

A fuzzy approach to sustainability II: The 2030 Agenda for Sustainable Development

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We use a t -measure derived from fuzzy logic to evaluate progress towards the 2030 Agenda for Sustainable Development adopted by the United Nations Member States. In the first of this two-part series, we examined each of the Sustainable Development Goals individually. We now build a composite index score for 163 countries using the t -measure to examine their progress towards the Sustainable Development Goals as a whole, rank them, and examine the characteristics of highly performing and of poorly performing countries. We also study the impact of income category and region on progress towards the Goals.

Keywords: Sustainable Development Goals; fuzzy mathematics

1. Introduction

The 2030 Agenda for Sustainable Development is a set of Sustainable Development Goals (SDGs) adopted by the United Nations Member States in 2015 as a successor to the Millennium Development Goals. The 17 Goals encompass a variety of emphasis areas related to advancing the environmental, social, and economic status of the world in a way that can be sustained over time. The Goals include eliminating deprivation in all its forms, ensuring fair access to necessary resources, and supporting the health of the environment.¹

The UN Secretary-General issues an annual SDG Progress Report prepared by the UN Department of Economic and Social Affairs which summarizes current status of the Goals in countries around the world.² Every 4 years starting in 2019, an independent group of scientists appointed by the Secretary-General produces the Global Sustainable Development Report, which weighs the evidence, analyzes the challenges, and makes recommendations where appropriate.³

In the first part of this two-article series,⁴ we applied a measure inspired by fuzzy math to study progress in the 17 individual Goal areas for 163 countries. We assigned scores called the t -scores and analyzed trends over the period from 2000

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to 2022. In this work, we will examine world progress towards the Goals considered as a whole; we will assign index t -scores to each country to assess their overall progress in the Agenda and rank them, and we will do the same for several regions and income categories.

Outline

In Section 2, we briefly review the dataset, our data processing, and the t -score derived from fuzzy math. In Section 3, we create an index t -score for 163 countries and examine the highest and lowest ranked countries and their characteristics (a full list of the 2022 index t -scores is given in the Appendix). In Section 4, we examine trends in the index t -scores from 2000 to 2022 and discuss the positively trending, negatively trending, and most volatile non-trending countries. Finally, in Sections 5 and 6, we calculate the Goal t -scores and index t -scores for 8 regions and 4 income categories to evaluate progress towards the 2030 Agenda, highlighting any areas where each region or income category is excelling or struggling and identifying commonalities across categories. We reflect on worldwide progress towards the Agenda.

2. Data and Calculations

See the first part of this series⁴ for full details on the dataset and calculations.

2.1. The dataset

The 2030 Agenda defined targets for each Goal,¹ and the Inter-Agency and Expert Group on Sustainable Development Goal Indicators promulgates a Global Indicator Framework to be used to judge progress in each Goal area.⁵ Due to the limitations of existing widespread data collection systems (or lack thereof), the annual SDG Progress Report is based on a set of variables which approximating these indicators but does not match them exactly. The variables and their data are available in the Global SDG Indicators Database,⁶ which is also the basis of the annual SDG Progress Report and quadrennial Global Sustainable Development Report.

2.2. The t -scores

We study the dataset using a measure inspired by fuzzy math. If S is a set of values between 0 and 100, then the t -measure of the set is:

$$t(S) = \begin{cases} \max\{s : s \in S\} & \text{if all } s < 50 \\ \min\{s : s \in S\} & \text{if all } s > 50 \\ 50 & \text{else} \end{cases}$$

Each of the variables in our dataset is a score normalized to fall between 0 (representing the 2.5th percentile of the distribution) and 100 (representing accomplishment of a target). The SDG Progress Reports combine these variables into

Goal scores by averaging. We can instead apply the t -measure to the variables to generate a number we will call the Goal t -score. For a country succeeding in an area, where all variables are high, then the t -score captures the lowest or lagging variable; for a country struggling, it captures the highest or leading variable; for a country with mixed high and low variables, it returns a placeholder score of 50.

As we saw in the first half of this article series,⁴ the t -score can be a valuable tool for time-series analysis: it can highlight subtle trends and detect movement of a single variable out of a set. This is not guaranteed; e.g., if the lowest in a set of low variables begins to climb, it will not be detected until after it has passed the others. That said, we saw in the previous article a number of cases where the t -score detected a climb more strongly than a traditional mean.

2.3. Calculations

We calculate a linear regression model to perform time-series analysis. We consider a t -score to show a positive (respectively, negative) trend if its regression slope is at least 0.1 (resp., at most -0.1) and if its coefficient of correlation is at least 0.6 (resp., at most -0.6). For countries whose index t -scores do not show trends, we will calculate standard deviation of the scores over time to assess their stability.

To understand regional and economic factors, we will generate an average Goal t -score for each region and each income group which is weighted by population.

To see an overhead view of progress across country borders, we will also generate an index t -score and a rank for each individual country and region or income category using an unweighted average of the Goal t -scores.

2.4. Data processing

We use the version of the database from the time of the 2022 SDG Progress Report. It includes 95 variables for 163 countries along with composite variables for 8 regional and 4 income categories (and incomplete data for 30 more countries and 1 more region).

A number of countries are missing data for an individual variable. We have imputed this data where possible from the average of its region/income category; where this may have changed a Goal t -score, we omitted the country from consideration in our previous time-series analysis,⁴ but we use those data here for the purpose of studying larger patterns through the index t -scores. Where it was necessary to impute missing data for region or income categories, we have followed the practices of the SDG Progress Reports and averaged the available countries' variables, weighted based on population. Note that we have calculated the index t -scores of groups by first averaging the relevant countries' variables (weighted by population) to generate variables for the groups and then applying the t -measure, not vice versa (applying the t -measure first and then averaging could result in a different score if, say, countries have different variables realized by the t -score).

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3. A Ranking for Sustainability

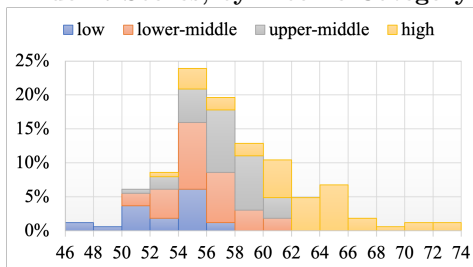
We calculate first an overall Sustainability score and rank for each country based on its 2022 *t*-scores for each of the Sustainable Development Goals. Our ranking agrees with the 2022 SDG Progress Report (within 10 places) for 80 of 163 countries (49.1%). At the other extreme, we rank Macedonia, New Zealand, Nicaragua, Cuba, Uzbekistan, Iran, and Brunei more than 40 places lower and Nepal, Afghanistan, Namibia, Nigeria, Lebanon, Yemen, Niger, and Syria more than 40 higher.

The Appendix gives a full list of the 163 countries, with their index *t*-scores and rank as well as trend and correlation or, if there is no trend, standard deviation. We also include the difference between our rank and the SDG Progress Report’s rank.

3.1. Distribution

We include a histogram of the index *t*-scores subdivided by income category. The distribution is approximately symmetric, centered in the 54-56 point range and skewed right. The individual income category distributions are similar, with center shifted right with higher income (high-income peaks in the 59-64 range, upper-middle-income in 54-58, lower-middle income in 54-56, and low-income in 50-54). This is consistent with the fact that several of the Goal *t*-scores were associated to income category:⁴ several Goals related to access to resources and fairness positively (Goals 1, 3-5, 7, 9, 11), and 3 of the 4 environmental Goals negatively (Goals 12-14).

Proportion of Countries with 2022 Index *t*-Scores, by Income Category



3.2. Highest Ranked Countries

The top 10 index *t*-scores came from high-income OECD countries, just as in the 2022 SDG Progress Report ranking; in fact, 7 of the same countries appeared, and the others were previously ranked top 25. Compared to the world average Goal *t*-scores, these countries did outstandingly well in the Goals associated to income. The other countries in the 2022 SDG Progress Report’s top 10 were France, Ireland, and Estonia, which ranked 11, 14, and 12 by *t*-index.

We graph the Goal *t*-scores for the top 5 countries, and we compare performance of the top 10 to the world by averaging the Goal *t*-scores, weighted by population.

Highest 2022 Index <i>t</i> -Scores			
	<i>t</i> -score	rank	(change)
Denmark	72.74	1	(1)
Sweden	72.42	2	(1)
Finland	71.34	3	(-2)
Norway	70.78	4	(0)
Austria	69.54	5	(0)
Iceland	67.68	6	(16)
Switzerland	67.08	7	(1)
Germany	66.88	8	(-2)
Czech Rep.	65.66	9	(4)
Belgium	65.63	10	(8)

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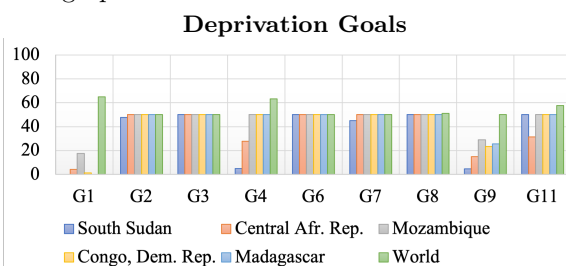
3.3. Lowest Ranked Countries

The bottom 10 countries by index *t*-score were all low- or lower-middle-income in sub-Saharan Africa. Zambia, Mozambique, and Burundi ranked noticeably worse than in the 2022 SDG Progress Report, and Congo slightly worse, while the other 6 were ranked very similarly. The other countries in the SDG Report’s bottom 10 were Chad, Sudan, Liberia, and Djibouti, which ranked 153, 124, 136, and 146 here. We include a table of the bottom 10, compare the group’s

Lowest 2022 Index <i>t</i> -Scores			
	<i>t</i> -score	rank	(change)
Congo, Rep.	51.34	154	(-6)
Angola	51.20	155	(-1)
Zambia	51.08	156	(-16)
Madagascar	50.88	157	(-1)
Congo, Dem. Rep.	50.84	158	(-1)
Mozambique	50.78	159	(-16)
Burundi	50.22	160	(-19)
Somalia	48.02	161	(-1)
Central Afr. Rep.	46.97	162	(0)
South Sudan	46.86	163	(0)

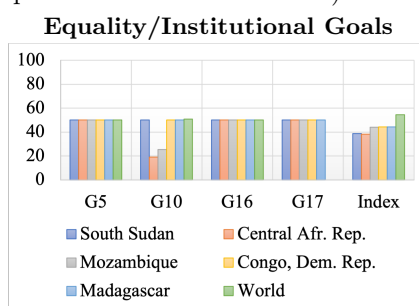
weighted average to the world’s, and graph the Goal *t*-scores for the bottom 5.

These countries performed near or below the world average in many of the Goals related to deprivation: in Goal 2 (No Hunger, where they all scored 50, the world average); in Goal 3 (Good Healthy and Well-Being, 50 vs 54.03); Goal

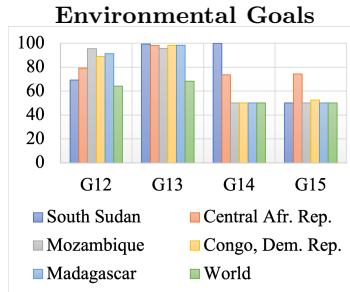


6 (Clean Water and Sanitation, 50 vs 52.02); Goal 7 (Affordable and Clean Energy, 50 vs 51.30); Goal 8 (Decent Work and Economic Growth, 50 vs 53.85); Goal 11 (Sustainable Cities and Communities, where the Central African Republic scored 31.31 and the others 50, comparable to the world at 54.35). In contrast, they performed poorly in Goal 1 (Zero Poverty, averaging 12.58 vs the world at 72.85); Goal 4 (Quality Education, where the world averaged 76.54, while Somalia scored 0.0, South Sudan 4.93, the Central Africa Republic 27.62, and the rest 50); Goal 9 (Industry, Innovation, and Infrastructure, where they ranged from Zambia at 50 to Somalia at 9.68, with an average of 26.33, compared to the world at 51.05).

These 10 countries were comparable to the world average in Goal 5 (Gender Equality, 49.84 vs 51.2), Goal 16 (Peace, Justice, and Strong Institutions, 50 vs 50.65), and Goal 17 (Partnership for the Goals, 50 vs 50.89). Their performance was inconsistent in Goal 10 (Reduced Inequalities): Somalia scored 53.85, near the world average of 56.19, with South Sudan, Burundi, Dem. Rep. of Congo, and Madagascar at 50, and the others ranging down to Zambia at 16.62.



These countries performed more strongly on the whole in Goals related to environmental impact: in Goal 12 (Responsible Consumption and Production), every country except South Sudan (69.26) outscored the world average of 74.12, themselves averaging 87.22; in Goal 13 (Climate Action), where they averaged 97.05 vs the world at 77.46; and in Goals 14 and 15 (Life below Water and Life on Land) where their averages of 50.00 and 51.92 were comparable to the world at 50.07 and 51.21.



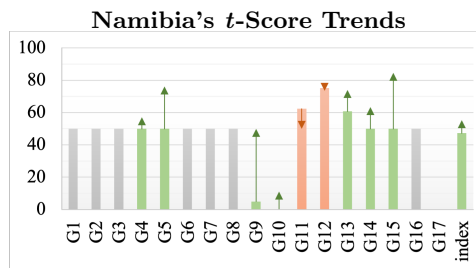
4. Trends in Sustainability

Positively Trending Countries

Of the 163 countries, 101 (62.0%) showed a positive trend, that is, a regression slope of at least 0.1 and correlation between year and index t -score with coefficient at least 0.6. We list the top 10 and discuss the time-series behavior of the top 5. They break into two groups: Estonia, Austria, and Germany started with high Goal t -scores and improved in at least half, while Namibia and Burkina Faso started with several low t -scores, and a few improved, especially low ones.

	2022 t -score	trend	correl.
Namibia	55.29	0.48	0.960
Estonia	65.35	0.44	0.955
Austria	69.54	0.38	0.933
Germany	66.88	0.36	0.953
Burkina Faso	54.72	0.36	0.946
Dominican Rep.	59.70	0.35	0.952
Finland	71.34	0.34	0.924
Maldives	60.27	0.34	0.964
Norway	70.78	0.34	0.963

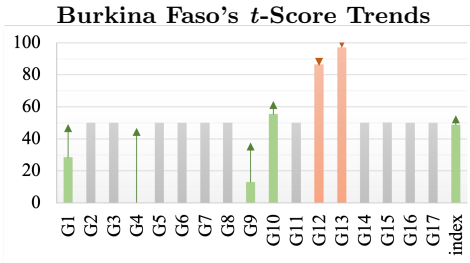
Namibia started with 3 lagging Goals, 2 of which climbed as the t -score tracked improvements in the leading variables: Goal 9 (Industry, Innovation, and Infrastructure) rose from 4.91 to 50 as internet and mobile broadband usage rose, Goal 10 (Reduced Inequalities) from 0 to 10.99. Another 3 started



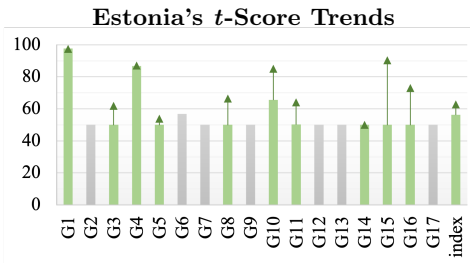
at 50 and improved as they tracked the lagging variables: Goals 14 and 15 (Life below Water, Life on Land) rose by 13.47 and 34.67 points respectively with increases in area under preservation, and Goal 5 (Gender Equality) by 26.24 points, tracking women in parliament. Additionally, Goal 13 (Climate Action) saw a net increase of 13.34 points, following variations in its lagging CO₂ emissions variable. There was also a drop in Goal 11 (Sustainable Cities and Communities) from 62.30 to 50 when public transportation fell sharply. Finally, Goals 4 (Quality Education) and 12 (Responsible Consumption and Production) saw variations less than 10 points.

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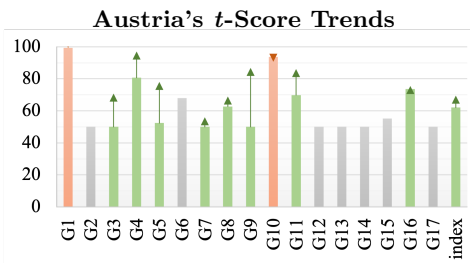
Burkina Faso also started with 3 lagging Goals, all of which improved significantly: the *t*-score rose by 20.69 in Goal 1 (No Poverty), by 46.96 in Goal 4 (Quality Education, as 3 of its 4 variables moved positively as a group), and by 24.63 in Goal 9 (Industry, Innovation, and Infrastructure, due to improvements in trade and transportation infrastructure). It saw variations less than 10 points also in Goals 7 (Clean and Affordable Energy), 10 (Reduced Inequalities), 12 (Responsible Consumption and Production), and 13 (Climate Action).



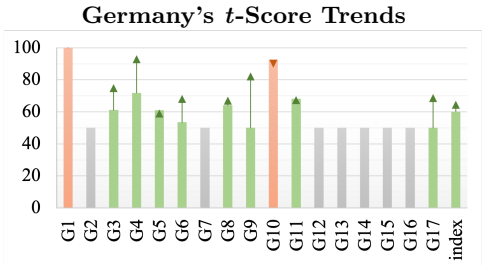
Alone in this group, Estonia saw no negative trends; all *t*-scores started at 50 or above, so changes were due to a lagging variable or variables catching up with the group. Two Goals climbed out of the mixed score of 50 as variables lagging below 50 caught up to the others: Goal 15 (Life on Land, by 42.90, as freshwater and land area under preservation climbed from very low scores into the 90s), as did Goal 16 (Peace, Justice, and Strong Institutions, by 25.44, due to improved perceptions of safety). Smaller improvements appeared in Goal 10 (Reduced Inequalities, 21.87 points), Goal 8 (Decent Work and Economic Growth, by 18.91 due to unemployment), Goal 3 (Good Health and Well-Being, by 14.40 due to cardiovascular disease), and Goal 11 (Sustainable Cities and Communities, by 15.23, due to public transportation). Finally, Goals 5 (Gender Equality) and 14 (Life below Water) saw increases under 10 points.



Austria performed nearly as well as Estonia. Two Goals exited the 50 range and climbed, Goal 9 (Industry, Innovation, and Infrastructure, improving by 36.78 points following internet and mobile broadband use) and Goal 3 (Good Health and Well-Being, by 20.87 following access to healthcare). There were also improvements in Goal 5 (Gender Equality, by 25.75, following women in parliament), Goal 4 (Quality Education, by 16.48, following early education participation), and Goal 11 (Sustainable Cities and Communities, by 16.23, following public transportation). There were minor changes under 10 points in Goals 1 (No Poverty), 7 (Clean and Affordable Energy), 8 (Decent Work and Economic Growth), 10 (Reduced Inequalities), and 16 (Peace, Justice, and Strong Institutions).



Germany also saw large movement in 2 *t*-scores of 50: Goal 9 (Industry, Innovation, and Infrastructure, by 34.68, following internet and mobile broadband usage) and Goal 17 (Partnership for the Goals, by 21.22, following development assistance given to other countries). There were also climbs in Goal 4 (Quality Education, by 23.54, following early education participation), Goal 6 (Clean Water and Sanitation, by 17.12, following strain on freshwater reserves), and Goal 3 (Good Health and Well-Being, by 16.18, following health care access) and movement under 10 points in Goals 1 (No Poverty), 8 (Decent Work and Economic Growth), 10 (Reduced Inequalities), and 11 (Sustainable Cities and Communities).

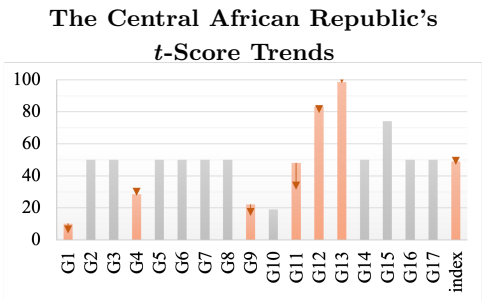


Negatively Trending Countries

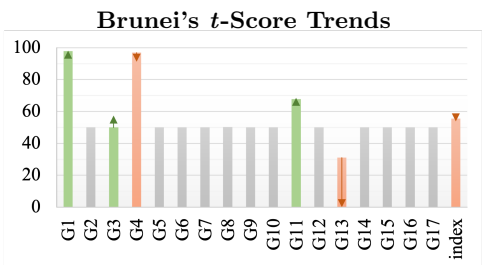
In our previous analysis,⁴ we used a regression slope of -0.1 as a hard cutoff for a negative trend. No countries in the dataset displayed such a trend in index *t*-scores, but 2 (or 1.2%) were within rounding error, both with moderately strong correlation.

Negative Trends in Index <i>t</i> -Scores			
	2022 <i>t</i> -score	trend	correl.
Brunei	54.11	-0.097	-0.746
Central Afr. Rep.	46.78	-0.099	-0.793

The Central African Republic showed the most negative trend, from 49.07 in 2000 to 46.97 in 2022 due mainly to a decrease in Goal 11 (Sustainable Cities and Communities, a change of -16.77 due to a drop in the top 2 variables, small particulate pollution and water access). There were smaller decreases of fewer than 10 points in in Goals 9 (Industry, Innovation, and Infrastructure), 1 (No Poverty), 12 (Responsible Consumption and Production), 4 (Quality Education), and 13 (Climate Action).



Brunei Darussalem's index *t*-score also displayed a negative trend, descending unevenly from 55.53 in 2000 to 53.87 in 2022, primarily reflecting a crash in Goal 13 (Climate Action, as its only nonzero variable fell from 31.10 to 0, CO₂ emission from fossil fuels and construction). This was accompanied by changes under 10 points in Goal 4 (Quality Education), 3 (Good Health and Well-Being), 1 (No Poverty), and 11 (Sustainable Cities and Communities).

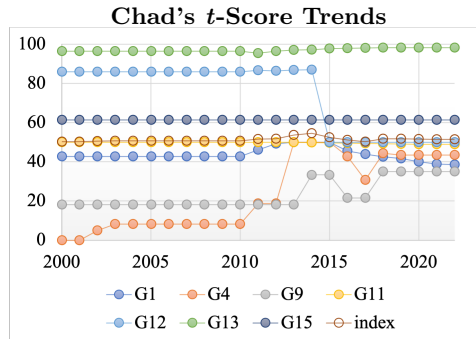


Highly Variable Countries

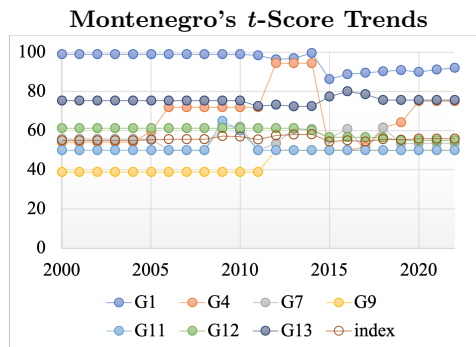
For the 60 of 163 (36.8%) of countries remaining, those with linear regression slopes between -0.1 and 0.1 , we do not consider the correlation coefficient as it may be misleading for such shallow slopes. Instead, we examine variability: the middle 50% of these countries had standard deviation between 0.694 and 0.870. We will graph and discuss the 5 countries with standard deviation near 1 (note: for readability, we omit from the graph all variables stable between 45.00 and 55.00). In general, they displayed more abrupt changes in Goal t -scores than the trending countries described above, and the changes in different variables were sometimes contradictory.

Highly Variable Index t -Scores			
	min.	max.	st. dev.
Chad	50.28	54.63	1.072
Montenegro	54.48	58.08	1.066
Venezuela, RB	51.95	55.07	1.018
Kazakhstan	57.36	60.24	0.982
Zambia	54.09	56.62	0.972

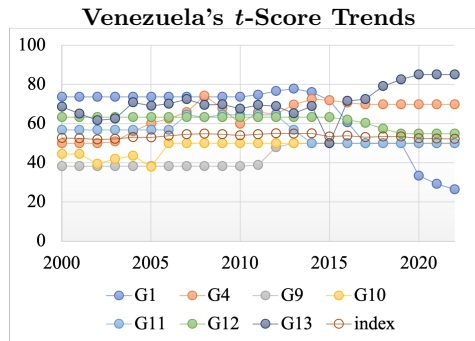
Chad’s index t -score displayed the highest standard deviation, primarily due to Goal 4 (Quality Education, which rose from 0 to peak at 50 and end at 43.39 following the only non-zero variable, primary education) and Goal 12 (Responsible Consumption and Production, which dropped from 85.99 to 50 in 2015 as a single variable crashed, reactive nitrogen from production). Additional instability arose from Goal 1 (No Poverty, from 42.76 to 50 then to 38.62) and Goal 9 (Industry, Innovation, and Infrastructure, from 18.18 to 35.09 tracking a single strongly leading variable, trade and transportation infrastructure).



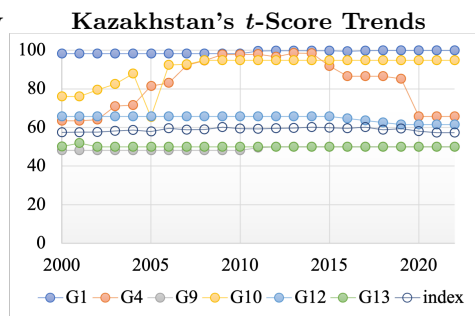
The primary driver of instability for Montenegro was Goal 4 (Quality Education), where 2 of the participation variables varied widely (early education between 42.35 and 100, secondary education between 71.93 and 96.00). Goal 9 (Industry, Innovation, and Infrastructure) also contributed: it started at 38.82, the only Goal below 50, and jumped to 50 in 2012 when internet usage soared. Goals 1 (No Poverty), 7 (Clean and Affordable Energy), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production) also varied slightly.



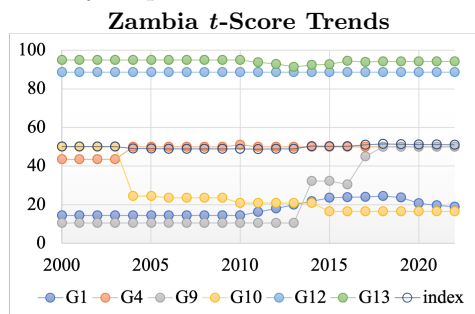
Venezuela's Goals were grouped more tightly and behaved more unpredictably, primarily because individual variables changed abruptly and not in concert. The biggest movement occurred in Goal 1 (No Poverty, from 77.81 to 26.38). Goal 13 (Climate Action) varied between 85.13 and 61.61, tracking CO₂ emissions from fossil fuels and combustion, with one outlier year at 50 due to CO₂ emissions from imports. Goal 4 (Quality Education) climbed unsteadily from 50 to 69.80 as secondary education increased smoothly but the other two education participation variables varied unpredictably. Goal 11 (Sustainable Cities and Communities) went from 56.82 to 64.44 then to 50 when public transportation crashed from 74.68 to 0. Goal 9 (Industry, Innovation, and Infrastructure) climbed from 38.27 to 50, initially tracking the trade and transportation infrastructure but then internet and mobile broadband use. Finally, Goal 10 (Reduced Inequalities) and Goal 12 (Responsible Consumption and Production) varied less than 10 points.



Kazakhstan's distribution was slightly higher with variability due primarily to Goal 4 (Quality Education, which climbed from 63.44 to 97.97 as early education rose and then fell to 65.76 as primary education dropped) and Goal 11 (Sustainable Cities and Communities, which tracked public transportation from 74.68 to 50). Additionally, Goal 10 (Reduced Inequalities) climbed smoothly from 76.06 to 94.81, with a momentary drop to 65.35 in 2005.



Zambia, like Chad, started with 3 variable t-scores below 50 and 2 above. Goal 10 (Reduced Inequalities) dropped 43.38 points with an aggressive drop in 2004 (from 50 to 24.51) and a continued decline to 16.62, while Goal 9 (Industry, Innovation, and Infrastructure) increased quickly between 2013 and 2018 (from 10.59 to 50). Additionally, there was slight unsteadiness in Goal 1 (No Poverty), Goal 4 (Quality Education), and Goal 13 (Climate Action).



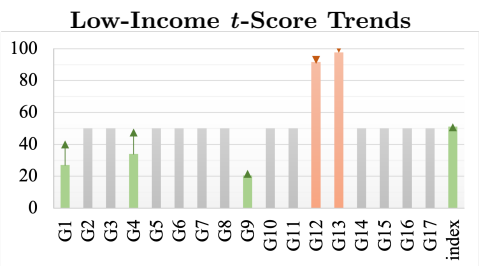
5. Sustainability and Income Category

When we studied the distributions of individual Goals in our previous work,⁴ we saw that several were associated to income category. We may further examine these patterns from a different perspective by assigning each income category its own *t*-scores: the database

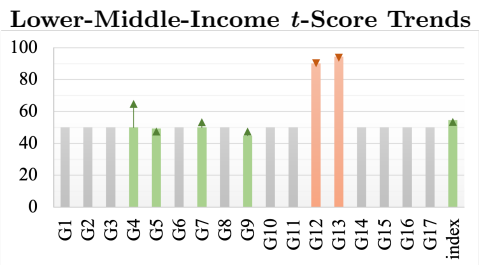
	2022 <i>t</i> -score	trend	correl.
Low	53.21	0.10	0.971
Lower-Middle	56.01	0.07	0.968
Upper-Middle	57.33	0.16	0.898
High	61.15	0.17	0.972

contains variables for them, the average of the countries' variables weighted by population. Since these are weighted averages, a small movement is more indicative of a trend than a larger movement would be for a single country.

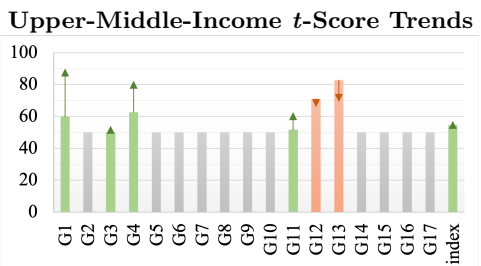
The low-income category started with only 2 Goals above 50, both of which dropped fewer than 5 points: Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action). Additionally, the 3 Goals under 50 grew: Goal 1 (No Poverty, by 15.49 points, from 27.11 to 42.60); Goal 4 (Quality Education, by 16.03 points, from 33.97 to 50 following participation in primary education); and Goal 9 (Industry, Innovation, and Infrastructure, by less than 5 points). The index *t*-score grew 1.97 points.



The lower-middle-income category started with most Goals at 50, except for Goals 12 (Responsible Consumption and Production) and 13 (Climate Action), which started in the 90s but dropped slightly, fewer than 5 points. Goal 4 (Quality Education) grew 17.32 points from 50 to 67.32 when all participation rates grew (and the *t*-score tracked the lowest, secondary education), and Goals 5 (Gender Equality), 7 (Affordable and Clean Energy), and 9 (Industry, Innovation, and Infrastructure) all grew less than 10 points. The index *t*-score for this category increased 1.38 points.

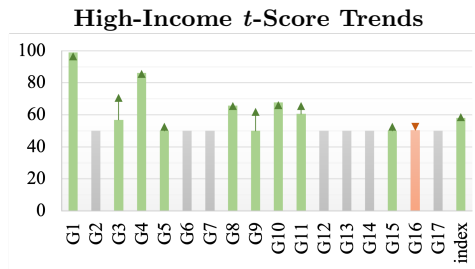


The upper-middle-income category started with 4 Goals above 50: 2 grew, Goal 1 (No Poverty, by 30.29 points, from 59.85 to 90.14) and Goal 4 (Quality Education, by 19.67, from 62.68 to 82.54, following primary education); the others dropped, Goal 13 (Climate Action, by 13.68 points from 82.80 to

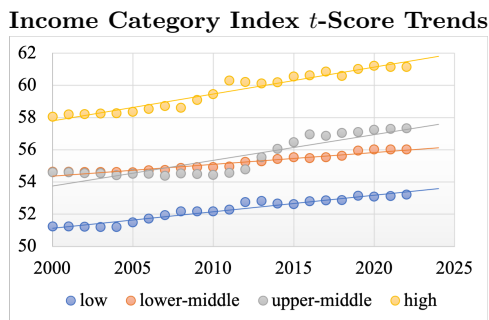


69.12 following CO₂ emissions from fossil fuels and construction) and Goal 12 (Responsible Consumption and Production, by less than 10 points). There were small increases in Goal 11 (Sustainable Cities and Communities, by 11.01 points from 51.71 to 62.72 as small particle pollution improved), and Goal 3 (Good Health and Well-Being, by less than 5 points). The index *t*-score grew 2.73 points.

The high-income category started with 6 Goals well above 50, and they all grew: Goal 3 (Good Health and Well-Being) by 16.18 points (from 56.92 to 73.10 following an improvement in healthcare access), and Goals 1 (No Poverty), 4 (Quality Education), 8 (Decent Work and Economic Growth), 10 (Reduced Inequalities), and 11 (Sustainable Cities and Communities) by less than 10 points. Several of the Goals at 50 also grew, Goal 9 (Industry, Innovation, and Infrastructure, by 14.46 points from 50 to 64.4 due to rise in internet and mobile broadband usage) and Goals 5 (Gender Equality) and 15 (Life on Land) by less than 10 points. Goal 16 (Peace, Justice, and Strong Institutions) started just above 50, at 50.54, and dropped to 50. The index *t*-score grew by 3.10 points.



There was enough variation within each income category that most Goals showed no distinct behavior based on income category, with a few exceptions. In Goal 1 (No Poverty), the upper-middle-income category grew aggressively and the low-income gently, though the other two categories did not. Goal 4 (Quality Education) saw the higher income categories grow more strongly, although the difference was less pronounced than it was when we examined Goal *t*-scores for individual countries.⁴ Goal 9 (Industry, Innovation, and Infrastructure) was more variable because the categories crossed over the mixed score of 50: low-income climbed slowly, lower-middle-income climbed to 50 and stalled, upper-middle-income stayed at 50, and high-income climbed away from 50. Goal 11 (Sustainable Cities and Communities) saw slightly better performance from the high-income category, while the upper-middle-income category vacillated but eventually climbed, and the others stayed at 50. Goal 12 (Responsible Consumption) and Goal 13 (Climate Action) were both strongly negatively correlated to income: the high-income category was stable at 50 in both, upper-middle-income was better scored but dropped, and lower-middle-income and low-income were both quite high and almost stable. Other Goals showing less distinct differences between categories were Goal 3 (Good Health and Well-Being) where the high-income category climbed



while the other categories were stalled near 50. Goals 8 (Decent Work and Economic Growth) and 10 (Reduced Inequalities) both similarly saw the high-income category stable in the upper 60s while the others sat at 50. Overall, the higher income categories saw greater growth in the Goal and index *t*-scores, in large part reflecting the fact that the lower-income categories had more variables captured at 50.

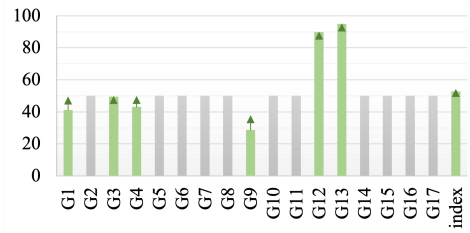
6. Sustainability and Geographic Region

We have noted a few regional associations with individual Goals in the first article of this series,⁴ but we now examine this possible relationship through the lens of population-weighted regional Goal *t*-scores and index *t*-scores.

Region Index <i>t</i> -Scores			
	2022 <i>t</i> -score	trend	correl.
Sub-Saharan Africa	54.29	0.08	0.972
Middle East/North Africa	54.85	0.03	0.651
East/South Asia	56.07	0.03	0.662
East Europe/Central Asia	60.73	0.10	0.892
Latin America/Caribbean	56.26	0.06	0.827
OECD members	60.60	0.13	0.980

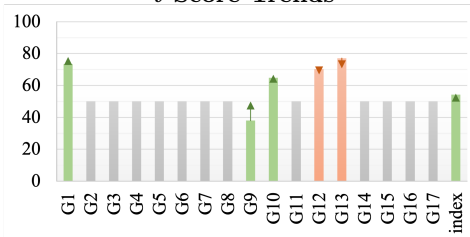
The weighted Sub-Saharan Africa started with 2 strong Goals, both of which improved slightly when a lagging indicator increased, Goal 12 (Sustainable Consumption and Production, from 89.90 to 90.11) and Goal 13 (Climate Action, from 94.95 to 95.25). The other 4 increases reflected a set of variables which climbed together, and two of these moved from a sub-50 score to the transition score of 50: Goal 1 (No Poverty, from 41.22 to 49.60), Goal 3 (Good Health and Well-Being, from 49.55 to 50; 9 of the 14 variables gained more than 20 points each, although a few lagged below 50), Goal 4 (Quality Education, from 43.13 to 50, where all 4 variables climbed more than 15 points), and Goal 9 (industry, Innovation, and Infrastructure, from 28.68 to 38.05, where 3 of 6 climbed more than 20 points).

Sub-Saharan Africa's *t*-Score Trends



The Middle East and North Africa started with 4 Goals above 50, 2 of which sank slightly, Goal 12 (Responsible Consumption and Production, from 70.27 to 66.99, when 6 of the 7 variables dropped) and Goal 13 (Climate Action, from 77.13 to 70.79, as CO₂ emissions from fossil fuels and construction rose). Three more climbed, including a big increase in the only one below 50: Goal 1 (No Poverty, 73.35 to 77.89), Goal 10 (Reduced Inequalities, from 64.92 to 66.75), and Goal 9 (Industry, Innovation, and

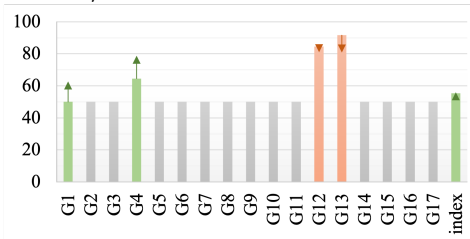
Middle East/North Africa's *t*-Score Trends



Infrastructure, from 38.00 to 50, which tracked trade and transport infrastructure much of the period, but internet and mobile broadband usage climbed from the single digits to around 70).

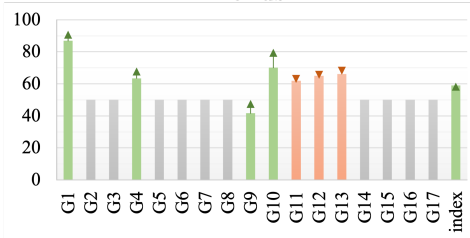
East and South Asia behaved much like the Middle East and North Africa, although the changes were more pronounced: Goal 12 (Sustainable Consumption and Production) dropped from 84.52 to 81.06 as its variables were all stable or slightly increasing except for the lagging variable, plastic waste, and Goal 13 (Climate Action) dropped from 91.59 to 80.77 as CO₂ emissions from fossil fuels and construction rose. The only other Goal above 50 rose, Goal 4 (Quality Education, from 64.58 to 78.76 - all variables rose together as a group, the slowest one climbing 14 points), as did Goal 1 (No Poverty, from 50 to 62.68).

East/South Asia's *t*-Score Trends



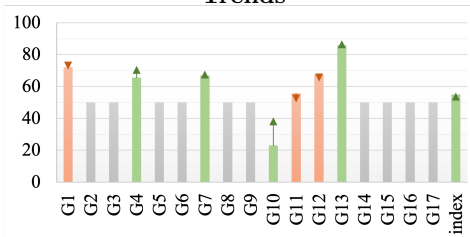
Eastern Europe and Central Asia started with only one Goal lower than 50, Goal 9 (Industry, Innovation, and Infrastructure, which rose from 41.66 to 50 as internet and mobile broadband usage outpaced the leading variables), along with 3 more above 50, Goal 1 (No Poverty, 86.88 to 93.25); Goal 4 (Quality Education, 63.42 to 70.17, as all 3 participation variables rose, in particular the lagging variable of early education); and especially Goal 10 (Reduced Inequalities, from 70.08 to 81.95). The remaining 3 Goals above 50 sank slightly, Goal 11 (Sustainable Cities and Communities, 62.01 to 60.51 due to a drop in slums from 67.62 to 60.51); Goal 12 (Responsible Consumption and Production, 64.99 to 63.12 following an increase in electronic waste); and Goal 13 (Climate Action, 66.15 to 65.73 as the lagging indicator sank, CO₂ emission from fossil fuels and construction). Note that Goal 14 (Life below Water) is tricky as most of the data have been imputed, which results in a stable reading at 50.

Eastern Europe/Central Asia's *t*-Score Trends



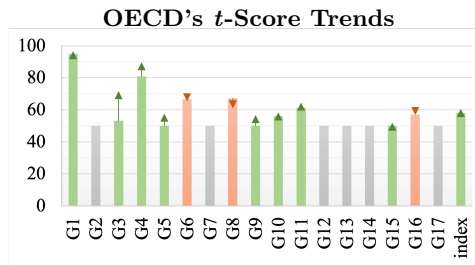
Latin America and the Caribbean started with a single lagging Goal, Goal 10 (Reduced Inequalities), which climbed strongly (from 23.04 to 40.68). Three more Goals climbed, Goal 4 (Quality Education, from 65.51 to 72.92 when 2 of the 3 participation variables climbed), Goal 7 (Affordable and Clean Energy, from 66.83 to 70.05 following a rise in renewables, although the other 3 variables climbed as well), and Goal 13

Latin America/Caribbean's *t*-Score Trends



(Climate Action, from 86.02 to 89.08 as 2 of the 3 CO₂ emission variables improved slightly). The final 3 Goals above 50 sank, Goal 1 (No Poverty, from 72.18 to 70.55), Goal 11 (Sustainable Cities and Communities, from 55.71 to 50 due to a drop in public transportation from 55.71 to 44.16), and Goal 12 (Responsible Consumption and Production, from 67.36 to 63.17 as electronic waste increased).

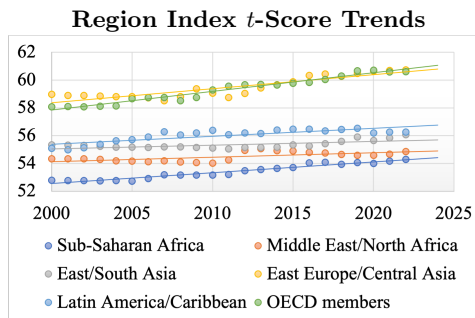
The Organization for Economic Co-operation and Development started with 7 Goal *t*-scores above 50 and the remaining at 50. Two grew aggressively: Goal 3 (Good Health and Well-Being, from 53.27 to 71.67 as health-care access improved: it was previously the lagging variable by more than 11 points) and



Goal 4 (Quality Education, from 80.96 to 89.72; all variables were high, but the lagging one, early education, improved slightly). Several others climbed slightly, Goal 1 (No Poverty, from 95.02 to 96.61), Goal 5 (Gender Equality, from 50 to 57.66 due to improvement in the single variable below 50, number of women in parliament), Goal 9 (Industry, Innovation, and Infrastructure from 50 to 56.76 as internet and mobile broadband usage improved from the 20s to above 80, while R&D funding also improved from 48.02 to 56.76), Goal 10 (Reduced Inequalities, from 56.19 to 58.32), and Goal 15 (Life on Land, from 50 to 51.97: both land and freshwater areas under preservation grew more than 25 points). Three more decreased slightly, Goal 6 (Clean Water and Sanitation, from 66.63 to 65.39 following its lagging variable of wastewater treatment), Goal 8 (Decent Work and Economic Growth, from 67.17 to 60.91 due to a drop in labor rights), and Goal 16 (Peace, Justice, and Strong Institutions, from 56.99 to 56.68 following the variable weapons exports).

We will not evaluate the trends for Oceania as only Fiji and Papua New Guinea had sufficient data to be included in the Goal analysis, so the sample size is too small to draw conclusions. Likewise, we will not discuss the Small and Developing Island States because its 30 countries do not have any historical data in the dataset.

Overall, all regions showed similar linear regression trends and moderately high correlation. Both OECD members and Eastern Europe and Central Asia began in the upper 50s and climbed assertively with trend at least 0.1. Following them were Latin America and the Caribbean, East and South Asia, the Middle East and North Africa, and sub-Saharan Africa, all climbing and well above 50. The individual Goals followed a similar pattern in many cases. Goal 1



(No Poverty) and Goal 10 (Reduced Inequalities) behaved like the index t -scores, with the exception that income inequality in Latin America and the Caribbean lagged far behind the other regions. Similarly, Goal 9 (Industry, Innovation, and Infrastructure) behaved like the index t -scores with a shallower regression slope, as did Goal 4 (Quality Education), although Eastern Europe and Central Asia performed at the bottom of the middle group rather than in the top one, and Goal 11 (Sustainable Cities and Communities), where the countries were more compressed in the 50-65 range. Goals 12 and 13 (Responsible Consumption and Production, Climate Action) both saw the inverse pattern of the index t -scores, with sub-Saharan Africa near 100 and OECD at 50.

The regions displayed more uniform behavior in the other Goals. The OECD stood out in Goal 3 (Good Health and Well-Being, 53.27 climbing to 71.67, vs steady at 50), Goal 6 (Clean Water and Sanitation, stable near 66, while the others were at 50), Goal 8 (Decent Work and Economic Growth, dropping from 67.17 to 60.91, while the others were at 50), and Goal 16 (Peace, Justice, and Strong Institutions, stable around 56, while the others were at 50). The OECD was slightly better than the others in Goal 5 (Gender Equality: it climbed from 50 to 57.7, while the others remained at 50). Latin America and the Caribbean stood out in Goal 7 (Clean and Affordable Energy, climbing slightly from 66.83 to 70.05, while the others were all at 50). The remaining Goals were indistinguishable among regions, all being at or near 50: Goals 2 (Good Health and Well-Being), 14 (Life below Water), 15 (Life on Land).

7. Conclusion

Overall, every income and regional category showed significant growth. Over 60% of countries showed a positive trend, that is, a slope of at least 0.1; that said, the strongest trend was less than 0.5, while meeting the 2030 Agenda and reaching the desired score of 100 in only 8 more years would require a slope of at least 3.41 even from Denmark, the highest ranked country. Our new index t -scores designate a group of OECD, high-income countries as the outstanding countries, all of them very strong in access to resources, of mixed performance in questions of equality, and performing in a mediocre fashion in climate and environmental areas. The countries ranked at the bottom were primarily low-income in sub-Saharan Africa, and many are well-studied for recent devastating geopolitical events outside the scope of this paper which surely have affected their status. The t -scores underline their biggest concerns, related to access to resources, and emphasize the importance of international support in addressing these issues in our interconnected world.

Acknowledgements

Many thanks to the researchers working tirelessly in both fuzzy math and sustainability studies who have provided the groundwork upon which we build.

Appendix

Country	2022 SDG Index			Trend		
	<i>t</i> -score	<i>t</i> -rank	(change)	slope	correl.	st.dev.
Afghanistan	56.55	90	(+57)	0.25	0.851	
Albania	60.04	43	(+18)	0.27	0.908	
Algeria	59.93	46	(+18)	0.15	0.906	
Angola	51.20	155	(-1)			0.850
Argentina	58.66	58	(-4)	0.15	0.927	
Armenia	56.13	97	(-31)			0.522
Australia	61.08	33	(+5)	0.28	0.965	
Austria	69.54	5	(+0)	0.38	0.933	
Azerbaijan	60.62	35	(+15)	0.2	0.953	
Bahrain	55.25	116	(-14)			0.544
Bangladesh	57.68	70	(+34)			0.594
Barbados	57.21	76	(-3)			0.600
Belarus	60.91	34	(+0)	0.11	0.861	
Belgium	65.63	10	(+8)	0.28	0.961	
Belize	55.82	102	(-2)	0.23	0.975	
Benin	53.61	141	(+12)			0.298
Bhutan	57.22	75	(-5)	0.29	0.940	
Bolivia	57.86	68	(+22)	0.28	0.967	
Bosnia & Herzegovina	56.56	89	(-30)			0.209
Botswana	51.79	151	(-35)	0.23	0.913	
Brazil	57.49	71	(-18)			0.717
Brunei Darussalam	53.87	138	(-45)			0.881
Bulgaria	57.44	72	(-30)	0.17	0.821	
Burkina Faso	54.72	129	(+9)	0.35	0.946	
Burundi	50.22	160	(-19)			0.595
Cambodia	55.09	118	(-11)			0.566
Cameroon	54.59	131	(+3)			0.537
Canada	62.16	26	(+3)			0.642
Central African Rep.	46.97	162	(+0)			0.843
Chad	51.51	153	(+8)			1.072
Chile	60.03	44	(-16)	0.2	0.916	
China	57.84	69	(-13)			0.861
Colombia	55.97	98	(-23)	0.1	0.801	
Congo, Dem. Rep.	50.84	158	(-1)			0.332
Congo, Rep.	51.34	154	(-6)			0.680
Costa Rica	59.48	49	(-2)	0.13	0.846	
Cote d'Ivoire	54.74	128	(-1)	0.12	0.828	
Croatia	61.73	30	(-7)	0.19	0.902	
Cuba	56.71	85	(-45)	0.1	0.906	
Cyprus	59.28	54	(-11)	0.13	0.814	

continued ...

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Country	2022 SDG Index			Trend		
	<i>t</i> -score	<i>t</i> -rank	(change)	slope	correl.	st.dev.
Czech Rep.	65.66	9	(+4)	0.29	0.960	
Denmark	72.74	1	(+1)	0.26	0.879	
Djibouti	52.51	146	(+9)	0.2	0.863	
Dominican Rep.	59.70	48	(+20)	0.35	0.952	
Ecuador	59.36	53	(+10)	0.32	0.925	
Egypt, Arab Rep.	55.93	100	(-13)			0.253
El Salvador	60.20	41	(+38)	0.23	0.973	
Estonia	65.35	12	(-2)	0.43	0.955	
Eswatini	52.44	147	(-10)			0.401
Ethiopia	55.64	107	(+21)	0.12	0.825	
Fiji	59.38	51	(+1)	0.11	0.740	
Finland	71.34	3	(-2)	0.34	0.924	
France	65.36	11	(-4)	0.24	0.944	
Gabon	56.49	92	(+21)	0.25	0.929	
Gambia, The	55.44	112	(+10)	0.12	0.904	
Georgia	56.82	81	(-30)	0.15	0.956	
Germany	66.88	8	(-2)	0.35	0.953	
Ghana	56.54	91	(+19)	0.11	0.898	
Greece	60.21	40	(-8)	0.14	0.901	
Guatemala	55.38	113	(+4)	0.16	0.932	
Guinea	54.63	130	(+22)	0.21	0.891	
Guyana	55.53	110	(-4)	0.16	0.924	
Haiti	53.92	137	(+14)			0.764
Honduras	53.86	139	(-27)			0.688
Hungary	60.59	36	(-15)			0.644
Iceland	67.68	6	(+16)	0.19	0.920	
India	56.42	93	(+28)			0.557
Indonesia	56.76	84	(-2)	0.11	0.976	
Iran, Islamic Rep.	54.27	133	(-45)			0.429
Iraq	54.87	125	(-10)			0.547
Ireland	64.60	14	(-5)	0.27	0.963	
Israel	61.87	29	(+20)	0.18	0.857	
Italy	60.31	38	(-13)	0.11	0.854	
Jamaica	56.31	94	(-11)			0.165
Japan	64.56	15	(+4)	0.15	0.882	
Jordan	58.42	63	(+17)			0.268
Kazakhstan	57.36	74	(-9)			0.982
Kenya	55.02	120	(-2)			0.721
Korea, Rep.	62.30	25	(+2)	0.13	0.840	
Kuwait	55.09	119	(-18)			0.743

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...continued

Country	2022 SDG Index			Trend		
	<i>t</i> -score	<i>t</i> -rank	(change)	slope	correl.	st.dev.
Kyrgyz Rep.	61.57	32	(+16)	0.32	0.910	
Lao PDR	55.29	114	(-3)			0.671
Latvia	65.04	13	(+1)	0.25	0.936	
Lebanon	59.78	47	(+50)			0.318
Lesotho	54.92	123	(+12)	0.16	0.871	
Liberia	54.10	136	(+22)			0.429
Lithuania	60.09	42	(-3)	0.18	0.702	
Luxembourg	62.13	27	(+9)			0.602
Madagascar	50.88	157	(-1)			0.552
Malawi	51.73	152	(-7)			0.451
Malaysia	57.11	78	(-6)			0.633
Maldives	60.27	39	(+28)	0.34	0.964	
Mali	53.11	143	(-1)	0.1	0.918	
Malta	62.39	23	(+10)	0.13	0.940	
Mauritania	55.62	108	(+24)	0.22	0.973	
Mauritius	58.16	65	(+24)	0.15	0.974	
Mexico	56.88	79	(-5)	0.17	0.909	
Moldova	60.44	37	(+9)	0.22	0.949	
Mongolia	56.82	82	(+27)	0.24	0.968	
Montenegro	55.96	99	(-13)			1.066
Morocco	57.18	77	(+7)			0.564
Mozambique	50.78	159	(-16)			0.552
Myanmar	57.94	66	(+37)	0.21	0.836	
N. Macedonia	55.29	115	(-58)	0.48	0.960	
Namibia	58.63	59	(+55)	0.18	0.940	
Nepal	64.53	17	(+81)	0.21	0.950	
Netherlands	64.54	16	(+1)	0.14	0.895	
New Zealand	56.81	83	(-57)	0.22	0.986	
Nicaragua	52.08	149	(-57)	0.18	0.884	
Niger	55.66	106	(+43)	0.11	0.888	
Nigeria	56.64	86	(+53)			0.870
Norway	70.78	4	(+0)	0.34	0.963	
Oman	56.58	88	(-7)			0.972
Pakistan	55.58	109	(+16)			0.747
Panama	53.36	142	(-37)	0.1	0.823	
Papua New Guinea	53.09	144	(+0)			0.557
Paraguay	56.30	95	(-4)	0.18	0.958	
Peru	58.77	56	(+2)	0.18	0.922	
Philippines	56.15	96	(-1)	0.12	0.921	
Poland	64.08	19	(-7)	0.28	0.924	

continued ...

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Country	2022 SDG Index			Trend		
	<i>t</i> -score	<i>t</i> -rank	(change)	slope	correl.	st.dev.
Portugal	63.24	21	(-1)	0.28	0.971	
Qatar	55.77	103	(-9)	0.15	0.922	
Romania	58.59	60	(-30)	0.18	0.669	
Russian Federation	58.31	64	(-19)	0.12	0.751	
Rwanda	53.62	140	(-16)	0.22	0.892	
Sao Tome & Principe	52.04	150	(-27)			0.807
Saudi Arabia	55.49	111	(-15)			0.479
Senegal	54.85	126	(+0)	0.1	0.924	
Serbia	59.40	50	(-15)			0.560
Sierra Leone	54.19	134	(+12)	0.14	0.809	
Singapore	58.50	62	(-2)	0.1	0.942	
Slovak Rep.	61.62	31	(-7)	0.25	0.955	
Slovenia	63.76	20	(-5)	0.2	0.942	
Somalia	48.02	161	(-1)			0.581
South Africa	52.63	145	(-37)			0.818
South Sudan	46.86	163	(+0)			0.653
Spain	62.79	22	(-6)	0.24	0.975	
Sri Lanka	59.37	52	(+24)	0.22	0.898	
Sudan	54.88	124	(+35)	0.16	0.940	
Suriname	55.92	101	(-39)	0.19	0.944	
Sweden	72.42	2	(+1)	0.3	0.982	
Switzerland	67.08	7	(+1)	0.32	0.952	
Syrian Arab Rep.	56.61	87	(+42)			0.281
Tajikistan	58.55	61	(+17)	0.21	0.977	
Tanzania	54.51	132	(-2)	0.11	0.889	
Thailand	58.68	57	(-13)			0.193
Togo	54.82	127	(+6)	0.12	0.893	
Trinidad & Tobago	55.14	117	(+2)	0.13	0.765	
Tunisia	57.92	67	(+2)	0.11	0.962	
Turkey	55.71	104	(-33)			0.418
Turkmenistan	57.41	73	(+26)			0.330
Uganda	55.00	121	(+15)			0.639
Ukraine	59.94	45	(-8)			0.693
United Arab Emir.	56.86	80	(+5)	0.21	0.920	
United Kingdom	64.48	18	(-7)	0.23	0.882	
United States	59.10	55	(-14)	0.13	0.829	
Uruguay	62.37	24	(+7)	0.21	0.817	
Uzbekistan	54.96	122	(-45)			0.459
Venezuela, RB	52.13	148	(-28)			1.018
Vietnam	61.93	28	(+27)	0.29	0.984	

continued ...

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...continued

Country	2022 SDG Index			Trend		
	<i>t</i> -score	<i>t</i> -rank	(change)	slope	correl.	st.dev.
Yemen, Rep.	55.67	105	(+45)			0.333
Zambia	51.08	156	(-16)			0.963
Zimbabwe	54.19	135	(-4)			0.933

References

1. General Assembly Resolution 70/1, *Transforming Our World: The 2030 Agenda for Sustainable Development*. A/RES/70/1, 2015. <https://sdgs.un.org/2030agenda>.
2. UN DESA, *The Sustainable Development Goals Report 2022: From Crisis to Sustainable Development - The SDGs as Roadmap to 2030 and Beyond*. New York: United Nations, July 2022. <https://unstats.un.org/sdgs/report/2022/>.
3. UN DESA, *Global Sustainable Development Report 2019: The Future is Now - Science for Achieving Sustainable Development*. New York: United Nations, 2019. <https://sustainabledevelopment.un.org/gedr2019/>.
4. M. I. Doig and D. S. Malik, "A fuzzy approach to sustainability I: A time-series analysis of the Sustainable Development Goals." 2023.
5. Inter-Agency and Expert Group on SDG Indicators, *Global indicator framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development*. G.A. Res. 71/313, U.N. Doc. A/RES/71/313 (Annex), refinements in E/CN.3/2020/2, 2023. <https://unstats.un.org/sdgs/indicators/indicators-list/>.
6. UN DESA, "Global SDG Indicators Data Platform," 2022. Available from <https://unstats.un.org/sdgs/dataportal/>.