considerably over the coming years.

Efforts to prevent biodiversity loss may deliver multiple benefits for the planet, people, and the economy.

ENVIRONMENTAL

The benefits that stem from high levels of biodiversity are well founded. For terrestrial environments, empirical research suggests a general, positive relationship between biodiversity and ecosystem services (Gamfeldt et al., 2013). Similarly, in marine environments, studies have found positive correlations between species and genetic diversity and ecosystem services, underscoring that biodiversity loss undermines the stability of ocean ecosystems (Worm et al., 2006, p. 790). Biomass production of reef fish as an ecosystem service itself has been found to be less affected by temperature changes in diverse fish communities than species — poor ones (Duffy, Lefcheck, Stuart-Smith, Navarrete, & Edgar, 2016).

Diversity of species and habitats emerge as critical factors in enabling resilience and enhanced recovery to environmental disturbance. Ecosystems and habitats serve important roles in mediating the effects of weather events and climate-related stressors and are thus important components of climate mitigation strategy. Uncertainty surrounding climate impacts suggests that ecosystems will benefit greatly from ensuring functional redundancy in order to safeguard key ecological activities when future effects are not fully known (McLeod, Salm, Green, & Almany, 2009, p. 367). Climate change will undoubtedly influence invasive species' distribution, spread, abundance, and impact. It may also worsen problems with invasive species, which, on their own, can have a severe financial and ecological toll (Hellmann, Byers, Bierwagen, & Dukes, 2008, p. 535). While some studies suggest that certain invasive species may be specifically favored under climate change, changing climatic conditions are likely to span a range of different and uncertain effects, including for existing invasive species and for the establishment of new invasive species (Hellmann et al., 2008, p. 536).

SOCIAL

The social dimensions of biodiversity and habitat protection range across many issues. Food security, human health, and cultural values are often deeply rooted in the natural environment. In the case of PAs, positive social impacts are often described as co-benefits of conservation strategies. The Convention on Biological Diversity (CBD) further recognizes that, "ultimately, the conservation and sustainable use of biological diversity will strengthen friendly relations among States and contribute to peace for humankind" (1992, p. 2). Key among the social benefits of biodiversity conservation is its contribution to meeting food, nutrition, and human health needs (1992, p. 2). As both the foundation of ecosystem services and a source of resources, biodiversity is fundamental to human health across different scales, from the global to the microbial level (WHO & CBD, 2015, p. 1). Healthy, diverse ecosystems also maintain critical services such as water and air filtration and pollination (WHO & CBD, 2015, p. 1), while many medicines on which humans depend are derived from biodiversity. From the perspective of equity, communities that are the most reliant on biodiversity and ecosystem services are most affected by their loss. These communities are also less likely to have the "social protection mechanisms" that help ensure resilience to environmental and anthropogenic disturbances (WHO & CBD, 2015, p. 2). In this way, a human dimension and equity approach underscores the importance of biodiversity and habitats.

ECONOMIC

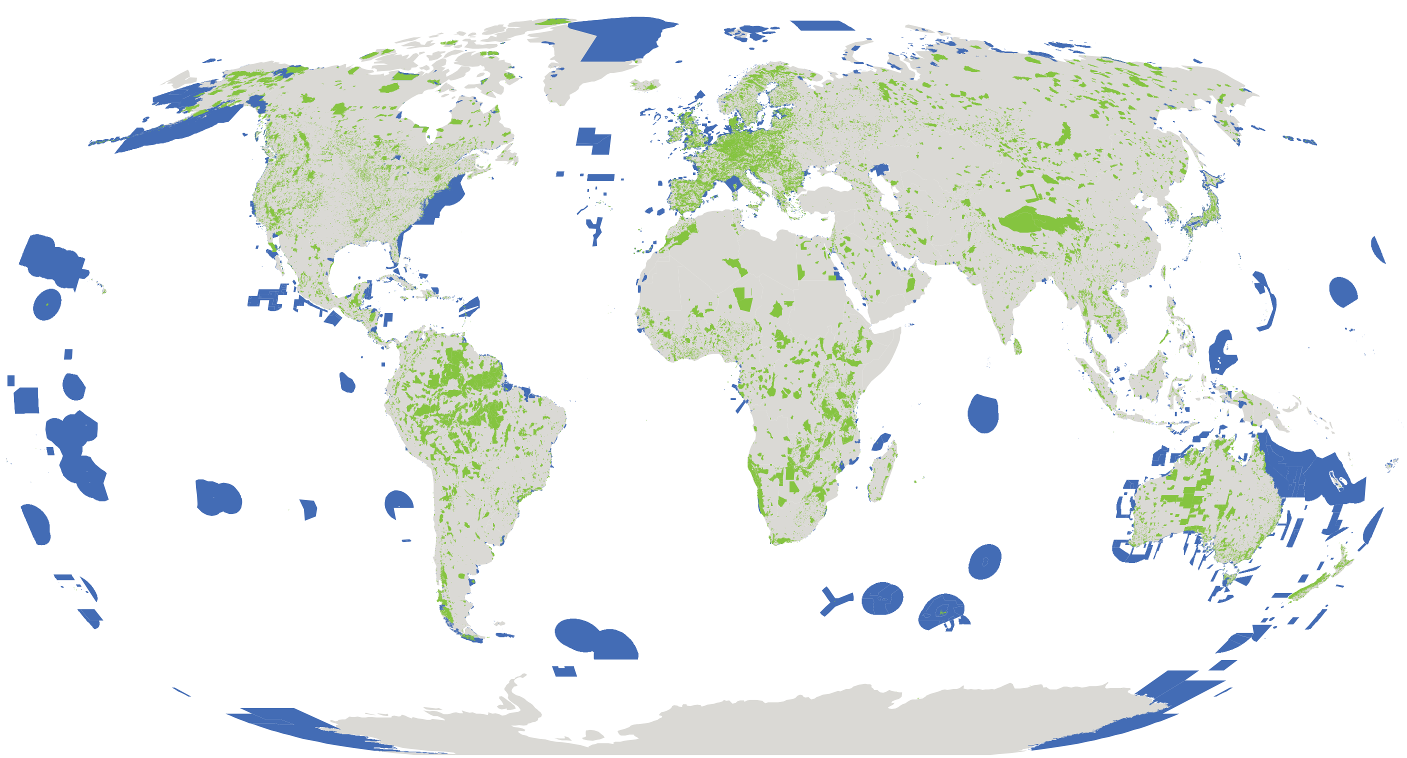
Careful analysis also suggests that biodiversity will be integral to many economic activities. Ensuring the provisioning of natural resources and the ecosystem services they support can help sustain or bolster economies (Secretariat of the CBD, 2016, p. 3). Subsistence and small-scale livelihood activities, such as agriculture and fishing, are especially reliant on the natural capital of healthy ecosystems. According to the CBD Secretariat, almost half of the world's population is directly dependent on natural resources for their livelihoods (2016, p.1). Protection and sustainable management of natural habitats can thus contribute to economic security in many parts of the world.

Ensuring the protection of natural resources requires significant capital investment. Globally, US$150–440 billion per year is needed to halt the loss of biodiversity by mid-century (UN, 2016). However, research from the WWF indicates that the economic benefits of protection may outweigh their costs. A recent report found the benefits that stem from expanding MPAs and effective protection of critical marine habitats outweigh the costs at ratios ranging between 3:1 and 20:1 (Reuchlin-Hugenholtz & McKenzie, 2015). Further, the total benefit of achieving the target of protecting 10% of marine areas is estimated at US$622–923 billion over a 35-year period (Reuchlin-Hugenholtz & McKenzie, 2015). If MPAs were to increase to 30% coverage, total economic benefits would range US$719–1,145 billion (Reuchlin-Hugenholtz & McKenzie, 2015).

Biodiverse ecosystems may also help reduce the cost of financial damage to human systems from weather events and climate change. Wetland loss and deterioration of the Mississippi Deltaic Plain exacerbated Hurricane Katrina's impact by allowing more storm surge waters to flood Lake Pontchartrain. To exemplify this, a regional survey of the value of wetlands in Louisiana, which included New Orleans, found that an increase in wetlands and their vegetation decreases potential property damage from a storm surge (Barbier, Georgiou, Enchelmeyer, & Reed, 2013). As warming of the Earth's oceans intensifies and the likelihood of coastal flooding and severe storms intensifies, habitat protection may offer coastal communities a way to stabilize and protect their shorelines from erosion and storm surge (Gedan, Kirwan, Wolanski, Barbier, & Silliman, 2011).

MAP 8-1 GLOBAL TERRESTRIAL, MARINE, AND COASTAL PROTECTED AREAS

Marine protected areas are in blue and terrestrial protected areas in green.



Source: United Nations Environment Programme World Commission on Protected Areas & International Union for Conservation of Nature.

In 1992 the international community established the CBD, recognizing the intrinsic, environmental, and economic value of biodiversity.

The CBD asserts that biodiversity conservation is a "common concern of humankind," and therefore one that spans present and future generations (1992, p. 2). The CBD defines biodiversity as, "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (1992, p. 3). This widely accepted definition encompasses not only species and genetic diversity but also the diversity of habitats and ecosystems. Through this broad perspective, the issue of biodiversity is linked to nearly every aspect of human and ecological well-being.

Globally, biodiversity and habitat protection efforts in this decade have been primarily guided by a set of internationally agreed-upon targets known as the Aichi Biodiversity Targets. Adopted in 2010 by the 196 parties to the CBD, these targets are meant to be achieved by 2020. The recently adopted United Nations Sustainable Development Goals (SDGs) reinforce the targets set under the CBD framework. In 2014 the CBD's Global Biodiversity Outlook 4 reported the international community was not on track to meet a majority of the Aichi Biodiversity Targets (CBD & UNEP, 2014). Other research confirms that, even with the recent escalation in policy responses around biodiversity conservation, these actions are still not enough to counter the threats to biodiversity and critical habitats and to achieve desired progress within a 2020 timeline (Tittensor et al., 2014, p. 241).

SUSTAINABLE DEVELOPMENT GOALS

Among the SDGs, two goals directly relate to Biodiversity & Habitat: Goal 14 on oceans and Goal 15 on terrestrial habitat.

GOAL 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

TARGET 14.5. By 2020, conserve at least 10% of coastal and marine areas, consistent with national and international law and based on the best available scientific information.

GOAL 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

TARGET 15.1. By 2020, ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements.

TARGET 15.2. By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and substantially increase afforestation and reforestation globally.

TARGET 15.4. By 2020, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

TARGET 15.5. Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity, and, by 2020, protect and prevent the extinction of threatened species.

INTERNATIONAL ORGANIZATIONS

Several international organizations are charged with orchestrating biodiversity protection at the global level. Key orchestrating bodies include:

Convention on Biological Diversity (CBD) Secretariat. The CBD Secretariat global governance serves as the support structure for the CBD, a multilateral treaty that aims to protect biological diversity and promote sustainable and equitable use of the resources where biodiversity can be found. The convention, now signed by 196 nations, launched at the Rio Earth Summit in 1992. https://www.cbd.int/

International Union for the Conservation of Nature (IUCN). The IUCN is a membership union composed of government and civil society groups. Its role is to provide public, private, and nongovernmental organizations with the information and tools they need to collectively promote economic development, human progress, and conservation. https://www.iucn.org

United Nations Division for Ocean Affairs and the Law of the Sea (UN DOALOS). UN DOALOS supports the wider acceptance, uniform and consistent application, and effective implementation of the United Nations Convention on the Law of the Sea. Its core functions include offering advice, studies, assistance, and research on the convention's implementation; maintaining a comprehensive information system; and providing training and technical assistance to States. http://www.un.org/depts/los/

MULTILATERAL EFFORTS

Multilateral efforts have engendered several relevant conventions and agreements which are used to coördinate action on habitat conservation and species protection. Significant outcomes and their resulting conferences include:

Convention on Biological Diversity Meetings of the Conference of the Parties. The Conference of Parties is the governing body of the CBD. Its purpose is to advance the implementation of the convention though decisions made at is periodic meetings. The thirteenth meeting of the Conference of Parties was held in Cancun, Mexico, in December 2016. https://www.cbd.int/cop/

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Established in 2012, the IPBES assesses the state of biodiversity and the ecosystem services it provides to society. As an implementing body for global conservation efforts, the IPBES provides policymakers with scientific assessments and knowledge on the state of biodiversity and the tools and methods they need to mitigate risks. IPBES has 126 Member States. NGOs, civil society groups, and individual also participate as observers. https://www.ipbes.net/

Meetings of the Preparatory Committee on General Assembly Resolution 69/292. Resolution 69/292 is an international legally binding instrument under the United Nations Convention on the Law of the Sea that addresses the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction.

2017 Global 'Our Ocean' Conference hosted by the European Union. The fourth 'Our Ocean' conference was held in October 2017 in Malta. The conference produced 437 commitments, US$8.4 billion in financial pledges, and nearly 1 million square miles in MPAs. The next three conferences will take place in Bali, Indonesia (2018); Norway (2019); and Palau (2020). https://www.ourocean2017.org/

Biodiversity conservation, as it exists today, largely consists of the management of defined territories,

also known as *in situ* or "on site" conservation. Area-based management gained political traction based, in part, on the belief that it can deliver social, economic, and environmental benefits. The relative simplicity of demarcating land and restricting land use options further contributed to their rise in popularity (Barnes et al., 2016, p. 2). PAs now cover 16.3% of the planet's terrestrial and inland water ecosystems, 4.12% of the global ocean, and 11.5% of coastal and marine areas under national jurisdiction; see Map 8-1 (UNEP-WCMC & IUCN, 2016a). Although approaches such as landscape and *ex situ* conservation are important—PAs remain a mainstay of conservation activity. For this reason, and because outcome measures such as species loss are more challenging to monitor or lack sufficient data, the EPI has adopted a series of six indicators to assess a country's performance in biodiversity and habitat conservations for both terrestrial and marine ecosystems.

There are various efforts to encourage consistency and promote a common framework in assessing biodiversity. Examples include the Biodiversity Indicators Partnership and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services' (IPBES) task force on knowledge and data. The SDGs, in combination with the Aichi Biodiversity Targets, include multiple indicators to benchmark progress in terrestrial conservation. Indicators include measuring forest area as a proportion of total land area. Another example is the Mountain Green Cover index, which measures progress toward mountain ecosystem conservation. The SDG Index also includes a spillover variable aimed at reflecting the biodiversity loss attributable to a country's imports of agricultural and other products (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017, p. 27). Finally, indices like the Living Planet Index and the IUCN Red List of Threatened Species also collect data that monitor species changes. The Red List is also listed as an indicator for SDG Target 15.5 (above).

Ideally, credible data on governance, management effectiveness, species declines, ecosystem-based adaptation to climate change, and economic impacts of biodiversity loss would assist in the formulation of a comprehensive biodiversity metric. Spatial data on PAs across countries, however, remain the most widely accessible, nationally specific indicators of progress. To understand both extent of coverage and siting of ecologically important areas, the EPI weights PAs in relation to their size and type of biome. Using EPI's PA data on the national scale as a foundation for drilling down to area-specific information can help generate a nuanced understanding of biodiversity conservation.

A country's Biodiversity & Habitat score is comprised of the combination of the weighted scores of six indicators. These indicators reflect the goals included in Aichi Biodiversity Targets 11, 12, and 5.

- **Terrestrial biome protection (national weights).**The percentage of biomes in protected areas, weighted by national composition of biomes.

- **Terrestrial biome protection (global weights).** The percentage of biomes in protected areas, weighted by global composition of biomes.

- **Marine protected area.** The percentage of marine protected areas (MPAs) within a country's exclusive economic zone (EEZ).

- **Species Protection Index.** The average area of species' distributions in a country with protected areas.

- **Protected Area Representativeness Index.** The extent to which terrestrial protected areas are ecologically representative.

- **Species Habitat Index.** The proportion of habitat within a country remaining, relative to a baseline set in the year 2001.

TERRESTRIAL BIOME PROTECTION: NATIONAL AND GLOBAL WEIGHTS

INDICATOR BACKGROUND. PAs are an important tool for biodiversity conservation (Rodrigues et al., 2004). Differences in land use in protected terrestrial areas are shown to have a positive impact on biodiversity. Species richness and abundance, for example, are 10.6% and 14.5% higher than nonprotected areas, respectively (Gray et al., 2016). The terrestrial biome protection indicators are aligned to Aichi Target 11, which aims to protect at least 17% of terrestrial and inland water areas by 2020 (UNEP-WCMC & IUCN, 2016a).

As of 2016, there are 200,467 terrestrial and inland water PAs covering 14.7% of the world's ecosystems (UNEP-WCMC & IUCN, 2016a). Despite continued growth in PAs, the global community has much work to do if it is to meet Aichi Target 11. The United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC) and the IUCN report that an additional 3.1 million square kilometers are needed to meet Aichi Target 11 and, as of 2016, less than half of the world's terrestrial ecoregions outside of the Antarctic mainland satisfy the 17% target (2016a, p. 43).

DATA DESCRIPTION. Data on PAs come from the World Database on Protected Areas (WDPA), a joint project between the United Nations Environment Programme (UNEP) and the IUCN. The WDPA, managed by UNEP's World Conservation Monitoring Centre (WCMC), is updated monthly and provides the most comprehensive data on PAs globally. Ecoregion boundaries are provided by the World Resources Institute's "Terrestrial Ecoregions of the World" dataset, based on the work of Olson et al. (2001).

The terrestrial world can be divided into fourteen biomes of ecological significance (Olson et al., 2001, p. 934). Nested within biomes are 867 ecoregions, defined as "relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change" (Olson et al., 2001, p. 933). Using this biogeographic framework can allow for greater recognition of distinctive habitats and globally important areas.

To measure the extent of conservation of terrestrial biomes, the EPI calculates the proportions of important biomes that fall within PAs. The proportion of a biome type that is protected is then weighted in two ways before being aggregated into a country-level score.

- For the *terrestrial biome protection (national weights)* indicator, scores are based on the fraction each biome occupies within a country's total biome area. This indicator attempts to reflect a country's effort to protect rare ecoregions within its own borders.

FOCUS 8-1 PILOT INDICATOR: MEASURING WETLAND CONSERVATION

Wetlands provide many natural resources and ecosystem services to humans, yet they have been extensively exploited, degraded, and modified worldwide. Measures to ensure wetland protection have not always been effective. Protected area plans are often not designed to incorporate the processes that sustain the optimal functioning of wetlands. Hydrological dynamics, ecological processes, and biodiversity should be key features of protected area design. In reality, conservation areas are often designated without adequately considering the role of upstream sources of water and nutrients, hydrological connectivity with rivers or other water bodies, wildlife habitat needs and migration corridors, and natural disturbance processes. These shortcomings in protecting wetlands limit their benefits to humans.

In light of the challenges facing wetlands, we aimed to provide a global-scale portrait of the current status of conservation and human influence on wetlands. We combined a global map of inundation extent derived from satellite images with data on threats from human influence and on protected areas. To quantify the local human pressures threatening wetlands, we used the Global Human Footprint Map, which calculates a Human Influence Index from nine global data layers covering population density, human land use, and infrastructure. Our combined dataset provides a comprehensive picture of where wetlands are in the world, how they are protected, and the pressures they face.

Currently, seasonal inland wetlands represent approximately 6% of the world's land surface, and about 89% of these are unprotected — as defined by protected areas under IUCN Categories I–VI and Ramsar sites; see Map 8-2 (opposite page). Wetland protection ranges from 20% in Central America and 18% in South America to only 8% in Asia. Particularly high human influence was found in Asia, containing the largest wetland area in the world. High human influence was also found in the wetlands of Europe, Central America, and North America — excluding the large area of boreal and Arctic wetlands in Canada and Alaska. Variable levels of human pressure were found in wetlands within protected areas. As a general trend, wetlands in protected areas of IUCN Categories I–IV were less impacted than the other categories and the Ramsar sites. Oceania was an exception, where the Ramsar sites were less subjected to impact.

It is concerning that only a small fraction of global seasonal wetlands is covered by protected areas — 11.3% overall. An even smaller fraction is protected under the stricter IUCN Categories I–IV. In addition, high levels of human influence in some of the protected wetland areas indicate that the local ecological condition of protected wetlands may also be compromised. These findings underscore the urgent need for more effective conservation measures.

The information provided in this study is important for wetland conservation planning and reveals that the current paradigm of wetland protection may be inadequate. Considering the rapid increase in human population and pressures on global wetlands, urgent action is needed to develop better frameworks for wetland conservation planning. Identifying specific conservation needs of the different wetland types, considering their variation in space and time, as well as their functions and landscape context, will help support the development of more effective conservation plans.

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- For the *terrestrial biome protection (global weights)* indicator, scores are weighted by the global extent of biomes, or their prevalence relative to all biomes. This results in an indicator that reflects a country's effort to protect rare biomes worldwide.

The methodology used to calculate different weights is described in further detail in the Technical Appendix.

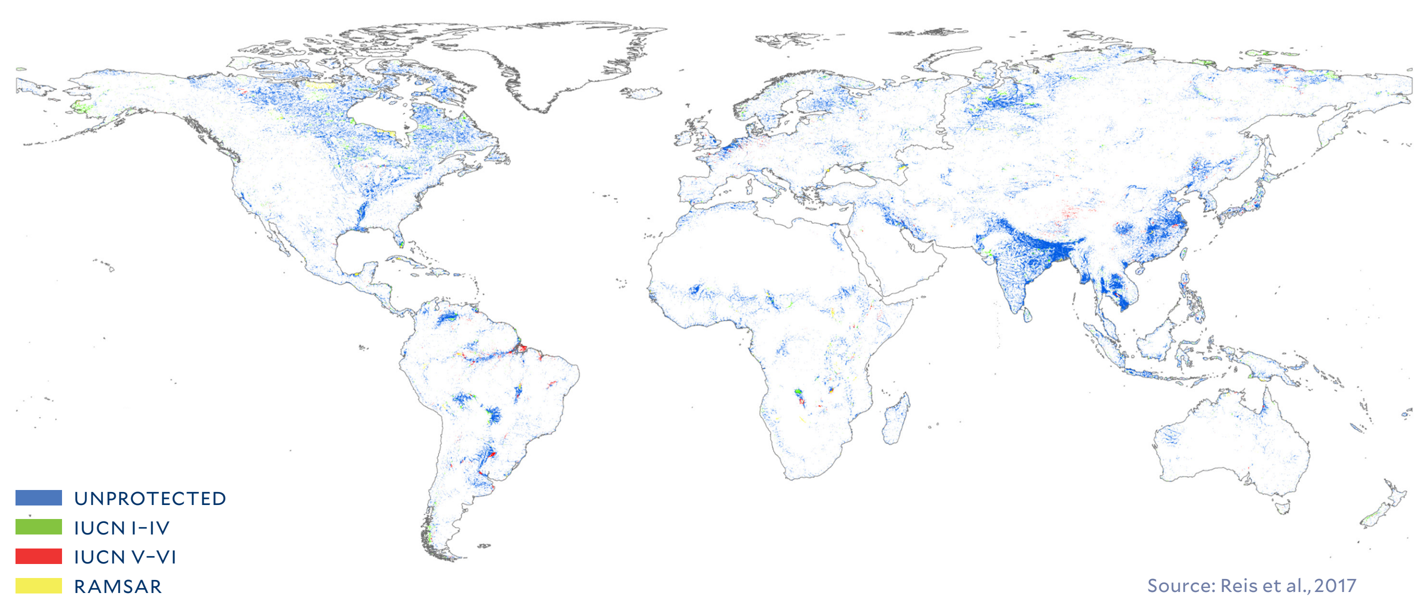
LIMITATIONS. The establishment of PAs is a necessary, but not sufficient, condition for biodiversity conservation. While the available evidence suggests that PAs have a positive impact on halting the rate of biodiversity loss, there is limited evidence and a weak understanding of the conditions for effective management (Chape, Harrison, Spalding, & Lysenko, 2005). This dilutes confidence in the ability of PAs to deliver lasting outcomes for habitat and species protection (Geldmann et al., 2013). Understanding and quantifying the factors that contribute to wildlife population change are thus a critical area of future study. Similarly, the need to break down the individual motivations and aims for each PA is also important, as they are often assessed uniformly (Geldmann et al., 2013, p. 230).

New evidence also suggests that PAs are vulnerable to unsustainable resource use and human disturbance (Schulze et al., 2018). A January 2018 study of nearly 2,000 terrestrial PAs identified negative impacts from recreational activities as the most commonly reported threat among site managers (Schulze et al., 2018). Differences in economic development levels also persist as a challenge in comparing the efficacy of PAs across geographic regions. In countries with low levels of economic development, threats from overexploitation emerged as an additional threat (Schulze et al., 2018). The threats emphasized in the study are difficult to monitor, even with remote sensing techniques. Thus, the need to develop new monitoring strategies and metrics that account for these challenges will be important to more accurately assess the state of conservation efforts.

MARINE PROTECTED AREAS

INDICATOR BACKGROUND. The *MPA* indicator is the only ocean indicator in the Biodiversity & Habitat issue category. It is aligned with a key objective in the Aichi Targets: the protection of 10% of coastal and marine areas globally (United Nations, 1992). MPAs, like terrestrial PAs, are central to conservation. Marine ecosystems have been adversely impacted by overfishing, habitat loss, and pollution on global and local scales. MPAs are the primary tool for protecting critical marine habitats. MPAs provide refuge for vulnerable species through the protection of habitats from unsustainable fishing practices and other destructive human activities (Gell & Roberts, 2003). They also serve as PAs for fish populations to spawn and reach maturity, critical life stages to protect in order to support population growth (Gell & Roberts, 2003). Finally, MPAs may promote resilience to climate change (McLeod et al., 2009). The protection of biodiversity in MPAs is furthermore beneficial to local cultures and economies dependent on

MAP 8-2 GLOBAL MAP SHOWING THE EXTENT OF SEASONAL INLAND WETLANDS IN UNPROTECTED AND PROTECTED AREAS, AS DEFINED BY IUCN I–VI AND RAMSAR SITES



Source: Reis et al., 2017

marine ecosystems (Reuchlin-Hugenholtz & McKenzie, 2015).

Global MPAs have increased in size steadily over the past decade. Since 2014, PAs under national jurisdiction have grown by 1.8% (UNEP-WCMC & IUCN, 2016a). According to the WDPA, there are 14,688 MPAs globally. Together, these areas cover 14.9 million square kilometers and make up 10.1% of global marine ecosystems (2016a). Recent growth in MPA coverage can be explained by a combination of existing site expansion and new site creation. According to the WDPA, most of the growth in MPAs has focused in national waters, including areas off Australia, New Zealand, the United States, the United Kingdom, and Spain (2016a). Under the leadership of President Obama, the U.S. expanded the Papahānaumokuākea Marine National Monument in the Hawaiian Islands from approximately 360,000 square kilometers to 1.5 million km^2 in August 2016, making it the largest PA on Earth (NOAA, 2016).

DATA DESCRIPTION. Under the United Nations Convention on the Law of the Sea, a country has "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds," defined as the area 200 nautical miles off its coastline (1982, p. 198). Our indicator *marine protected areas* reports on the percentage of a nation's EEZ. It is derived from publicly available data from WDPA, which catalogues data for 245 countries and territories for the years 1990–2017 (UNEP-WCMC, 2017). This indicator is also constructed, in part, with data from the Flanders Marine Institute's Maritime Boundaries Database. The Center for International Earth Science Information Network (CIESIN) uses these datasets to calculate the *marine protected areas* indicator. It is calculated by dividing the area of MPAs within a country's EEZ by its total EEZ area.

FOCUS 8-2 CONSERVATION OUT OF PLACE: MARINE GENETIC RESOURCES AND NEW FRONTIERS FOR BIODIVERSITY

Marine biodiversity conservation in the high seas and deep seas represents a new frontier. Marine areas beyond national jurisdiction comprise 65% of the ocean's surface and 95% of the ocean's volume. This territory represents tremendous potential for exploring a new realm of biodiversity, and demands strong and coördinated conservation policies (FAO, 2016).

Until relatively recently, exploiting the resources of the deepest parts of the oceans was impossible. Even now, deep-sea environments represent a largely uncharted pool of vastly diverse marine organisms. The exploration of such extreme conditions, for which unfamiliar forms and ways of life are likely to have developed, is believed to have great potential for generating innovations (Jaspars et al., 2016, p. 155). For example, marine research in the deep sea and elsewhere in the oceans has led to the development of cancer-fighting drugs derived from sponges and cosmeceuticals derived from bacteria living in hydrothermal vents (Jaspars et al., 2016, pp. 152,155). Today, marine genetic resources (MGR), another term that reflects the biodiversity of the oceans, are attracting increasing attention as negotiations continue around the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction.

No state has sovereignty over marine biodiversity and MGR in the high seas, but all states, both coastal and landlocked, have rights in areas beyond national jurisdiction Protected areas beyond national jurisdiction—typically >200 nautical miles—have remained constant in recent years, making just 0.25% of total MPAs (UNEP-WCMC & IUCN, 2016a). The question of how to manage and protect the biodiversity of the high and deep seas falls under the United Nations Convention on the Law of the Sea, which currently does not explicitly regulate the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (Broggiato, Arnaud-Haond, Chiarolla, & Greiber, 2014, p. 178).

The CBD, which aims to sustainably manage biodiversity and therefore might be expected to regulate marine biodiversity in the high seas, applies "[in] the case of components of biological diversity, in areas within the limits of its national jurisdiction," and "[in] the case of processes and activities, regardless of where their effects occur, carried out under its jurisdiction or control, within the area of its national jurisdiction or beyond the limits of national jurisdiction" (1992, pp. 4–5). In part because of their potential to be highly profitable, MGRs have become a contentious issue in the negotiations (Harden-Davies, 2017, p. 505). These negotiations currently revolve around UN General Assembly Resolution 69/292. Among the key issues being discussed is the fair and equitable access to and benefit sharing from MGR—whether *in situ* (in natural habitat), *ex situ* (outside natural habitat), or *in silico* (in digital form) (Broggiato et al., 2014, p. 183).

LIMITATIONS. There are several limitations to our *MPA* indicator. First, while Aichi Target 11 includes protection of coastal and marine waters, separately assessing marine from terrestrial protected habitats may not always be practically useful or ecologically sensible since terrestrial land use and pollution affect coastal marine life. Second, assessing MPAs in EEZs does not include areas beyond national jurisdiction, i.e., the high seas, which represent almost two-thirds of total ocean surface and 80% of the world's living space (The Pew Charitable Trusts, 2015). That said, most fishing occurs in national jurisdictions, suggesting that the most formidable impacts on known marine species still occur within EEZs. Evidence suggests that conservation targets based solely on area will do little to optimize protection of marine biodiversity (Edgar et al., 2014). Studies on the size of MPAs on fish populations have revealed negligible or weak effects, suggesting an inherent complexity in ecosystem management (Côté, Mosqueira, & Reynolds, 2001; Halpern, 2003; Vandeperre et al., 2011). Longevity, isolation, protection, and enforcement also impact the ability of MPAs to deliver lasting impacts for ecosystem health and biodiversity. Thus a metric that can assess the simultaneous interplay between different variables in management strategy would present a more nuanced and holistic assessment of both the driving forces behind success and the arenas in which MPAs are failing to meet their full potential (Halpern, 2014).

SPECIES PROTECTION INDEX

INDICATOR BACKGROUND. The *Species Protection Index (SPI)* measures how much suitable habitat for a country's species is under protection and estimates the biodiversity representativeness of terrestrial protection areas (GEO BON, 2015). We use the *SPI* to assess CBD Aichi Target 11, which aims to increase global protected terrestrial and inland water areas to 17% of total land area by 2020 (1992).

DATA DESCRIPTION. The GEO BON Secretariat developed the *SPI* as part of a new set of indicators for biodiversity in collaboration with Map of Life and Commonwealth Scientific and Industrial Research Organisation (CSIRO). Data for the indicator are available for a rapidly growing list of more than 30,000 species of terrestrial vertebrates, invertebrates, and plant species (GEO BON, 2015). The *SPI* leverages remote-sensing data, a global biodiversity informatics infrastructure, and integrative models. The index uses annual terrestrial species and environmental data from Landsat and moderate-resolution imaging spectroradiometer (MODIS) satellites to map and measure suitable species habitat at high resolutions (GEO BON, 2015). The proportion under protection are quantified and updated on an annual basis to reflect any changes in PAs and suitable habitat. The index thus represents the aggregate of species-level metrics for a given spatial unit, such as individual countries or biomes, and may be calculated for varying minimum sizes or categories of PAs separated by biological group (GEO BON, 2015). All underlying data and metrics for the *SPI* are available through the Map of Life (https://mol.org/), a web interface developed with Google Earth that leverages biodiversity data and high resolution habitat information to map suitable species locations. *SPI* data are validated with over 350 million field records on species locations from surveys and citizen science (GEO BON, 2015).

LIMITATIONS. While remote sensing provides information on biodiversity at global and local scales with relative ease, limitations stem from its ability to match spatial resolution with the granularity required for species conservation on the ground (Zeller, Nijhawan, Salom-Pérez, Potosme, & Hines, 2011). Differences in satellite imagery resolution can also engender stark differences in land cover classifications and subsequent patch-level metrics, such as habitat size, shape, and connectivity (Boyle et al., 2014). The *SPI* uses MODIS and Landsat data with resolutions ranging from 1 km to 30 m (GEO BON, 2015). The lower the resolution, the more difficult it becomes to evaluate ecosystem connectivity and corridors with accuracy without field verification (Zeller et al., 2011). Improving the resolution of free or low-cost sources of satellite imagery will assist in monitoring and benchmarking progress in conservation at scale.

PROTECTED AREA REPRESENTATIVENESS INDEX

INDICATOR BACKGROUND. The *Protected Area Representativeness Index (PARI)* indicator measures the extent to which terrestrial PAs are representative of the ecosystems and habitats within a country. Globally, there are eight biogeographic terrestrial realms and 14 biomes that contain 867 ecoregions (Olson et al., 2001, p. 933). Past conservation efforts prioritized areas that did not conflict with other human needs, rather than where protection was most important for biodiversity (Pressey, Visconti, & Ferraro, 2015). Today, nations are making a concerted effort to protect under-represented areas and ensure fair ecological representation of species. However, much progress remains if countries are to meet the ecological representativeness requirement in Aichi Target 11. Evidence from a recent study suggests fewer than half of the 25,000 listed species in most groups had a sufficient proportion of their distributions covered by PAs (Butchart et al., 2015). Our *PARI* indicator recognizes the importance of designating conservation areas that reflect the ranges and habitats of the species they wish to protect.

DATA DESCRIPTION. The *PARI* provides a cost-effective approach to assess the extent to which global terrestrial PAs are ecologically representative

(GEO BON, 2015). The *PARI* is calculated for ecological representativeness, measured as the proportion of biologically scaled environmental diversity included in PAs. The index uses remote environmental mapping, biodiversity informatics (information sharing), and microeconomic logical modeling to track progress on Aichi Target 11. Data are sourced from the WDPA and NASA's MODIS Land Cover Change Dataset at a 1-km grid resolution. Biodiversity composition is derived by scaling environmental and geographical gradients from over 300 million local records of more than 400,000 plant, invertebrate, and vertebrate species (GEO BON, 2015). Data are then integrated with PA boundaries from the WDPA and land use data for surrounding landscapes, derived from NASA's MCD12Q1 dataset.

LIMITATIONS. Datasets, such as the WPDA, make it possible to develop a standardized set of metrics to track conservation progress at the local and global level. However, biodiversity datasets may fail to provide local governments, managers, and communities with the sufficient spatial and thematic detail required to effectively monitor biodiversity in single PAs (Chape et al., 2005) or regional park networks

FOCUS 8-3 THE ROLE OF CITIZEN SCIENCE IN BIODIVERSITY DATA COLLECTION AND MONITORING

High-level biodiversity targets, like the CBD Aichi Targets, rely on accurate reporting of changes in the status and trends of global biodiversity. Remote sensing through Earth observation systems can help scientists track changes in ecosystem composition by type, nutrient retention, and ecosystem fragmentation on a large scale with improved efficiency and standardization. Unfortunately, remote sensing and aerial imagery are limited in their ability to assess all changes in biodiversity. Thus, assessment of certain measures of biodiversity still require human-assisted data collection (O'Connor et al., 2015; Proença et al., 2017), a process often hindered by a limited number of professionals with adequate funding.

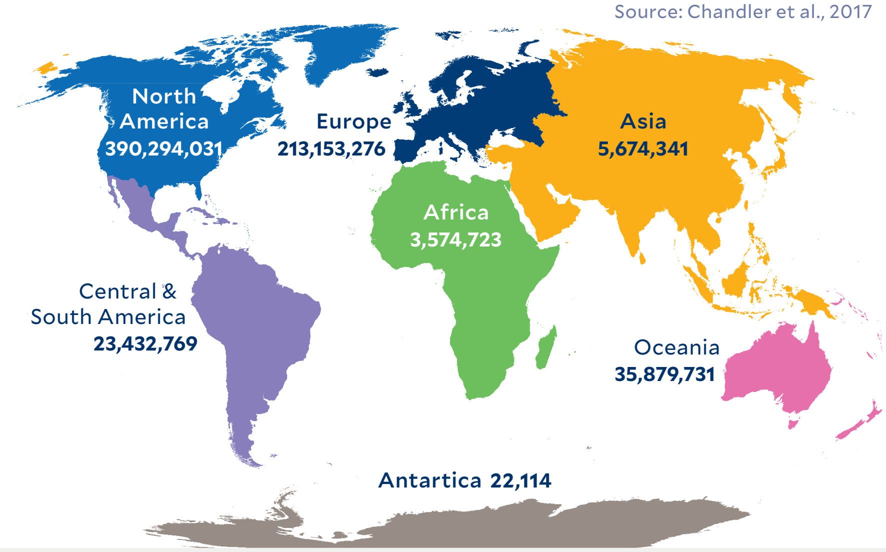
Recent changes in technology and the rise of crowdsourcing data-collection applications have made it possible to access data collected by members of the interested public, called citizen scientists, over large geographic regions with ease (Howe, 2006; Lepczyk et al., 2009). Citizen science thus offers the scientific community another way to monitor changes in biodiversity, which could improve the way it monitors species populations and ecosystems at regional and global scales.

While citizen science programs cover a wide range of taxonomies of global biodiversity, uneven distributions in the type, spatial range, and frequency of recorded observations across different taxonomic groups generate imbalances in the types of organisms who benefit from them. Birds, for example, have benefitted the most from citizen science. Global Biodiversity Information Facility (GBIF), for example, has 300 million recorded bird observations and make up 54% of all records; reptiles, by comparison, make up just 1% of all GBIF observations (Chandler et al., 2017).

Spatial distributions of citizen science observations, like taxa, are also unevenly distributed; see Map 8-3. One assessment of citizen science programs found data collection efforts are most focused in North America, with 184 programs or 44% of total, and Europe, with 136 programs or 32% of total (Chandler et al., 2017). Few citizen science programs were found in Africa, Asia, and Central and South America. Expansion of citizen science efforts in these areas could aid in the collection of data on rare species and serve as an early detection system for invasive species. However, environmental managers and scientists should also note that citizen science can often produce its own biases and limitations (Bonney et al., 2014).

MAP 8-3 DISTRIBUTION SPECIES RECORDS FROM CITIZEN SCIENCE PROJECTS IN THE GBIF BY CONTINENT—AS OF MARCH 31, 2016

Source: Chandler et al., 2017



(Pereira & Cooper, 2006). As with the *SPI* indicator, concerns over MODIS's and other remote sensing products' abilities to produce images at the fine resolution necessary to draw accurate conclusions about the state of conservation remain a large limitation in their applicability and use.

SPECIES HABITAT INDEX

INDICATOR BACKGROUND. The *SHI* indicator is new to the 2018 EPI. It measures the proportion of habitat that remains within a country relative to a baseline set in the year 2001. Habitat loss is a primary driver in species extinction, particularly in areas of high biodiversity (Brooks et al., 2002). The *SHI* indicator serves as a proxy for potential population losses and assesses the extinction risk at regional and global levels. It is intended to assess progress on CBD Aichi Targets 5 and 12, which aim to halve or reduce habitat loss and fragmentation and prevent extinction (1992).

DATA DESCRIPTION. The *SHI* data come from the Map of Life, a biodiversity mapping and monitoring tool using Google Earth Engine that leverages remote sensing data, local observations, and models in a web-based informatics infrastructure to report progress on CBD Aichi Targets (GEO BON, 2015). Habitat range indices are available for over 20,000 terrestrial vertebrate, invertebrate, and plant species (GEO BON, 2015). Data are validated using a growing pool of over 300 million location records (GEO BON, 2015). Each species' suitable habitat range is constructed from remote sensing data and modeled using scientific literature, expert-based data on habitat restrictions, and published land cover products from MODIS and Landsat satellites. Maps are validated by field data on species locations sourced from surveys and citizen science. Changes in species habitat are quantified and reported annually.

LIMITATIONS. Datasets used to evaluate Aichi Targets 5 and 12 are often limited by inadequate geographic representation, coarse disaggregation and temporal resolution, lack of transparency, and lack of scientific validation (GEO BON, 2015). The *SHI* aims to address these limitations by making use of highly resolved remote sensing data near the global level and pairing them with biodiversity observations and transparent modeling frameworks. Remote sensing assessment tools, however, may be insufficient in their ability to accurately report on land use and land cover change. A 2016 survey of over 300 geospatial data sources found that existing products still cannot produce a global standardized view of landscape change on a timescale that allows for appropriate conservation action (Joppa et al., 2016).

FOCUS 8-4 PILOT INDICATOR: BIODIVERSITY HABITAT INDEX

Due to the key role habitat plays in maintaining biodiversity, habitat loss and degradation are primary causes for biodiversity loss worldwide (Juffe-Bignoli et al., 2014; Wilson et al., 2016). In 2010, parties to the Convention on Biological Diversity (CBD) agreed to adopt 20 ambitious conservation goals, called the Aichi Targets. Among the targets, the CBD requires nations to take urgent and effective action to halt the loss of biodiversity. Aichi Target 5 specifically addresses the importance of habitat protection, stating: "By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced."

Different indicators are used to measure progress toward the Aichi Targets. Each provides distinct ways of understanding the magnitude of threats and pressures to various dimensions of biodiversity (Leverington, Costa, Pavese, Lisle, & Hockings, 2010; Tittensor et al., 2014). The Biodiversity Habitat Index (BHI) is one indicator in a suite of new indicators developed under the auspices of the Group on Earth Observations Biodiversity Observation Network (GEO BON) in order to assess progress toward various Aichi Targets (2015). The BHI, created by Australia's Commonwealth Scientific and Industrial Research Organization in partnership with the Global Biodiversity Information Facility, Map of Life, and the Projecting Responses of Ecological Diversity In Changing Terrestrial System Project, assesses progress toward Aichi Target 5 by estimating the impacts of habitat loss, degradation, and habitat fragmentation on the retention of terrestrial biodiversity. The BHI uses modeling to link remote-sensing data to occurrence records for more than 400,000 species of plants, vertebrates, and invertebrates, thereby assessing change across the entire terrestrial surface of the planet at a one-km grid resolution (GEO BON, 2015, p. 6). The BHI for each grid cell is derived by estimating the proportion of habitat remaining across all grid cells that are ecologically similar to that cell, with ecological similarity ranging from zero, for cells predicted to have no species in common, to one, for cells predicted to have exactly the same set of species. The BHI for a given reporting unit — e.g., a country or an ecoregion — is then calculated as a weighted geometric mean of the scores obtained for all cells (GEO BON, 2015).

GLOBAL TRENDS

Global trends reveal measurable improvements in three indicators: marine protected areas, *terrestrial biome protection,* and Protected Area Representativeness Index; see Table 8-1. Data indicate that, globally, countries are expanding the total area of land and marine environments under protection and focusing those conservation efforts on biomes that may require it most. Global trend data are not available for the *Species Protection Index* and *Species Habitat Index* indicators.

Over the past ten years, the world has witnessed a considerable improvement in marine ecosystem protection. Global MPA scores increased by a staggering 52.1 points from a 47.9 baseline. Recent efforts to expand MPAs translate into large improvements in its respective EPI score. The perfect score (100) indicates that, globally, nations have achieved the 10% conservation goal outlined in Aichi Target 11. Our results conform with statistics reported in the UNEP-WCMC and IUCN's 2016 *Protected Planet Report,* which found that the international community has achieved Aichi Target 11 for marine protection in areas under national jurisdiction (UNEP-WCMC & IUCN, 2016a). Our 2018 data show a 6.7-point increase in marine protected areas — as a percentage of a country's EEZ — from a 4.8% baseline to 11.5%.

Recent growth in *marine protected area* coverage can be explained by a combination of existing site expansion and new site creation (UNEP-WCMC & IUCN, 2016a). Most of the growth in MPAs has occurred within the jurisdiction of a small group of countries:

FOCUS 8-5 PILOT INDICATOR: INVASIVE SPECIES

Invasive species significantly threaten biodiversity (WWF, 2016). In addition to their negative impacts on biodiversity, invasive species can impose significant additional economic and health costs (Leung et al., 2002; Molnar, Gamboa, Revenga, & Spalding, 2008; Pimentel, Zuniga, & Morrison, 2005). Our 2018 Biodiversity & Habitat issue category features six indicators that measure a country's ability to expand spatial demarcations for conservation and improve habitat integrity. Introducing an additional indicator that quantifies the effects of invasive species on biodiversity into future iterations of the EPI would thus produce a more comprehensive metric. However, global efforts to inventory and assess invasive species uniformly at the global level are still relatively nascent.

Photograph 8-1. Image of invasive species *Phragmites australis.*
Photograph taken at Willows Lakes in Hertfordshire, United Kingdom.
Credit: Peter O'Connor, 2012 (CC BY-SA 2.0)

Designing a comprehensive metric for invasive species poses many challenges. First, developing an exhaustive list of invasive species and their geographic penetration is difficult (Turbelin, Malamud, & Francis, 2017, p. 82). Second, the impacts of a single invasive species vary depending on the ecological and economic characteristics of the geographic area facing invasion (Paini et al., 2016). In one study, 75 species of non-native crops were analyzed in Britain and Canada. None of the species became pests in Britain. However, three were found to be pests in Canada, illustrating the differential effects of the same species across ecosystems (Williamson & Fitter, 1996, p. 1662). Even if a species becomes a pest in multiple locations, the economic impacts could still be very different. For example, a pest will have a greater economic impact on a

CONTINUES ON NEXT PAGE

FOCUS 8-5 PILOT INDICATOR: INVASIVE SPECIES (CONTINUED FROM PREVIOUS PAGE)

nation that is heavily reliant on the damaged crop. Finally, even if a metric satisfying the conditions above is created, it would still be of limited use to the EPI because it would penalize countries for introductions beyond their control, and thus would not necessarily be responsive to policy choices. These challenges demonstrate the difficulty in creating a consistent, simple, policy-relevant metric that can be applied to all countries.

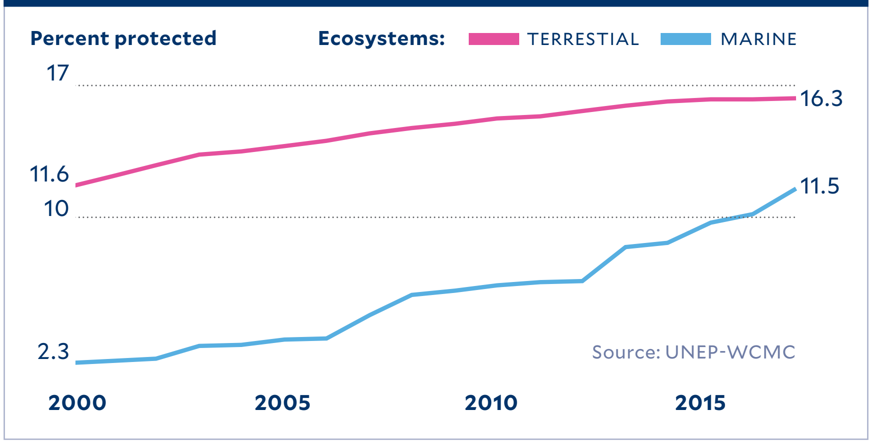
Currently, there is no metric that satisfies these requirements, but efforts are currently under way to address these gaps. The International Union for the Conservation of Nature (IUCN) developed the Global Invasive Species Database (http://www.iucngisd.org/gisd/) and more recently collaborated with the Secretariat of the CBD to create the Global Register of Introduced and Invasive Species (http://www.griis.org/). While these resources describe the presence of various invasive species across the globe, they do not yet provide comprehensive information about species' impacts. The databases also lack a rigorous method of summarizing the total impact of invasive species at the country level. However, these sources provide an important foundation for further work to measure countries' performance in managing invasive species.

While GISD and GRIIS provide raw information about invasive species, other organizations are also working to transform data into metrics that can be used to assess performance. Paini et al. created a country-level agricultural threat index specifically for invasive insect pests and pathogens (2016). This study calculates a score and rank for 124 countries, but data are limited to a small subset of invasive species, and only measure the impacts on agricultural production. While Paini et al. (2016) provide valuable information about the potential threats of invasive species, they do not focus on their current impacts. Nonetheless, the agricultural threat index is a promising step forward in metrics on invasive species, especially because it also touches on the issue category of Agriculture.

Specifically referencing the focus on the harms caused by invasive species in the Sustainable Development Goals (Target 15.8) and Aichi Biodiversity Targets (Target 9), the IUCN promoted a more comprehensive effort to classify invasive species by heir ecosystem threats (IUCN, 2016). The proposed system, the Environmental Impact Classification for Alien Taxa, classifies non-native species based on their maximum observed impact as invasive species (Blackburn et al., 2014). Explicit calls on governments and scientists to adopt and apply the EICAT by the IUCN may help spur action to collect data to implement this classification system (IUCN, 2016). However, even if countries accomplish this task, there are still hurdles that will need to be overcome before the EICAT system can serve as a useful metric, such as ensuring standardized measurement techniques (Kumschick et al., 2017) and finding a way to account for the heterogeneous impact of invasive species across countries. This final step is important, as the impacts of non-native species vary by location (Williamson & Fitter, 1996). While these challenges must still be resolved, much progress has been made in recent years in developing more comprehensive metrics to address the environmental threats posed by invasive species.

Australia, New Zealand, the United States, the United Kingdom, and Spain. In the U.S., President Barack Obama expanded the Papahānaumokuākea Marine National Monument in the Hawaiian Islands from approximately 360,000—1.5 million km^2 in August 2016, making it the largest PA on Earth (NOAA, 2016). Other significant conservation efforts over the past ten years include Chile's proposed Nazca-Desventuradas Marine Park (300,035 km^2), the United Kingdom's proposed MPA in St. Helena (444,916 km^2), Palau's National Marine Sanctuary Act

FIGURE 8-1 PROGRESS TOWARD ECOSYSTEM PROTECTIONS UNDER AICHI TARGET 11, 2000–2017



(~500,000 km²), and the United Kingdom's Pitcairn Islands Marine Reserve (800,000 km²) (UNEP-WCMC & IUCN, 2016b, pp. 32–33).

New commitments in marine protection indicate a growing momentum to expand conservation efforts beyond existing global targets. In late 2017, Mexican President Enrique Peña Nieto established four new MPAs (IUCN, 2017b). Mexico's PA at Revillagigedo is now the largest no fishing area in North America (IUCN, 2017a). The Revillagigedo *MPA* supports nearly 360 species of fish, coral colonies, and for species of sea turtle (Bello, 2017). If global trends continue, national expansion of MPAs, coupled with effective regulation and management, could yield considerable improvements for global marine ecosystems and the economic systems they power.

Our 2018 data also reveal improvements in *terrestrial biome protection* and Protected Area Representativeness Index. *Terrestrial biome protection* scores increased 7.3 points to 64.3 — relative to a 57.0-point baseline in 2007. We estimate that 10.9% of terrestrial biomes are protected globally in 2018, up from their 2007 baseline of 9.7%. We find that *terrestrial biome protection* must increase substantially to meet the 17% goal outlined in Aichi Target 11. The modest change in 2018 *terrestrial biome protection* scores from their baseline may have been impacted by changes to the WDPA. The total area reported in the database fell from 15.4% in 2014 to 14.7% in 2016 due to boundary changes in reported PA coverage (UNEP-WCMC & IUCN, 2016a). Additionally, the UNEP-WCMC and IUCN acknowledge the lag time associated with registering new PAs and acknowledge that many recently added PAs remain to be captured in the WDPA coverage (2016a).

PARI scores increased by 10.4 points — now 37.0 — from a 26.6 baseline in 2000. According to the UNEP-WCMC and IUCN, 10% of the world's terrestrial ecoregions have at least half of their area protected, 43% have at least 17% protected, and 6% have less than 1% protected (2016a). Data indicate that conservation efforts should continue to promote conservation in underrepresented ecoregions of biological importance.

TABLE 8-1 GLOBAL TRENDS IN BIODIVERSITY & HABITAT

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Marine protected area	4.8%	11.5%	47.9	100.0
Terrestrial biome protection	9.7%	10.9%	57.0	64.3
Protected area representativeness index	0.08	0.10	26.6	37.0

Note: MPA metric represents the percentage of EEZ protected. Terrestrial Biome Protection measures the percentage of biomes protected, capped at 17%. Representativeness is a unitless measure that evaluates the extent to which PAs are representative of a country's ecosystems and habitats. Current refers to the most recently available data, and Baseline refers to historic data approximately ten years previous to Current.

LEADERS & LAGGARDS

Global leaders in Biodiversity & Habitat are relatively consistent with their baseline scores. Zambia maintains its position as a global leader, receiving high scores for both baseline and current years, while Botswana (+1), Germany (+3), the United Kingdom (+12), Luxembourg (+5), Namibia (+42), Belgium (+1), and Spain (+11) move up relative to their respective baseline scores, as seen in Table 8-2.

Global leader Zambia is a country of rich biological diversity. In recent years, the Government of Zambia has focused conservation efforts on sustainable management of its forests, water resources, and wetlands (Zambian Ministry of Lands, Natural Resources, and Environmental Protection, 2015, p. v). These efforts are reflected in its high Biodiversity & Habitat score. According to the World Protected Area Database, Zambia has 635 PAs covering 37.9% of its total land area (UNEP-WCMC, 2018a). Zambia's aggregate 2018 Biodiversity & Habitat score is 98.75, a 0.5-point reduction from its baseline. The small decline in its aggregate score results from a drop in its *Species Habitat Index* score — 97.99 in 2000 and 91.67 in its baseline year. Declines in *SPI*, however, were largely offset by improvements in its *PARI* score — 97.76 in 2000 and 100 in 2016.

Today, Zambia's efforts to protect biodiversity are outlined in its National Biodiversity Strategy Action Plan and Strategic Plan on Biodiversity, which outline a strategy for conservation from 2011 to 2020 aligned to the 2020 Aichi Targets (Zambian Ministry of Lands, Natural Resources, and Environmental Protection, 2015, p. preface). Current goals and targets include:

- **Strategic Goal A.** Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society.
- **Strategic Goal B.** Reduce the direct pressures on biodiversity and promote sustainable use.
- **Strategic Goal C.** Improve the statue of biodiversity by safeguarding ecosystems, species and genetic diversity.
- **Strategic Goal D.** Enhance the benefits to all from biodiversity and ecosystem services.

- **Strategic Goal E.** Enhance implementation through participatory planning, knowledge management and capacity building (Zambian Ministry of Lands, Natural Resources, and Environmental Protection, 2015).

Other global leaders include several European nations — Germany, United Kingdom, Luxembourg, Poland, Belgium, and Spain — all of which belong to the European Union (EU). The EU has an extensive biodiversity framework, which began with its Birds Directive (79/409/EEC) in April 1979. The EU's Natura 2000, a network of core breeding and resting sites for rare or threatened species, spans all land and sea territories of all 28 Member States (Sundseth, 2008). Today, Natura 2000 covers 18% of the EU's land area and nearly 6% of its marine environment, making it the largest coördinated network of PAs in the world (Sundseth, 2008).

Among the EU leaders, the United Kingdom's impressive 12-place increase in the global Biodiversity & Habitat rankings stands out. The United Kingdom's strong score increase was largely due to large improvements in its *MPA* indicator score, which increased from 88.33 in 2007 to 100 in 2017. The United Kingdom's score increase can be attributed to the creation of new PAs in its overseas territories. In 2016 the governor or the Pitcairn Islands established the 830,000-square-kilometer Pitcairn Islands MPA (Islands of Pitcairn, Henderson, Ducie, and Oeno, 2016). The government also plans to create a new PA nearly the size of the United Kingdom off the waters of Ascension Island (Harrabin, 2016).

Global laggards in Biodiversity & Habitat are relatively consistent between their current and baseline years. Afghanistan maintains its 180th position, while many countries experienced drops in global standings: Haiti (-3), Lesotho (-1), Cabo Verde (-4), Libya (-4), Singapore (-4), Jordan (-4), Turkey (-7), Solomon Islands (-4); see Table 8-3. Global laggard trends reveal the difficulties in sustainably managing biological diversity countries with spatial constraints and economic and political instability.

TABLE 8-2 LEADERS IN BIODIVERSITY & HABITAT

RANK	COUNTRY	SCORE
1	Zambia	98.75
2	Botswana	98.31
3	Germany	96.92
4	United Kingdom	96.69
5	Luxembourg	96.54
6	Poland	96.37
7	Bhutan	96.30
8	France	96.25
9	Venezuela	96.21
10	Slovenia	95.78

TABLE 8-3 LAGGARDS IN BIODIVERSITY & HABITAT

RANK	COUNTRY	SCORE
171	Solomon Islands	26.66
172	Turkey	25.16
173	Jordan	23.85
174	Maldives	23.61
175	Singapore	21.46
176	Libya	20.72
177	Cabo Verde	20.67
178	Lesotho	17.43
179	Haiti	14.39
180	Afghanistan	13.44

Singapore's low score is largely the result of its small land area and rapid economic development. Over a 182-year period, Singapore lost over 95% of its original forest and vegetative cover, first to agricultural production and later to urbanization and industrialization (Corlett, 1992). This has caused high rates of species loss and extinction (Brook, Sodhi, & Ng, 2003). A 2003 study estimated that forest reserves, which covered 0.25% of Singapore's land area, harbored over 50% of its remaining biodiversity (Brook et al., 2003, p. 420). Today Singapore has four PAs covering 5.6% of its total land area (IUCN-WCMC, 2018b).

Singapore is developing new strategies to improve biodiversity in its highly urbanized landscape. Singapore has increased natural cover to half of its land area over the past 30 years (Conniff, 2018). Urban parks, like the 250-acre Gardens by the Bay park, demonstrate creative ways to integrate built and natural environments in an increasingly urbanized world (Kolczak, 2017). Singapore's City Biodiversity Index arose in response to the need to monitor species diversity in the built environment. The index gives environmental managers a tool to self-report and benchmark conservation efforts in their cities (Singapore National Parks Board, 2015). If successful, Singapore's efforts could serve as a model for how growing urban environments may incorporate species conservation into their development plans.

Turkey, ranked 172nd out of 180 countries, presents another interesting learning opportunity for how countries might build a conservation strategy from the ground up. Turkey is in the midst of a conservation crisis (Şekercioğlu et al., 2011). Three of the world's 34 biodiversity hotspots are found within Turkey's geographic borders (Mittermeier, 2004). To date, Turkey has protected only 0.2% of its land area and 0.11% of its marine environment (IUCN-WCMC, 2018c). Efforts are under way to achieve the 2020 Aichi Targets in Turkey. The United Nations Food and Agriculture Organization (FAO) and Global Environment Facility are working with Turkish government to enhance conservation and sustainable management in its steppe ecosystems though PA management and conservation. The project will facilitate the development of new management practices, provide support to PA managers, and assist in the creation of supplemental policy and regulatory supports (Global Environment Facility, 2014).

Our 2018 results also reveal interesting narratives outside of the highest and lowest performing countries. Namibia — ranked 11th — improved its Biodiversity & Habitat score by 12 points over a ten-year period. Namibia's deep commitment to biodiversity and environmental protection is embedded in its history. Namibia was the first African country to incorporate the environment into its constitution. Following its independence in 1990, the government returned ownership of its wildlife to the people, employing a successful, community-based management system that gave its citizens the right to create conservancies (Conniff, 2011; WWF, 2011). Today Namibia has 148 PAs covering 37.89% of its terrestrial environmental and 1.71% of its EEZ (UNEP-WCMC, 2018a). Many PAs are managed by local community groups, whose members often have little formal education. According to the Ministry of Environment and Tourism, there are 83 registered conservancies in Namibia covering 19.8% of the country's land area (NASCO, 2018). Most conservancies earn revenue through trophy hunting, a contentious issue that continues to complicate conservation efforts in the region (Nuwer, 2017).

Another story of interest is Colombia. Colombia, the second-most biodiverse country in the world (Palmer, 2017), made modest gains, an 8.34-point increase, over a ten-year period. Shifting political dynamics within the country following the peace deal between the government and the Revolutionary Armed Forces of Colombia (FARC) presents an interesting challenge for the government: how it can expand conservation efforts while promoting economic development in post-conflict regions (Palmer, 2017). As FARC vacates its territory, new areas of land are opening for business. Land grabs for timber harvesting, illegal gold mining, and expansion of grazing land for cattle threaten natural rainforest habitat (Moloney, 2017). To address illegal logging, the government plans to train 1,100 former FARC fighters to track and report illegal logging and promote sustainable farming and ecotourism (Moloney, 2017). Efforts to protect rainforest habitat are also expanding. The government has doubled the area of its national parks since 2010 and plans to expand PAs in post-conflict regions in 2018 (Palmer, 2017). Colombia's uphill battle to protect its wildlands is far from over; however, if it can design and implement effective policy, it may be a country to watch in the subsequent EPI rankings.

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9

FORESTS

Environmental Performance Index

Forests

SNAPSHOT

Forests are vital for economic development and human well-being.

CATEGORY DESCRIPTION

Forests are vital for economic development and human well-being. Forests, for example, offer a source of income for over 1.6 billion people globally (UN, 2016, p.1). Forests also regulate the global climate and provide important habitat for more than 80% of terrestrial animals, plants, and insects (UN, 2016, p. 1; WWF, 2017b). Understanding where changes in forest cover occur is thus essential for sustainable development (FAO, 2016a). The Forests issue category uses one indicator to measure the threats to forests worldwide: tree cover loss. We include tree cover loss as an indicator for forest health due to its significant implications for ecosystem health, habitat preservation, climate change mitigation, and other environmental services.

INDICATORS INCLUDED

Tree cover loss. We measure the total area of tree loss in areas with greater than 30% tree canopy cover divided by the forest cover in the year 2000. We apply a five-year rolling average to better capture trends in forest management strategies.

FOREST INDICATORS	
Tree cover loss	%, 5-year

CATEGORY OVERVIEW

Forests are dynamic ecosystems vital to sustaining humans, biodiversity, and environmental services worldwide (FAO, 2016a).

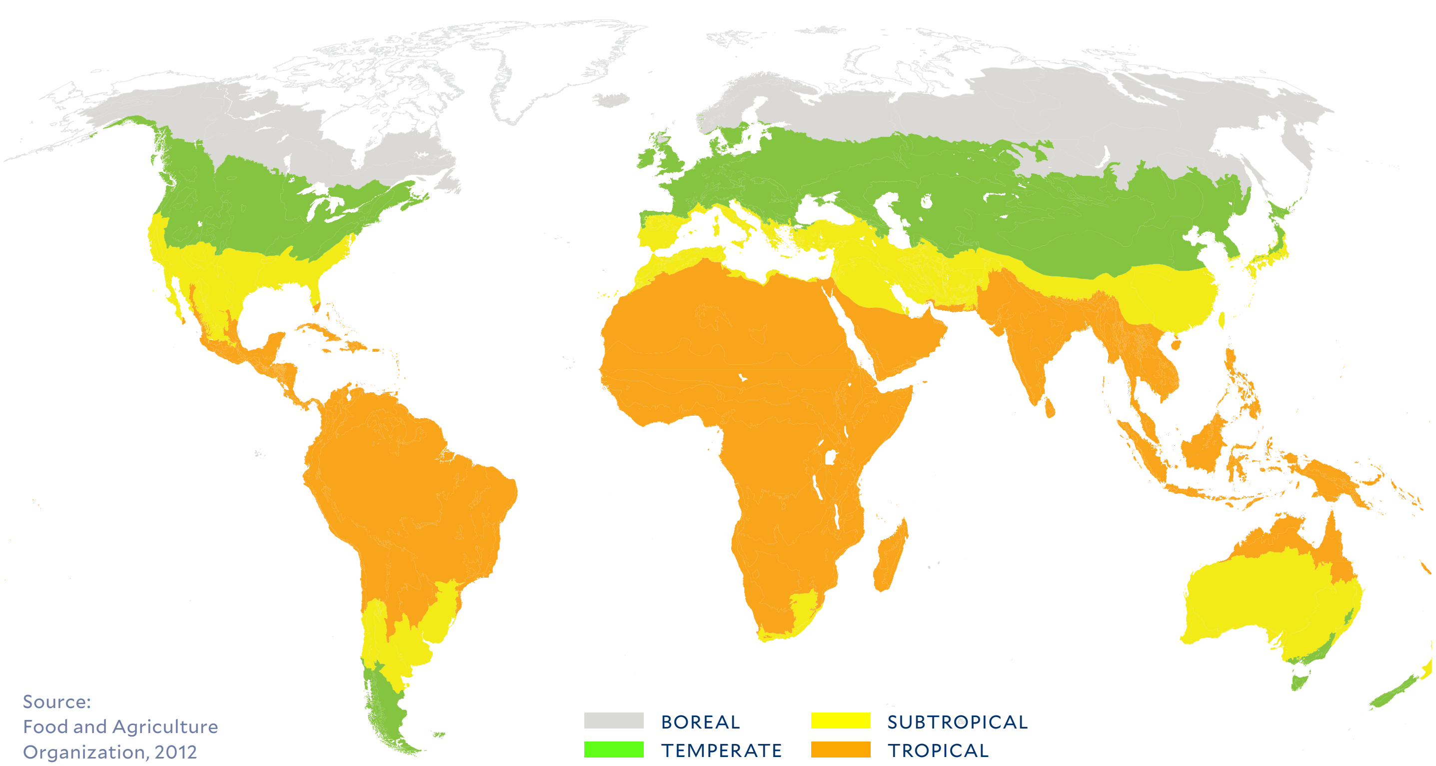
Covering almost one-third of the world's land area, forests provide shelter to over 80% of all terrestrial biodiversity (UN, 2016). The global economic system is also heavily dependent on forests. Approximately 1.6 billion people worldwide are reliant on forest ecosystems as their source of income (UN, 2016). Despite their numerous benefits, forests worldwide are severely threatened. According to data published by the Food and Agriculture Organization (FAO), the world lost almost 130 million hectares of forest between 1990 and 2015, which is about the size of South Africa (2016a).

There is no single, overarching definition of a forest, or a single definition for sustainable forest management (Chazdon et al., 2016). The FAO defines a *forest* as "lands of more than 0.5 hectares, with a tree canopy cover of more than 10%, which are not primarily under agricultural or urban land use" (Davis & Holmgren, 2000, p.7), whereas the United Nations Framework Convention on Climate Change defines a *forest* as "a minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30% with trees having the potential to reach a minimum height of 2–5 m at maturity *in situ*" (Chazdon et al., 2016). There has also been debate in many regions about how to include tree crops—especially short-rotation and fast-growing crops such as cocoa, rubber, oil palm, and pulpwood plantations—in forest definitions.

There are also many different types of forest, each with its own management needs. Four of the major types of forests are tropical, subtropical, temperate, and boreal forests. These categories are distinguished by their climates and locations, shown in Map 9-1 (FAO, 2012). According to a recent UN report on progress toward achieving the Sustainable Development Goals (SDGs), efforts to manage forests sustainably are unevenly distributed across world regions (UNESCO, 2017). The report identifies declining land productivity as a serious concern and emphasizes sustainable forest management as a way to curb its effects while improving the lives of more than 1 billion people.

Notwithstanding efforts to combat deforestation in some regions, we have seen a substantial loss of forests worldwide (Potapov et al., 2017). Understanding the dominant threats to each type of forest has the potential to aid in sustainable forest management practices (FAO, 2016b). According to the World Resources Institute (WRI), only 15% of forests remain intact (2017). Table 9-1 lists some of the most prevalent threats to forest loss differentiated by the type of forest.

MAP 9-1 FOREST ECOLOGICAL ZONES



Source: Food and Agriculture Organization, 2012

Forests may be degraded economically or ecologically by removal of just a few trees per hectare, while from above they may seem intact.

ENVIRONMENTAL

As seen in Table 9-2, forests provide many essential ecosystem services (FAO, 2016a). At local and regional levels, forests reduce the risk of natural disasters by regulating water flows and preventing runoff. At the global level, forests mitigate climate change by storing carbon in biomass and soils.

SOCIAL

Forests provide numerous ecosystem benefits to humans including shelter, livelihoods, and food security. Approximately 300 million people live in forests, including 60 million indigenous people (UN, 2016). Agroforestry and silvopastoral practices — where combinations of trees, crops, and livestock are incorporated into one system — can result in higher overall yields and are important in sustaining local livelihoods (Ranjit, Singh, Valerie, & Irland, 2011). The FAO reports that agroforestry has the potential to increase income and efficient crop production in rural areas, thus removing some of the stresses on the local population (El-Lakany, 2004). Forests also provide habitat for wildlife, often economically important to the local population. The UN estimates that about 75% of the world's poor are affected by forest degradation and deforestation (UN, 2016, p. 1). Forest resources are estimated to provide 1.6 billion people with livelihoods, therefore playing a vital role in efforts to reduce poverty (UN, 2016, p. 1).

TABLE 9-1 FOREST LOSS THREATS BY ECOREGION

Tropical	• Clearing land for agriculture and deforestation • Road construction	
Subtropical	• Extensive forestry land used for crops and agriculture	
Temperate	• Logging and strip mining • Road construction • Fire	• The spread of invasive or non-native species • Storm damage • Climate change
Boreal	• Fire • Climate change	

Source: FAO, 2016b; Hansen et al., 2013

TABLE 9-2 ECOSYSTEM SERVICES PROVIDED BY FORESTS

Air quality	Forests absorb toxic pollutants such as ozone, SO_2, and NO_2.
Carbon sequestration	Trees absorb and sequester CO_2 from the atmosphere through photosynthesis. However, the carbon that trees store is emitted into the atmosphere when they are burned or decompose.
Natural disaster	Deforestation or poor management can increase flooding, landslides, and soil erosion.
Pollination	Forests provide food and shelter for pollinators, such as bees, birds, and bats. Pollinators in a forest increase the levels of pollination which thus encourages the regrowth of trees.
Soil erosion	Vegetation cover, such as canopy structure and tree spacing, stops soil erosion through nitrogen fixation, among other processes.

Source: FAO, 2017

ECONOMIC

Forests also have significant economic value and contribute to a country's GDP in multiple ways. According to the FAO, the forest sector contributes approximately 0.9% of global GDP, and creates employment opportunities for over 50 million people worldwide (FAO, 2016b). Forest biodiversity also delivers multiple services for the global food economy. The UN estimates that three-quarters of prescription drugs contain a component derived from a forest plant extract (UN, 2016, p. 2). Unsustainable forest practices threaten these important services. The UN Forum on Forests Secretariat estimates that US$70–160 billion per year is needed to scale up sustainable land uses, halt deforestation, and finance restoration projects (UN, 2016, p. 2).

The UN defines *sustainable forest management* as "a dynamic and evolving concept, [which] is intended to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations" (UN, 2008, p. 2). To provide for both present and future generations, sustainably managed forest resources are necessary. Policies such as the Convention on Biological Diversity (CDB) Aichi Targets, the Bonn Challenge, and the addition of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program to the Paris Agreement are driving a new focus on sustainable forest management (Chazdon et al., 2016).

SUSTAINABLE DEVELOPMENT GOALS

GOAL 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

TARGET 15.1. By 2020, ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements.

TARGET 15.2. By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and substantially increase afforestation and reforestation globally.

TARGET 15.B. Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.

Forests are also essential for achieving other SDGs (Seymour & Busch, 2017). The WRI notes numerous contributions from forests including:

GOAL 1. End poverty in all its forms everywhere.

GOAL 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.

GOAL 3. Ensure healthy lives and promote well-being for all at all ages.

GOAL 13. Take urgent action to combat climate change and its impacts.

INTERNATIONAL ORGANIZATIONS

Food and Agriculture Organization of the United Nations (FAO). FAO is an intergovernmental organization. One of FAO's priorities is making agriculture, forestry, and fisheries more productive and sustainable. http://www.fao.org/home/en/

International Tropical Timber Organization (ITTO). The ITTO is an intergovernmental organization established under the International Tropical Timber Agreement. It aims to promote sustainable management and legal harvesting of tropical forests. http://www.itto.int/

International Union of Forest Research Organizations (IUFRO). IUFRO is an international network of forest scientists working to enhance the understanding of the ecological, economic, and social aspects of forests. It is made up of more than 15,000 forest scientists from almost 700 Member Organizations based in over 110 countries. https://www.iufro.org/

United Nations Environment Programme (UNEP). UNEP is the agency within the United Nations coördinating and implementing environmental actions. As one of its many duties, UNEP is tasked with helping implement the SDGs. https://www.unenvironment.org/

World Resources Institute (WRI). WRI is a global, nonprofit organization with a mission to promote environmental sustainability, economic opportunity, and human health and well-being. One of the core efforts of the organization is the Global Forest Watch, which is an online forest tracking and alert system. http://www.wri.org/ http://www.globalforestwatch.org/

World Wildlife Fund (WWF). WWF's mission centers on wildlife and endangered species conservation. Through this lens, WWF is working to increase funding and influence policies that conserve the world's forest. https://www.worldwildlife.org/initiatives/forests

MULTILATERAL EFFORTS

African Forest Landscape Restoration Initiative (AFR100). A country-led effort that complements ARLI and aims to bring 100 million hectares of land in Africa into restoration by 2030. http://www.wri.org/our-work/project/AFR100/about-afr100

Bonn Challenge. A global commitment to restore 150 million hectares of land around the world by 2020, and 350 million hectares by 2030. http://www.bonnchallenge.org/content/challenge

Convention on Biological Diversity Aichi Targets.

- **Target 5.** By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
- **Target 7.** By 2020, areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.
- **Target 15.** By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration, including restoration of at least 15% of degraded ecosystems,

thereby contributing to climate change mitigation and adaptation and to combating desertification. https://www.cbd.int/sp/targets/default.shtml

Initiative 20x20. A country-led effort to bring 20 million hectares of land in Latin America and the Caribbean into restoration by 2020. http://www.wri.org/our-work/project/initiative-20x20

Millennium Ecosystem Assessment (MEA). The MEA was comprehensive assessment initiated in 2001 to evaluate human impacts on the environment. The findings demonstrate that human actions are exhausting ecosystem services, but if appropriate actions are taken, it is feasible to reverse ecosystem degradation over the next 50 years. https://www.millenniumassessment.org/en/index.html

New York Declaration on Forests. This declaration seeks to cut natural forest loss in half by 2020, and strives to end it by 2030. http://forestdeclaration.org/

United Nations Framework Convention on Climate Change (UNFCC) REDD+. REDD+ is a mechanism that creates incentives for forest preservation by having wealthy nations — which often have high emissions intensities — invest in forest conservation in developing countries. http://redd.unfccc.int/

United Nations Forum on Forests (UNFF). The UNFF, composed of all Member States of the UN, is an intergovernmental body that was established by the UN Economic and Social Council to promote "management, conservation, and sustainable development to all types of forests and to strengthen long-term political commitment to this end." http://www.un.org/esa/forests/index.html

World Forestry Congress (WFC). Held every six years since 1926 under the FAO, the WFC is the largest meeting of the world's forestry sector aimed at sharing information on forestry conservation and management. http://www.fao.org/about/meetings/world-forestry-congress/en/

The variation among and across forest types makes the application of universal indicators challenging.

Despite vast improvements in the quality and quantity of forest data over the past 25 years, more information is needed on a more granular level to measure forests accurately at the global scale (Chazdon et al., 2016). Chazdon et al. (2016) present seven criteria for precise forest measurement: the value for timber, the value for carbon storage, the impact on the livelihoods of forest-dependent people, whether forests are natural or planted, whether forests are preëxisting or newly established, whether forests are continuous or fragmented, and whether forests are made up of native or non-native species. Unfortunately, there are no existing data measurement systems that collect and report data on these metrics at the global scale.

Forest change is measured in two ways: through bottom-up or top-down techniques. The Global Forest Resources Assessment published by the FAO applies a bottom-up approach. Countries submit reports through national forest inventories or government registries (FAO, 2016a). This approach benefits from obtaining local knowledge of forests. Bottom-up approaches, however, such as self-reporting, can lead to potentially incomplete or inaccurate data. In contrast, the Global Forest Watch (GFW) uses top-down methods that apply satellite technology to remotely monitor tree cover loss worldwide. These methods provide more consistent geographic and temporal comparisons, but data are limited to what can be observed from satellites. As with all remote sensing, data are ideally verified by on-the-ground observations, which can often prove to be a time- and labor-intensive process.

While both top-down and bottom-up methods provide valuable insight into the status of forests globally, they differ substantially in terms of scope and approach. Lack of a universal definition for a forest (FAO, 2016a) and little information on wood consumption in many regions further complicate monitoring efforts (Irland, 2010a). Many forest managers think of sustainability in terms of capacity to maintain a forest in the long term. Forest management thus requires maintaining a large inventory of "growing stock" to ensure sustainable regeneration. Simply measuring forest cover within a given land area thus glosses over many of the nuances that shape modern forestry.

Acknowledging the existing barriers to obtaining quality forest data, the 2018 EPI uses *tree cover loss* to measure how forests change over time. Despite its flaws, *tree cover loss* can capture many of the ecosystem services that forests provide by tracking changes across geographic and temporal coverage consistently. Using the best data available, we aim to assess the state of forest ecosystems and to identify trends or differences among and between geographic regions.

TREE COVER LOSS

INDICATOR BACKGROUND. We quantify *tree cover loss* by constructing a five-year moving average of forest loss, which is calculated for each year based on that year's percentage *tree cover loss* and the four previous years. This is compared with the forest cover in the reference year 2000. We define a *forest* as any land area with over 30% canopy cover. While *tree cover* generally refers to any wooded area, *tree cover loss* refers to "stand replacement disturbance," which can be due to human or natural causes (Goldman & Weisse, 2017).

DATA DESCRIPTION. The data on *tree cover loss* come from GFW, who ranks countries by total *tree cover loss* to quantify the change in global forest coverage. The GFW is an open-source platform organized by the WRI in collaboration with other partner organizations. *Tree cover loss* data are available from 2001 to 2016 for 210 countries. Data are obtained through satellite images provided by the Global Land Analysis and Discovery laboratory, a collaboration between the University of Maryland, Google, United States Geological Survey (USGS), and the National Aeronautics and Space Administration (NASA). The data gathered measure the death or removal of trees at least five meters tall within 30x30 meter resolution pixels. Comparing pixels over the years gives us an idea of *tree cover loss* in that area. *Tree cover loss* provides a snapshot of the current state of global forest resources, as well as changes over the last 15 years. GFW works continuously to improve the accuracy of data. The 2018 EPI incorporates the most recent changes. We include data through 2016 with updated calculations of values for previous years' *tree cover loss* from newly available satellite images.

LIMITATIONS. While the EPI uses the best available data, the GFW dataset and the 2018 EPI *tree cover loss* indicator have several limitations. Foremost is the fact that no global data measurement system yet exists to collect all the information necessary to conduct a comprehensive assessment of forests (Chazdon et al., 2016). Given the global scope and lack of information on a significant number of countries, forest cover is the only practical method to obtain information on the status of forests worldwide, but admittedly is only a partial indicator. While they are the best available, the GFW data go back only to 2000, and we cannot obtain historic data on forest cover before this year. Thus the 2000 baseline is somewhat arbitrary. As a result, we lack information about historical forest extent on longer time scales. The GFW also uses two different calculations – one from 2001 to 2010 and the other from 2011 to 2016 — to compile the *tree cover loss* dataset.

The calculation for the latter period provides a more comprehensive picture of forests globally, but is available only for that period. The EPI uses a five-year average for each year based on that year's percentage *tree cover loss* and the four previous years, so the data from 2011-2016 will not be impacted by this change in the algorithm, but policymakers should be cautious when comparing results across the time periods. The GFW is working with the University of Maryland to back-process the data to include data to 2001, but this information is not currently available.

We identify three primary limitations to the GFW dataset. First, the dataset also cannot distinguish which forest cover losses are due to natural causes from losses from human causes (Weisse & Goldman, 2017). Second, current technology cannot distinguish between different forests types. The area that satellite images capture can represent many possible activities, and loss in one type of forest, such as an old-growth or primary forest, may be more harmful, longer-lasting, or require different policy responses than loss in another type. Third, the dataset cannot distinguish how much forest retained is truly wild preserved land. GFW data show gross *tree cover loss,* not net of any afforestation. For example, Zhai et al. analyzed rubber and pulp plantations in Hainan, China, and found that from 1988 to 2005 the area of natural forests decreased by 22%, but the total forest cover remained relatively unchanged (Zhai, Cannon, Slik, Zhang, & Dai, 2012).

Further limitations stem from top-down approaches using satellite data to obtain information about realities on the ground. In the GFW dataset, satellite-generated pixels representing tree loss only register loss of canopy cover. If a tree's leaves are lost in a fire or new forest growth is still too small to be detected by satellite imagery, that forest cover may likely be excluded from the GFW dataset (Goldman & Weisse, 2017). Our definition of a forest— a land area containing 30% canopy cover — may potentially bias *tree cover loss* estimates. Due to differing definitions for "forests" globally, many satellite measurements do not generate forest data for the gradient between shrub lands, woodlands, and open, dry savannah. Examples of these forests include sagebrush, pinyon-juniper, and low elevation ponderosa pine, respectively. Ecologically important trees, especially in drylands, are sometimes missed altogether (Irland, 2010a, p. 10). Despite these limitations, we believe that the GFW data on *tree cover loss* provides meaningful indication of countries' trends in forest management and the health of their ecosystem services.

GLOBAL TRENDS

Over the past decade, we have seen a substantial loss of the planet's forests. Our data show a 0.16% increase in *tree cover loss* globally, from 0.43% to 0.59% — shown in Table 9-3. As a result, global *tree cover loss* scores have decreased by 5.37 points, from 99.41 in 2006. Global trends are troubling given the work required to meet global development goals and protect the essential services forests provide.

Since 2000 the world has lost approximately 18.1 million hectares annually (Hansen et al., 2013). In 2016 alone, however, the world lost almost 30 million hectares of forests (Weisse & Goldman, 2017). The GFW estimates that more than one-quarter of the recent global *tree cover loss* occurred in Indonesia and Brazil (Weisse & Goldman, 2017). Forest loss in these countries may help explain global trends. For example, the increase in forest fires in Indonesia and Brazil may significantly contributed to the large increase in *tree cover loss* observed in 2016 (Weisse & Goldman, 2017).

Data for *tree cover loss* show that forests are decreasing globally; however, certain countries have successfully implemented effective policies targeting deforestation nationally. In reporting progress toward achieving the SDGs, the UN notes that sustainable forest management practices are unevenly distributed across global regions (UNESCO, 2017). Increasing our knowledge of where and why forests change over time shows meaningful indications of countries' trends in forest management and the health of forest ecosystem services. This knowledge allows policymakers to implement more effective sustainable forestry management practices within their countries. If well implemented at scale across multiple countries, these changes may influence global trends and translate into higher scores on future iterations of the EPI.

TABLE 9-3 GLOBAL TRENDS IN TREE COVER LOSS

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Tree cover loss	0.43%	0.59%	99.41	94.04

Note: Metrics are in percent loss over a five-year moving average. *Current* refers to data from 2016, and *Baseline* reflects to historic data from 2006.

LEADERS & LAGGARDS

2016 data show that certain countries with limited forest resources are successfully preventing further *tree cover loss*. The 2018 leaders, Afghanistan, Pakistan, Kyrgyzstan, and Tajikistan; see Table 9-4 — have the highest increases in scores over the past decade, collectively averaging an increase in score of 41.3. Notwithstanding the importance of these improvements, we acknowledge score increases may be influenced by the relatively small areas of forests within these countries and declining performance elsewhere. According to data from the World Bank (2017), only about 2% of land in Afghanistan is covered with forests, 2% of land in Pakistan, 3% of land in Kyrgyzstan, and 3% of land in Tajikistan. Given the small amount of forest resources that are reported left in each these four countries, deforestation of even a minor amount could have substantial effects on their overall score (Akhmadov, 2008). Scores among these leaders are also potentially increasing because environmental performance in other countries is declining. For example, prior to Tajikistan's independence in 1991, large amounts of forested areas were destroyed to make more land available for agricultural production. Beginning in 1992, the Tajikistan government recognized the importance of managing forests to protect the environment, allotting all forests as state property (BBC, 2017; CBD, 2017).

TABLE 9-4 LEADERS IN RETAINING FORESTS

RANK	COUNTRY	SCORE
1	Micronesia	100.00
2	Saint Vincent and the Grenadines	100.00
3	Kyrgyzstan	99.81
4	Afghanistan	99.07
5	Iran	91.80
6	Pakistan	90.56
7	Georgia	86.20
8	Tajikistan	85.43
9	Sudan	74.65
10	Azerbaijan	74.20

TABLE 9-5 LAGGARDS IN RETAINING FORESTS

RANK	COUNTRY	SCORE
136	Cambodia	0
136	Côte d'Ivoire	0
136	Ghana	0
136	Guinea	0
136	Guinea-Bissau	0
136	Liberia	0
136	Madagascar	0
136	Malaysia	0
136	Paraguay	0
136	Portugal	0
136	Sierra Leone	0
136	South Africa	0
136	Uruguay	0
136	Vietnam	0

After the five-year civil war ended in 1997, Tajikistan has experienced increases in economic growth and a renewed focus on sustainability (BBC, 2017). By prohibiting logging in all Tajikistan forests, along with other state policy measures, Tajikistan has been able to retain the limited amount of forest resources that remain (CBD, 2017).

Countries in the Mekong region of Southeast Asia have seen a significant increase in *tree cover loss*. Vietnam (rank: 136), Cambodia (rank: 136), and Laos (rank: 136) all place at the bottom of the 2018 rankings; see Table 9-5. Myanmar (dropped in score from 33.46 to 9.69, a change of 23.77) and Thailand (dropped in score from 22.44 to 11.07, a change of 11.37) also saw significant increases in *tree cover loss* over the past decade. *Tree cover loss* in the Mekong region has increased for several significant reasons, with development and logging often listed as top causes. In 2006 only 3% of Myanmar's natural forests were managed sustainably (Irland & Robert, 2008). In Laos, recent reports suggest illegal logging efforts account for the massive increases in *tree cover loss* (Harfenist, 2015; Prentice-Dunn, 2015). Part of the reason for this increase in illicit exports is the high export value of Laos timber. In 2014, for example, China's importation of timber from Laos accounted for 63% of national exports. Timber exports increased in value from US$44.7 million in 2008 to over US$1 billion in 2014 (Harfenist, 2015).

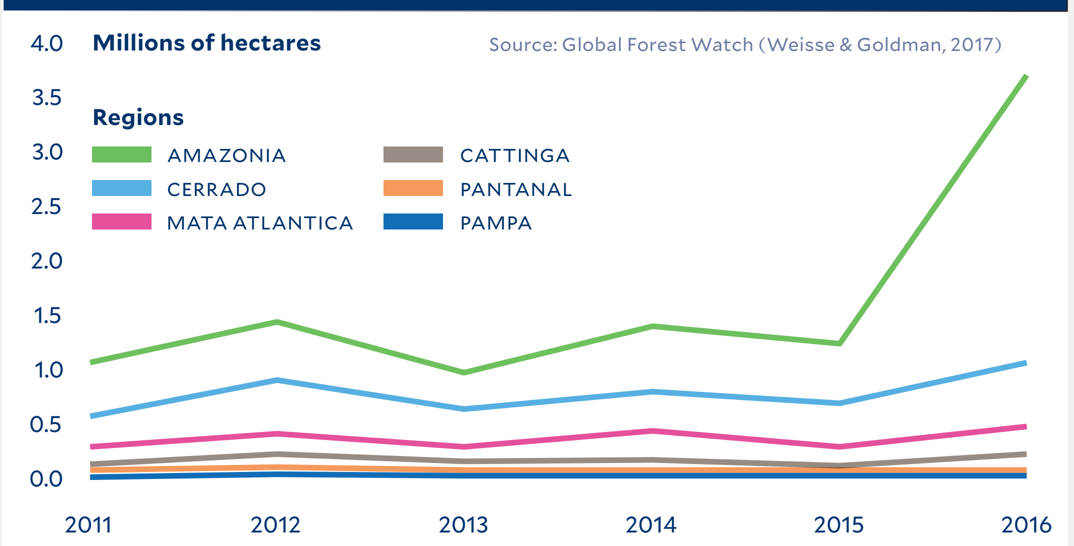
FOCUS 9-1 TREE COVER LOSS IN BRAZIL

Brazil is one of the most biodiverse countries in the world, encompassing about one-third of the world's remaining rainforests (Lewinsohn & Prado, 2005; WWF, 2017a). Local communities depend on the resources provided by rainforests, including fuel, food, and medicines (Irland, 2010b, p. 400). Recent evidence suggests that rainforest ecosystems are most threatened by forest fires. The National Institute for Space Research, the Brazilian government's official deforestation monitoring system, estimated 1,200 fire-related incidents in 2016 — a 44% increase from previous year. In September 2017, Brazil witnessed more forest fires than any other month since record keeping began in 1998 (Weisse & Goldman, 2017). An increase in fires makes it difficult for humans and wildlife to survive by altering their habitats.

The vast tree cover of Brazil's Amazon rainforest also plays a vital role in global carbon storage. However, the carbon sequestered in trees is emitted back into the atmosphere when the trees are burned. Brazil emits significant amounts of carbon from tropical deforestation, accounting for about 20% of the emissions worldwide (Zarin et al., 2016, p. 1336). The forests of the Amazon therefore have the potential to significantly contribute to global climate change if not appropriately managed (WWF, 2017a).

According to the most recent data from GFW, Brazil's Amazon region lost 3.7 million hectares of trees in 2016 due to an increase in forest fires, nearly three times greater than losses observed in 2015; see Figure 9-1 (Weisse & Goldman, 2017). Natural fires in tropical rainforests are exceedingly rare. Most fires in tropical rainforests are a result of human activity, typically slash-and-burn land clearing for agricultural conversion (Weisse & Goldman, 2017). One contributor to the increase in fires in 2016 was the lack of rainfall due to El Niño, which altered global temperatures and impacted the incidence of rain (Goldman & Weisse, 2017). The spike in tree cover loss emphasizes the need to implement more effective sustainable forestry management policies. Brazil has already implemented several policies aimed at limiting slash-and-burn agricultural practices during the dry season, but ineffective enforcement and lack of funding impede successful results (Goldman & Weisse, 2017; Weisse & Goldman, 2017). Source: Global Forest Watch (Weisse & Goldman, 2017).

FIGURE 9-1 YEARLY TREE COVER LOSS IN BRAZIL'S FOREST REGIONS



Forest loss in the region has also been shown to be correlated with global demand for estate crops, such as rubber. This suggests that as estate crop prices increase, deforestation for estate crop plantations will continue (Grogan, Pflugmacher, Hostert, Kennedy, & Fensholt, 2015; Petersen, Sizer, Hansen, Potapov, & Thau, 2015).

Similar to countries in the Mekong region, Indonesia has witnessed considerable declines in its forest cover over the past decade. Our data show a substantial decrease in Indonesia's *tree cover loss* score, dropping from 12.73 in 2006 to 0.01 in 2016. Indonesia fell 11 places in our rankings. The increase in *tree cover loss* can be explained by fires that decimated areas across the country in 2015. Forest fires are an annual problem during the dry season, but palm oil producers also use slash-and-burn agricultural practices, which send large quantities of smoke across Indonesia every year. Fires in 2015 occurred in areas containing peat soil, which is extremely flammable, produces substantial amounts of GHG emissions (Davies, Gray, Rein, & Legg, 2013), and allows fire to spread quickly throughout the region (Weisse & Goldman, 2017).

Western African countries, such as Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, and Sierra Leone, also face complicated challenges in sustainable forest management. This is partly due to an increase in palm oil production throughout western Africa over the last several years, which has been associated with high rates of tree removal and deforestation (Vijay, Pimm, Jenkins, & Smith, 2016). To address the environmental consequences of palm oil production, the governments of the Central African Republic, Côte d'Ivoire, Democratic Republic of Congo, Ghana, Liberia, the Republic of Congo, and Sierra Leone signed the Marrakesh Declaration for the Sustainable Development of the Oil Palm Sector in Africa at COP22 in 2016. The declaration allows for palm oil production only if production complies with the principles of sustainability, transparency, and the protection of human rights (Tropical Forest Alliance 2020, 2018). These seven countries make up 13% of the world's total forests — over 250 million hectares of tropical forests (Gaworecki, 2016). With global demand for palm oil increasing, the Marrakesh Declaration sends a signal to the world that governments are beginning to recognize the benefits of sustainable management practices to reduce deforestation loss. We anticipate that future EPI scores will reflect the implementation of this declaration in the region.

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10

FISHERIES

Environmental Performance Index

Fisheries

SNAPSHOT

Global fisheries are a critical resource for food security, as well as employment and income.

CATEGORY DESCRIPTION

Fish also function as an integral part of marine ecosystems. In virtually all developing countries, fisheries provide vital sources of protein and micronutrients (Golden et al., 2016, p. 317). As of 2014, more than 56 million people worked in capture fishing and aquaculture (FAO, 2016, p. 5). Despite their global importance and growing attention to overfishing, fish stocks continue to decline across most of the world. Unsustainable fishing emerges as the main cause of this decline, with 31% of stocks considered overfished (WWF, 2016, p. 38). Experts predict this decline will continue into the future, as no fish stocks are expected to be underexploited within 20 years (Pauly & Zeller, 2017, p. 178). Dramatic changes in fisheries management are needed to protect global marine systems, and the societies dependent on these resources.

INDICATORS INCLUDED

The EPI utilizes two indicators to evaluate country performance in fisheries management: **fish stock status** and **Regional Marine Trophic Index (*RMTI*).**

- *Fish stock status*. This indicator is based on an assessment of the percentage of fish stocks caught within a country's Exclusive Economic Zone (EEZ) that are overexploited or collapsed.

- *RMTI*: This indicator is a measure of the mean trophic level of fish caught by a country, which represents the overall health of the ecosystem.

FISHERIES INDICATORS	
Fish stock status	% of catch
RMTI	Unitless

Fisheries play three major roles in global sustainability.

Fish stocks act as integral parts of global ocean ecosystems. Seafood serves as a critical resource for food security, especially in developing countries. Finally, fisheries provide important employment and income in many nations.

ENVIRONMENTAL

The environmental impacts of the fisheries sector reverberate well beyond reductions in targeted fish stocks. Disturbances caused by fishing affect the marine environment through several pathways. Overharvesting affects the composition of marine ecosystems. Changes in the population of targeted fish species can alter food webs, affecting predator and prey dynamics. For example, the populations of larger fish, higher in a food web, sometimes decrease more quickly than those of smaller fish. Over time, fishing pressure in systems exhibiting these dynamics can cause the mean size of fish, and the average trophic level of species within a food web, to decrease. This decline is referred to as fishing down marine food webs (Kleisner, Mansour, & Pauly, 2015, p. 2). Different types of fishing gear, such as dredging or trawling, can also have negative impacts on the marine environment by damaging biological structures on the seafloor. Bottom trawling can result in high mortality among marine organisms, which in turn degrades critical fish habitat (Clark et al., 2016; Collie et al., 2016). Furthermore, marine life other than targeted fish species may also be caught in fishing gear. This incidental catch, referred to as bycatch, can increase the mortality of vulnerable species in a fishing area (Hilborn & Hilborn, 2012, p.110). Between 2000 and 2010, an estimated 10.3 million tonnes of bycatch were discarded by industrial fishing boats (Pauly & Zeller, 2016, p. 3). Addressing the complex environmental impacts of the fisheries sector on habitat and marine communities can improve the sustainability of a nation's seafood industry.

SOCIAL

Sustainable societies rely on healthy fisheries because of their role in food security. For example, the populations of 49 countries depend on seafood for over 20% of their animal-based food. Of those nations, 46 are considered developing (Golden et al., 2016, p. 318). In 2013, 17% of all animal protein consumed globally, and 6.7% of all protein from any source, came from fish (FAO, 2016, p. 4). In addition to protein, fish provide vital micronutrients in bioavailable forms, including iron, zinc, and omega-3 fatty acids (Golden et al., 2016, p. 317). If fish stocks continue to decline at the current pace, it is estimated that 845 million people could be faced with micronutrient deficiencies (Golden et al., 2016, p. 317). Developing countries at low latitudes may become particularly vulnerable. Poorer countries often lack the capacity to enforce fisheries regulations and compensate for fishery declines through intensive agriculture. Fisheries of low-latitude countries also may be most exposed to the effects of climate change (Golden et al., 2016, p. 318). Ensuring the health of global fisheries is crucial to supporting food security.

ECONOMIC

Global fisheries represent an important economic force, as fish are among the most heavily traded products worldwide (FAO, 2016, p. 6). Across all related sectors, marine and inland fisheries, as well as aquaculture, created an estimated economic impact of US$660 billion in 2006 (Sumaila, Bellmann, & Tipping, 2016, p. 173). In 2014, capture fisheries and aquaculture provided a source of employment for 56.6 million people worldwide (FAO, 2016, p. 5). With 78% of seafood products traded internationally, trade associated with fisheries plays a particularly important role for developing countries. The production from these nations alone accounts for 54% of the total value of fishery exports (FAO, 2016, p.7). Effective fisheries management must be implemented to protect the communities dependent on these resources for income and employment.

Global fish stocks and marine ecosystems face severe threats.

However, identifying and understanding trends in global fisheries data sparks ongoing controversy. Yet there is room for optimism that improved management could greatly improve the status of global fisheries.

Overfishing drives the decline in global fish stocks. The Food and Agriculture Organization of the United Nations (FAO) statistics consider an estimated 31% of global fish stocks overfished (WWF, 2016, p. 38). The *Sea Around Us*, a research project at the University of British Columbia, predicts that given current trends, within 20 years no fisheries stocks will be underexploited (Pauly & Zeller, 2017, p.178). *Underexploited* fisheries include fisheries which are not yet considered to be exploited, with fisheries landings exceeding 50% of maximum landings (Kleisner & Pauly, 2011; Kleisner, Zeller, Froese, & Pauly, 2013). Understanding the status of these species is critical to the design of meaningful management policies. The FAO's most recent State of World Fisheries and Aquaculture (SOFIA) report claimed that world catch peaked in 1996 at 86.4 million tonnes and has since declined steadily at a rate of 0.2 million tonnes per year (FAO, 2016, p.38; Pauly & Zeller, 2017, p.177). However, analysis from *Sea Around Us* shows a much greater rate of decline at 1.2 million tonnes per year (Pauly & Zeller, 2017, p.177). Improved fisheries management is critical to reversing these trends.

Evidence suggests that despite the degradation of marine habitats, strong fisheries policies could still improve the health of global fish stocks. Mismanagement of global fish stocks has had significant economic ramifications. For example, the World Bank estimates that in 2012, poor fisheries management practices cost the world US$83 million in annual revenues (World Bank, 2016, p.3). Given current levels of fisheries exploitation, it is estimated that the median fishery would take ten years to reach recovery targets. However, implementing strong fisheries management techniques around the world could result in annual catch increases of over 16 million metric tonnes, creating US$53 billion in profit (Costello et al., 2016, p.5125). If countries act to restore global fisheries, the World Bank estimates that the biomass of fish in the ocean has the potential to increase by a factor of 2.7, allowing for an increase in annual harvests of 13% (World Bank, 2016, p.3).

A variety of policy options can help nations achieve these targets. Of principal importance is reducing fisheries subsidies, which have contributed to overfishing and overcapacity of the global fishing fleet (Sumaila et al., 2016, p.174). Over US$30 billion is spent by governments around the world on fisheries subsidies each year (Global Ocean Commission, 2016, p.7). Furthermore, illegal, unreported, and unregulated fishing (IUU) is a primary concern in global fisheries management. IUU fishing often contributes to overexploitation, as well as lost revenue and employment opportunities (Doumbouya et al., 2017). The practice is estimated to cost nations US$10 to US$23.5 billion through the loss of 11 to 26 million tonnes of catch from the regulated market (Agnew et al., 2009). Strong initiatives to curb IUU fishing could profoundly improve the health of global fisheries. Finally, to holistically improve their fisheries governance, many nations are moving toward ecosystem-based fisheries management (EBFM). In 2014, 67% of member nations reported to the FAO that they were incorporating elements of EBFM into their fisheries policy (Bundy et al., 2017, p.18). A study evaluating EBFM determined that nations with high scores for management effectiveness and governance quality also scored well on ecological indicators. Specifically, the researchers found that fisheries governed by long-term management plans that considered the ecosystem impacts of fishing pressures performed best (Bundy et al., 2017, pp. 2, 22). There is much to be gained across all indices of sustainability from recovering global fisheries.

SUSTAINABLE DEVELOPMENT GOALS

GOAL 1. End poverty in all its forms everywhere.

GOAL 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.

GOAL 8. Promote inclusive and sustainable economic growth, employment, and decent work for all.

GOAL 12. Ensure sustainable consumption and production patterns.

GOAL 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

TARGET 14.4. By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.

TARGET 14.6. By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation.

TARGET 14.7. By 2030, increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism.

TARGET 14.B. Provide access for small-scale artisanal fishers to marine resources and markets.

INTERNATIONAL ORGANIZATIONS

Committee on Fisheries (COFI). COFI is a subsidiary of the FAO that serves as a forum to address international fisheries and aquaculture challenges, including through the creation of global agreements and nonbinding legal instruments. The organization evaluates FAO programs of work in fisheries and aquaculture and conducts reviews of global fisheries and aquaculture problems. http://www.fao.org/fishery/about/cofi/en

International Maritime Organization (IMO). The IMO is a United Nations agency which is responsible for setting standards for the safety, security, and environmental performance of international shipping, including fishing vessels. http://www.imo.org/en/Pages/Default.aspx

International Whaling Commission (IWC). The IWC is an international organization composed of 88-member nations which are signatories of the International Convention for the Regulation of Whaling. The commission pursues the conservation of whales and management of whaling under the convention. Responsibilities include setting catch limits for aboriginal subsistence whaling and studying non-whaling threats to whale species. https://iwc.int/home

Regional Fisheries Management Organizations (RFMOs). RFMOs are intergovernmental organizations or arrangements developed to manage high seas fisheries. Their functions include collecting statistics on fisheries, monitoring activity in fishing areas, and facilitating coöperation between governments of fishing nations. Additional information on existing RFMOs:

- **Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).** https://www.ccamlr.org/
- **General Fisheries Commission for the Mediterranean (GFCM).** http://www.fao.org/gfcm/en/
- **Northwest Atlantic Fisheries Organization (NAFO).** https://www.nafo.int/
- **North East Atlantic Fisheries Commission (NEAFC).** https://www.neafc.org/about
- **North Pacific Fisheries Commission (NPFC).** https://www.npfc.int/
- **South East Atlantic Fisheries Organisation (SEAFO).** http://www.seafo.org/
- **South Indian Ocean Fisheries Agreement (SIOFA).** http://www.siofa.org/
- **South Pacific Regional Fisheries Management Organisation (SPRFMO).** http://www.southpacificrfmo.org/
- **World Trade Organization (WTO) Negotiating Group on Rules.** The WTO has held negotiations to address fisheries subsidies that contribute to overcapacity and overfishing through measures such as strengthened WTO disciplines. https://www.wto.org/english/tratop_e/rulesneg_e/fish_e/fish_intro_e.htm

MULTILATERAL EFFORTS

Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas. This Agreement is part of the CCRF and establishes requirements for Parties regarding the use of national flags on fishing vessels, as well as fisheries conservation and management practices. Parties must permit only authorized fishing vessels to fly national flags and ensure that applicable fisheries rules are observed by authorized vessels. Furthermore, Parties are required to collect data on catch from vessels on the high seas and submit a list of vessels to the FAO. http://www.fao.org/docrep/MEETING/003/X3130m/X3130E00.HTM

Convention on Biological Diversity (CBD). The CBD's objectives are the conservation and sustainable use of biodiversity, and the fair and equitable sharing of benefits from genetic resources. The agreement has a strong focus on sustainable fisheries, including decision X/29 calling on Parties to implement ecosystem-based management, eliminate IUU fishing, minimize harmful fishing practices, and mitigate bycatch. Several of the Aichi Biodiversity Targets (8, 9, 10, and 11) under the CBD address coastal habitats important for fisheries, and Target 6 directly addresses sustainable fishing (Ainsworth & Hedlund, 2016). https://www.cbd.int/marine/

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES Parties must apply certain controls to the trade of endangered species, including the creation of a licensing system under a designated Management Authority. Species are categorized into three appendices depending on the level of protection needed. Species protected under CITES include 147 species of fish. https://cites.org/

Convention on the Conservation of Migratory Species of Wild Animals (CMS). The CMS is a United Nations Environment Programme (UNEP) treaty focused on the conservation and sustainable use of migratory animals and their habitats. Parties agree to protect these species, especially through transboundary coöperation to promote migration. The agreement covers many migratory fish species such as sturgeon, as well as sharks and marine mammals. http://www.cms.int/en/legalinstrument/cms

FAO Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. The Port State Measures Agreement was created through the FAO to address illegal, unreported, and unregulated (IUU) fishing. Parties to the agreement are expected to develop and implement measures in ports to reduce IUU fishing and harmonize governance at the regional level. http://www.fao.org/fishery/psm/agreement/en

FAO Code of Conduct for Responsible Fisheries (CCRF). The CCRF builds on agreements for straddling and migratory fish stocks established under UNCLOS by establishing nonmandatory principles and standards for the conservation, management, and development of fisheries. The code was created by the FAO and is voluntarily implemented by Member States. http://www.fao.org/docrep/005/v9878e/v9878e00.htm

International Convention for the Regulation of Whaling (ICRW). The ICRW founded the International Whaling Commission. The agreement sets catch limits for whaling, including for commercial and aboriginal subsistence sectors. https://iwc.int/convention

United Nations Convention on the Law of the Sea (UNCLOS). UNCLOS establishes rules for use of the oceans and their resources. Key features pertaining to fisheries include the establishment of "sovereign rights over the continental shelf (the national area of the seabed) for exploring and exploiting it." http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm

FOCUS 10-1 UNITED NATIONS OCEAN CONFERENCE

The high-level United Nations Conference to Support the Implementation of **Sustainable Development Goal 14:** Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development was held in June 2017.

The conference resulted in voluntary commitments and the negotiated call for action, "Our Ocean, Our Future: Call for Action."

https://oceanconference.un.org/about

Voluntary commitments made in the agreement with regard to fisheries include:

- "Enhance sustainable fisheries management, including to restore fish stocks in the shortest time feasible at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.
- "End destructive fisheries practices and illegal, unreported and unregulated fishing.
- "Accelerate further work and strengthen coöperation and coördination on the development of interoperable catch documentation schemes and traceability of fish products.
- "Strengthen capacity building and technical assistance provided to small-scale and artisanal fishers in developing countries.
- "Act decisively to prohibit certain forms of fisheries subsidies that contribute to overcapacity and overfishing.
- "Support the promotion and strengthening of sustainable ocean-based economies.
- "Actively engage in discussions and the exchange of views in the Preparatory Committee established by General Assembly Resolution 69/292."

FOCUS 10-2 FISHING IN THE ARCTIC

Four million square miles of melting sea ice in the Arctic Ocean have the potential to become open ocean, and in turn available for fishing. This potential resource poses a significant management challenge. The "Arctic Five," a group composed of the United States, Canada, Denmark, Norway, and Russia, signed a non-binding agreement in 2015 committing not to fish the region before further scientific study evaluates the ecosystem (Hoag, 2017). In a March 2017 meeting in Reykjavik, Iceland, ten nations moved toward establishing a precautionary, legally binding agreement to protect the fisheries of the Central Arctic Ocean (Ganey, 2017). The fifth and final round of negotiations was held on November 30, 2017, resulting in the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean. The agreement will last 16 years and be automatically renewed every five years unless a party nation is opposed or alternative science-based fisheries rules are implemented. In addition to preventing unregulated fishing in the region, the agreement also created a Joint Program of Scientific Research and Monitoring for the Arctic Ocean (Wahlén, 2017).

The measurement of fisheries health connects to the efforts of policymakers to conserve living marine resources. Historically, the management of fish stocks has taken place through fisheries management plans, which require assessments of single species to set catch targets. International agreements have similarly built their benchmarks on these single-species assessments (Rice, 2014). Increasing emphasis is now being placed on ecosystem-based fisheries management, informed by indicators which reflect the impacts of fishing activities on habitats, accurate assessment of bycatch mortality, and the effects of fishing on ecological community composition. This broader set of ecological indicators reflects a shift in focus among policymakers beyond commercial fisheries management to more holistic goals (Jennings, 2014). The call for improved ecosystem metrics to assess the sustainability of fisheries is reflected in seafood eco-labeling. One example, the Marine Stewardship Council, evaluates seafood in accordance with three categories of criteria: target stock health, ecosystem health, and management agency responsiveness. However, the implementation of true ecosystem-based fisheries management is limited by a lack of data on factors like bycatch, discard rates, and gear impacts on underwater habitats (Selden, Valencia, Larsen, Cornejo-Donoso, & Wasserman, 2016). Stronger monitoring, reporting, and verification systems are needed for all dimensions of fisheries to better equip policymakers to create sound management plans.

The FAO collects and harmonizes the only database that includes all fisheries data reported by individual countries globally. They publish the results of their analysis in a biannual SOFIA report (Pauly & Zeller, 2017, p. 176). The FAO collects fisheries statistics submitted by national correspondents in each country's fisheries ministry or related institution. The data are often complemented or replaced by data from other institutions, such as regional bodies, to incorporate the best available statistics. The FAO database includes catch data by country, FAO fishing area, and species item. Species items can be the species, genus, or other taxonomic levels used to describe the fish caught (Garibaldi, 2012, pp. 761–763).

However, there are many gaps in the foundational FAO dataset, as identified by *Sea Around Us*. Catch data are reported using 19 large marine statistical areas, arguably a resolution too coarse to inform policy. Furthermore, reported data are disaggregated into broad taxonomic groups, not at the species level. FAO data also do not include discarded catch, a significant environmental factor in evaluating the sustainability of a fishery. Finally, FAO data do not distinguish between catches from various sectors—for example subsistence versus commercial fishing—and gear types, which again influence the environmental impact of a fishery (Pauly & Zeller, 2016).

The majority of data available are specific to commercial fish stocks of species caught by nations with effective fisheries management in place. As a result, significant data gaps exist for catch that is part of artisanal, subsistence, and recreational fishing. Most importantly, data are lacking to characterize IUU fishing, as well as global bycatch (WWF, 2016, p. 41). To accurately understand the health of global fisheries, these data gaps must be addressed.

Scientific initiatives have been developed to better characterize the impact of fishing on marine ecosystems through a broader set of ecological indicators. For example, indiSeas is a program that, while currently limited to a subset of countries, assesses marine ecosystems according to indicators in three categories: ecological and biodiversity; climate and environment; and human dimensions (indiSeas, 2013). Expanded research and monitoring efforts are needed to continue to improve our understanding of the status of global fisheries.

To capture a more complete picture of the impact of global fisheries and the success of fisheries management programs, the EPI uses the *Sea Around Us* reconstructed data. Their methodology attempts to correct for the gaps in FAO data, drawing on additional information from several sources. In particular, the *Sea Around Us* researchers conduct literature searches, evaluate data with local experts, and identify additional archives and data sets to be included (Pauly & Zeller, 2016).

FISH STOCK STATUS

INDICATOR BACKGROUND. The first EPI indicator for fisheries is based on an assessment of whether a stock is overexploited or collapsed (Pauly et al., 2008):

Overexploited. Following a peak in the catch of a stock, annual catches will decline. If the catch of a stock falls to 10 to 50% of its peak catch, the stock is considered overexploited.

Collapsed. If the catch of a stock is less than 10% of the peak catch, the stock is considered collapsed.

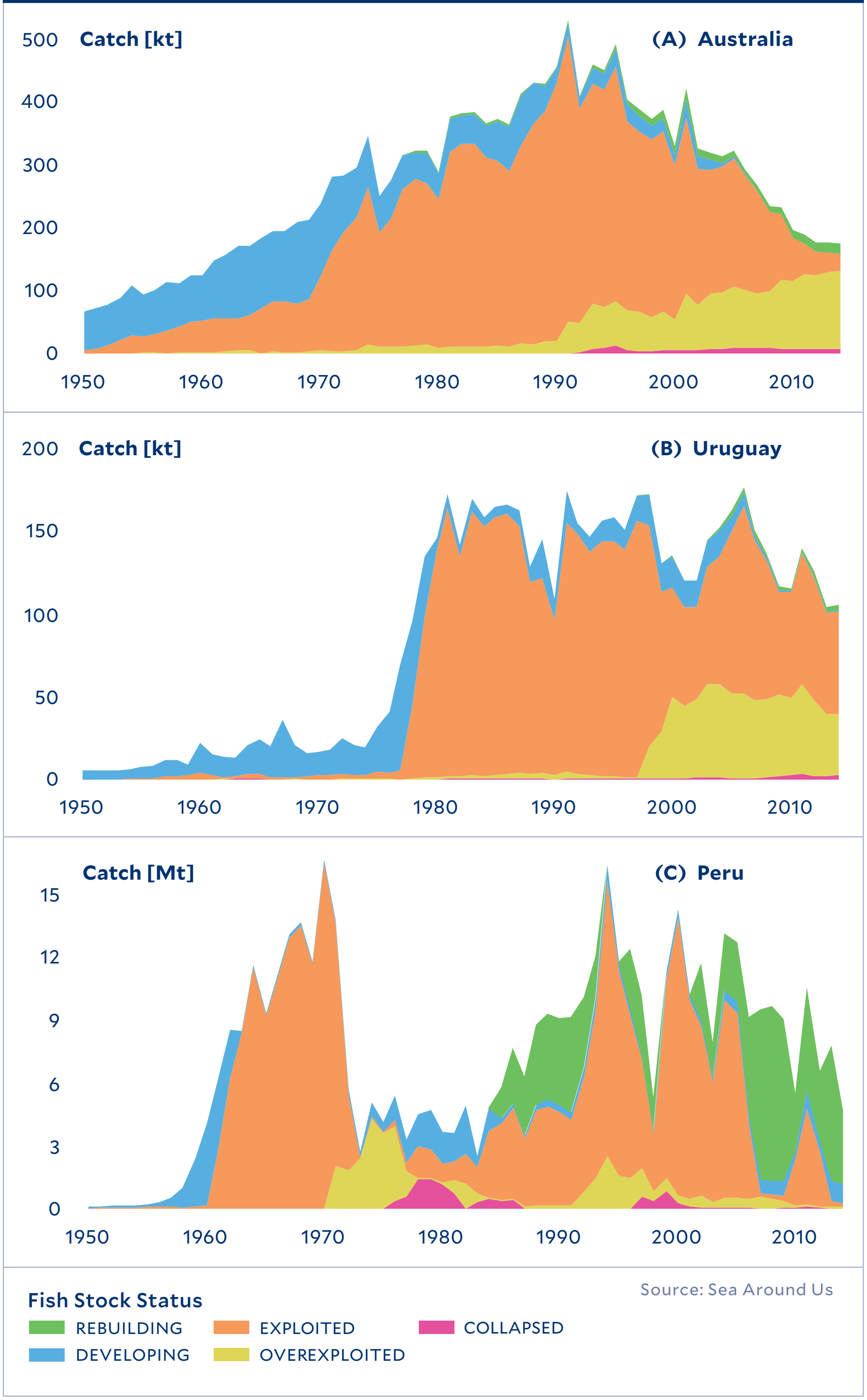
We derive our indicator from an assessment of all fish stocks caught within a country's EEZ. We then calculate the percentage of the country's total catch that comes from stocks determined to be overexploited or collapsed. We use this percentage as the country's indicator, see Figure 10-1. For countries with multiple EEZs, we average the percentages for each EEZ into a single country value, weighted by the catch of the EEZ. The target for each country assessed is for 0% of the fish stocks harvested in their EEZ to be overexploited or collapsed. The indicator is designed to approximate the sustainability of a country's fishing practices through their harvest levels.

REGIONAL MARINE TROPHIC INDEX

INDICATOR BACKGROUND. The share of fishing catch coming from overexploited or collapsed stocks might provide an incomplete picture of ecosystem health. **The Marine Trophic Index** (MTI) attempts to account for possible behavior of a nation's fishing fleet. As fish species higher in the food web are 'fished-out,' fleets may respond by targeting species at lower trophic levels. For example, primary producers like phytoplankton are considered to be on the lowest level, zero, while larger predators are at a higher trophic level (Mace et al., 2004). If the MTI for a fishery is trending downward, this is a sign that a fishing sector has exploited larger, high-level species and is increasingly catching smaller, lower-level species, negatively impacting ecosystem health (Kleisner et al., 2015, p. 2). While stable MTI values may indicate healthy ecosystems, such stability might also mask other shifts in the behavior of the fishing fleet, especially expansion of fishing effort into new regions further offshore (Kleisner et al., 2015). In order to account for this expansion, we use the **Regional Marine Trophic Index** (*RMTI*), which develops one or more MTIs within each EEZ over time, based on the composition and size of observed catches (Kleisner et al., 2015). Scores for this indicator are developed by looking at the relationship of recent and long-term trends in *RMTI*. We evaluate countries on whether *RMTI* trends are stable over time, increasing, or decreasing. Figure 10-2 illustrates the progression from catch data to *RMTI* trends, and additional details are provided in the Technical Appendix.

DATA DESCRIPTION. For our fisheries indicators, we work with *Sea Around Us,* a research project at the University of British Columbia, located within the Institute for Oceans and Fisheries. Sea Around Us collects data first through FAO reported landings data.

FIGURE 10-1 THREE EXAMPLES OF HISTORIC FISH STOCK STATUS, 1950–2014

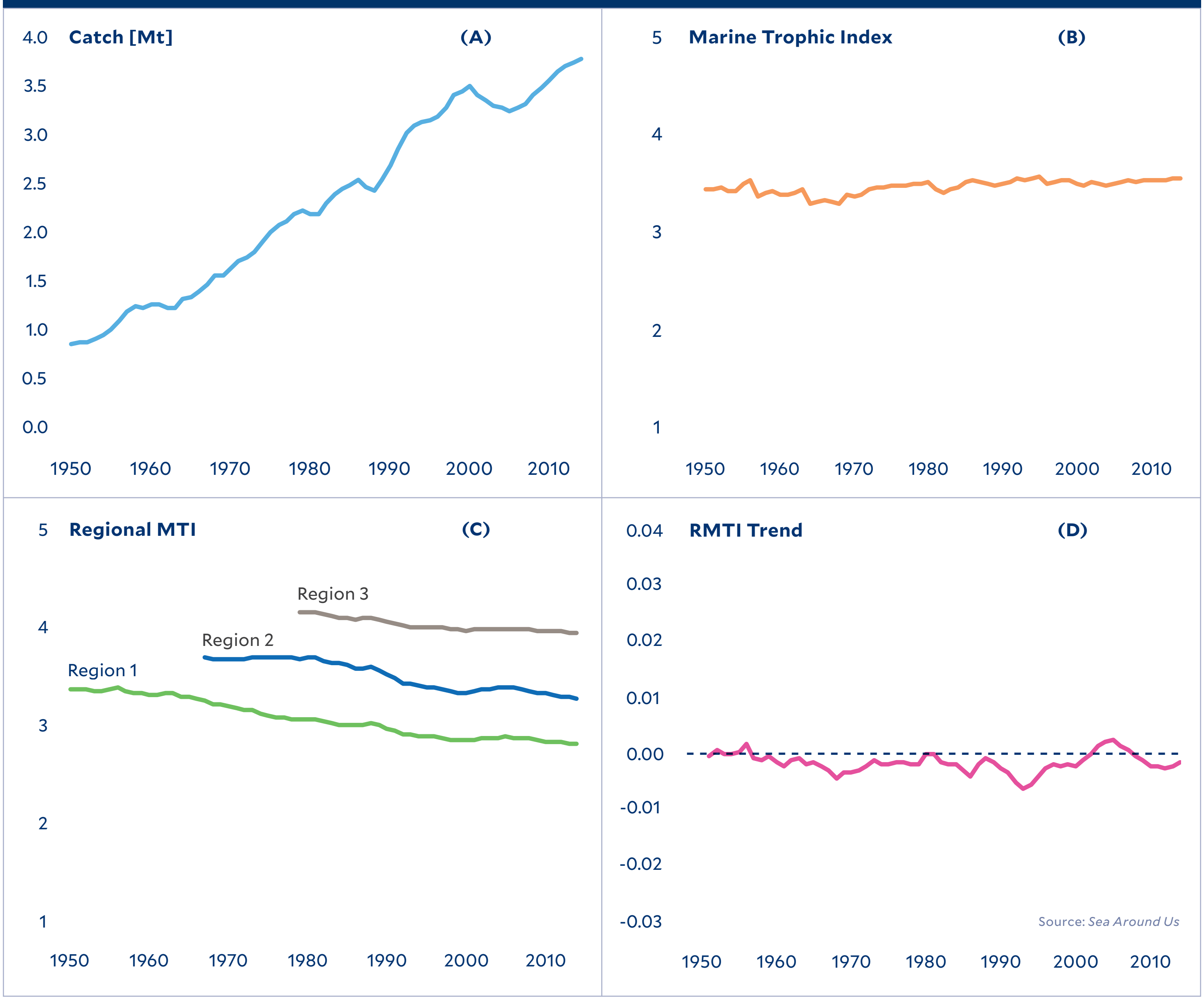


Source: Sea Around Us

It then identifies any missing data, components. To fill in the gaps, the team conducts extensive literature searches, consults with local experts, and studies additional archives and data sets. The initiative conducts these searches as an iterative process, consistently aiming to create the best estimate of time-series data for all marine fisheries catches since 1950 (Zeller & Pauly, 2016). *Sea Around Us* makes its data publicly available through its website. The initiative actively invites experts and practitioners to critique its data and identify areas for improvement (Zeller & Pauly, 2016).

LIMITATIONS. While fishing down may be occurring in some systems, other fisheries exhibit different use patterns. For example, fishermen also have shifted from lower to higher trophic levels or, alternatively, maintained predator catch while simultaneously expanding fisheries on lower-trophic species (Branch, 2012). Some scholars argue that the targeting of species is driven not by trophic level, but by which species yield the highest profits (Sethi, Branch, & Watson, 2010). Furthermore, critics find that trophic level does not predict the price of species. As a result, the development of a fishery cannot be predicted based on size or trophic level. Rather, fisheries tend to develop for high-priced, large-volume shallow-water species, and then shift toward lower-priced, small-volume, deeper-water species. The consequences for lower-trophic species can be severe, as they are more likely to collapse when subject to fishing pressure. Twice as many fisheries for lower-trophic species have collapsed when compared to predator fisheries, with ecosystem-wide consequences for organisms feeding on these lower-trophic levels (Pinsky, Jensen, Ricard, & Palumbi, 2011). Studies have further shown that marine trophic level isn't a reliable predictor of the health of marine ecosystems (Branch et al., 2010). Therefore, the *RMTI* should be interpreted only as one of a suite of indicators of the health of marine systems.

FIGURE 10-2 ILLUSTRATION OF FISHING TRENDS IN THE INDIAN MAINLAND EEZ, 1950–2014



FOCUS 10-3 CLIMATE CHANGE

A growing body of literature shows that climate change is significantly altering the physical and chemical properties of the ocean, with consequences for fisheries management. Increasing ocean temperatures are causing certain fish species to shift into waters at higher latitudes or greater depths to maintain their temperature. Rising temperatures are also causing an overall increase in the abundance of warm-water species and alterations in fish life cycles. Finally, ocean acidification is negatively affecting species that incorporate calcium into their outer shells, including shellfish (Poloczanska et al., 2016).

The consequences of climate change for fisheries remain uncertain. Maximum catch potential could rise 30–70% in high-latitude regions yet decline 40% in the tropics by 2055 (Cheung et al., 2010, p. 24). Scientists are also investigating how different species might adapt to the rate and direction with which bands of water of a given temperature move through the ocean, including how such shifts interact with fish harvesting (Fuller, Brush, & Pinsky, 2015). Warming waters have also been found to reduce concentrations of phytoplankton in the ocean, which has severe impacts throughout the marine food web. Fewer young fish, which normally depend on phytoplankton as a food source, survive into adulthood to reproduce, contributing to declines in fish populations (Britten, Dowd, & Worm, 2016). Governments will be increasingly confronted by the challenge of adapting their fisheries management policies to the dynamics of climate change impacts in the world's oceans.

FOCUS 10-4 ILLEGAL, UNREPORTED, UNREGULATED FISHING (IUU)

IUU fishing is a persistent policy problem in global fisheries. In 2016 a new technological advance was launched to combat the practice. A satellite-based surveillance system called Global Fishing Watch was deployed by Oceana, SkyTruth, and Google to help governments and other observers monitor fishing vessels which may be illegally withholding their locations. The system was successfully implemented by Kiribati to prosecute a vessel illegally fishing for tuna in one of its protected areas, resulting in the collection of a US$1 million fine (Dennis, 2016). The deployment of such technology is a promising opportunity to improve global fisheries management.

The development of new tools to combat IUU fishing is particularly critical for West Africa. Mauritania, Senegal, the Gambia, Guinea-Bissau, Guinea, and Sierra Leone make up one of the regions most affected by IUU fishing in the world. Illegal catches result in annual losses of nearly US$2.3 billion for nations in the area (Doumbouya et al., 2017, p. 8). Due to poor fisheries governance, high corruption, and high costs of monitoring, the equivalent of 65% of the legal reported catch is removed from West African ecosystems through illegal fishing (Doumbouya et al., 2017, p. 1).

Underreporting was the principal form of illegal fishing, but the region is exposed to impacts from the use of illegal gear, fishing of juvenile fish or prohibited species, and illegal fishing activity in prohibited zones (Doumbouya et al., 2017, p. 4). IUU fishing poses a dire threat to the livelihoods of fishing communities in West Africa, jeopardizing a critical protein source as well as opportunities for regional development (Daniels et al., 2016, p. 16). West Africa is particularly vulnerable to illegal fishing by Chinese companies. Studies estimate that $28 million worth of fish are illegally taken from Senegalese waters each year by Chinese ships (Jacobs, 2017). Ships involved in IUU fishing often load catch directly onto large freezing and processing ships at sea, rather than landing the catch to be recorded. Furthermore, container ships face less stringent reporting requirements than standard fishing vessels, allowing illegal fish to travel between nations undetected (Daniels et al., 2016, p. 7). Additional support is needed in the region to strengthen existing enforcement frameworks (Doumbouya et al., 2017).

GLOBAL TRENDS

Marine fish stocks are declining globally, with consequences for food security, income and employment, and marine ecosystems.

Our 2018 results confirm findings by the FAO that the share of commercial fish stocks from biologically sustainable harvests has fallen (FAO, 2016). Negative trends in fish stock status and comparatively lower scores in both periods for *RMTI* indicate the magnitude of the challenge of restoring global fisheries. Scores for fish stock status are higher than those of *RMTI* in both periods. However, between 2004 and 2014, the global score for fish stock status fell by nearly 10%. In contrast, *RMTI* improved by over 20%. These contradictory trends could suggest that nations are increasingly harvesting fish from stocks that are overexploited or collapsed, while also targeting higher trophic-level species. The negative trend in fish stock status is of particular concern, as overfishing is the primary cause of decline in global fisheries (WWF, 2016, p. 38). To reach a global score of 100, significant progress must be made both in rebuilding and harvesting sustainable stocks, and in restoring the health of marine ecosystems.

TABLE 9-4
LEADERS IN FISHERIES

RANK	COUNTRY	SCORE
1	Eritrea	94.09
2	Colombia	92.93
3	Peru	85.72
4	Israel	85.34
4	Lebanon	85.34
6	Brazil	81.42
7	Saint Vincent and the Grenadines	79.13
8	Sudan	78.40
9	Sri Lanka	78.34
10	Tonga	76.86

TABLE 9-5
LAGGARDS IN FISHERIES

RANK	COUNTRY	SCORE
129	Japan	36.79
130	Guinea-Bissau	36.45
131	Montenegro	36.18
132	Russia	35.48
133	Netherlands	34.60
134	Portugal	32.11
135	Jamaica	29.07
136	Georgia	27.36
137	Papua New Guinea	27.35
138	El Salvador	0

The results for fisheries were in some cases surprising, perhaps pointing to significant remaining limitations in the data used to create the relevant indicators. For example, the United States is known for sustainable fisheries management, with 84% of stocks with a known status not overfished by 2014 (NOAA. 2017, p. 1). In contrast, China's overexploitation of its own fisheries and those of West African nations continues to be a serious problem (Jacobs, 2017). However, the U.S. was ranked 68th, well below China in the 18th position. Continued improvement in the quality of data on global fisheries is necessary to accurately evaluate management performance between nations.

LEADERS & LAGGARDS

Of the top ten nations with the greatest marine capture production, only Peru appeared in the list of leaders, see Figure 10-1 (C). Three Peruvian Fisheries Acts were enacted after 1995 and greatly improved the sustainability of the nation's anchovy fishery. The legislation served to regulate foreign involvement in the fishery, control fishing quotas, and establish fishing seasons (Arias Schreiber, 2012). Peru in fact ranked first in a comparative ranking of the sustainability of fisheries management among 53 maritime nations by the Fisheries Centre at the University of British Columbia (Mondoux & Pauly, 2008, p. 18).

Despite the establishment of a Common Fisheries Policy (CFP), European Union (EU) countries varied widely in their ranking, from Estonia, ranked 11th, to Portugal, ranked 132nd. The aim of the CFP was to ensure that all stocks were harvested at their maximum sustainable yields by 2015—or 2020 at the latest—through a variety of management controls. Targeted practices included minimizing by catch, controlling which vessels have access to fishing areas, limiting fishing capacity and vessel usage, and finally regulating gear usage (European Commission, 2018). Perhaps historic conditions or varying degrees of success in the implementation of the CFP are leading to the diverse results in environmental performance among EU countries.

TABLE 10-1 GLOBAL TRENDS IN FISHERIES

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Fish stock status	24.4%	31.0%	73.17	65.89
RMTI	-0.0002	0.0015	41.87	50.54

NOTE: The BASELINE year for fisheries uses data from 2004 while CURRENT reflects data from 2014.

One of the laggards in the rankings, Montenegro, received specific instructions for improvements in fisheries management necessary to comply with EU fisheries regulations as part of its accession process to join the EU (Montenegro Ministry of Agriculture and Rural Development, 2015, p. 11). These instructions illustrate potential explanations of Montenegro's low score and present ways that other countries might improve their performance on fisheries management. Montenegro was required to draft national management plans in compliance with the Mediterranean Regulation and implement a ban on discarding bycatch. The country was also criticized for its inadequate data collection processes for its fishing fleet, catch landings, the biological state of fish stocks, and impacts of fishing activity on marine ecosystems. Such data would be necessary to introduce a fishing capacity ceiling on the sector, as mandated by the EU fleet policy. Additional EU requirements to control IUU fishing also need to be incorporated into Montenegro's legal system. Finally, Montenegro has not yet ratified the UN Convention Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, which would be necessary for its fisheries policy to conform to EU standards (Montenegro Ministry of Agriculture and Rural Development, 2015, p. 11). Implementing such recommendations would likely benefit other laggard nations as they design improved policies for sustainable fisheries.

Improved data collection will be critical for all nations to better understand the status of their commercial fish stocks and marine environments. As measurement and reporting improve, countries will be better equipped to implement fisheries management legislation to ensure the sustainable harvest of their stocks, compliance with regional and international fisheries agreements, and protection of marine ecosystems. Such measures are critical for the preservation of global fish stocks, and the resilience of communities dependent on them.

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11

CLIMATE & ENERGY

Environmental Performance Index

Climate & Energy

SNAPSHOT

Climate change lies at the heart of some of the most pervasive and intractable environmental problems.

CATEGORY DESCRIPTION

Global energy and transport systems release heat-trapping gases into the atmosphere that warm the surface of the planet and degrade public health. Growing demand for food, commodities, and new development further shape spatial structures and landscapes in ways that alter the Earth's ability to reflect or absorb heat. These impacts, and others, are producing a strong cascade of effects that imperil existing social and economic structures and threaten the sustainability of our planet. Curtailing the effects of anthropogenic climate change will require immediate, concerted action by all countries at all scales.

INDICATORS INCLUDED

The Climate & Energy issue category uses five indicators to track a country's progress in reducing three critical greenhouse gases and one climate pollutant. In adding non-CO_2 indicators to the 2018 EPI, we have broadened the gauge of national climate change performance. We leverage new emissions inventories to construct a series of metrics intended to yield a more comprehensive assessment of a country's overall performance.

We measure each country's Climate & Energy score across the following five indicators:

- *Carbon dioxide emission intensity (total)*. This CO_2 metric tracks trends on carbon intensity from the entire economy, in tonnes of CO_2 emissions per unit of GDP.

- *Carbon dioxide emission intensity (power)*. This CO_2 metric tracks trends on carbon intensity from the power sector, in tonnes of CO_2 emissions per unit of kWh of electricity and heat.

- *Methane emission intensity*. Tracks trends in national emissions intensities of methane gas, reported in tonnes of CO_2-equivalent per unit of GDP.

- *Nitrous oxide emission intensity*. Tracks trends in national emissions intensities of nitrous oxide emissions, reported in tonnes of CO_2-equivalent per unit of GDP.

- *Black carbon emission intensity*. Tracks trends in national emissions intensities of black carbon emissions, reported in Gg of black carbon per unit of GDP.

CLIMATE & ENERGY INDICATORS	
Carbon dioxide emission intensity (total)	kt CO_2/$B
Carbon dioxide emission intensity (power)	kt CO_2-eq/$B
Methane emission intensity	kt CO_2-eq/$B
Nitrous oxide emission intensity	kt CO_2-eq/$B
Black carbon emission intensity	kt CO_2-eq/$B

CATEGORY OVERVIEW

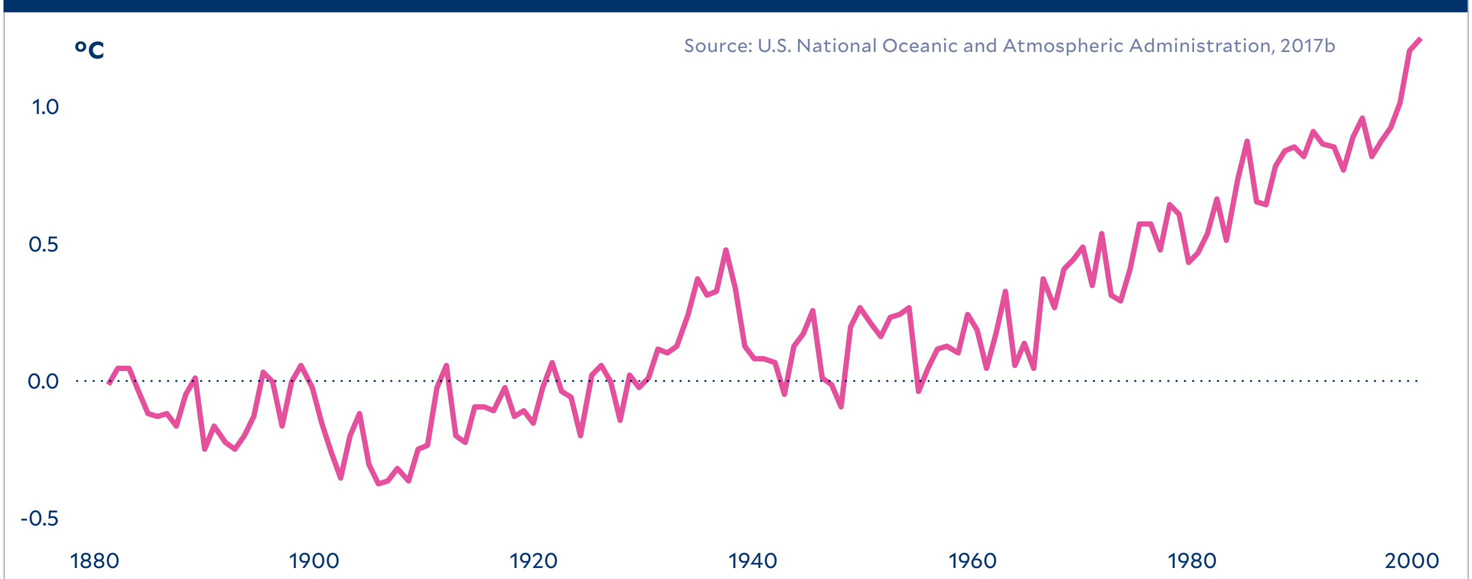
Scientists recognize that anthropogenic climate change represents a powerful driver of environmental degradation worldwide — impacting natural, economic, and social systems in all countries. Greenhouse (GHG) emissions are driving large, unprecedented changes in the atmosphere and global climate system (Christensen et al., 2013). Evidence of human impact on the natural environment include warming in the lower atmosphere and ocean surface, declines in snow and ice masses, and increases in global sea level (Stocker et al., 2013a). Global average temperatures have increased at an average rate of 0.07°C (0.13°F) per decade since 1800 (NOAA, 2017a). Recent warming trends have been more pronounced. Global average temperatures have increased at an average rate of 0.17°C (0.31°F) per decade since 1970 (NOAA, 2017a); see Figure 11-1. Without efforts to curtail anthropogenic emissions, Earth's surface temperature is projected to exceed a preindustrial baseline by 3°C by the end of the century (IPCC, 2013). Climate change must be understood as an inescapable international problem. Its impacts will affect the well-being and livelihoods of people everywhere. Addressing climate change thus requires nations to work together to implement policies, mobilize finance, and engage key stakeholders at all scales.

The 2015 Paris Climate Agreement recognizes the magnitude of the climate challenge and embodies the urgency and spirit of collaboration required to combat it. One hundred and seventy of the 197 parties to the United Nations Framework Convention on Climate Change (UNFCCC) have agreed to voluntarily reduce emissions, with the explicit goal of limiting global atmospheric warming to 2°C. The voluntary, bottom-up structure of the Paris Climate Agreement emerged in response to concerns over the binding, top-down emissions reduction targets that characterized the Kyoto Protocol and the failed Copenhagen Accord. Ratifying parties have agreed to work collectively toward the Agreement's goals through a set of individual, country-defined mitigation targets, called Nationally Determined Contributions (NDCs). Interventions for achieving reduction targets vary by country. Examples include fuel switching; renewable energy portfolio standards; and adoption of sustainable agricultural practices that curtail carbon dioxide (CO_2) emissions from forest loss.

As countries begin to implement new climate policies, timely and targeted performance metrics become increasingly important. While the Paris Climate Agreement represents a monumental first step in climate action, commitments may be inadequate in achieving the goals of the Agreement according to analyses of Intended Nationally Determined Contributions. One study found that, if all nations were to meet their NDCs, average global temperatures would increase 3°C by 2100 (Rogelj et al., 2016). As reporting requirements under the Paris Climate Agreement enter effect, the environmental indicators benchmarked in the EPI may serve as a tool to assess and validate the efficacy of new interventions and policies in reducing domestic and global emissions.

The Paris Climate Agreement's call for urgent action stems from climate

FIGURE 11-1 ANNUAL GLOBAL LAND AND OCEAN TEMPERATURE ANOMALIES, 1880–2016



change's potential to radically alter important environmental, social, and economic structures. While climate impacts will be more acute for some geographic regions, their effects have the potential to inflict damage at the global scale.

ENVIRONMENTAL

Evidence of climate change can be observed through its impacts on Earth's natural systems (Field et al., 2014). Atmospheric concentrations of CO_2 and global radiative forcing have already changed important environmental processes. Research suggests that we are encroaching on important Earth system thresholds for global climate, which, if crossed, could cause abrupt and irreversible system changes to critical environmental processes (Rockström et al., 2009). Evidence of the climate system in disequilibrium includes sharp declines in Arctic summer sea ice (Stroeve et al., 2007), loss of polar ice sheets (Cazenave, 2006; Velicogna, 2009), changes in glacial mass and annual snowfall (Barnett, Adam, & Lettenmaier, 2005), and disruptions to precipitation and weather patterns (Field et al., 2014).

Changes in the complex interactions between Earth's climate and core environmental processes have far-reaching implications for many ecosystems. Oceans, for example, absorb approximately 25% of human emissions (Rockström et al., 2009). At the ocean surface, CO_2 reacts with salt water and carbonate ions to increase ocean acidity, making it difficult for some living organisms to grow and survive (Field et al., 2014). Estimates indicate that the current rate of acidification is at least 100 times faster than that of any other period in the past 200 million years (Rockström et al., 2009).

Rising greenhouse gas (GHG) emissions also have far-reaching implications for terrestrial biodiversity. Climate-induced changes to terrestrial and aquatic ecosystems are impacting the geographic ranges and behaviors of many species (Field et al., 2014), often outpacing species' abilities to adapt. Elevated rates of species loss suggest a sixth mass extinction may be under way (Barnosky et al., 2011; Thomas et al., 2004). Continued warming and environmental degradation may have irreversible consequences for the biotic environment and the ecosystem services it provides (Rockström et al., 2009).

SOCIAL

Social development and climate change must be seen as closely related. While most people will be forced to cope with changes to their natural landscapes, individuals in many developing countries may well shoulder a disproportionate share of climate-related damages (Mendelsohn, Dinar, & Williams, 2006). Failure to address these burdens will constrain development pathways and limit opportunities for social advancement. Climate-related natural disasters and widespread changes in regional climate may cancel out gains in development by threatening the health and livelihoods of members of subsistence communities, entrenching them in cycles of poverty (Heltberg, Jorgensen, & Siegel, 2008).

Climatic shifts threaten a wide range of crops, which could, in turn, jeopardize global food production (Field et al., 2014). Subsistence and smallholder farmers in emerging economies will feel impacts of climate change more acutely than others. Smallholder farmers make up a significant portion of the global agricultural system. They manage at least 400 million of the world's 500 million small farms and provide over 80% of the food consumed in developing nations (International Fund for Agricultural Development, 2013). Food and Agriculture Organization of the United Nations (FAO) studies reveal that variability in precipitation patterns and above-average temperatures adversely impact crop yields in sub-Saharan Africa (FAO, 2016). Climate sensitivity is further exacerbated by limitations in subsistence and smallholder farmers' adaptive capacities to implement effective responses to sustained changes in regional climate, such as water management and improved crop varieties (FAO, 2016). Without sufficient adaptation measures, food security and viable employment opportunities in climate-sensitive regions will likely worsen.

Continued exposure to environmental shocks will likely incentivize people to leave their homes en masse. Climate change seems likely to be already contributing to displacement and changes in human migration patterns (Warner, 2009). In coming decades, flooding, more intense storms, drought, and gradual shifts in regional climate may force millions to leave their homes in search of viable livelihoods and security. In the climate-sensitive Ganges-Brahmaputra Delta, increases in the severity of seasonal floods and land subsidence may put as many as 250 million people at risk by 2050 (Schiermeier, 2014). Continued tidal amplification from sea level rise could drive mass movements into urban centers in the coming decades as families seek new ways to cope with environmental risks (Warner et al., 2009).

ECONOMIC

Climate change poses myriad threats to the global economy. The costs of climate change are likely driven by alterations to hydrological systems, lower crop yields, species extinction, natural disasters, public health crises, increased conflict, and lowered economic productivity (Field et al., 2014).

Estimating and comparing the economic damages from climate change are also central to informed policymaking. While modeling all damages from climate change is difficult, various integrated assessment models have attempted to evaluate impacts of increased emissions, rising population, and economic productivity (see Nordhaus, 1993 and Stern, 2007. Projections from these models, however, vary due to different assumptions, including differences in how market and nonmarket risks are quantified.

Climate change mitigation policies can deliver several co-benefits. Synergies between climate policies and other environmental or public health policies can produce a “double dividend” that benefits both environment and society. Reductions in methane (CH_4) emissions would decrease atmospheric GHG concentrations while improving human health and crop yields (Bollen, Guay, Jamet, & Corfee-Morlot, 2009). Another policy scenario shows that a 50% cut in GHG emissions relative to 2005 levels could reduce the number of premature deaths between 20% and 40% in 2050 relative to a business-as-usual scenario (Bollen et al., 2009).

The severity of the global climate challenge requires a concerted response from the international community. Recent multilateral efforts suggest nations have neared consensus on the need to urgently address the issue and its related social and economic concerns.

The year 2015 was important for multilateral coöperation and international diplomacy. On September 25, 2015, a total of 193 Member States of the United Nations adopted the Sustainable Development Goals (SDGs), a global agenda that prioritizes inclusive, sustainable growth (UN, 2015). On December 15, 2015, representatives from 195 countries adopted the Paris Climate Agreement, which entered into force on November 4, 2016. Ratifying parties agree to submit NDCs, or individual pledges, to voluntarily reduce GHG emission by a set amount by 2030.

SUSTAINABLE DEVELOPMENT GOALS

GOAL 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

GOAL 3. Ensure healthy lives and promote well-being for all at all ages.

GOAL 7. Ensure access to affordable, reliable, sustainable, and modern energy for all.

TARGET 7.2. By 2030, increase substantially the share of renewable energy in the global energy mix.

GOAL 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

GOAL 11. Make cities and human settlements inclusive, safe, resilient and sustainable.

GOAL 12. Ensure sustainable consumption and production patterns.

TARGET 12.2. By 2030, achieve the sustainable management and efficient use of natural resources.

TARGET 12.5. By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

GOAL 13. Take urgent action to combat climate change and its impacts.

GOAL 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

GOAL 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

INTERNATIONAL ORGANIZATIONS

Intergovernmental Panel on Climate Change (IPCC). The IPCC is a scientific and intergovernmental body tasked with assessing the scientific, technical, and socioeconomic aspects of climate change. The IPCC was formed in 1988. To date, the IPCC has published five assessment reports that review the latest climate science and assess impacts on the human and natural landscape. The most recent report was published in 2013. https://www.ipcc.ch

United Nations Environment Programme (UNEP). UNEP is a program of the United Nations tasked with setting the global environmental agenda, promoting sustainable development, and serving as the global authority and advocate for the global environment. https://www.unenvironment.org/

World Meteorological Organization (WMO). The WMO is an intergovernmental organization with 191 active members. Its mandate is to serve as the authoritative voice of the United Nations on the "state and behavior of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources. https://www.wmo.int

MULTILATERAL EFFORTS

United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC entered into force on March 21, 1994. To date, 197 countries have ratified the Convention. The UNFCCC's mission is to, "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." http://unfccc.int

Kyoto Protocol. The Kyoto Protocol is an international agreement linked to the UNFCCC that commits parties to meeting internationally binding emissions targets through market-based mechanisms. The Kyoto Protocol entered into force on February 16, 2005. The treaty was the first international treaty charged with stabilizing global emissions. http://unfccc.int/kyoto_protocol/items/2830.php

Paris Climate Agreement. The Paris Climate Agreement is an international agreement that builds on past efforts of the UNFCCC. The agreement outlines an international commitment to limiting global temperature rise to 2°C above pre-industrial levels. The architecture of the Paris Climate Agreement deviates from previous international agreements, in that parties are permitted to submit their own Nationally Determined Contributions to global emissions reduction efforts. The Paris Climate Agreement entered into force on November 4, 2016, 30 days after it was signed. http://unfccc.int/paris_agreement/items/9485.php

High-quality and transparent GHG emission data are necessary to inform sound policy decisions.

In an ideal world, global GHG emission inventories would provide detailed information for all sources of emissions across all sectors of an economy within all countries. Accurate, exhaustive, and precise data reduce uncertainty in emission inventories. Reduced uncertainty allows scientists to generate more accurate estimates of GHG emissions, ultimately driving better-informed policymaking.

For over 20 years, the UNFCCC has required its members to regularly measure and report their GHG emissions using a standardized reporting framework developed by the IPCC (Eggleston, Buendia, Miwa, Ngara, & Tanabe, 2006). The IPCC framework offers counries the option to collect and report detailed GHG emission data; however, few countries have the resources and internal capacity to do so. Most counties estimate their emissions based on a standardized process that allows them to report generally on anthropogenic emissions by source and removal by sinks.

Many organizations compile emission data beyond the scope of the UNFCCC framework. The Emissions Database for Global Atmospheric Research (EDGAR) includes inventories for GHG and climate pollutants, such as black carbon. The 2018 EPI obtains data from several organizations that aggregate global emission data—including EDGAR and World Resources Institute Climate Analysis Indicators Tool (WRI CAIT) data — to develop the best metrics for

FOCUS 11-1 PILOT INDICATOR: TECHNOLOGY-ADJUSTED CONSUMPTION-BASED ACCOUNTING

While GHGs have global impacts, assigning responsibility for their emission poses challenges. Researchers have relied on two primary methods: production-based and consumption-based accounting (PBA and CBA, respectively). Under PBA, a country bears the blame for every tonne of GHG emitted in a country's territory, from whatever activity. The Kyoto Protocol uses PBA (Domingos, Zafrilla, & López, 2016, p. 729), and the UNFCCC rules apply a similar methodology (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017, p. 23). The 2018 EPI also uses PBA to measure emissions from each country in the index. PBA, however, fails to capture some nuances of a globalized economy. If GHG are emitted from activities producing goods or services that are then traded internationally, who should bear the responsibility for those emissions: the exporting country or the importing one? This so-called 'leakage problem' rewards countries who outsource the GHG emissions of their economy by locating, for example, manufacturing processes in other countries (Kander, Jiborn, Moran, & Wiedmann, 2015, p. 431).

CBA methods attempt to correct or the leakage problem by accounting for the embodied GHG emissions in internationally traded goods. Under CBA, a country is responsible for all GHG emissions resulting from its economic activity, regardless of where those emissions occur (Domingos et al., 2016, p. 729). Thus, a country cannot improve its performance by outsourcing GHG-intensive processes. The limitation of CBA, however, is that it also does not incentivize exporting countries to reduce the emissions intensity of its GHG-emitting activities, and countries who have low-GHG industries can be penalized for exporting to less efficient countries (Kander et al., 2015, pp. 431–433; Sachs et al., 2017, p. 23).

There is a tension between PBA and CBA that resolves around the dilemma between accounting for outsourced GHG emissions and recognizing the comparative advantage of some countries with production processes with low GHG emission intensities. Technology-adjusted consumption-based accounting (TCBA) (Kander et al., 2015) attempts to resolve this tension by correcting for the each country's emission efficiency. Countries are rewarded for shifting production to countries with cleaner-than-average production processes and penalized for outsourcing emissions to dirtier countries. By treating the trade of an individual good as a contribution to net global emissions, rather than an isolated event occurring between only two countries, TCBA rewards trade that reduces global emissions (Kander et al., 2015, p. 432).

While more useful for providing deeper insights into how countries influence the flow of GHG into the atmosphere, the sophistication of TCBA comes at a cost. Accounting for the GHG emission efficiency of every export sector in every country requires an enormous amount of information — on the volume and destination of traded goods and the country-specific processes all along the value chain. Currently, such data are too sparse to provide robust estimates of responsibility for GHG emissions. As global data systems mature, future versions of the EPI may be able to incorporate the insights of TCBA into calculations of environmental performance in this important issue category.

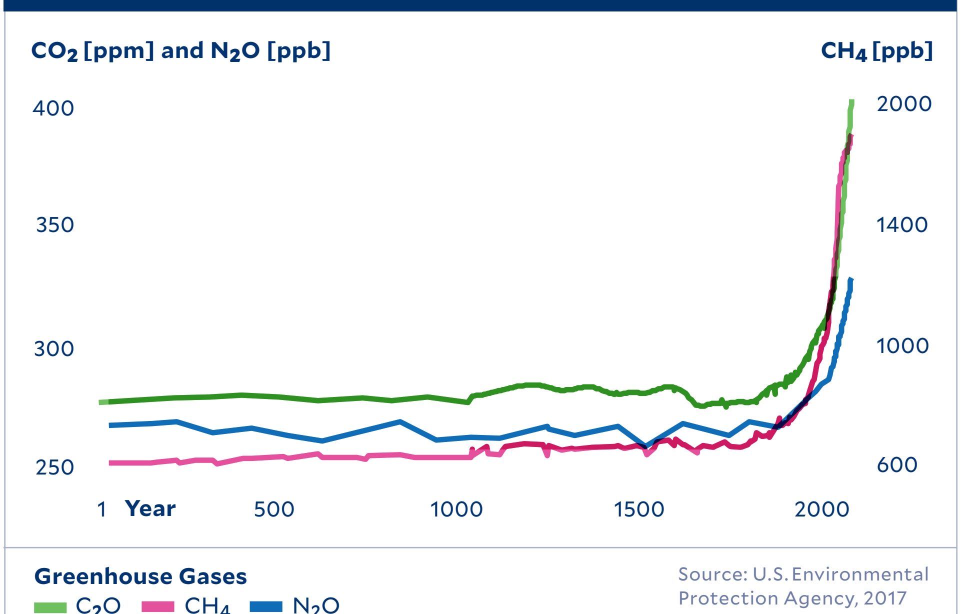
assessing environmental performance. Our data sources and methodology are explained in the Data Sources, Limitations, and Indicator Construction sections of this chapter.

Effective decisionmaking also hinges on an understanding of how factors outside of the energy sector, such as trade and land use change, impact the global GHG budget. An integrated, globalized economy complicates emission accounting considerably. Consumer goods produced in one country are often exported to another, raising the question of whether responsibility for emissions should rest on the producing or consuming country. Solutions like technology-adjusted consumption-based accounting (TCBA) offer policymakers an alternative method that quantifies emissions based upon whether the production technologies in the exporting country emit more or less GHGs per unit of output than the production technologies of the importing country; see Focus 11-1. Similarly, changes in land use change and forestry (LUCF) complicate global accounting methods. A significant portion of GHG emissions—4% in 2010—originate from the agriculture sector (Russell, 2014). Accounting for how these changes impact the carbon budget is difficult. Finally, rising emissions from the growing transportation sector indicate a need to improve monitoring and performance metrics. For more information on transportation emissions, see Focus 11-2.

INDICATOR BACKGROUND

As the need to reduce emissions intensifies, so will the demand for monitoring of all GHGs and their sources.

FIGURE 11-2 HISTORIC ATMOSPHERIC CONCENTRATIONS OF SELECT GREENHOUSE GASES, AD 1–2016



Source: U.S. Environmental Protection Agency, 2017

While CO_2 is the dominant contributor to global climate change by volume, policymakers must be mindful of other GHGs and climate pollutants. Recognizing the need to mitigate other significant contributors to climate change, the 2018 EPI has adapted its Climate & Energy score construction to include new indicators that assess national contributions to climate change from three additional warming agents: CH_4, N_2O, and black carbon. The change in score construction reflects improvements in the quality of non-CO_2 emission inventories and our commitment to sound reporting driven by the best available data.

CARBON DIOXIDE

Carbon dioxide emissions are the single greatest driver of anthropogenic climate change, explaining approximately 78% of GHG-driven warming from 1970 to 2010 (Edenhofer et al., 2014). In 2016 the atmospheric CO_2 concentration reached 403.3 parts per million (UN News Centre, 2017), the highest concentration in the last 800,000 years (Collins & Knutti, 2014).

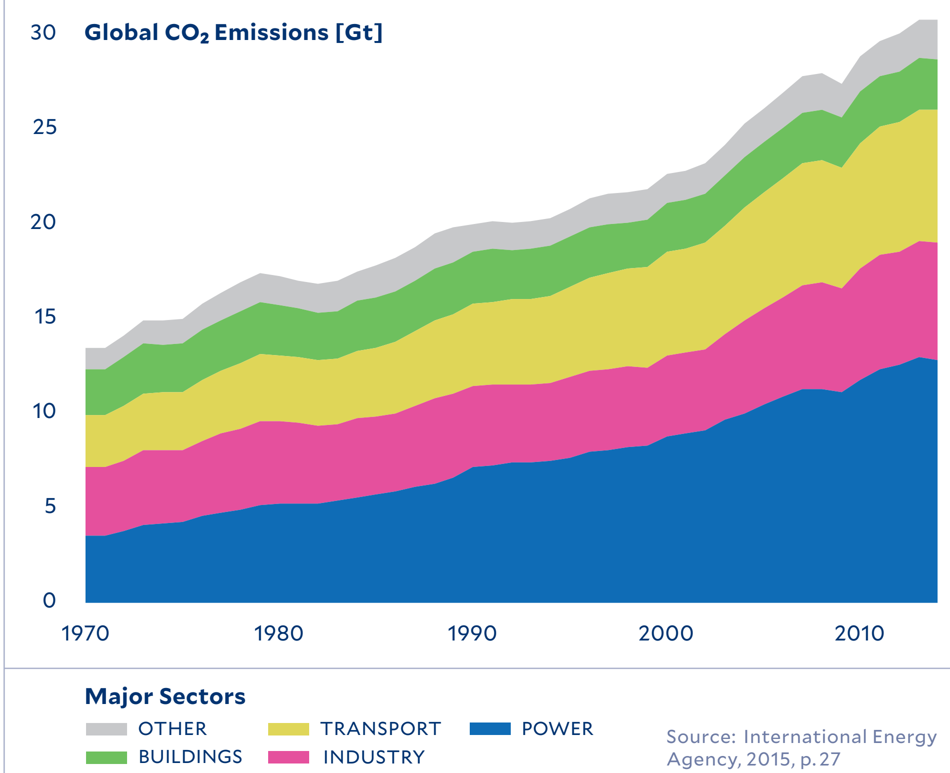
Atmospheric CO_2 does not readily degrade through chemical reactions. While close to half of emissions are exchanged with ocean or land sinks within a few decades, up to 40% of emissions are expected to persist in the atmosphere for longer than 1,000 years (Collins & Knutti, 2014). The accumulation of atmospheric CO_2 is often described as a commitment from past emissions toward future climate change—or as the inertia of the climate system. This inertia means that historic anthropogenic CO_2 emissions will account for a large proportion of climate change and that current emissions will impact the climate system long into the future (Collins & Knutti, 2014).

Country-level progress toward reducing CO_2 intensity is an important measure of environmental performance. We characterize this trend by using two CO_2 emission indicators: (1) total emissions, excluding LUCF; and (2) emissions from electricity and heat production, the most CO_2-productive sector (IEA, 2016a); see Figure 11-3. The 2018 EPI includes both indicators to measure progress on CO_2 mitigation both generally and within this important sector.

METHANE. Methane is the second-most abundant GHG in the atmosphere after CO_2. The amount of CH_4 in the atmosphere has more than doubled in the past 250 years due to human activity (Edenhofer et al., 2014; Etheridge, Pearman, & Fraser, 1992). While CH_4 has a short atmospheric lifespan—estimates typically range between nine and 12 years—it is 34 times more effective at trapping heat than CO_2 (Christensen et al., 2013; Forster et al., 2007; Hartmann et al., 2013; Lelieveld, Crutzen, & Dentener, 1998). The IPCC estimates that CH_4 is responsible for nearly 20% of anthropogenic global warming since 1750 (Edenhofer et al., 2014).

Up to 60% of global CH_4 emissions result from human activity (Edenhofer et al., 2014). Most anthropogenic emissions come from agriculture, fossil fuel extraction and use, waste, and off-gassing from landfills (Edenhofer et al., 2014). Emissions from livestock, such as ruminant animals, produce an estimated 7.1 Gigatons of carbon dioxide equivalent (CO_2-eq) per year and make up 14.5% of global anthropogenic emissions (Gerber et al., 2013). Methane

FIGURE 11-3 GLOBAL CO_2 EMISSIONS BY SECTOR, 1970–2014



Source: International Energy Agency, 2015, p. 27

FOCUS 11-2 PILOT INDICATOR: TRANSPORTATION CARBON INTENSITY

GHG emissions from transportation are an important contributor to climate change. Transportation-related emissions accounted for 14% of GHG emissions worldwide in 2010 (Edenhofer et al., 2014, p. 9); see Figure 11-3. Emissions from this sector have grown over time. While total GHG emissions in Europe fell by 22% between 1990 and 2015, emissions from transportation increased by 16% (European Environment Agency, 2017, p. 237). While the 2018 EPI tracks CO_2 emissions from the power sector, no such comparable metric is currently available from the transportation sector to capture these trends.

Developing a metric of the GHG intensity from transportation consists of two major components. First is accounting for the GHG emissions from transportation services. Second is choosing the proper standardization across countries. While the GHG emissions from an entire economy can be denominated by GDP and from the power sector by kWh, the transportation sector has two proposed factors: passenger-kilometer traveled and tonne-kilometer traveled. Indeed, these components are used by both the World Bank (2017) and the International Transport Forum (2017, pp. 182–194). These datasets are incomplete, however, with the latter containing records for fewer than 60 countries. They also do not provide a method to allocate emissions to passenger versus freight transport, nor do they allow for more detailed analysis regarding the causes of transportation efficiency differences across countries.

More nuanced approaches address some of these limitations. CE Delft and the UK government have developed methodologies that estimate emissions for individual companies, demonstrating two ways of measuring transportation carbon intensity more thoroughly (Otten, Hoen, & den Boer, 2017; U.K. Department for Environment, Food & Rural Affairs, 2013). While the scope of data collection required to fully implement these approaches is potentially infeasible on an international scale, the CE Delft and UK government methodologies reflect he complexity of this task and pose questions that must be addressed. Global efforts to collect data and make appropriate estimates are the third and most significant piece required to develop a usable transportation carbon intensity metric.

emissions from rice paddies and agriculture are also large contributors to global emissions (Edenhofer et al., 2014). Emissions from fossil fuel development contribute between 132 and 165 million tonnes of the 623 million tonnes of CH_4 emitted each year (Nisbet et al., 2016).

Methane is also emitted from the natural environment. Wetlands are the largest single natural emissions source, contributing 217 Teragrams (Tg) of CH_4 to the global budget annually (Ciais et al., 2013). Other important sources include biogeochemical cycles (54 Tg/year), freshwater ecosystems (40 Tg/year), wild animals (15 Tg/year), and termites (11 Tg/year) (Ciais et al., 2013). Rapid warming and future fossil fuel extraction of methane hydrates could release large quantities of CH_4 from deposits in marine and permafrost sediments (Harden et al., 2012; Krey et al., 2009; Mascarelli, 2009). The IPCC estimates that between 2 and 8 million Tg of CH_4 are stored in ocean hydrates and less than 530,000 Tg are stored in permafrost hydrates (Ciais et al., 2013). However, scientific understanding of how climate change may impact the release of these stocks into the atmosphere is not widely understood (Ciais et al., 2013; Schuur et al., 2015).

NITROUS OXIDE. Nitrous oxide (N_2O) is a potent, long-lived GHG. Its global warming potential (GWP) is 300 times higher than CO_2 (Forster et al., 2007; UNEP, 2013). N_2O's long atmospheric lifespan of 121–141 years ensures that today's emissions will have a lasting impact on our climate system (Myhre et al., 2013). N_2O also poses severe risks to the ozone layer, which warrant additional and immediate attention from the international community (Ravishankara, Daniel, & Portmann, 2009).

Human-induced disturbances in the nitrogen cycle have increased N_2O emissions in recent years (Butterbach-Bahl, Baggs, Dannenmann, Kiese, & Zechmeister-Boltenstern, 2013; Pinder et al., 2012). Anthropogenic N_2O sources — which now account for 40% of global N_2O emissions—have risen steadily over the past two decades. Recent estimates place global emissions at 6.9 Tg of N_2O per year — roughly eight times greater than pre-industrial estimates (Ciais et al., 2013). Major sources of anthropogenic N_2O emissions are agricultural activities, fossil fuels and industry, and biomass burning, which account for 60%, 10%, and 10% of gross N_2O, respectively (Ciais et al., 2013).

UNEP estimates that moderate mitigation, when compared to a business-as-usual scenario, could reduce N_2O emissions by 1.8 Tg in 2020 (UNEP, 2013). The Clean Development Mechanism of the Kyoto Protocol initiates action on N_2O emissions, but most abatement efforts are narrowly focused on emissions mitigation in the industrial sector

FOCUS 11-3 CHANGING CATTLE FEED TO REDUCE EMISSIONS FROM AGRICULTURE

Revised bottom-up estimates of global livestock methane emissions, particularly from cattle, account for a sizable portion of the significant increase in observed CH_4 emissions over the past decade (Nisbet et al., 2016). Several impacts of modern food production are thought to have influenced recent livestock emission quantities, such as the proportion of animals in large feeding operations, animal body mass or productivity, and animal feed quality and quantity (Wolf, Asrar, & West, 2017). A recent study finds that emission data from cattle and other ruminants — buffalo, sheep, goats, and camels — are 11% higher than previously estimated due to outdated emission factor estimates (Wolf et al., 2017). As incomes rise in developing nations, so will the demand for animal products. Meat consumption in developing nations is expected to more than double by 2030 (Bruinsma et al., 2003). Changing diets increase the need to address emissions from raising animals for food.

Large livestock, such as cattle, are substantial contributors to global CH_4 emissions (Wolf et al., 2017). A recent study suggests that incorporating *Asparagopsis taxiformis,* a certain type of kelp, into a cow's diet can significantly reduce CH_4 emissions. Using an artificial cow's stomach in a laboratory, researchers found that adding less than 2% dried seaweed to a cow's diet reduced CH_4 emissions from enteric fermentation (digestion) by 99% (Kinley, Nys, Vucko, Machado, & Tomkins, 2016).

While the results of introducing Asparagopsis taxiformis into cattle feed are promising, it cannot yet be considered a quick fix for reducing CH_4 emissions. Production could prove to be a bottleneck for rapid implementation. For example, it would take 6,070 hectares (15,000 acres) of seaweed to supply kelp to feed just 10% of Australia's 29 million cattle (Rupp, 2016). There are also environmental risks associated with adding seaweed to animal feed. Seaweed contains high concentrations of bromoform (Gribble, 2000). Bromoform is known to mix with ozone in the atmosphere to form bromine oxide radicals, which contribute to stratospheric ozone depletion (Carpenter & Liss, 2000). Innovative efforts such as the addition of kelp to animal feed represent the type of creative solutions required to address a growing environmental burden and demonstrate the need for future study (Patra, Park, Kim, & Yu, 2017).

(Schneider, Lazarus, & Kollmuss, 2010). Countries can reduce emissions and meet their climate goals by expanding efforts to address agriculture and other high-emitting sectors. Improving nitrogen use efficiency and reducing meat consumption, food waste, and food loss are all viable mitigation options (UNEP, 2013).

As with many environmental challenges, developing nations are often constrained in their ability to effectively address problems. Barriers to N_2O reduction efforts include the high capital costs of abatement technologies, lack of training and technology transfer on abatement techniques, and knowledge gaps in site-specific or situational mitigation options (UNEP, 2013). Potential mitigation policies to address these barriers could involve removing subsidies that encourage misuse or overuse of nitrogen fertilizer, putting a price on nitrogen, increasing support for good management practice for farmers, and setting clear targets for emission reductions (UNEP, 2013).

BLACK CARBON. Black carbon is a short-lived, light-absorbing component of particulate matter produced through incomplete combustion of fossil fuels, biofuels, and biomass (UNEP & WMO, 2011). Black carbon was excluded from the Kyoto Protocol due to uncertainties about its net impact on global climate change (Levitsky, 2011), but recent studies show black carbon to be a potent, heat-trapping pollutant (Bond et al., 2013). Black carbon's global warming potential is 900 times that of CO_2, and its emissions may be responsible for up to 30% of warming in the Arctic (Bond et al., 2013; Shindell & Faluvegi, 2009). Black carbon also contributes substantially to poor air quality. Efforts to address black carbon emissions thus have the potential to deliver co-benefits for climate, air quality, and public health (Wang et al., 2014).

Black carbon influences the climate system in two ways: first, by altering radiative properties in the atmosphere and, second, by increasing surface albedo, or reflectivity. In the atmosphere, black carbon particles trap heat and contribute to warming (Bond et al., 2013). While recent estimates of black carbon's direct influence on the atmosphere indicate that it has a warming effect much greater than previously thought,

FOCUS 11-4 NITROUS OXIDES FROM ARCTIC PEATLANDS

Permafrost soils in the Arctic are large nitrogen reservoirs. Historically, Arctic peatlands have not been a significant source of N_2O, but a warming planet may change that. Land areas in the Arctic are expected to warm 5.6–12.4°C (Christensen et al., 2013). Continued warming will thaw permafrost soils and produce N_2O (Butterbach-Bahl et al., 2013). Approximately 40% of the Arctic has a high probability of releasing N_2O (Voigt et al., 2017). One conservative estimate places the stored mass of nitrogen in deep permafrost soil at 67 billion tonnes, nearly 500 times the global annual nitrogen load added to soil as fertilizer (Bouwman et al., 2013; Harden et al., 2012; Stocker et al., 2013b). Rapid release of N_2O and other warming gases stored in permafrost soils has the potential to further drive atmospheric warming, weakening or reversing the impacts of successful mitigation policy.

Thawing permafrost also has implications for local environments. Continued thawing is likely to have widespread impacts on Arctic hydrology and geology (Frey & McClelland, 2009). Research from the Northwest Territories Geological Survey indicates that permafrost collapse causes landslides into rivers that can impact downstream watersheds; thawing produced increased suspended sediment concentrations in Arctic streams and waterways (Kokelj et al., 2013). Accelerated thawing also places additional stress on biological communities in lakes, threatening aquatic ecosystems (Thienpont et al., 2013).

PHOTOGRAPH 11–1. Thawing permafrost in Gates of the Arctic National Park and Preserve, Bettles, Alaska, USA.
Source: U.S. National Park Service Climate Change Response, 2014

Limited knowledge of complicated climate feedback loops lowers the degree of confidence with which scientists can predict the volume, timing, and likelihood of N_2O release from permafrost peatlands (Ciais et al., 2013). However, policymakers should be aware of the potential for thawing-induced N_2O emissions from Arctic peatlands, and how the emissions may factor into the global N_2O budget in the future.

researchers are still trying to understand black carbon's indirect effects through interactions with other gases (Bond et al., 2013). Like all aerosols, black carbon has a short residence time. After a period of days to weeks, black carbon will eventually settle on Earth's surface. When deposited on snow or ice, black carbon accelerates melting by altering surface albedo and increasing heat absorption (Levitsky, 2011; Ramanathan & Carmichael, 2008). Mitigating black carbon emissions could thus lower the amount of soot deposited on climate-sensitive regions, like the Arctic.

Black carbon emissions have strong local impacts. Atmospheric transport consolidates black carbon in regional hotspots, where it influences local climate systems (Levitsky, 2011). Atmospheric heating and dimming from black carbon contributed to a 50-year decline in precipitation patterns in Africa, South Asia, and northern China (Bond et al., 2013). Emissions deposited on Himalayan glaciers impact the intensity and distribution of seasonal monsoons (Turner & Annamalai, 2012). One billion people rely on seasonal precipitation patterns for their livelihoods in South Asia; disturbances in quantity and distribution of regional water supply have the potential to threaten the delicate food-water nexus (Turner & Annamalai, 2012).

FOCUS 11-5 MEXICO'S INDC: AN EMPHASIS ON BLACK CARBON

Mexico's INDC to the Paris Climate Agreement sets explicit targets for black carbon emissions. These political priorities are mirrored in its national policies. Mexico's General Law on Climate Change (LGCC) requires the government to prioritize low-cost actions with high mitigation potential that also deliver co-benefits for public health and wellness (Government of Mexico, 2014). The government plans to meet the obligations of the LGCC and Paris Climate Agreement, in part, by reducing black carbon emissions by 51% by 2030 from a baseline business-as-usual scenario that begins in 2013 (Government of Mexico, 2016). If achieved, the reduction would translate to a 3% decrease in national emissions of CO_2-equivalent.

Mexico plans to reduce black carbon emissions by incentivizing more efficient technologies and fuel-switching in high-emitting sectors (Government of Mexico, 2014). Mexico's National Strategy on Climate Change and the Special Climate Change Program outline a path of action for reducing emissions in the oil and gas, energy, agricultural, and residential sectors; specific lines of action for these industries are detailed in Table 11-1.

Sources: Government of Mexico, 2013, 2014, 2016; Herrera et al., 2017

TABLE 11-1 SUMMARY OF BLACK CARBON MITIGATION STRATEGIES

INDUSTRY	SOLUTIONS
Energy and Industry	• Substitute coke fuel, fuel oil, and diesel with natural gas, clean energy, and biomass in medium-to-large-scale industries • Control black carbon emissions in industrial equipment though installation of filtration technologies and promotion of efficient processes in medium-to-large-scale industry • Promote productive reconversion, technological change, and energy efficiency in key micro- and small-scale industries, e.g., brick making • Better monitoring of power sector emissions
Transport	• Harmonize North American Free Trade Agreement (NAFTA) regulations for new and existing vehicles and locomotives • Increase the availability and consumption of ultra-low sulfur fuel • Encourage the use of particle filters in internal combustion engines • Deploy at least 1 million new vehicles by the end of 2018 • Reduce used vehicle imports • Implement clean transportation systems in freight corridors • Implement low-carbon urban public transportation corridors powered by natural gas
Agriculture	• Reduce the practice of burning sugar cane with other green crops in agricultural sectors
Residential	• Replace traditional open stoves with fuel-efficient, wood-saving stoves in poor and marginalized communities

Note: Mexico currently ranks 107th out of 180 countries in black carbon emission intensity. If it succeeds in meeting its INDC, it could serve as an example for similar countries seeking to address black carbon emissions within their own borders.

Black carbon's significant contribution to radiative forcing and its short lifespan present unique opportunities for coördinated efforts to mitigate warming trends in the near term (UNEP & WMO, 2011). Global emissions have increased from 5.3 Tg of black carbon in 1960 to 9.1 Tg in 2007, signifying a growing global appetite for energy due to population growth and rising incomes (Wang et al., 2014). Overall emission intensity, measured as the amount of black carbon emitted per unit of energy, however, has declined substantially since 1960, largely due to efficiency and technology improvements in the energy and transport sectors (Wang et al., 2014). Black carbon emission intensities have declined without concerted policy incentives for abatement. However, political action aimed at reducing black carbon emissions could be an effective tool for climate change mitigation.

The international community now recognizes black carbon and other short-lived climate pollutants as a component of global climate mitigation. On May 27, 2016, leaders of the even (G7) issued a declaration that recognized the importance of reducing emissions of black carbon, CH_4, and hydrofluorocarbons (HFCs) to slow warming in the near term (Group of Seven, 2016). Many nations outside of the G7 also recognize the importance of mitigating black carbon and other short-lived climate pollutants and have included them in their Intended Nationally Determined Contributions (INDCs); see Focus 11-5.

DATA SOURCES

The 2018 EPI uses emission data from three sources: the WRI CAIT database, the IEA, and the EDGAR database produced by the European Commission Joint Research Center and the Netherlands Environmental Assessment Agency.

WORLD RESOURCES INSTITUTE CLIMATE ANALYSIS INDICATORS TOOL. We source data for the CO_2 (total), CH_4, and N_2O indicators from the WRI CAIT. CAIT compiles data from peer-reviewed and internationally recognized GHG inventories and other government agencies. CAIT data are available at HTTP://CAIT.WRI.ORG/HISTORIC. CAIT data also include estimates of emissions and sinks associated with land use and forestry activities, which come from global estimates compiled by the FAO.

CAIT provides country-level coverage for the indicator CO_2 emission intensity (total) for the 186 members of the UNFCCC over the period 1850–2014 (WRI, 2015). The dataset compiles emission data from three widely cited CO_2 emissions accounting sources: the IEA, the Carbon Dioxide Information Analysis Center (CDIAC), and the U.S. Energy Information Administration (EIA). The total CO_2 emissions reported for each country are the aggregate emissions from two sources: fossil fuels and cement manufacture, which represent the bulk of anthropogenic CO_2 emissions. Due to uncertainties in the underlying data, we do not use estimates that include fluxes from LUCF.

CAIT also estimates country-level coverage of emissions estimates for total CH_4 and N_2O for 188 countries for the years 1990–2014. CAIT draws emission estimates from two sources: a 2012 United States Environmental Protection Agency (US EPA) report detailing historic and projected non-CO_2 emission data from 1990 to 2030 in five-year intervals, and a 2014 FAO report detailing land-use and agriculture emission data from 1990 to 2012 (WRI, 2015). Data are linearly interpolated between reported EPA values to provide country, gas, and sector estimates, all expressed in CO_2-equivalents using 100-year GWP values (WRI, 2015).

INTERNATIONAL ENERGY AGENCY. We source data on CO_2 from electricity and heat production from the IEA. The IEA tracks emissions from fossil fuel combustion for more than 150 reporting countries and regions, covering the years 1971–2014. The IEA reports data in grams of CO_2 per kWh, a measure of energy intensity. The IEA's calculation involves multiplying the amount of fuel burned in a power plant by an emission factor. These emissions are summed across all fuels and plants in a country to produce an annual total amount of emissions.

EMISSIONS DATABASE FOR GLOBAL ATMOSPHERIC RESEARCH. EDGAR is a joint project of the European Commission Joint Research Center and the Netherlands Environmental Assessment Agency. EDGAR calculates estimates for black carbon using energy balance statistics from the IEA. The most recent data release, EDGAR v4.3.1, evaluates black carbon emissions from a variety of sectors ranging from open burning to manufacturing. Emission data are estimated for years 1970–2010 and are reported in Gigagrams (Gg) of black carbon.

LIMITATIONS

Much of our underlying data are subject to the limitations of existing GHG inventories. These inventories develop their emission estimates by multiplying "activity" data, e.g., the amount of a certain type of fuel consumed using a given technology, by a corresponding emission factor, or the amount of GHG released per unit of activity. One important limitation is the shortage of country- and sector-specific emission factors required for highly accurate emission estimates. The WRI CAIT tool relies on standardized emissions factors (WRI, 2015). The IEA employs a similar system. Standardized emission factors mask variations across individual sites both within and between countries. Uncertainties are higher for non-CO_2 gases. For example, inventories tracking black carbon emissions often have high degrees of uncertainty due to the large volume of data required to compute them, the variability between them, and existing limitations in the applicability of emissions derived from trends in developed nations to developing nations (Wang et al., 2014).

Another limitation to existing GHG inventories concerns the accuracy of reported data. Many nations lack the technology, internal capacity, and resources to monitor GHG sources and sinks effectively. Improper data collection and assessment methods can produce discrepancies between reported and actual emissions. Missing data, such as the unavailability of data in certain countries for individual indicators, also complicate the assessment of country-level performance (WRI, 2015, pp. 14–15). To overcome these gaps, WRI and other organizations use gap-filling methods that produce additional challenges in trend analysis. Gap filling can introduce additional uncertainty, as the data reported for each source are not necessarily equivalent.

INDICATOR CONSTRUCTION

The 2018 EPI evaluates national performance using GHG emission intensity trends. Mitigating GHG emissions—and meeting international goals for climate change—will require decoupling emissions from economic growth. This is most clearly measured by standardizing a country's emissions. In the cases of total CO_2, NH_4, N_2O, and black carbon, this is derived from dividing emissions by a country's gross domestic product (GDP). In the case of the CO_2 from the power sector, CO_2 emissions are divided by kWh of electricity and heat. These measures of emission intensity allow for cross-country comparisons, putting all countries, large and small, on a common scale. Single-year measures of emission intensity, however, can be misleading due to the vicissitudes of a country's economy. Recessions and commodity price fluctuations have the potential to influence emission intensity through both the GHG emissions and GDP. A more typical representation of a country's emission intensity can be obtained by averaging observations over several years. Better still is to calculate a trend in emission intensity over time, as this metric captures each country's progress in decoupling GHG emissions from economic activity. Ten-year emission intensity trends are the organizing framework of the EPI GHG indicator construction.

Decoupling GHG emissions from economic growth often proves to be a difficult feat, and countries vary in their ability to promote lower emission intensities. Wealthy countries may be positioned to lower GHG emissions as they transition to postindustrial, service-based economies. Developing nations are also poised to act, but many must find new, creative solutions that address conflicting priorities in tandem with GHG emissions. Potential conflicts include investing in mitigation, population growth, rising consumption, industrialization, and financial constraints. As in previous versions of the EPI, we attempt to control for these differences by comparing each country to its economic peers. We operate from the assumption that countries at

FOCUS 11-6 FOREST DEGRADATION AS A NET CO_2 SOURCE

Forests play an important role in climate change, but until recently scientists have been unsure whether forests are net sources or sinks of carbon. The disagreement stems from two different modeling approaches. Top-down satellite-based models show forests as important carbon sinks, whereas bottom-up ecological studies find forests to be a net carbon emitter. A recent paper from the Woods Hole Research Center clarifies the role of forests in the global carbon cycle by matching satellite-based imagery with ecological field data. The study finds forests to be a net carbon emitter, with most emissions caused by the degradation and disturbance of forest land (Baccini et al., 2017).

Baccini et al. (2017) improve on previous studies by measuring both changes in forest size and changes in the stored carbon of standing forests. The latter was not considered in previous top-down models, which apply remote sensing to track changes in forest cover over large geographic areas due to land use change. Many top-down models use net change in forest area as a proxy for carbon storage and have largely ignored or understimated losses or gains in carbon storage due to changes in forest density. Bottom-up direct sampling is better suited for measuring changes in forest density due to degradation and disturbance. Activities that degrade or distribute forests include selective logging, which reduces biomass but does not transform the forest into another land use.

Carbon losses from degradation and disturbance of forests are highly important to the role of forests in the global carbon cycle. Baccini et al. (2017) report that reductions in forest density due to degradation or disturbance contributes nearly 70% of carbon emissions from forests—more than double the emissions that result from land-use change. These losses are missing from previous top-down models, and their inclusion shows forests as a net source of atmospheric carbon. When managing forest land for climate change mitigation, policymakers should consider carefully the impacts of forest management and avoid forest degradation when possible.

similar levels of economic development will have roughly equal opportunities and capacities for decoupling.

Accounting for differences in the economic development of countries requires constructing an appropriate measure of the typical GHG intensity trend for each income group. The EPI does this by comparing the trend in every country against its wealth, measured in GDP *per capita*. The line in Figure 11-4 represents an average level of performance across the range of observations. Following from the logic that richer countries find it easier to decouple emissions from economic growth, the line slopes downward. Each country's performance can then be compared to this typical line. Countries with emission intensities below the line are rewarded for beating expectations, while countries above the line are penalized. The indicators used in the EPI are therefore trends in GHG emission intensity relative to peers.

To accurately reflect the efforts of top performers in the Climate & Energy category, we adjust the weighting within the indicator. Some countries have significantly decoupled emissions and economic growth in the past, so that their current performance approaches the lower limit of emission intensity. Norway has so successfully decarbonized their power sector that their trend is flat rather than declining; see Figure 11-5. An indicator score constructed on the basis of this flat trend would be poor, while an indicator constructed on the bases of a single-year GHG emission intensity would be excellent. In these cases, the EPI places a large amount of weight on the single-year indicator, in order to reflect the past policy commitments of countries toward reducing emissions. More complete descriptions of the construction of theClimate & Energy indicators can be found in the Technical Appendix.

FIGURE 11-4 RELATIONSHIP BETWEEN TREND IN CO_2 EMISSION INTENSITY AND GDP *PER CAPITA*

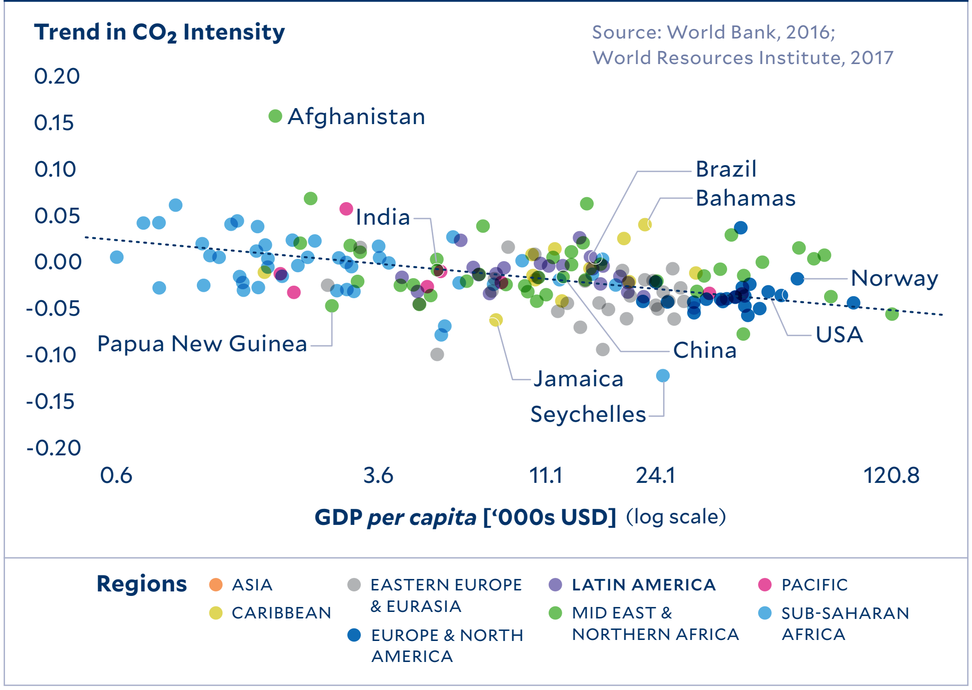
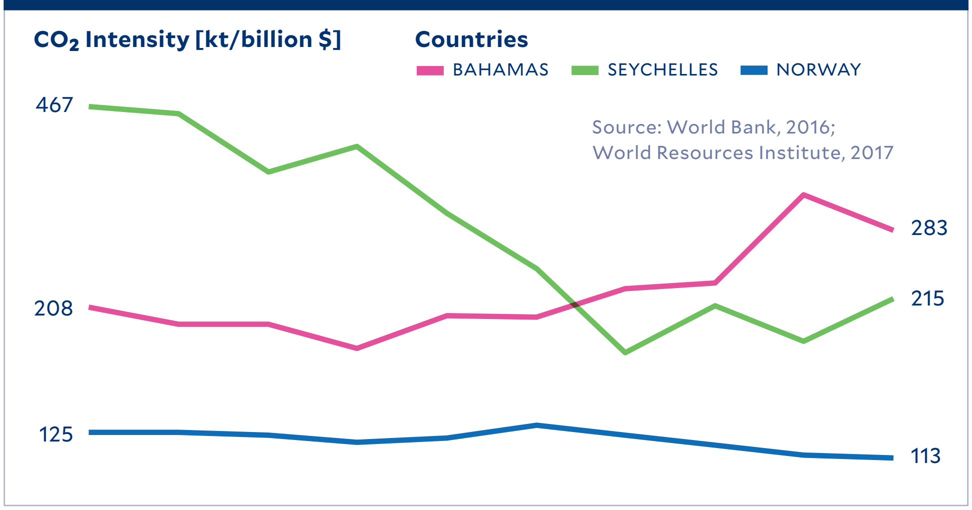


FIGURE 11-5 TRENDS IN CO_2 EMISSION INTENSITY (TOTAL) FOR THE BAHAMAS, SEYCHELLES, AND NORWAY, 2005–2014



GLOBAL TRENDS

We find that global CO_2 *emission intensity (total)* trends are improving; see Figure 11-6. We also observe emission intensity reductions for CH_4, N_2O, and black carbon. These improvements show signs of global decarbonization; i.e., emissions are leveling off or declining relative to GDP. Emission intensities for CO_2, which accounts for 72% of global GHG emissions, have decreased relative to their respective baselines. The reductions in emission intensities have resulted in a 5.8-point and 1.6-point increase in total and power sector emissions scores, respectively. Non-CO_2 GHG emission intensities have also decreased relative to their baselines; see Table 11-2.

Note: Metrics are expressed in emission intensities. Total CO_2, CH_4, N_2O, and black carbon are expressed in either kt of CO_2 or CO_2-equivalent per $US billion. Power sector CO_2 emissions are expressed in g CO_2 per kWh. Current refers to the most recently available data, and Baseline refers to historic data approximately ten years previous to Current.

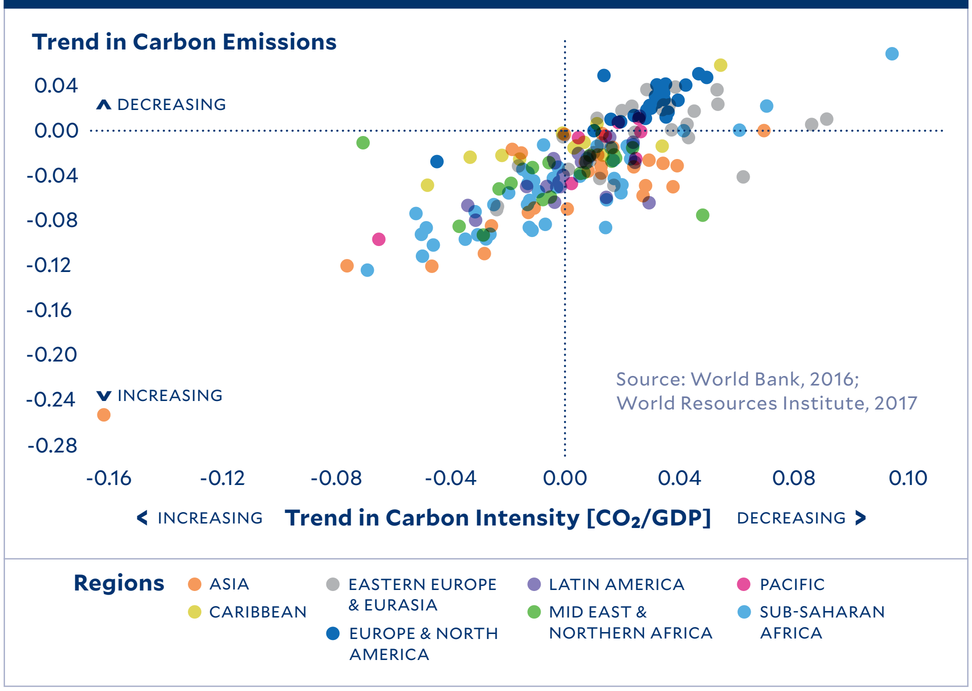
Our results support global decarbonization trends. In 2016, GHG emissions, excluding land use change and forestry, increased by 0.5% — the slowest rate of increase since the early 1990s (Olivier, Schure, & Peters, 2017, p. 8). Dynamic shifts in global emission trends are the result of several factors including replacement of coal by natural gas and increases in modern renewable power generation, such as wind and solar energy (Olivier et al., 2017, p. 8). Recent decarbonization efforts in large economies have driven substantial changes in emission trends over the past five years (Olivier et al., 2017, p. 15).

TABLE 11-2 GLOBAL TRENDS IN CLIMATE & ENERGY

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
CO_2 emission intensity (total)	363.8	320.2	25.5	31.3
CO_2 emission intensity (power)	506.2	492.7	40.8	42.4
CH_4 emission intensity	93.5	71.9	58.2	64.6
N_2O emission intensity	38.4	29.3	52.6	58.3
Black carbon emission intensity	64.3	52.6	20.4	29.1

Note: Metrics are expressed in emission intensities. Total CO_2, CH_4, N_2O, and black carbon are expressed in either kt of CO_2 or CO_2-equivalent per $US billion. Power sector CO_2 emissions are expressed in g CO_2 per kWh. CURRENT refers to the most recently available data, and BASELINE refers to historic data approximately ten years previous to CURRENT.

FIGURE 11-6 TRENDS IN CO_2 EMISSIONS AND CO_2 EMISSION INTENSITY (TOTAL), 2005–2014



China's efforts to modernize its energy sector and combat air pollution, coupled with investment trends in modern renewable energy, will continue to transform the global energy system well into the future (IEA, 2017b, pp. 2–4). However, our data show that in most countries where emission intensities are decreasing, total emissions are still increasing; see Figure 11-6.

Similarly, evidence suggests that non-GHG emissions are increasing due to a slowing in the growth rate of global CO_2 emissions since 2013, underscoring the need to focus more attention on curtailing emissions across a diversity of sectors (Olivier et al., 2017, p. 9).

LEADERS & LAGGARDS

Our results reveal a new group of global leaders in the Climate & Energy category; see Table 11-3. The Republic of Seychelles makes an impressive leap in the global rankings from its 179th baseline position to first place. Switzerland (+13 places) and Sweden (+1) round out the top three countries. Other leaders make impressive leaps in their rank from their baselines. Taiwan jumped eight places to number four, while Turkmenistan (+153), Uruguay (+110), Laos (+92), Myanmar (+1), and Slovakia (+17) also improved their global standing.

TABLE 11-3
LEADERS IN CLIMATE & ENERGY

RANK	COUNTRY	SCORE
1	Seychelles	93.25
2	Switzerland	90.55
3	Sweden	86.80
4	Taiwan	82.23
5	Turkmenistan	81.39
6	Uruguay	79.01
7	Laos	77.39
8	Myanmar	76.26
9	Slovakia	74.21
10	Nigeria	73.85

The Republic of Seychelles' rise in the global Climate & Energy issue category is a result of new policy choices that place climate change at the center of its development strategy. Seychelles is a net sink for global GHG emissions (Republic of Seychelles, 2015, p.1). The government has integrated decarbonization more purposefully into its actions than most small states (IMF, 2017, p. 6). The 2009 Seychelles National Climate Strategy prioritizes GHG reductions through diversification of its energy portfolio, modernization of its energy legislation, and monitoring and sharing of energy data (Seychelles National Climate Change Committee, 2009, pp. 80–81). Subsequent policies, such as the 2010–2030 Seychelles Energy Policy, outline a core vision for energy sector development and further reinforce Seychelles' commitment to low-carbon development (IEA, 2017a).

As a party to the UNFCCC and signatory of the Paris Climate Agreement, Seychelles has committed to reducing absolute, economy-wide emissions 21.4% by 2025 and 29.0% by 2030, relative to baseline emissions (Republic of Seychelles, 2015, p.1). Seychelles will meet its future emissions reduction targets by switching to renewable energy, improving energy efficiency, and increasing the size of its electric vehicle fleet (IMF, 2017, p. 6; Republic of Seychelles, 2015). In 2017 the Institute for Environmental Analytics partnered with the government of Seychelles to develop an energy planning tool to help small islands transition from fossil fuels to renewable energy (Institute for Environmental Analytics, 2017; U.K. Space Agency, 2017). If the tool is implemented in concert with innovative financial instruments and regulatory changes, Seychelles may be in a better position to realize greater implementation of low-carbon energy solutions.

SWEDEN — ranked third — remains a leader in the Climate & Energy issue category, holding its place in the top five. Sweden has a long record of strong climate policy. In 1990, Sweden adopted The Carbon Tax Act, which introduced an initial tax of $US 120/tonne of CO_2 on coal, oil, natural gas, petrol, and domestic aviation fuel, subsequently raised in 2013. Since then, the Swedish government has adopted several laws and policies to meet domestic and European Union (EU) climate goals. Sweden's most recent climate policy, which entered into force in January 2018, seeks to achieve zero net emissions by 2045 and negative emissions shortly thereafter (Government of Sweden, 2017, 2018).

URUGUAY, ranked sixth, has also emerged as a climate leader, blazing a path for a clean energy transition (Watts, 2015). Modern renewable energy is driving a large shift in Uruguay's energy system. According to 2015 data, Uruguay generates 95% of its electricity from renewable energy (Z. Zhu, 2017). For the past two decades, Uruguay has not expanded its hydroelectric capacity; meanwhile, it has increased its wind capacity from almost 0% in 2007 to over 20% in 2015 (Thwaites, 2016). Investment in modern renewable resources is largely a result of efforts to address national energy security concerns and meet national climate goals (Z. Zhu, 2017). Uruguay's National Energy Policy, adopted in 2010, outlines a series of short-, medium-, and long-term climate and energy goals (IRENA, 2015, p. 3). To drive further renewable energy deployment, the government has prioritized auctions and feed-in tariffs to incentivize investment in biomass and modern renewable energy through much of the electricity sector (IRENA, 2015, p. 3). Many laggards in the Climate & Energy category face unique challenges in their energy transition ranging from poverty and spatial constraints to political instability; see Table 11-4. Four of the bottom ten countries — Mozambique, Central African Republic, Madagascar, and Burundi — are least developed countries (LDCs) (UN CDP, 2017). Conflicting priorities, like low rates of access to modern energy, complicate development efforts. Despite growth in the power sector within most LDCs, 62% of people living in LDCs do not have access to electricity (UN Conference on Trade and Development, 2017, p. 4). Implementation of small-scale, high-impact policies that prioritize distributed or off-grid solar power generation could offer a way for LDCs to meet their energy access and climate goals (Adolwa et al., 2017, p. 80).

LIBYA — ranked 178th — has a very high resource potential for low-carbon energy solutions, like solar photovoltaic and concentrated solar power, yet its ongoing civil war and high fossil fuel subsidies have stunted efforts to decarbonize its economy. It is estimated that if Libya designated 0.1% of its land to solar energy production, it could produce the equivalent of 7 million barrels of oil per day, nearly five times the daily amount of energy it produced from oil in 2012 (Bridle, Kiston, & Wooders, 2014, p.10; Mohamed, Al-Habaibeh, & Abdo, 2013). In 2007 the Ministry of Electricity and Renewable Energy established the Renewable Energy Authority of Libya and assigned it the task of developing and implementing plans for both renewable energy and energy efficiency (Nachmany et al., 2016, p. 3). According to a 2015 climate legislation survey, Libya intends to meet 10% of energy needs from renewable energy by 2030 (Nachmany et al., 2016, p. 4). Despite modest advances, Libyan progress remains hampered by political unrest. Electric transmission lines and supporting infrastructure have suffered interruption and physical damage from fighting (Fasanotti, 2016). Underpricing of energy from fossil fuel subsidies in Libya, and much of the world, also encourages wasteful use of energy and discourages the development of renewable resources (Bridle et al., 2014, p.11). To meet its clean energy target, Libya will need to focus future attention on developing a strong legal and regulatory framework to support renewable energy and energy efficiency, while simultaneously addressing inefficacies that result from its existing subsidies.

TABLE 11-4
LAGGARDS IN CLIMATE & ENERGY

RANK	COUNTRY	SCORE
171	Mozambique	23.49
172	Grenada	21.67
173	Iraq	19.73
174	Bahamas	18.76
175	Central African Republic	17.55
176	Madagascar	16.23
177	Burundi	16.18
178	Libya	11.87
179	Antigua and Barbuda	11.26
180	Niger	6.36

ANTIGUA AND BARBUDA's low score—ranked 179th—reveals the unique

FOCUS 11-7 ENERGY EFFICIENCY IN CHINA

Energy efficiency improvements in China are driving substantive reductions in global energy consumption statistics. China has decreased its total emissions and emission intensity. According to the International Energy Agency (IEA), Chinese efforts to reduce consumption were responsible for 22% of global energy intensity reductions in 2015 (2016b). While several economic factors independent of national willingness to lower energy intensity help explain China's significant efficiency gains, the country's progress serves as an interesting case study demonstrating how high-emitting nations with large manufacturing sectors may begin to decouple CO_2 emissions from economic growth.

Most of China's improvements in energy intensity may be traced back to political mandates directed at high energy consumers (IEA, 2016b). In 2006 the Chinese government launched its Top 1,000 Program, a four-year mandatory energy savings program for the largest 1,000 enterprises accounting for 33% of China's total final energy consumption (NDRC, 2006). Under the program, enterprises in nine industrial sectors—iron and steel, petroleum and petro chemicals, chemicals, electric power generation, nonferrous metals, coal mining, construction materials, textiles, and pulp and paper—were instructed to reduce energy consumption by 100 Mt CO_2-eq from their expected consumption in 2010 over a four-year period. Provincial and local governments worked with participants to negotiate targets, train staff, access national funds, and monitor and evaluate progress (Price, Wang, & Yun, 2010). The Top 1,000 Program exceeded its original target by 50% and was expanded to cover the 10,000 largest enterprises, representing roughly two-thirds of China's energy consumption, in 2011 (IEA, 2016b; Lu et al., 2014).

According to IEA estimates, China must reduce its energy intensity by 4.7% per year to stay within the Paris Climate Agreement's 2°C warming goal (2016b). Growing concerns about air pollution and economic changes continue to drive substantial policy reform in China's most energy-ntensive sectors. China's Five-Year Plans have been one of the most impactful actions to reduce GHG emissions any national government has made in the past ten years (X. Zhu, Bai, & Zhang, 2017). China's current Five-Year Plan includes compulsory energy conservation policies, which may build on existing momentum generated from previous policies. In early 2017 the Chinese National Energy Administration (NEA) revealed details of its blueprint for the next five years. Targets include reducing energy intensity by 15% from 2015 levels by 2020 (People's Republic of China, 2016). The government has outlined a cap for national coal consumption. It intends to lower coal primary energy consumption from 62% to 58% by 2020 (Tianjie, 2017). Transitioning the Chinese economy away from carbon-intensive fuels and practices will not be easy, but thus far China has been a model for other transitioning economies.

challenges small islands and developing states (SIDS) face in lowering their GHG emissions. Limited access to energy resources, manufacturing and transportation, lack of power generation capacity, outdated power generation infrastructure, and inefficient electrical grids create a dependence on inefficient and expensive forms of power generation that exacerbate energy security challenges (Dornan & Shah, 2016, p. 650). Until recently, Antigua and Barbuda satisfied 99.99% of its energy generation needs from mostly foreign petroleum (NREL, 2015, pp. 1–2). Renewable energy may help Antigua and Barbuda transition away from carbon-heavy fossil fuels. As with many SIDS, Antigua and Barbuda has significant renewable energy and energy efficiency potential (NREL, 2015, p. 3). Recognizing the many benefits of a low-carbon energy system, the government has established a series of ambitious renewable energy targets and implemented several policy reforms to incentivize renewable power generation and energy efficiency (IRENA, 2016b). Prior to the 2017 hurricane season, the International Renewable Energy Agency (IRENA) found Antigua and Barbuda was in a strong position to develop renewable energy. Thus far, the government has already met its national target of 15% installed renewable energy capacity by 2030 (IRENA, 2016a). Action plans, new policies, and tariff structures could further incentivize investment and drive large-scale changes in high-emitting sectors of Antigua and Barbuda's economy. Such progress could potentially translate into elevated scores on future iterations of the EPI.

Despite improvements in emission intensity trends over the past decade, leader and laggard trends indicate countries still have much work to do if they are to meet existing energy and climate goals outlined in the Paris Climate Agreement and the SDGs. The IEA's Sustainable Development Scenario — a pathway to achieving climate stabilization, cleaner air, and universal access to modern energy — finds low-carbon sources must double their share in the energy mix — to 40% — by 2040 (IEA, 2017b, p. 7). The Sustainable Development Scenario also finds that countries must pursue all available avenues of energy efficiency, while decreasing demand for coal and oil resources (p. 7). To satisfy the Paris Climate Agreement and the SDGs, countries must continue to test and implement new policy and market frameworks that leverage the numerous interconnections across different sectors and dimensions of sustainable development. Policy and regulatory shifts, coupled with significant increases in investment, will thus be essential to realizing the changes in global scores required to drive significant, long-lasting change.

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12

AIR POLLUTION

Environmental Performance Index

Air Pollution

SNAPSHOT

Air pollutants negatively affect ecosystem integrity and function.

CATEGORY DESCRIPTION

Both sulfur dioxide (SO_2) and nitrogen oxides (NO_X) can cause acidification, which can degrade soil and water quality. NO_X deposition can further cause eutrophication, the excessive enrichment of nutrients. The addition of reactive nitrogen to a system can further trigger a cascade of ecological effects that reduce plant biodiversity. As a result, these pollutants are very harmful to both natural vegetation and agricultural crops. Acidification and eutrophication driven by atmospheric pollutants can be difficult or impossible to reverse, persisting long after emission reduction policies are implemented. It is therefore imperative, especially in industrializing nations, to reduce emissions of long-range air pollutants to protect the health of global ecosystems.

INDICATORS INCLUDED

The two indicators used for air pollution are NO_X and SO_2 emission intensity. The 2018 EPI uses data from the Emissions Database for Global Atmospheric Research (EDGAR) v4.3.1 global anthropogenic emissions inventory of gaseous and particulate air pollutants.

AIR POLLUTION INDICATORS	
Sulfur dioxide	Mt/$
Nitrogen oxide	Mt/$

Long-range air pollutants are a significant threat to ecosystem health.

These pollutants can be transported across distances greater than 100 km through the atmosphere, extending the range of their harmful effects far from their original sources (UN, 1997). The pollutants of concern include sulfur, nitrogen, ground-level ozone, particulate matter, heavy metals, and persistent organic pollutants (Wit, Hettelingh, & Harmens, 2015, p. 9). Emissions of sulfur oxides (SO_X) and NO_X typically co-occur with other air pollutants and are therefore a useful metric for assessing overall air quality impacts on ecosystems. These compounds cause a variety of negative environmental impacts through the chemical and biological processes of acidification and eutrophication.

Both pollutants are emitted from anthropogenic sources. Sulfur oxides are principally released from coal combustion (Lovett et al., 2009, p. 101). The shipping sector represents a major source of sulfur emissions today (UNEP, 2012, p. 43). Any type of combustion can result in the emissions of NO_X (Lovett et al., 2009, p. 101), with 58% of total NO_X emissions originating from fuel combustion (Fowler et al., 2015, p. 13861). Reactive nitrogen refers to all forms of nitrogen except atmospheric N_2 (Clark et al., 2013, p. 519). Of concern in the EPI are biologically active forms, which are limiting nutrients in many ecosystems. Emissions of reactive nitrogen have major environmental consequences, as atmospheric transport and deposition is now the principal mechanism for the distribution of reactive nitrogen (Galloway et al., 2008, p. 88). NO_X emission and deposition levels are projected to double by 2050 as compared to 1995 levels (Galloway et al., 2008, p. 88). After traveling through the atmosphere, the pollutants then enter ecosystems through both wet and dry deposition. Wet deposition, commonly called acid rain, is the process in which pollutants reach the Earth incorporated into rain, snow, or vapor. However, SO_X and NO_X can also be deposited directly on systems as particulates and as gases through dry deposition (Burns, Aherne, Gay, & Lehmann, 2016, p. 1). The introduction of these pollutants can then negatively affect the health and functioning of ecosystems.

ENVIRONMENTAL

Scientists recognize atmospheric deposition of NO_X to be a major threat to biodiversity loss worldwide due to the suite of complex impacts it generates (Clark et al., 2013, p. 519). Nitrogen is necessary for the production of proteins and other biological molecules. As a result, it is often a limiting nutrient for primary production in ecosystems. When reactive nitrogen is deposited onto an otherwise nitrogen-limited system, it can then cause a cascade of harmful effects, including eutrophication, direct toxicity to sensitive plants, increased ammonia and ammonium availability, soil and water acidification, and increased vulnerability of plants to secondary stressors (Bobbink et al., 2010; Galloway et al., 2003). In addition, NO_X is a precursor to ozone, which can also have harmful effects on plants (Royal Society, 2008). The effects of NO_X deposition can vary widely across ecosystems depending on the degree of nitrogen loading and the typical inputs of reactive nitrogen into the system. Historic characteristics of the system, such as previous deposition and the sensitivity of plants living in the ecosystem, can also influence the magnitude of the effect of NO_X inputs (Bobbink et al., 2010, pp. 31, 42, 44, 51). More research is needed to understand the effects of air pollution on animals species (Clark et al., 2013, p. 519). Ongoing impacts on global plant communities is a serious concern for biodiversity conservation.

The effects of sulfur deposition are less complicated than those of nitrogen, but SO_X emissions still have severe consequences for ecosystems. Sulfur is not typically a limiting nutrient in many ecosystems, so it does not cause the same cascading effects (Lovett et al., 2009, p. 108). However, sulfur deposition can similarly lead to acidification of both aquatic and terrestrial systems (Lovett et al., 2009, p. 99). In forested systems, acidic rain flows through tree canopies and soils, leaching critical nutrients like calcium and magnesium. Acidic soils also risk mobilizing aluminum, as ions of the metal are released into an aqueous solution, which is toxic to plants (Lovett et al., 2009, p. 103). In wetlands, increased sulfate deposition can lead to the methylation of mercury by bacteria, which makes this toxic metal more bioavailable in surrounding ecosystems (Lovett et al., 2009, p. 106). In aquatic systems, increased acidity can affect species composition. Acidification can also clarify water. Increased sunlight can then warm the water column and affect physical characteristics of water bodies (Lovett et al., 2009, p. 117). The effects on animals, as with nitrogen deposition, are less well known when compared to plants, but acidification can be toxic to fish (Burns et al., 2016, p. 1). Some studies have further shown that invertebrates are also sensitive to acidity, with ramifications for bird species that prey on them (Lovett et al., 2009, p. 109). Reducing global SO_X emissions is critical to protect ecosystems from acidification.

Acidification and eutrophication can have long-term impacts that are difficult or impossible to reverse (Clark et al., 2013, p. 532; Driscoll et al., 2001). Even if current emissions were abated, the buildup of pollutants can reach levels that make regions unsuitable for native species. For example, the consequences of acidification, including the loss of base cation nutrients in soils, linger for decades or even centuries after leaching stops (Driscoll et al., 2001). Sulfate remains the dominant cause of soil acidification today, even in regions with reduced emission levels. Legacy sulfur is still being released from soils, which are efficient at retaining these pollutants (Wit et al., 2015, p.10). Even in the United States, where significant air emission reductions were achieved after the passage of the Clean Air Act and Amendments in 1990, surface waters have only shown limited recovery from acidification (Burns et al., 2016, p.3). Similarly, reductions in nitrogen deposition have been found to be insufficient to reverse changes in species composition (Payne et al., 2017, p.4). The latent and chronic nature of these impacts mean policy change to address global emissions is even more urgent.

These impacts are of concern for natural areas. SO_X and NO_X deposition is concentrated regionally around sources such as coal plants and downwind of industrial centers (Burns et al., 2016, p.1). However, 7–17% of the global area of natural ecosystems exceed harmful levels of acidification, and similarly 7–18% of these systems exceed critical loads for eutrophication (Bouwman, Beusen, & Billen, 2009, p.349). An estimated 16.3 million km^2 of natural vegetation is impacted by harmful levels of nitrogen deposition (Dentener et al., 2006, p. 1). It is predicted that atmospheric nitrogen deposition will increase in most regions by 2030 (Dentener et al., 2006). The fate of these pollutants varies, with 36–51% of SO_X emissions deposited over oceans, while 50–58% of SO_X deposition on land is on nonagricultural vegetation (Vet et al., 2014, p.10). Many of the world's biodiversity hot spots are exposed to or will be exposed to harmful levels of nitrogen deposition. Hot spots in developing countries in the tropics and Asia, which will experience increased emissions and deposition, are at significant risk of degradation (Phoenix et al., 2006). Some of the ecoregions most vulnerable to reductions in plant diversity in response to nitrogen deposition are tropical areas in Latin America and Africa, Mediterranean ecoregions, and eastern and southern Asia (Bobbink et al., 2010, p.30). Policy interventions to protect these natural systems must address the threat of air pollutants to normal ecosystem functioning.

SOCIAL

Air pollution has negative impacts on ecosystem health, with further consequences for global biodiversity, and thus for communities. Biodiversity loss threatens human populations reliant on a range of services including food production and human health needs. The social dimensions of biodiversity are further explored in Chapter 8 on Biodiversity & Habitat of this report. In addition to natural ecosystems, air pollution threatens global crop yields, with consequences for sustainable agriculture (Gurjar, Molina, & Ojha, 2010, p.463). These negative impacts can threaten food security and nutrition, as further reported in Chapter 14 on Agriculture. Finally, air pollution threatens our cultural heritage. Many pollutants can cause the recession or corrosion of materials used in historic buildings, monuments, and artworks. For example, limestone is vulnerable to erosion due to acid rain, and other materials can become discolored from interaction with sulfate deposition. Corrosion of copper and bronze is also caused by air pollution (Di Turo et al., 2016, p. 586). Recent work has further specified that dry deposition may play a greater role in the degradation of outdoor marble and bronze sculptures than previously thought (Livingston, 2016). Particulate matter and certain gases resulting from air pollution can also negatively affect visibility, degrading natural vistas and cultural experiences (Malm, 1999). The loss of irreplaceable cultural heritage is a major concern motivating regulations to curb NO_X and SO_X emissions.

ECONOMIC

As developing nations pursue food and energy security, air pollution can be a significant economic concern. Industrialization can lead to increased air emissions, risking the degradation of ecosystems, agriculture, and public health. For example, acidification can have negative impacts on farms, reducing yields of many crop species, as much as it harms vegetation in natural systems (Gurjar et al., 2010, p.463). Air pollution threatens many valuable ecosystem services including crop yields, capture fisheries, aquaculture, wild foods, timber, fiber crops like cotton, genetic resources, natural medicines, climate regulation, recreation and tourism, nutrient cycling, and primary production (Persson et al., 2010, p.39). With respect to public health consequences, the benefits of policies to limit air pollution can vastly outweigh their costs. In the experience of the United States, the Clean Air Act created over $2 trillion in benefits, while resulting in only $65 billion in costs. Specifically, improved crop and timber yields generated $5.5 billion in benefits in those sectors, while improved visibility in national parks and metropolitan areas generated $34 billion (EPA, 2011). The reduction of air pollution impacts on ecosystems can provide significant economic benefits.

The environmental impacts of air pollution are significant concerns due to their latent and chronic effects. The slow recovery of ecosystems following SO_X and NO_X deposition threatens the biodiversity of developing countries, currently experiencing increased air emissions. These areas are of particular concern as the risks of acidification and eutrophication are expected to significantly increase in Asia, Africa, and South America, as they decline in North America and Western Europe (Bouwman, Vuuren, Derwent, & Posch, 2002, p. 349).

Nations have addressed the negative effects of SO_X and NO_X by defining critical loads, or levels of deposition that, when exceeded, can harm ecosystems. Policymakers have developed regulations to limit atmospheric deposition levels accordingly to protect their environments (Burns et al., 2016, p. 3). Additional research is necessary to establish accurate critical loads for ecosystems outside of Europe and North America (WallisDeVries & Bobbink, 2017, p. 387). To address these and other knowledge gaps in addressing the effects of air pollution, a variety of international research and monitoring networks have emerged.

TABLE 12-1 INTERNATIONAL RESEARCH AND MONITORING NETWORKS

Acid Deposition Monitoring Network in East Asia	EANET
Canadian Air and Precipitation Monitoring Network	CAPMoN
Co-Operative Programme for monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe	EMEP
Deposition of Biogeochemically Important Trace Species	DEBITS
US Global Precipitation Chemistry Program	GPCP
US National Atmospheric Deposition Program	NADP
World Meteorological Organization Global Atmosphere Watch Scientific Advisory Group for Precipitation Chemistry	WMO GAW SAG-PC
World Data Centre for Precipitation Chemistry	WDCPC

SUSTAINABLE DEVELOPMENT GOALS

There is no specific Sustainable Development Goal (SDG) for air pollution, although the problem is mentioned in two targets under SDG 3 (health and well-being) and SDG 11 (sustainable cities and communities). The impacts of air pollution on ecosystems are also related to the following goals:

GOAL 7. Ensure access to affordable, reliable, sustainable, and modern energy for all.

TARGET 7.2. By 2030, increase substantially the share of renewable energy in the global energy mix.

GOAL 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

GOAL 12. Ensure sustainable consumption and production patterns.

TARGET 12.5. By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.

GOAL 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

GOAL 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

MULTILATERAL EFFORTS

No international agreement has been created to control global SO_X emissions or regulate human inputs of reactive nitrogen into the atmosphere (Fowler et al., 2015, p. 13850). However, several regional and bilateral agreements have developed to control SO_X and NO_X emissions.

Aichi Biodiversity Targets. The Aichi Biodiversity Targets of the Convention on Biological Diversity present goals for the protection of global biodiversity. Target 8 is to reduce pollution, including from excess nutrients, to levels not detrimental to ecosystem functions and biodiversity by 2020. https://www.cbd.int/sp/targets/

Association of Southeast Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution. The ten governments of the Association of Southeast Asian Nations signed the ASEAN Haze Agreement to address transboundary haze pollution from land and forest fires. The agreement created the ASEAN Coördinating Centre for Transboundary Haze Pollution Control t o facilitate coöperation among member countries in addressing air pollution. http://haze.asean.org/asean-agreement-on-transboundary-haze-pollution/

Convention on Long-Range Transboundary Air Pollution (CLRTAP). The CLRTAP is composed of eight protocols which establish targets for pollutants including sulfur, NO_X, persistent organic pollutants, volatile organic compounds, ammonia, and toxic heavy metals. Within this agreement, the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone further created stricter targets for SO_2, NO_X, volatile organic compounds, and ammonia. Thirty-two nations are signatories to the CLRTAP, and 51 are parties to the agreement, including European Union countries, Canada, Russia, and the United States. https://www.unece.org/env/lrtap/welcome.html

European Union Directives for Air Quality. The European Union has passed legislation establishing health-based standards and objectives for air pollutants including SO_2 and nitrogen dioxide. Directive 2008/50/EC merged much existing legislation into an encompassing directive, which was amended by Directive 2015/1480/EC, establishing rules for reference methods, data validation, and sampling points. http://ec.europa.eu/environment/air/quality/existing_leg.htm

International Convention for the Prevention of Marine Pollution from Ships (MARPOL). MARPOL Annex VI establishes emission limits for SO_X and NO_X in ship exhaust gas. The agreement further bans deliberate emissions of ozone depleting substances. Finally, Annex VI regulates incineration on ships, and in particular the emissions of volatile organic compounds from tanker ships. http://www.imo.org/en/OurWork/environment/pollutionprevention/airpollution/pages/air-pollution.aspx

To best address the effects of air pollution, policymakers would ideally have access to measurements of pollutant emissions and deposition,

as well as a greater understanding of the complex factors shaping ecosystem impacts. Relevant measurements would include connections between sources of air pollution and ambient concentrations, studies of precipitation chemistry, deposition rates, and the effects of pollutants on biogeochemical and broader ecological systems globally. Research efforts have so far focused mainly on biogeochemical impacts and studies of responses in plant communities. Less is known about the impacts of air pollutants on biodiversity (Clark et al., 2013, p. 525).

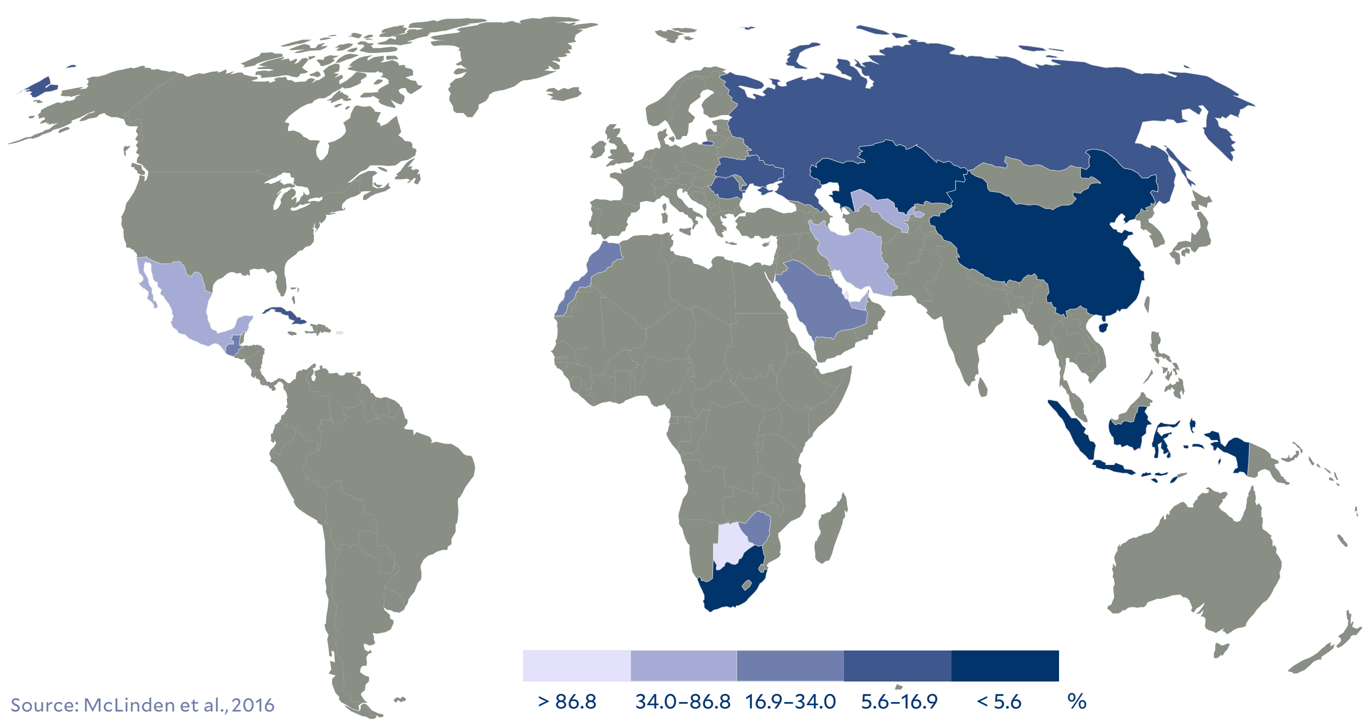
To address the lack of global precipitation chemistry measurements, some studies base estimates of precipitation composition and deposition rates on transport model predictions (Vet et al., 2014, p. 4). However, many research gaps remain.

Global standards for sampling and analytical methodologies should be established to allow for the evaluation of international data and benchmarking

FOCUS 12-1 MISSING SULFUR DIOXIDE SOURCES

Studies of emissions using satellite monitoring, such as the Ozone Monitoring Instrument aboard NASA's Aura satellite, provide significant insight into emissions of pollutants including NO_2 and SO_2 (Vet et al., 2014, p.10). Local monitoring efforts to measure SO_2 often prove to be inadequate. While some nations measure emissions directly on industrial sites, others, especially in the developing world, rely largely on estimates. However, monitoring efforts using NASA's Aura satellite, which was launched in 2002, have helped scientists bridge some of the gaps in our current understanding of emission levels (Chung, 2016). Scientists found that of the nearly 500 large sources in their satellite-based global emissions inventory, 40 had not been identified in conventional emission reporting programs. The missing sources came principally from developing countries lacking emission reporting requirements and sophisticated measurement infrastructure. Roughly one-third of sources originated in the Persian Gulf region. By including missing anthropogenic sources as well as SO_2 emissions from volcanoes, the corrected satellite measurements highlighted discrepancies with conventional emission measures by as great a factor as three (McLinden et al., 2016)

MAP 12-1 PERCENT OF SO_2 EMISSIONS MISSING FROM GLOBAL INVENTORIES



Source: McLinden et al., 2016

across nations. Inadequate information currently exists on how air pollution deposition occurs differently across its various forms, such as wet deposition from fog (Vet et al., 2014, pp. 5, 90–91). Furthermore, much uncertainty remains about how atmospheric chemistry works over the long term (Pascaud et al., 2016, p. 28). NO_X in particular poses a monitoring challenge. Not all nitrogenous species are measured in existing monitoring schemes (Clark et al., 2013, p. 533), which presents a significant knowledge gap. NO_X enters systems in a variety of oxidized and reduced forms, causing cascading effects through biological and chemical transformations before returning to the atmosphere as N_2 (Fowler et al., 2015, p.13850). More complex monitoring could address these dynamics. Finally, because there is an overall lack of data on long-term atmospheric deposition, researchers find it challenging to identify overall trends (Burns et al., 2016, p. 2). Increased monitoring to account for these complexities is needed on a global scale to address air pollution challenges.

Ecological responses to NO_X and SO_X depositions should also be further characterized. More research is needed into how soils affect ecosystem recovery and which factors affect how biota respond to varying levels of deposition. Furthermore, gaps in knowledge regarding how SO_X and NO_X interact with other pollutants, climate change, and the carbon cycle limit the ability to identify appropriate solutions (Burns et al., 2016, p. 1). Additional research is needed to improve models used to determine critical loads (Bobbink et al., 2010, p. 47). Current knowledge about ecological responses is also geographically limited. South America, remote areas of North America, Asia, Africa, Oceania, the polar regions, and the ocean have all been insufficiently studied (Vet et al., 2014, p. 4). The magnitude of acidification in oceans caused by NO_X and SO_X is also largely uncertain because of gaps in knowledge about the flux of these pollutants into the ocean and subsequent biogeochemical responses (Doney et al., 2007, p.14584). Ecological studies are needed to address these uncertainties.

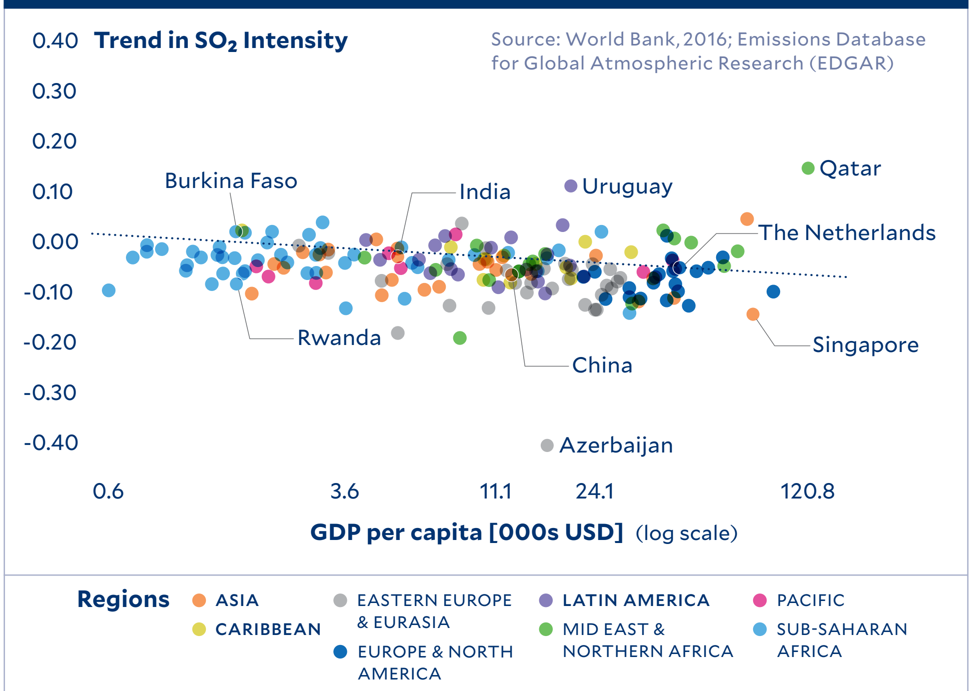
Taking these measurement and knowledge gaps into consideration, the 2018 EPI uses two indicators to measure NO_X and SO_2 emission intensity. To construct these indicators, the EPI used data from the EDGAR v4.3.1 global anthropogenic emissions inventory of gaseous and particulate air pollutants. The advantage of the EDGAR data is the near completeness and consistency of estimated emissions of multiple pollutants. EDGAR includes continuous time-series data for emissions across the globe (Janssens-Maenhout et al., 2017).

INDICATOR BACKGROUND

The 2018 EPI evaluates national performance in the reduction of air pollution through emission intensity trends, the rate of emissions per unit of GDP. The construction of the indicator reflects the importance of decoupling economic growth from emissions by standardizing each country's pollution levels by its economic activity. For NO_X and SO_2, emissions are divided by GDP to allow for cross-country comparison on a common scale. Then, to account for annual variations in emission intensity tied to regular economic cycles, a ten-year average of emission intensity is also used for the indicator construction.

The construction of the indicator compares countries to their economic peers. Countries at similar levels of economic development are assumed to have roughly equivalent capacities for decoupling emissions from their growth. The 2018 EPI compares the trend in every country against its wealth in per capita GDP. As it is easier for richer nations to decouple their growth from emissions, their average emission intensity predictably decreases. Each individual country's performance can then be compared to this trend. Countries with emission

FIGURE 12-1 RELATIONSHIP BETWEEN TREND IN SO_2 EMISSION INTENSITY AND GDP *PER CAPITA*



Note: Expressed as cg of sulfur dioxide emissions per US$ (log scale).

intensities below the trendline receive improved scores for performing better than expected, while countries above the trendline are penalized.

Finally, the construction of the indicator identifies top performing nations that have approached the lower limit of emission intensity following successful decoupling. The Netherlands is an example of a country whose SO_2 emissions trend is flat rather than declining. To account for nations that would be scored poorly based on their flat trend line, EPI places greater weight on the single-year indicator. As a result, the indicator reflects past policy successes of nations that have significantly reduced their emissions.

The final indicator therefore represents trends in NO_X and SO_2 emission intensity relative to economic peers. A more complete description of the construction and calculation of the Air Pollution indicators can be found in the Technical Appendix online.

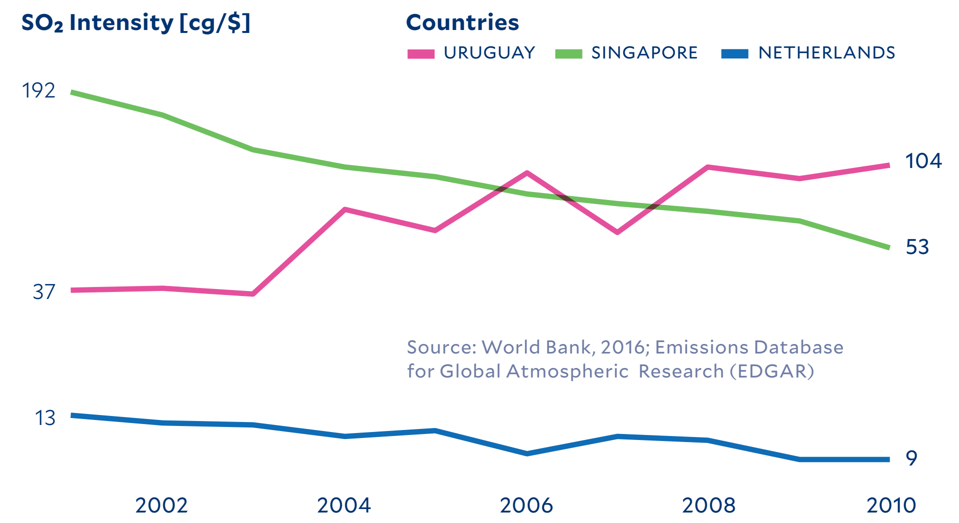
DATA DESCRIPTION

EDGAR is a collaborative research effort of the European Commission Joint Research Centre and the Netherlands Environmental Assessment Agency. Emission data are calculated using a technology-based emission factor approach. Emissions for each pollutant of interest are calculated by sector for every country annually. Abatement by end-of-pipe measures are accounted for in the calculation. A geographical database includes the location of sources such as energy facilities, roads, shipping routes, areas of high population density, and agricultural land use. Emission data related to the energy sector are based on energy balance statistics from the International Energy Agency. Agricultural data are collected from the Food and Agriculture Organization. The full dataset is publicly available for download from the EDGAR website: http://edgar.jrc.ec.europa.eu/methodology.php.

LIMITATIONS

The EDGAR data set has several limitations with regard to the pollutants of interest for this indicator. The data cannot account for sources beyond those gleaned from the combustion of fossil fuels. In addition, the data cannot be used to attribute emissions to actual damages resulting from their deposition. Finally, the most recent year included in the data set is 2010. Ideally, more recent data would be used to conduct EPI's analysis. SO_2 emissions are used in the creation of the indicator, rather than all SO_X compounds, because SO_2 data are most readily available and will be highly correlated with other SO_X emissions.

FIGURE 12-2 TRENDS IN SO_2 EMISSION INTENSITY (TOTAL) FOR URUGUAY, SINGAPORE, AND THE NETHERLANDS, 2001–2010



Note: The final indicator therefore represents trends in NO_X and SO_2 *emission intensity* relative to economic peers. A more complete description of the construction and calculation of the Air Pollution indicators can be found in the Technical Appendix online.

FOCUS 12-2 THE SENTINEL-5P SATELLITE

On October 13, 2017, the European Union and the European Space Agency's Copernicus program launched the most sophisticated air-pollution satellite ever created. The Sentinel-5P satellite will be used to measure the chemistry of Earth's atmosphere and analyze the global distribution of pollutants using its TROPOspheric Monitoring Instrument (Tropomi). The device will be able to capture extremely high-resolution data on NO_X and SO_X emissions, and address many existing uncertainties about pollution transport and chemical reactions in the atmosphere (Pultarova, 2017). The first images were returned from the satellite in December 2017, highlighting elevated concentrations of NO_2 over parts of Europe and high levels of emissions from power plants in India. The satellite's data are processed at the DLR German Aerospace Center, where daily maps of the entire Earth will be generated. Data from the Sentinel-5P will be invaluable in informing air pollution mitigation policies globally as more data become available (European Space Agency, 2017).

The results of the 2018 EPI demonstrate that progress is being made globally to address air pollution.

GLOBAL TRENDS

Emissions of SO_2 and NO_X have both fallen from 2000 to 2010, with strong improvements in the scores for each indicator. However, progress may continue to be uneven as industrialized nations curb their emissions, while those of developing nations are expected to increase (Bouwman et al., 2002, p. 349). This trend is reflected in the 2018 EPI results. With some exceptions, the leaders were generally wealthier nations than the laggards. Globally, nations performed better on NO_X than SO_2 emissions, highlighting long-term acidification as a serious concern in terms of ecosystem health. Much more progress is needed on reducing air pollution to protect the world's ecosystems, and in particular vulnerable biodiversity hot spots (Phoenix et al., 2006).

TABLE 12-2 GLOBAL TRENDS IN AIR POLLUTION

INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
SO_2 emissions	363.8	320.2	25.5	31.3
NO_X emissions	506.2	492.7	40.8	42.4

Note: Metrics are in units of Mt/constant 2011 international $. CURRENT refers to data from 2010, and BASELINE refers to historic data from 2000.

TABLE 12-3 LEADERS IN AIR POLLUTION

RANK	COUNTRY	SCORE
1	Equatorial Guinea	99.97
2	Switzerland	98.70
3	Singapore	97.76
4	France	96.82
5	Netherlands	96.56
6	Azerbaijan	95.36
7	Germany	93.30
8	Afghanistan	91.44
9	Taiwan	89.75
10	Italy	88.55

TABLE 12-3 LAGGARDS IN AIR POLLUTION

RANK	COUNTRY	SCORE
171	Honduras	17.68
172	Liberia	15.49
173	Djibouti	11.01
174	Bahamas	10.60
175	Zimbabwe	8.21
176	Chile	3.37
177	Seychelles	2.63
178	Brunei Darussalam	2.51
179	Oman	0.65
180	Uruguay	0.01

LEADERS & LAGGARDS

One of the leaders in this category, Switzerland has significantly improved its air quality over the past 25 years (European Environment Agency, 2015). As a result, Switzerland rose from fourth to second place in the EPI rankings between the baseline and current years. Switzerland's Ordinance on Air Pollution Control came into force in 1986 and is enforced in two stages. The first stage, called the precautionary stage, implements best available technologies which are economically feasible for several classes of pollutants. Quality requirements for fuel and gasoline are also set through this law. In the second stage, air pollution is assessed according to ambient air quality standards, which must be achieved through emission control measures. The ordinance is largely enforced at the local level by cantons. In addition to the ordinance, the Swiss government also implements an overall air pollution control strategy specifically to limit SO_2, NO_X, and volatile organic compounds (VOCs) (Purghart, 1992).

Switzerland's regulatory framework has evolved over time. Existing regulations include strict emission rules for heating systems, industrial facilities, and vehicles. In addition, Switzerland has implemented incentive-based measures including the mileage-related heavy vehicle tax and a levy on VOCs (European Environment Agency, 2010). The Swiss Federal Council has taken the nation's commitments under the UNECE's CLRTAP very seriously. The National Focal Center was established in the Federal Office for the Environment, charged with modeling and mapping critical loads and ecosystem sensitivity across Switzerland (Federal Office for the Environment, 2016, p. 11). The Swiss Federal Council has set a target to reduce ammonia emissions by 40% and NO_X emissions by 50% as compared to 2005 levels (Rihm & Achermann, 2016). As of 2011, Switzerland was meeting emission levels set forth by the EU National Emissions Ceilings Directive (2016/2284/EU) and LRTAP Convention's Gothenburg Protocol for NH_3, non-methane VOCs (NMVOCs), NO_X, and SO_2 (European Environment Agency, 2017).

Because of the transboundary nature of long-range air pollutants, the poor performance of laggards is a global concern for ecosystem health. Both India and China are dependent on coal, which can contain up to 3% sulfur, for their energy production. Because of their coal consumption, both countries face significant challenges in addressing air pollution from SO_2 emissions. Recent satellite studies have found that while Chinese emissions of SO_2 have declined by 75% since 2007, India's emissions have increased by 50%. As a result, India has overtaken China as the world's largest emitter of anthropogenic SO_2 (Li et al., 2017). International coöperation on pollution control is needed to curb transboundary emissions. For example, a 2015 study calculated that the rapid industrialization of China has offset more than 40% of the improvements in air quality seen in the western United States between 2005 and 2010 (Verstraeten et al., 2015). Both India and China must address their air pollution emissions to prevent acidification and other negative ecosystem impacts.

As expected from the NASA satellite results (McLinden et al., 2016), many Persian Gulf nations were lower in the rankings, including Oman (179), Iran (167), Kuwait (162), Saudi Arabia (159), and Iraq (133). These results suggest that increased attention should be paid to curbing air emissions from the oil refinery and natural gas infrastructure in this region. For example, the World Health Organization reported in 2016 that among the world's top ten most polluted cities, Zabol in Iran was at the top of the list, with Riyadh and Al Jubail in Saudi Arabia placing fourth and fifth, respectively (Reuters Staff, 2016). In 2010, when trade sanctions restricted Iranian imports of refined gasoline, Iran started producing greater amounts of gasoline, and in 2014, Oil Minister Bijan Zanganeh acknowledged that the main source of the smog was substandard gasoline (Tehran Bureau correspondents, 2014). Our results show that Iran's score decreased by 9.2 points to 20.7 in 2010, further emphasizing the effects of Iran's increase in substandard gasoline production. Middle Eastern nations would benefit from the implementation of improved policies to control air pollution.

Stringent national air pollution regulations, as well as compliance with strong regional agreements, are key tools to improve environmental performance on air pollution. Industrializing nations will likely face policy and enforcement challenges to curb harmful emissions while growing their economies. Nations with ecosystems sensitive to acidification and eutrophication will be vulnerable to the effects of increased emissions. Continued reductions in SO_X and NO_X emissions will be essential to protect global ecosystems. While the 2018 EPI reveals positive trends in tackling long-range air pollutants, much work remains to promote environmental health and ecosystem vitality.

Studies of emissions using satellite monitoring, such as the Ozone Monitoring Instrument aboard NASA's Aura satellite, provide significant insight into emissions of pollutants including NO_2 and SO_2 (Vet et al., 2014, p.10). Local monitoring efforts to measure SO_2 often prove to be inadequate. While some nations measure emissions directly on industrial sites, others, especially in the developing world, rely largely on estimates. However, monitoring efforts using NASA's Aura satellite, which was launched in 2002, have helped scientists bridge some of the gaps in our current understanding of emission levels (Chung, 2016). Scientists found that of the nearly 500 large sources in their satellite-based global emissions inventory, 40 had not been identified in conventional emission reporting programs. The missing sources came principally from developing countries lacking emission reporting requirements and sophisticated measurement infrastructure. Roughly one-third of sources originated in the Persian Gulf region. By including missing anthropogenic sources as well as SO_2 emissions from volcanoes, the corrected satellite measurements highlighted discrepancies with conventional emission measures by as great a factor as three (McLinden et al., 2016).

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13

WATER RESOURCES

Environmental Performance Index

Water Resources

SNAPSHOT

Effective wastewater management is essential to human and ecosystem health.

CATEGORY DESCRIPTION

Untreated wastewater contaminates rivers, lakes, and oceans. It spreads diseases that kill millions of people each year. Ecosystem impacts from wastewater range from eutrophication to increased water temperature, depending on the wastewater source. Wastewater pollution threatens ecosystem vitality and clean water resources in all countries, but the need for wastewater management is especially pressing in countries facing water scarcity. Growing populations also threaten the ability of some countries to ensure clean freshwater resources. Connecting people to adequate wastewater collection and treatment systems mitigates these damages by preventing pollution and making treated water available for re-use.

INDICATOR INCLUDED

Wastewater treatment. We measure wastewater treatment as the percentage of wastewater that undergoes at least primary treatment in each country, normalized by the proportion of the population connected to a municipal wastewater collection system.

Countries can minimize the negative environmental impacts of sewage by treating wastewater. Water treatment can remove pathogenic microorganisms and other harmful pollutants, minimizing health risks to humans and ecosystems. Maximizing wastewater treatment is an effective way to assess the cleanliness of each country's water resources. Our wastewater treatment indicator captures only water treatment by centralized municipal utilities, as global data from independent water treatment such as private septic systems are lacking.

WATER RESOURCES INDICATOR	
Wastewater treatment	%, weighted by connection rate

Clean water is essential for all life. In many countries, the lack of wastewater treatment poses a major threat to clean water resources.

Wastewater refers to polluted water that is unfit for drinking, irrigation, or other useful purposes (Malik, Hsu, Johnson, & de Sherbinin, 2015). Approximately 80% of all wastewater produced globally is discharged into the environment untreated (UN WWAP, 017). Untreated wastewater threatens human life, human livelihoods, and ecosystem health.

Many human activities pollute water systems. The pollutants contained in wastewater vary depending on their source. These different pollutants dictate the health impacts of untreated wastewater. Major sources of wastewater include domestic water use, agriculture, industrial activities, and groundwater runoff. Domestic wastewater, or sewage, contains organic materials that can carry pathogenic microorganisms. Sewage can also contain pharmaceutical drugs and other chemicals that are commonly disposed through household toilets and sinks. Agricultural wastewater often carries excess nutrients from fertilizer, pesticide residues, and growth hormones used on livestock. Industrial wastewater can contain hazardous chemicals, metals, or excess heat. Groundwater runoff picks up surface pollutants, ranging from plastics and oil in urban areas to concentrated hazardous metals and chemicals from dumps (UN WWAP, 2017). While the impacts of wastewater pollution vary by source, all untreated wastewater harms human and ecosystem health.

Managing and treating wastewater can be complex and expensive. Collection infrastructure must respond quickly to environmental pressures. Storms and flooding, for example, can overwhelm wastewater treatment infrastructure and cause untreated wastewater to overflow directly into the environment. Preventing overflow events challenges wastewater management planning in wealthy and developing countries (UN WWAP, 2017). Wastewater treatment is often classified in progressively more effective and expensive tiers. Primary treatment simply filters suspended organic solids, and wastewater treated in this way is not typically potable. More advanced secondary and tertiary treatment ensures higher water purity (Malik et al., 2015).

Wastewater collection and treatment data can help countries develop and justify policies designed to protect water resources. A 2004 World Health Organization (WHO) report found that wastewater treatment and disposal costs are small compared to damages from untreated wastewater (Hutton & Haller, 2004). Expanding and standardizing data collection can help clarify the economic argument for expanding treatment infrastructure, and support other policies and innovations that improve wastewater management (Mateo-Sagasta, Thebo, & Raschid-Sally, 2015). Gathering such data is logistically complex, especially in rural areas where collection and treatment are often distributed. City-level data is therefore more common than country-level data (Malik et al., 2015).

Clean water is essential for environmental, economic, and social well-being. In 2010 the United Nations formally acknowledged that access to clean water and sanitation are fundamental human rights. The 2015 Sustainable Development Goals (SDGs) and their predecessor, the Millennium Development Goals (MDGs), emphasize the importance of clean water in sustainable development. Both note the global threats to water quality and availability posed by rising demand for water, increased pollution, and greater wastewater generation. Wastewater treatment can alleviate many of these problems.

ENVIRONMENTAL

Pollution from untreated wastewater causes many environmental problems. Pollutants that are toxic or that reduce oxygen levels in water can kill aquatic species and dramatically disturb ecosystems. Decaying organic matter from domestic and municipal sources captures dissolved oxygen. High concentrations of phosphorous and nitrogen from agricultural fertilizer also create oxygen poor environments through eutrophication. Metals, salts, and pesticides create a host of problems including toxicity for animals and plants (UN WWAP, 2017).

Treated wastewater can also harm ecosystems. Basic wastewater treatment filters out suspended solids and organic matter but does not remove all pollutants. Wastewater that is recycled for irrigation can lead to soil salinization, as salts remaining in the treated wastewater accumulate and gradually prevent proper water adsorption by crops (Welle & Mauter, 2017). "Emerging pollutants" including pharmaceutical drugs and contraceptives are often difficult to remove, even with tertiary treatment. Small concentrations of these pollutants have been found to disrupt hormonal processes in animals, causing birth defects and cancers, among other health problems (UN WWAP, 2017).

SOCIAL

Pathogens that pollute drinking water pose multiple threats to human health (Environment and Climate Change Canada, 2014). Diseases associated with poor water and sanitation include cholera, dysentery, typhoid, and polio. The UN estimates that almost 2 billion people have access to drinking water containing bacteria from fecal matter (UN-Water, 2017b). Worldwide, approximately 1.3 million people die each year from diarrheal diseases. Poor hygiene and unsafe water are major contributors to these deaths (Troeger et al., 2017).

Women and children are most affected by the unsafe management of human waste due to their primary household roles, especially in developing countries (UN WWAP, 2017). This includes collecting water, which is a time-consuming, difficult, and sometimes dangerous task for women and girls. These responsibilities can compromise school participation, health and disease management, and other components of a safe, productive, and healthy life (UN-Water, 2017a). Diseases related to water and sanitation remain among the major causes of death globally in children under five years of age (UN, 2016).

ECONOMIC

In 2004 the WHO published a cost-benefit evaluation of water and sanitation service options for 17 WHO subregions in Europe, Africa, and Asia. These subregions cover more than 55% of the global population. The study found that, for all water and sanitation improvement options, health benefits outweighed implementation costs. The estimated return to society ranged from US$5 to US$28 for every US$1 spent on sanitation, depending on the region (Hutton & Haller, 2004). The global average is US$5.5 per US$1 spent (UN WWAP, 2017). Economic benefits from water and sanitation improvements include a decrease in illness, medical treatment, and death rates from diarrheal disease, as well as better water resource management for agriculture and aquatic- and marine-derived food sources.

SUSTAINABLE DEVELOPMENT GOALS

Several UN SDG goals and targets relate to wastewater management, demonstrating the broad importance of clean water resources to global sustainable development.

GOAL 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

TARGET 2.3. By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

TARGET 2.4. By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

GOAL 3. Ensure healthy lives and promote well-being for all at all ages.

TARGET 3.3. By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases, and combat hepatitis, water-borne diseases, and other communicable diseases.

TARGET 3.9. By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.

GOAL 6. Ensure availability and sustainable management of water and sanitation for all.

TARGET 6.1. By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

TARGET 6.2. By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

TARGET 6.3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

TARGET 6.5. By 2030, implement integrated water resources management at all levels, including through transboundary coöperation as appropriate.

TARGET 6.A. By 2030, expand international coöperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

GOAL 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

TARGET 9.1. Develop quality, reliable, sustainable, and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.

TARGET 9.4. By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.

TARGET 9.A. Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological, and technical support to African countries, least developed countries, landlocked developing countries and small island developing states.

GOAL 11. Make cities and human settlements inclusive, safe, resilient and sustainable.

TARGET 11.1. By 2030, ensure access for all to adequate, safe, and affordable housing and basic services, and upgrade slums.

TARGET 11.5. By 2030, significantly reduce the number of deaths and the number of affected people, and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

GOAL 12. Ensure sustainable consumption and production patterns.

TARGET 12.4. By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment.

INTERNATIONAL ORGANIZATIONS

International Water Association (IWA). IWA organizes events and projects that connect professionals working on solutions for water and wastewater management. The NGO aims to place water on the global political agenda and to influence best practices in regulation and policy-making. http://www.iwa-network.org/

International Water Resources Association (IWRA). IRWA aims to spread information and best practices about water resources management. The NGO organizes international water conferences to connect scientists with policymakers. http://www.iwra.org/

United Nations Children's Fund (UNICEF). UNICEF's water, sanitation, and hygiene team works in over 100 countries to improve water treatment services for children and their families. https://www.unicef.org/wash/

UNESCO World Water Assessment Program (UN WWAP). UN WWAP serves as a central organizer of information, data, research, and tools for water managers and other decision-makers, enabling them to pursue policies for freshwater resources. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/about/

United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC organizes studies on water resource management best practices. http://www4.unfccc.int/sites/NWP/Pages/water-page.aspx

United Nations Water (UN-Water). UN-Water coördinates the water-related activities of more than 30 UN organizations and other international groups. http://www.unwater.org/

MULTILATERAL EFFORTS

UN World Toilet Day. Raises awareness and inspires action to tackle the global sanitation crisis, which requires both access to toilets and solutions for connecting and treating wastewater for sustainable development. http://www.un.org/en/events/toiletday/

World Water Week. The annual event addresses the theme "water and waste — reduce and reuse." The most recent event was held August 2017 in Stockholm, Sweden. http://www.worldwaterweek.org/

Ideally, a wastewater treatment indicator would capture the percentage of all wastewater that is treated within each country.

Such an indicator would require the volumes and locations of wastewater generation and collection from all sources. This ideal indicator would also require data showing the volume of wastewater that is treated by utilities and by distributed treatment systems. Limited wastewater generation and collection data make construction of the ideal indicator impossible, as do limited data on distributed treatment systems. Malik et al. (2015) describe an ideal wastewater indicator considering data limitations. This indicator would be constructed to show the volume of wastewater collected and treated within each country, normalized by the population served by each utility.

Regular wastewater treatment data collection and reporting would support the realization of SDGs related to clean water resources. Unfortunately, national and municipal data collection for wastewater generation, collection, and treatment are sometimes unavailable and rarely updated regularly. The most robust data include basic information about connections to wastewater collection or treatment. Countries that collect data typically focus on centralized municipal utility treatment, which is easier to collect than data on distributed rural wastewater treatment. Some cities collect detailed wastewater generation and treatment data. These data can support the indicator proposed by Malik et al. (2015), but not an indicator that captures water treatment in rural areas. Countries and cities that do collect data make infrequent updates, and tracking progress across time is difficult. Developing countries tend to update data less frequently than developed countries, but France and Australia are examples of developed countries that do not have recent wastewater treatment data (Malik et al., 2015).

Further difficulty arises from attempts to standardize monitoring approaches for cross-country comparisons. Global data sharing is poor, and access to original data sources can get lost in data aggregation (Hering, 2017). To systemize monitoring globally, several UN agencies are developing the Integrated Monitoring of Water and Sanitation Related SDG Targets (GEMI). This initiative aims to synchronize and expand existing monitoring efforts on wastewater treatment. Given limitations in wastewater treatment data collection and reporting, the water resources indicator developed by Malik et al. (2015) for the 2014 EPI is the best measure to compare global wastewater treatment.

INDICATOR BACKGROUND

Malik et al. (2015) provide the first global wastewater treatment indicator, which uses municipal utility collection as a proxy for national collection. The 2018 EPI uses the wastewater indicator introduced first in the 2014 EPI. This indicator measures the percentage of wastewater from sources connected to a centralized treatment system that is treated. This percentage is calculated by multiplying two proportions: the wastewater treatment level in each country, and the connection rate of the population to the wastewater system. The wastewater treatment level is the amount of wastewater that is treated, divided by the total amount of wastewater generated. The connection rate is the number of people within the country who are connected to a sewer system, divided by the total population of the country (Malik et al., 2015).

DATA DESCRIPTION

Most data in the EPI wastewater collection and treatment dataset are compiled from four sources: the UN Statistics Division (UNSD), the Organization for Economic Co-operation and Development (OECD), the Pinsent Masons Water Yearbook, and the UN Food and Agriculture Organization's (FAO) Aquastat system. EPI supplements these sources with data from publicly available and country-specific reports to form a more comprehensive dataset. In cases where national-level data are unavailable, data are gathered from cities and utilities. In total, the EPI dataset includes information about wastewater treatment and sewer system connections for 176 countries.

LIMITATIONS

The 2018 EPI wastewater treatment indicator reveals data limitations and can inform future data collection and reporting to support more robust metrics. There are many limitations to international wastewater data. Available datasets are infrequently updated. As a result, new values for the 2018 EPI were available only for a handful of countries. Data from different sources occasionally have different values for the same country, indicating differences in definitions or methods. Where national-level data are unavailable, municipal data sources are used to extrapolate national values. This data may not be representative of a country's overall wastewater treatment rate, as important wastewater sources such as agriculture and industrial plants can be located in rural areas (Malik et al., 2015). Most datasets do not distinguish simple filtration from more intensive wastewater treatment. Detailed information about the level of wastewater treatment is available from some developed countries, but such information is not common enough to create an indicator that compares the treatment level across countries. Greater international attention is needed to provide standardized, accurate, detailed, and frequent data on protection of water resources.

RESULTS

Ensuring clean water resources is an important measure of a country's environmental performance.

TABLE 13-1 GLOBAL TRENDS IN MANAGING WATER RESOURCES				
INDICATOR	METRIC		SCORE	
	BASELINE	CURRENT	BASELINE	CURRENT
Wastewater treatment	N/A	62.1%	N/A	62.13

Note: For most EPI indicators, CURRENT refers to the most recently available data. For the *wastewater treatment* indicator, BASELINE and CURRENT data are the same due to lack of regularly updated datasets.

GLOBAL TRENDS

As demand for water from agriculture, industry, and residential users increases, countries will need to collect and treat wastewater to prevent pollution from harming human and ecosystem health. Our results reflect the preliminary assessment of global wastewater treatment conducted by Malik et al. (2015). Some countries score well on wastewater treatment, but there is room for improvement across all countries and regions.

Due to unavailability of global wastewater treatment data, the global performance in wastewater treatment has not changed from the baseline. Data quality is especially poor in Latin America and the Caribbean, as 82.2% of countries in this region lack recent wastewater data. Europe has the best data of any region, with 31.7% of countries missing recent data (Malik et al., 2015). Improving wastewater treatment data collection and reporting is an essential step in moving the world toward 100% wastewater treatment. Countries may begin to improve wastewater treatment data quality and performance in response to the UN SDG 6, which targets global reduction in untreated wastewater.

LEADERS & LAGGARDS

While most countries can improve their wastewater treatment performance, some countries score very highly in the Water Resources category. All leading countries are wealthy, and most are threatened by water scarcity. Strong policies in the European Union, Singapore, and Israel have also encouraged high performance in wastewater treatment.

All of the top ten countries in the Water Resources category are relatively wealthy. According to the World Bank, each leading country in Table 13-2 ranks within the top third globally in GDP per capita. This result is expected, as wastewater treatment rates are typically higher in developed countries. Wealthier countries also use advanced treatment for a higher percentage of wastewater (UN WWAP, 2017).

Most leading countries also experience water stress. Water-stressed nations have high incentive to treat and recycle wastewater. According to WRI Aqueduct, seven of the countries in Table 13-2 will experience medium to high water stress under a business-as-usual scenario by 2020 (WRI Aqueduct, 2015). This scenario places Singapore and Israel in the top ten water-stressed countries globally. Germany, Netherlands, and Switzerland are the only leaders that are not expected to experience medium to high water stress (WRI Aqueduct, 2015).

In the European Union, the Urban Waste Water Treatment Directive (91/271/EEC) requires Member States to report performance on wastewater collection and treatment. This directive tracks collection rates, secondary treatment rates, and more stringent treatment rates. Compliance rates with the directive vary between Member States. Most EU countries that rank within the top ten for the 2018 EPI fully comply with the directive. Malta is a notable exception. While Malta has wastewater treatment infrastructure in place, the country's water quality is threatened by discharges of agricultural waste and high concentrations of salt in sewage (European Commission, 2017). These problems are not captured by the wastewater treatment indicator. Future versions of the EPI may capture more detailed variations in performance including the level of treatment applied in each country.

TABLE 13-2 LEADERS IN WATER RESOURCES

RANK	COUNTRY	SCORE
1	Malta	100
2	Singapore	100
3	Netherlands	99.90
4	United Kingdom	99.82
5	Luxembourg	99.75
6	Spain	99.71
7	Switzerland	99.67
8	Germany	99.65
9	Israel	99.49
10	Australia	99.44

There are 38 countries with a score of zero. All are developing countries in Africa, Asia, Eastern Europe, and Central and South America. Countries with zero scores have available data, but Malik et al. (2015) indicate difficulty finding good wastewater treatment and connection values for some of these countries. In some cases, national values are extrapolated from city-level data. Other cases required interpreting anecdotal or qualitative descriptions of wastewater treatment. As an example, the wastewater connection value for Guyana interpreted from a water utility report, which states that "there are no treatment processes" in the capital city (Malik et al., 2015). This qualitative statement gives Guyana a score of zero.

Water resources are threatened in many sub-Saharan African countries. Ethiopia receives a zero score for wastewater treatment in the 2018 EPI and faces many of the pressures common to the region. In sub-Saharan Africa, urban populations are growing more rapidly than in any other region globally. Addis Ababa has struggled to connect growing populations to wastewater treatment. While treatment infrastructure exists, treatment plants in the city are under capacity due to a lack of municipal wastewater connections. A 2009 study found that in one area of the city, less than 3% of wastewater reached a treatment facility (UN WWAP, 2017). Connecting households and businesses to wastewater treatment in growing cities is a financial and logistical challenge but is important to maintain human and ecosystem health.

FOCUS 13-1 FRAMING WASTEWATER AS A RESOURCE, NOT A WASTE

In addition to protecting human and ecosystem health, wastewater treatment can be used to recover valuable resources. Wastewater holds a potentially high value as an unconventional water resource in water-stressed regions (UN, 2016). Singapore's NEWater program is a successful example of wastewater recycling. Household wastewater in Singapore is collected and treated using intensive processes that remove living organisms and other contaminants. The recycled water is then used in industrial processes. Although the recycled water is potable, NEWater supplies only a small percentage of Singapore's drinking water supply. Public fears over the safety of recycled wastewater have prevented wider use in the municipal water supply. Singapore is attempting to change public perception through education campaigns (UN WWAP, 2017).

Properly managed wastewater can be a source of nutrients, energy via anaerobic digestion of organic material into methane, and even high-value by-product recovery like metals (Asano, 1998). Some companies use heat from wastewater to drive industrial proscesses. The trend toward wastewater recycling and resource recovery was demonstrated on World Water Day 2017, when UNESCO released its annual World Water Development Report, focusing on wastewater as an untapped resource (UN WWAP, 2017).

Understanding wastewater as a resource instead of a burden is still uncommon. To increase demand for wastewater recycling and resource recovery, countries must develop flexible regulatory and institutional frameworks and provide funding for new or modified wastewater treatment infrastructure. Status quo regulatory frameworks consider wastewater a pollutant to be minimized, and new rules are needed to accommodate the range of potential applications (Mateo-Sagasta et al., 2015). Advanced treatment for wastewater reuse is capital-intensive, but nutrient recovery can add significant new value streams to the treatment process (Rao, Drechsel, Hanjra, & Danso, 2015). Certain wastewater treatment technologies, like anaerobic digestion, can reduce or even neutralize wastewater treatment's energy burden (Lazarova, Asano, Bahri, & Anderson, 2013). Wastewater is not merely a collect-and-treat problem. Rather, wastewater can be a valuable resource providing sustainable opportunities for water, nutrient, and energy recovery.

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14

AGRICULTURE

Environmental Performance Index

Agriculture

SNAPSHOT

Agriculture is crucial to sustaining life, but agricultural productivity has often come at the expense of agricultural inputs.

CATEGORY DESCRIPTION

such as land, water, and minerals (Alexandratos & Bruinsma, 2012). Sustainable farming and ranching thus depend on better and more efficient use of resources to break this link. Fertilizers rich in nitrogen support plant growth and are thus vital to the agricultural sector (Zhang et al., 2015, p. 51). Nitrogen pollution, however, has the potential to cause widespread damage if managed inadequately (Bodirsky et al., 2014). The EPI uses one indicator to track nitrogen management as a measure of environmental performance.

INDICATOR INCLUDED

Sustainable Nitrogen Management Index (SNMI). As a gauge of efficiency, the SNMI indicator uses nitrogen use efficiency (NUE) and crop yield to measure the environmental performance of agricultural production (Zhang & Davidson, 2016).

AGRICULTURE INDICATOR	
Sustainable Nitrogen Management Index	Unitless

Agriculture, while vital to our quality of life, can be harmful to the environment when poorly managed.

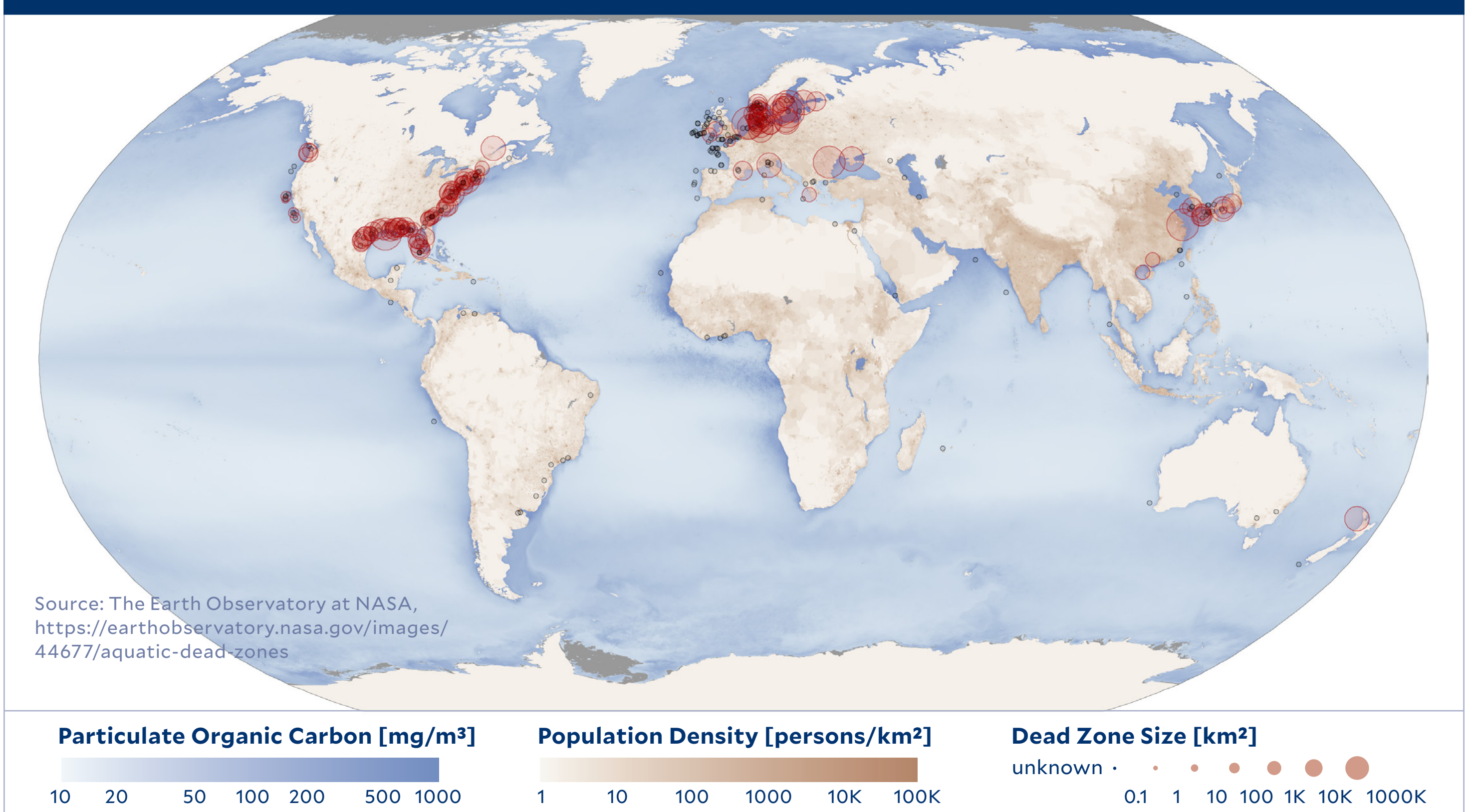
The world population is expected to increase to over 9 billion by 2050 (World Bank, 2017b). As a result, food security has emerged as a front-burner issue. To feed a growing population, the Food and Agriculture Organization of the United Nations (FAO) estimates food production will need to increase by 60% by 2050 (2016, p.1). Improving agricultural practices can help protect the environment, public health, and communities. Sustainable agriculture enables food production without compromising the needs of future generations (World Bank, 2017b).

Food security has become a top-tier global issue. One of the challenges of sustainable agriculture centers on using fertilizer efficiently to grow crops without polluting the environment. Unsustainable agricultural practices have substantial, negative environmental impacts (FAO, 2016, p. 1). Significant issues facing the agricultural sector today include a loss of arable land for crop production and a loss of crop diversity. Over the past 40 years, over 30% of arable land globally has been degraded (Milman, 2015). Industrialized agricultural practices have also led to higher levels of monocultures because it is more economically efficient to produce large quantities of the same type of crop (FAO, 2011).

Agriculture intersects with several other environmental issues addressed in this report. Within the context of nutrient pollution, however, agriculture poses a distinct threat (Rockström et al., 2009b). Over the past century, massive amounts of both nitrogen and phosphorus have entered into agricultural practices (DeFries et al., 2015, p. 238). Adding nutrients — like nitrogen and phosphorous — to the soil allows for an increase in agricultural output. These additions also create substantial costs to the environment, e.g., groundwater contamination, runoff of excess fertilizer that damages water quality, nitrous oxide emissions, degradation of habitat for biodiversity, and fragmentation of economic and social conditions in rural communities (DeFries et al., 2015, p. 238; World Bank, 2017b). Nitrogen pollution, therefore, has the potential to cause extensive damages if not sustainably managed (Bodirsky et al., 2014).

The SNMI indicator tracks nitrogen management to assess how well a country uses fertilizer for efficient crop production. We use nitrogen

MAP 14-1 GLOBAL MAP OF DEAD ZONES, 2008



Note: The black points are observed sites of dead zones, although the size of those dead zones is not known.

management as a proxy for phosphorus fertilizer management, as both nitrogen and phosphorus are supplied in fertilizers.

ENVIRONMENTAL

The agriculture sector's impact on the environment varies based on the farming practices employed. Excess nitrogen runoff can cause algae blooms, loss of oxygen from the water, and death of aquatic animals (Sutton et al., 2013, p. 32). Some of the best-known examples of dead zones are in the Gulf of Mexico and the Chesapeake Bay (Charles, 2017). Map 14-1 depicts where dead zones have been observed worldwide.

Nitrogen fertilizers also produce greenhouse gas emissions in the form of nitrous oxide (N_2O). Nitrous oxides are also released when excess nitrogen fertilizer is broken down by soil bacteria. These gases are about 300 times more potent than carbon dioxide (CO_2) as greenhouse gases (GHGs) (Sutton et al., 2013, p. 32). The manufacturing of reactive nitrogen is also an energy-intensive process, accounting for approximately 2% of the world's energy use (Sutton et al., 2013, p. 32).

SOCIAL

Unsustainable agricultural practices are one of the most significant causes of food scarcity. According to the UN, almost 800 million people globally are undernourished, and by 2050 that number is expected to increase by an additional 2 billion people (UN News Centre, 2016). To alleviate undernourishment and hunger, agricultural yields must increase. In areas with minimal amounts of fertilizer use, adding nitrogen to the soil is unlikely to cause large amounts of pollution; however, when more nitrogen fertilizer is applied "in regions that have high nitrogen fertilization rates [...] most of the added nitrogen is lost as air and water pollution" (Zhang, 2017, p. 322).

ECONOMIC

Agriculture plays an important role in economic development. According to the UN, the agricultural sector is the largest employer in the world and provides livelihoods for approximately 40% of the world's population (UN, 2015). The value added of world's agricultural production was estimated at US$3.18 trillion in 2016 (World Bank, 2017a).

FOCUS 14-1 CONNECTIONS TO OTHER CHAPTERS

Agriculture is a significant cause of deforestation, climate change, and water degradation. The management challenges that arise from nitrogen use are particularly difficult due to the ways it interacts with other elements (Sutton et al., 2013). The different chemical forms of nitrogen are addressed in part by other chapters in the EPI, including Climate & Energy, Air Pollution, Forests, and Water & Sanitation. Examples of excess nitrogen's impact on the environment in other issue indicators include:

- **Climate & Energy.** Nitrous oxides (NO_X) are potent GHGs that are about 300 times the global warming potential of CO_2 (Sutton et al., 2011).

- **Biodiversity.** Excess nitrogen in aquatic systems can lead to algae blooms. When algae decompose, they consume oxygen in the water column, which can kill other aquatic species (Galloway et al., 2003).

- **Air Quality & Air Pollution.** NO_X is a precursor to ozone, which can have harmful effects on humans, animals, and plants (Royal Society, 2008).

- **Forests.** Excess NO_X in the atmosphere forms acid rain, which can damage tree roots and make it more difficult for trees to take up nutrients (Sutton et al., 2011).

While the chapters are analyzed separately, their relationships to one another should be understood, and addressed, collectively. In the context of this issue category, sustainable nitrogen management is essential to support plant growth, but has the potential to cause widespread damage if managed inadequately (Bodirsky et al., 2014).

Nitrogen supports productivity and sustains life.

While some reactive nitrogen occurs naturally, anthropogenic inputs of reactive nitrogen are now double natural levels (Holtgrieve et al., 2011). Human influence on the nitrogen cycle has exceeded the natural bounds for ecosystem functions globally (Rockström et al., 2009a). Many factors contribute to this proliferation in nitrogen pollution, but agriculture is the most prevalent source of reactive nitrogen (Rockström et al., 2009a).

The industrialization of agriculture has allowed for significant increases in crop yields over the past century (DeFries et al., 2015, p. 238). The use of synthetic fertilizers became widespread in the 1900s through the Haber-Bosch process, an energy-intensive method that synthesizes nitrogen compounds from the atmosphere (Sutton et al., 2013, p. 4). The Haber-Bosch process has permitted the development of both more-varied and richer diets (Sutton et al., 2013, p. 4). To date, no region has been able to increase agricultural growth without increasing fertilizer use as well (World Bank, 2017b, p. 27). Now, more than half of the world population is dependent on crops grown with nitrogen-rich fertilizers (Zhang et al., 2015, p. 51). Agricultural productivity has substantially increased, but it has come at the expense of sustainability and equitable development (Alexandratos & Bruinsma, 2012).

SUSTAINABLE DEVELOPMENT GOALS

United Nations Sustainable Development Goal (SDG) 2 aims to address the challenges of global food security by making agriculture more sustainable.

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

Target 2.3. By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

Target 2.4. By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

Target 2.5. By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.

Target 2.A. Increase investment, including through enhanced international coöperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries.

Target 2.B. Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round.

INTERNATIONAL ORGANIZATIONS

Consultative Group on International Agricultural Research (CGIAR). CGIAR is a global research partnership working for "[a] world free of poverty, hunger and environmental degradation." http://www.cgiar.org/

Food and Agriculture Organization of the United Nations (FAO). FAO is an intergovernmental organization working to make agricultural production more productive and sustainable. FAO comprises 194 Member States, two associate members, and one member organization — the European Union. http://www.fao.org/home/en/

Global Partnership on Nutrient Management (GPNM). This partnership was launched with governments, scientists, policymakers, and international organizations to research and promote effective nutrient reduction strategies in agriculture. http://www.nutrientchallenge.org/

United Nations Environment Programme (UNEP). The UNEP is the agency within the UN coördinating and implementing environmental actions. As one of its many duties, UNEP is tasked with helping to implement the SDGs. https://www.unenvironment.org/

World Bank Group. The World Bank Group is a leading investor in agriculture globally, working with countries and providing infrastructure and resources to the food and agriculture sector. http://www.worldbank.org/en/topic/agriculture

World Trade Organization (WTO). One of the WTO's international treaties, the Agreement on Agriculture, aims to limit barriers to trade in agriculture and to open agricultural market access. https://www.wto.org/english/tratop_e/agric_e/agric_e.htm

MULTILATERAL EFFORTS

Convention on Biological Diversity Aichi Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity. https://www.cbd.int/sp/targets/default.shtml

Global Environmental Facility (GEF). Established during the 1992 Rio Earth Summit, the GEF assists with climate change adaptation, working on issues spanning sustainable agriculture, food security, and land use. https://www.thegef.org/

International Fund for Agricultural Development (IFAD). The IFAD is a specialized agency of the UN that funds agricultural development projects in areas that depend largely on agriculture. https://www.ifad.org/

International Plant Protection Convention (IPPC). The IPPC is a multilateral treaty of FAO that aims to protect, preserve, and extend plant biodiversity for food and agriculture. https://www.ippc.int/en/

International Treaty on Plant Genetic Resources for Food and Agriculture (IT PGRFA). Adopted in 2001, the objectives of this legally binding treaty incorporate the conservation and sustainable use of plant genetic resources for food and agriculture. http://www.fao.org/plant-treaty/en/

UN Framework Convention on Climate Change (UNFCC). The UNFCC includes the promotion of sustainable agriculture and climate change mitigation through agricultural adaptation technologies. http://unfccc.int/land_use_and_climate_change/agriculture/items/8793.php

UN's Oceans Compact Goal 1, Target 1. Reducing pollutants from sea- and land-based activities, including gas and oil extraction, marine debris, harmful substances and nutrients from wastewater, industrial and agricultural runoff entering the world's oceans. http://www.un.org/depts/los/ocean_compact/oceans_compact.htm

World Food Program (WFP). The WFP is a branch of the UN that aims to prevent hunger and deliver food aid. http://www1.wfp.org/

When assessing sustainable agriculture, data are needed for several systems.

World Resources Institute's (WRI) Indicators of Sustainable Agriculture: A Scoping Analysis report evaluated research that has studied different agricultural systems (Reytar, Hanson, & Henninger, 2014). Surveying past and potential measurements, WRI identified five areas in which agricultural indicators are needed (Reytar et al., 2014, pp. 10–11):

- **Water.** Indicators that best reflect agricultural pressure on water resource use.
- **Climate change.** Indicators that best capture the impact of agriculture on GHG emissions.
- **Land conversion.** Indicators that best capture the conversion of natural land into agricultural land.
- **Soil health.** Indicators that best reflect the impact of agriculture on soil health and productivity.
- **Pollution.** Indicators that best capture the environmental degradation caused by agricultural nutrient inputs, agricultural pesticides, and other pollutants.

WRI emphasizes the need to improve data quality and scope, despite the number of studies and datasets that address some of these indicator areas (Reytar et al., 2014). These data issues—combined with countries' resource limitations—lead to numerous methodological problems. The WRI uses seven specific criteria to evaluate agriculture indicators, but two of them illustrate the largest gaps in the measurement of agricultural sustainability: the lack of globally available and regularly collected data (Reytar et al., 2014, pp. 10, 12–16). Improving existing indicators and developing new ones to address these gaps is vital to ensure that policymakers can compare their country's performance against other nations and against historic benchmarks. An EU handbook highlights the importance of broadening discussions of nutrients to explicitly include phosphorus in addition to nitrogen to capture more nuance in the measurement of agricultural pollution (Eurostat, 2013, p. 25).

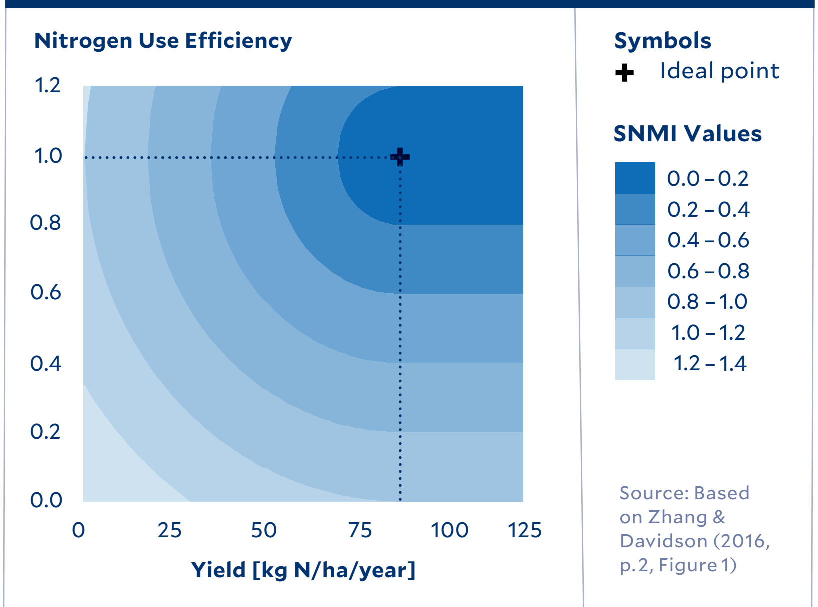
Indicators that measure the environmental impacts of agriculture are an important tool to gauge global efforts toward a sustainable food future. We identify the SNMI indicator as the best representation of environmental performance given existing limitations with consistent, comprehensive data on sustainable agriculture practice. The SNMI measures how much excess nitrogen enters the environment, where it could have negative effects. While the EPI's analysis on agricultural sustainability provides a starting point to understand fertilizer use in a country, it does not provide countries with data at the level of detail required to inform policy action. Policymakers should find ways to incorporate local data into their decisionmaking.

INDICATOR BACKGROUND

The 2018 EPI uses the SNMI as a proxy of agricultural drivers of environmental damage. This novel metric, proposed by Zhang and Davidson (2016), seeks to balance the two elements of sustainable agriculture. First, countries are assessed by their NUE, which is a measure of the portion of nitrogen input harvested in crops (Zhang et al., 2015). Second, countries are then assessed on nitrogen yield, or the mass of nitrogen harvested per unit of land.

Ideally, a country should have optimal NUE to avoid excess inputs of fertilizer into the environment, while main-

FIGURE 14-1 SUSTAINABLE NITROGEN MANAGEMENT INDEX (SNMI)



Sustainable Nitrogen Management Index (SNMI) values are based on the Euclidean distance from an ideal point defined by Nitrogen Use Efficiency (NUE) = 1, i.e., nitrogen is neither over-applied nor mined from the soil, and Yield = 90 kg N/ha/yr, a general standard for sufficient production of harvested nitrogen. The greater the distance from the ideal point, the worse the performance on SNMI.

taining yields that meet the needs of its people. The SNMI is a composite score of how far away a country is from its ideal point of perfect NUE and yield, as depicted in Figure 14-1. It is based on how far a country falls from the reference point, which is defined as a certain yield target. Zhang and Davidson (2016, p. 2) define this reference yield level as 90 kg N/ha/yr, based on the FAO's estimate of the "required nitrogen yield, averaged globally, to meet 2050 crop production targets without expanding the current crop land" (Alexandratos & Bruinsma, 2012; Zhang & Davidson, 2016, p. 2).

DATA DESCRIPTION

Our metric is focused specifically on agriculture disruption of the nitrogen cycle. Data are available for 147 countries for 2010 and are provided by Xin Zhang and her team at the University of Maryland Center for Environmental Science. Zhang's team has data over the period of 1961–2011, but the SNMI has been calculated for 2015. NUE and yield are computed using country-level data obtained by Zhang et al. from FAO's Corporate Statistical Database (FAOSTAT) and published in *Nature* (Zhang et al., 2015). The SNMI is the Euclidean distance of a country's normalized NUE and yield from an ideal point. The methodology for SNMI is described in further detail in Zhang and Davidson (2016).

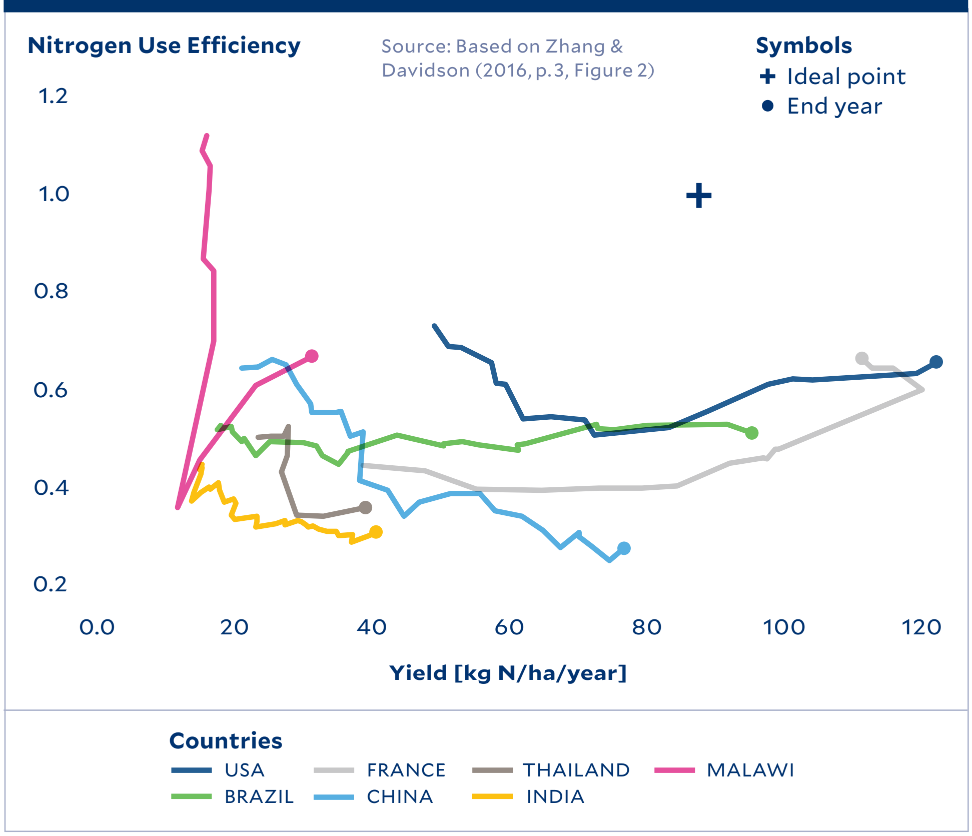
As shown in Figure 14-2, the historical performance of countries should trend toward the ideal point in the SNMI framework. Over four decades, Brazil and the United States have made remarkable progress in increasing yields, with the USA exceeding the FAO's simple baseline of 90 kg N/ha/yr more than two decades ago. However, there has been very little change in NUE over this period for these two breadbaskets. In contrast, France has managed to increase both yields and NUE, with the largest gains in NUE occurring over the recent past. The rest of the developing world shows less progress in yields and worrying declines in NUE. The challenge of sustainable agriculture is to bend these trajectories toward the ideal point.

LIMITATIONS

SNMI is a proxy for agricultural environmental performance and only tangentially measures the environmental problems associated with agriculture. Certain limitations arise because countries can have the same score for very different reasons. For example, a country can be in nitrogen excess and deficiency at the same time (Zhang & Davidson, 2016). Regions also have varying amounts of nutrients found in their soils and thus require different amounts of fertilizer to support agricultural yields. Rather than using FAO's 2050 yield target of 90 kg N/ha/yr (Alexandratos & Bruinsma, 2012; Zhang & Davidson, 2016, p. 2), country-specific benchmarks are needed for normalizing nitrogen yield (Reytar et al., 2014, p. 5).

The SNMI encompasses only part of the information necessary to capture country-specific agricultural management practices resources (Reytar et al., 2014). The indicator does not consider the impact from international trade. If international trade across croplands is improved, nitrogen pollution has the potential to decrease (Zhang, 2017, p. 322). This fact also illustrates the need to account for the impacts of global trade in nitrogen emissions, as export- and import-oriented food production models influence the distribution of nitrogen pollution (Lassaletta et al., 2016). Using research by Oita et al. (2016), the SDG Index includes a metric that captures the nitrogen pollution from a country's net imports (Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2017, p. 26). This metric accounts for the environmental impacts of the food consumed, but not

FIGURE 14-2 SMOOTHED HISTORICAL TRENDS OF SEVEN COUNTRIES SHOWING YIELD COMPARED TO NUE OVER TIME, 1961–2011



produced domestically by each country (Oita et al., 2016, p. 111; Sachs et al., 2017, p. 26), while the SNMI is based only on production.

Additional limitations in our dataset arise because the SNMI is only comprehensively available for the year 2010 thus far and only encompasses a limited number of countries. Further, the straight-line distance between the sets of yield & NUE for equivalent scores, as represented by the iso-performance curves in Figure 14-2, illustrate the path countries should follow to improve overall performance. Top performers would achieve high yields along with efficient nitrogen use. The target for nitrogen yield in each country may differ from the FAO's general standard of 90 kg N/ha/yr. More research is needed to set country-specific targets. Finally, while the FAOSTAT database provides historical records of nitrogen fertilizer use, it does not provide a breakdown of how the fertilizers have been used for pastures versus different crop types (Zhang et al., 2015). SNMI, while still a work in progress, represents an intermediate step toward measuring sustainable agricultural productivity globally.

GLOBAL TRENDS

Globally, sustainable nitrogen management has improved very slightly, with the global indicator score increasing by 3.7 points; see Table 14-1. The 6.5% decrease in the metric score, from 0.61 to 0.57, reflects a smaller difference between actual and ideal nitrogen efficiency and yields, demonstrating global progress on this issue. However, these small score improvements reflect increasing yields rather than improvements in efficiency. An index value of zero indicates that the nitrogen use efficiency is 1, i.e., all nitrogen added to the soil is removed in the food, and that agricultural yields are above a certain reference point, chosen to be 90 kg N/ha/yr in this index (Zhang & Davidson, 2016, pp. 1–2). Nitrogen use efficiencies can increase above 1 when more nitrogen is being removed from the soil than added. In general, net nitrogen removal reduces the fertility of the soil; however, Zhang & Davidson argue that this also presents an opportunity to add fertilizer to produce higher yields without causing substantial nitrogen pollution (Zhang et al., 2015, p. 54).

Our reference yield of 90 kg N/ha/yr reflects the "required nitrogen yield, averaged globally, to meet 2050 crop production targets without expanding the current crop land" (Alexandratos & Bruinsma, 2012; Zhang & Davidson, 2016, p. 2). To produce these yields while staying within sustainable emission limits for nitrogen pollution, nitrogen use efficiency must increase by roughly 0.3 by 2050 (Zhang et al., 2015, p. 56). Progress from all countries in all regions will help achieve 2050 goals (Zhang et al., 2015, pp. 55–56). In the United States and European Union, the agriculture sector will need to continue trends of increasing yields while decreasing nitrogen inputs to increase efficiency (Zhang et al., 2015, p. 56). Transitioning economies, such as China and India, will need to make sharp increases in efficiency to reduce pollution and begin to move in the direction of the developed world (Zhang et al., 2015, p. 56).

There are many potential pathways for improving nitrogen efficiency and increasing crop yields. Carefully increasing fertilizer use in places with low fertilizer usage, such as sub-Saharan Africa, can raise yields with relatively low nitrogen pollution (Zhang, 2017, pp. 322–323). On a broader scale, increasing fertilizer use in the regions where it would have the greatest impact, and reducing it where it does not, may maintain yields while reducing nitrogen pollution by as much as 41% over a 15-year period (Mueller et al., 2017, p. 251). Technological improvements can also help produce higher yields without increasing nitrogen pollution. The development of crop varieties that can produce high yields in low-nitrogen soils is one example (Hirel, Le Gouis, Ney, & Gallais, 2007, pp. 2369–2370; Moll, Kamprath, & Jackson, 1982, p. 562). Finally, removing subsidies that create perverse incentives to overfertilize can encourage sustainable nitrogen management (Zhang, 2017, p. 323; Zhang et al., 2015, pp. 52–54).

Efforts to sustainably manage nitrogen have produced mixed results. Figure 14-2 highlights the progress made by a variety of countries thus far. Trends in France, the United States, and Brazil show constant or increasing trends in nitrogen efficiency, even in the face of increasing agricultural yields. China's decreasing trend in nitrogen use efficiency, on the other hand, may be cause for concern. Developing strategies to improve sustainability in large developing countries is becoming increasingly important. China and India, for example, create more than half of the world's nitrogen pollution, compared to less than 15% caused by the United States and Europe combined (Zhang et al., 2015, p. 55).

LEADERS & LAGGARDS

The top performers, shown in Table 14-2, reflect broader trends in global nitrogen management and demonstrate that advanced economies are generally better able to achieve high crop yields while managing nitrogen fertilizer use efficiently (Zhang et al., 2015, p. 53). However, the fact that the global leader, Paraguay, has incomes roughly six times lower than that of the second-place United States, shows how factors separate from economic development matter substantially as well. The presence of very wealthy countries, such as Singapore and the United Arab Emirates, among the laggards, shown in Table 14-3, reinforces this point further.

Three different explanations beyond economic development levels may help account for the position of Paraguay at the top and Singapore and the United Arab Emirates near the bottom, as well as broader trends observed in the tables above. The first and most policy-relevant explanation centers on direct regulations that limit nitrogen application to prevent pollution. The European

TABLE 14-2 LEADERS IN SUSTAINABLE NITROGEN MANAGEMENT

RANK	COUNTRY	SCORE
1	Paraguay	75.77
2	United States of America	72.38
3	Austria	71.34
4	Argentian	70.69
5	Hungary	69.15
6	France	67.77
7	Denmark	67.02
8	Uruguay	62.38
9	Czech Republic	62.17
10	Lithuania	62.01

TABLE 14-3 LAGGARDS IN SUSTAINABLE NITROGEN MANAGEMENT

RANK	COUNTRY	SCORE
1	Costa Rica	6.04
2	Georgia	5.70
3	Singapore	4.59
4	Mauritius	4.51
5	Saint Vincent and the Grenadines	3.22
6	Granada	0.76
7	Dominica	0.00
8	Saint Lucia	0.00
9	Trinidad and Tobago	0.00
10	United Arab Emirates	0.00

Union implemented rules related to nitrogen fertilizer in 1991 under Directive 91/676/EEC, which likely contributed to improvements in nitrogen use efficiency in Europe (van Grinsven et al., 2012, pp. 5150–5151, 5158; Zhang et al., 2015, p. 53). These concerted policy efforts may help explain the presence of six EU countries among the top ten.

Large fertilizer subsidies may partially explain high levels of nitrogen pollution in China and India (Zhang et al., 2015, pp. 53–54). The cost of fertilizer relative to prices for agricultural products is important because it impacts the incentives of farmers to purchase and use fertilizer (Zhang et al., 2015, pp. 53–54). The ability to subsidize or tax agricultural products or fertilizer highlights the role policymakers play in setting these prices, and thus in encouraging both higher yields and sustainable application of nitrogen fertilizers. In particular, low fertilizer costs or high agricultural prices can incentivize farming practices that lower efficiency (Zhang et al., 2015, p. 54). Countries with high agricultural subsidies may benefit from the study of efforts to remove agricultural subsidies elsewhere. In the case of European nations, the removal of agricultural subsidies contributed to declines in nitrogen pollution (Zhang et al., 2015, pp. 53–54).

The types of crops grown in Argentina, Paraguay, Uruguay, and the United States help account for their high scores. Nitrogen use efficiency varies by crop type; therefore, differences in crops produced can have a major impact on the observed efficiency of a country (Zhang et al., 2015, pp. 51, 54, 55). Fruits and vegetables tend to have the lowest nitrogen efficiencies, while cereal crops tend to have higher efficiencies (Zhang et al., 2015, p. 55). Nitrogen-fixing crops, such as soybeans, tend to have the highest efficiencies of all crops (Zhang et al., 2015, p. 55). Soybeans account for a disproportionately large fraction of agricultural production in Argentina, Paraguay, Uruguay, and the United States, helping explain their success in managing nitrogen use (Leff, Ramankutty, & Foley, 2004, p. 11; CIA, 2017; Zhang et al., 2015, p. 55). Similarly, the composition of the agricultural sector among the laggards further illustrates the role of crop type in determining nitrogen sustainability. Countries such as Singapore and the United Arab Emirates are known producers of nitrogen-inefficient crops (CIA, 2017). The high proportion of fruit and vegetable production in these countries may help explain their poor performance.

In summary, the impacts of fertilizer or agricultural subsidies and regulations on fertilizer usage show the importance of government policy in encouraging the efficient use of nitrogen fertilizers. However, the differences in efficiency across crop types is important as well (Alexandratos & Bruinsma, 2012, pp. 124–125). The difference in crop mix also accounts for nearly half of the NUE difference between China and the USA (Zhang et al., 2015, p. 55). Thus technological efforts to increase yields without increasing fertilizer use for different types of crops—especially among the most nitrogen-inefficient crops—must become a key component of global strategies to improve agricultural sustainability (Zhang et al., 2015, p. 55).

FOCUS 14-2 FEEDING THE WORD WELL: HUMAN NUTRITION INDICATORS

Stephen Wood, The Nature Conservancy; Yale School of Forestry & Environmental Studies

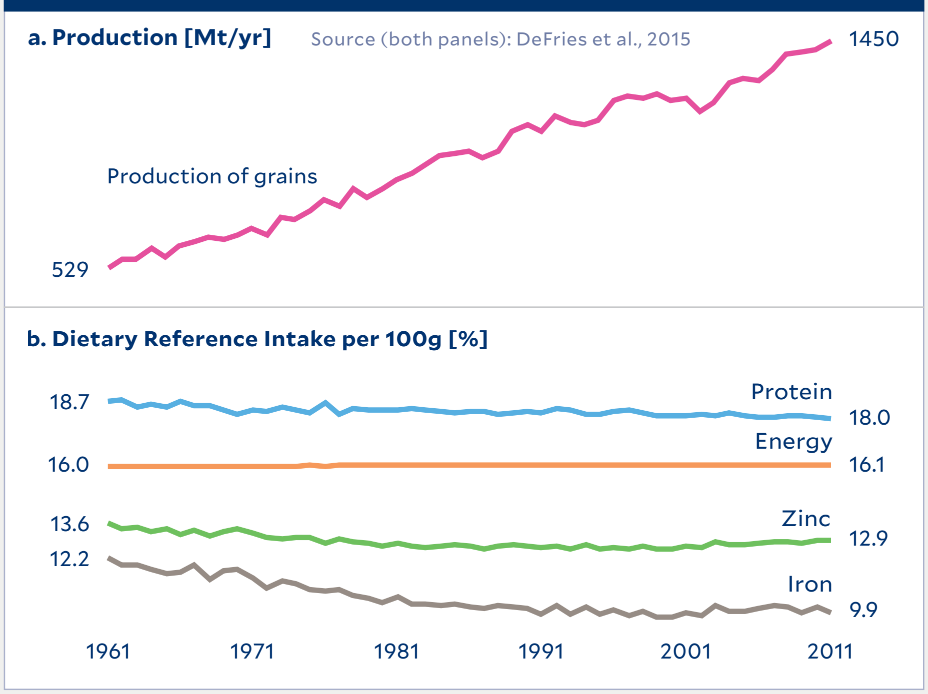
Global crop yields, and the ability to meet caloric needs, have risen dramatically since the mid-20th century. Yet crop yield — the most common metric of agricultural efficiency — is not necessarily a good proxy for the more than 50 nutrients needed in a balanced human diet. In fact, crop nutrient production was stagnant or declining while yields increased through the 20th century; see Figure 14-3 below. If the challenge of the 20th century was to feed the world, the challenge of the 21st century is to feed the world well, while minimizing impact on the environment.

In our team's work, we have shown that nutrient diversity in national food supplies can be as important to nutrition-related health outcomes as total caloric availability (Remans, Wood, Saha, Anderman, & DeFries, 2014). There is growing consensus that optimizing food systems for micro- and macro-nutrients could more effectively address hunger and undernutrition than strictly increasing total food production (Cassidy, West, Gerber, & Foley, 2013; DeFries et al., 2015, 2016; Negin, Remans, Karuti, & Fanzo, 2009; Remans et al., 2014). In recognition of this shift in attention, we have developed new diversity metrics to understand global and national patterns in diversity of food nutrients (DeFries et al., 2015, 2016; Remans et al., 2014; Wood, 2018; Wood, Smith, Fanzo, Remans, & DeFries, 2018). Understanding the nutritional deficiencies of food systems is essential to targeting the appropriate environmental footprint of agriculture so that both human and environmental needs are met.

What are the indicators?

Nutritional yield is the number of people whose nutrient needs could be met per hectare, for a specific crop and nutrient combination. It is calculated by multiplying the amount of a crop produced by the content of a particular nutrient for that crop and the dietary requirements for that nutrient. The advantage of this metric is its simple interpretation. A shortcoming is that it is not easily applied to systems with many food items and many nutrients since it is calculated on a per-nutrient-per-food-item basis. Potential nutrient adequacy is a single score that can be used to describe an entire food system, which is its advantage. To calculate potential nutrient adequacy, the nutrient content for all food items grown in a country is summed to get the total number of people whose nutritional needs could be met. Then the average value across all nutrients is multiplied by the fraction of nutrients for which more than 100% of the country's population can have their nutrient needs met. The score is therefore a combination of the magnitude of nutrient adequacy, i.e., average value across all nutrients, and the number of nutrients for which there is adequacy, i.e., fraction of nutrients potentially meeting > 100% needs. This reflects both that a population needs to meet multiple nutrients simultaneously, and that providing more nutrients can nourish more people. These metrics align with the goal of sustainable agriculture, which is to optimize potential nutrient adequacy rather than maximize total yield, while minimizing degradation of natural resources.

FIGURE 14-3 WHILE GLOBAL STAPLE GRAIN YIELDS HAVE INCREASED (A), NUTRITIONAL PRODUCTION HAS STAGNATED OR DECREASED (B)



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ABBREVIATIONS

BLL Blood lead level

CAIT Climate Analysis Indicators Tool (WRI)

CBD Convention on Biological Diversity

CDIAC Carbon Dioxide Information Analysis Center

CFP Common Fisheries Policy (EU)

CH_4 Methane

CIA Central Intelligence Agency (US)

CIESIN Center for International Earth Science Information Network

CO_2 Carbon dioxide

COP Conference of the Parties (UNFCCC)

CSIRO Commonwealth Scientific and Industrial Research Organisation (Australia)

DALY Disability-adjusted life-year

EBFM Ecosystem-based fisheries management

EDGAR Emissions Database for Global Atmospheric Research

EEZ Exclusive Economic Zone

EIA Energy Information Administration (US)

EPA Environmental Protection Administration (US)

EPI Environmental Performance Index

ESI Environmental Sustainability Index

EU European Union

FAO Food and Agriculture Organization (UN)

FAOSTAT FAO's Corporate Statistical Database

G-20 Group of Twenty

G7 Group of Seven

GBD Global Burden of Disease

GDP Gross domestic product

GFW Global Forest Watch (WRI)

Gg Gigagrams

GHG Greenhouse gas

GWP Global warming potential

HAP Household air pollution

IEA International Energy Agency

IHME Institute for Health Metrics and Evaluation

IMF International Monetary Fund

INDC Intended Nationally Determined Contribution

IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC Intergovernmental Panel on Climate Change

IRENA International Renewable Energy Agency

IUCN International Union for Conservation of Nature

IUU Illegal, unreported, and unregulated (fishing)

JMP Joint Monitoring Program for Water Supply and Sanitation

kWh Kilowatt-hours

LUCF Land use change and forestry

LDCs Least Developed Countries

LPG Liquified Petroleum Gas

MDG Millennium Development Goal

MENA Middle East and North Africa

MODIS Moderate-resolution imaging spectroradiometer

MPA Marine Protected Area

MTI Marine Trophic Index

N Nitrogen

N_2O Nitrous oxide

NASA National Aeronautics and Space Administration (US)

NDC Nationally Determined Contributions

NO_2 Nitrogen dioxide

NO_x Nitrogen oxides

NOAA National Oceanic and Atmospheric Administration (US)

NUE Nitrogen use efficiency

OECD Organization for Economic Co-operation and Development

PA Protected area

PARI Protected Area Representativeness Index

PM Particulate matter

$PM_{2.5}$ Particulate matter having a diameter ≤ 2.5 microns

PRC People's Republic of China

REDD+ Reducing Emissions from Deforestation and Forest Degradation

RMTI Regional Marine Trophic Index

SAU Sea Around Us

SHI Species Habitat Index

SIDS Small Island Developing States

SDG Sustainable Development Goal

SNMI Sustainable Nitrogen Management Index

SO_2 Sulfur dioxide

SO_x Sulfur oxides

SOFIA State of World Fisheries and Aquaculture

SPI Species Protection Index

Tg Teragram

UN United Nations

UNEP United Nations Environment Programme

UNESCO United Nations Educational, Scientific, and Cultural Organization

UNICEF United Nations Children's Fund

UNFCCC United Nations Framework Convention on Climate Change

UNSD United Nations Statistics Division

US Unites States

USGS United States Geological Survey

VOC Volatile organic compound

WB World Bank

WCMC World Conservation Monitoring Centre

WDPA World Database on Protected Areas

WEF World Economic Forum

WHO World Health Organization

WMO World Meteorological Organization

WRI World Resources Institute

WWAP World Water Assessment Program (UNESCO)

WWF World Wildlife Fund for Nature

YALE CENTER FOR ENVIRONMENTAL LAW & POLICY

The Yale Center for Environmental Law & Policy advances fresh thinking and analytically rigorous approaches to environmental decisionmaking across disciplines, sectors, and boundaries. In addition to its research activities, the center aims to serve as a locus for connection and collaboration by all members of the Yale University community who are interested in environmental law and policy issues. The center supports a wide-ranging program of teaching, research, and outreach on local, regional, national, and global pollution control and natural resource management issues. These efforts involve faculty, staff, and student collaboration and are aimed at shaping academic thinking and policymaking in the public, private, and NGO sectors.

CIESIN

The Center for International Earth Science Information Network (CIESIN) is part of the Earth Institute at Columbia University. CIESIN works at the intersection of the social, natural, and information sciences, and specializes in online data and information management, spatial data integration and training, and interdisciplinary research related to human interactions in the environment. Since 1989, scientists, decision-makers, and the public have relied on the information resources at CIESIN to better understand the changing relationship between human beings and the environment. From its offices at Columbia's Lamont-Doherty Earth Observatory campus in Palisades, New York, CIESIN continues to focus on applying state-of-the-art information technology to pressing interdisciplinary data, information, and research problems related to human interactions in the environment.

WORLD ECONOMIC FORUM

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation. The Forum engages the foremost political, business, and other leaders of society to shape global, regional, and industry agendas. Its activities are shaped by a unique institutional culture founded on the stakeholder theory, which asserts that an organization is accountable to all parts of society. The institution carefully blends and balances the best of many kinds of organizations, from both the public and private sectors, international organizations, and academic institutions.

McCALL MacBAIN FOUNDATION

The McCall MacBain Foundation is based in Geneva, Switzerland, and was founded by John and Marcy McCall MacBain. Its mission is to improve the welfare of humanity through focused grants in education, health, and the environment. Believing that strong, dedicated, and creative leadership are required in these areas to achieve positive outcomes, much of its funding is designed to identify and support individuals having such qualities.

MARK T. DEANGELIS

Mark DeAngelis is a former finance professional and currently devotes his time to philanthropic endeavors. Mr. DeAngelis spent 17 years in various positions in the finance industry after graduating from Yale in 1992 with a B.A. in sociology. From 2004 until 2008, he ran the U.S. research office for International Asset Management, a multi-billion dollar hedge fund of funds based in London. Mr. DeAngelis became a Trustee of the Nature Conservancy's (TNC) New Jersey chapter in 2012 and currently serves as its Board Chair.

DISCLAIMER

The 2018 Environmental Performance Index tracks national environmental results on a quantitative basis, measuring proximity to policy targets using the best data available. Data constraints and methodological considerations make this a work in progress. Please refer to the Technical Appendix and other materials at https://epi.yale.edu for documentation of our methods, assumptions, and decisions. Comments, suggestions, feedback, and referrals to better data sources are welcome at epi@yale.edu.

We use the word *country* loosely in this report to refer to both countries and other administrative or economic entities. Similarly, the maps presented are for illustrative purposes and do not imply any political preference in cases where territory is under dispute.

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