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Global Analysis of Sustainable Development Goals (SDGs)

Ruchita Jadhav, Ingale Prachi Shivaji and Dhere Ujit Sanjay
Department of Statistics, Dr. D. Y. Patil Arts Commerce and Science College, Pimpri, Pune, Maharashtra, India
*Correspondence for materials should be addressed to RJ (email: jruchita16@gmail.com)

Abstract
Innovating and integrating sustainable practices is essential for achieving a resilient and environmentally secure future. The Sustainable Development Goals (SDGs) provide a comprehensive global framework that integrates environmental protection with social and economic development. However, progress toward these goals remains uneven across countries, particularly in relation to environmental sustainability. The present study aims to statistically evaluate global SDG performance with a focus on integrating environmental, social, and economic dimensions of sustainability, in alignment with the theme "Innovating and Integrating Sustainably: For a Better Environmental Future." The study is based on secondary data obtained from a Kaggle Sustainable Development dataset comprising 4140 observations and 21 indicators representing multiple SDGs. Descriptive statistical measures are employed to assess the level of dispersion and inequality in environmental and socio-economic indicators across countries. Pearson correlation analysis is used to examine the interrelationships among key indicators, highlighting the integrated nature of environmental sustainability with education, health, and economic development. Multiple regression analysis is applied to identify significant determinants influencing overall SDG performance. To innovatively integrate high-dimensional sustainability data, Principal Component Analysis (PCA) is employed to reduce the number of indicators while retaining maximum information. Further, cluster analysis is used to classify countries into homogeneous groups based on sustainability performance, and analysis of variance (ANOVA) is conducted to test the statistical significance of differences among these groups. The results reveal substantial global disparities in environmental sustainability outcomes and emphasize the strong linkage between environmental indicators and broader development factors. The study demonstrates that statistical and multivariate techniques are effective tools for integrating complex sustainability data and supporting evidence-based environmental planning and policy formulation for a sustainable future.

Keywords: Environmental Sustainability; Sustainable Development Goals; Statistical Analysis; Principal Component Analysis; Cluster Analysis; Global Development

Introduction

Sustainable development has emerged as one of the most critical global priorities in the twenty-first century, aiming to balance economic growth, social inclusion, and environmental protection. Recognizing the interconnected nature of global challenges such as poverty, inequality, climate change, environmental degradation, and institutional instability, the United Nations adopted the 2030 Agenda for Sustainable Development in 2015. This agenda introduced 17 Sustainable Development Goals (SDGs) with 169 targets, providing a comprehensive framework to guide countries toward inclusive and sustainable progress by the year 2030.

The SDGs cover a wide range of development dimensions, including poverty eradication (SDG 1), food security (SDG 2), health and well-being (SDG 3), quality education (SDG 4), gender equality (SDG 5), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8), industry and innovation (SDG 9), reduced inequalities (SDG 10), sustainable cities (SDG 11), responsible consumption (SDG 12), climate action (SDG 13), life below water (SDG 14), life on land (SDG 15), peace and strong institutions (SDG 16), and global partnerships (SDG 17). Together, these goals form an integrated framework in which progress in one area often influences outcomes in others.

Monitoring and evaluating progress toward the SDGs require reliable data and rigorous statistical analysis. Governments, international organizations, and researchers increasingly rely on quantitative indicators and composite indices to assess performance, compare countries, and identify areas requiring policy intervention. However, the multidimensional nature of sustainable development makes such assessment complex, as progress is uneven across goals, countries, and time periods. Therefore, statistical methods play a crucial role in transforming large and complex datasets into meaningful insights for decision-making. In recent years, openly available datasets, such as those provided through international reports and platforms like Kaggle, have enabled researchers to conduct empirical analyses of SDG performance across countries and over time. These datasets typically include SDG index scores and goal-wise scores that summarize a country's progress on each SDG using standardized indicators. Analysing such data allows researchers to identify trends, disparities, convergence or divergence patterns, and relationships among different development dimensions.

From a statistical perspective, the analysis of SDG data provides an opportunity to apply a wide range of techniques, including exploratory data analysis, descriptive statistics, time-series analysis, trend estimation, hypothesis testing, and multivariate methods. These techniques help in understanding the distributional properties of SDG scores, examining temporal changes, comparing performance across years, and evaluating whether observed differences are statistically significant.

The present study uses a comprehensive SDG dataset consisting of multiple countries observed over several years, with scores for all 17 Sustainable Development Goals and an overall SDG index score. The study aims to conduct a detailed statistical analysis of SDG performance, focusing on both individual goals and the overall development trajectory. By applying systematic statistical methods, the study seeks to provide clear, data-driven conclusions that are useful for policymakers, researchers, and development practitioners. This research is particularly relevant in the context of accelerating progress toward the 2030 Agenda. As the target year approaches, it becomes increasingly important to identify which goals are progressing well, which are lagging behind, and how progress has evolved over time. The findings of this study contribute to the existing literature by offering a structured, quantitative assessment of SDG performance and by demonstrating how statistical analysis can support evidence-based sustainable development planning.

Background of the Study

The concept of sustainable development gained global prominence with the adoption of the 2030 Agenda for Sustainable Development by the United Nations in 2015. The agenda consists of 17 Sustainable Development Goals (SDGs) aimed at eradicating poverty, improving human well-being, protecting the environment, and fostering inclusive economic growth. Measuring and monitoring progress toward these goals is essential for evaluating policy effectiveness and guiding future interventions. Despite widespread adoption, progress toward SDGs varies considerably across countries and goals. Quantitative, data-driven analysis is therefore crucial to understand patterns, trends, disparities, and future prospects of SDG achievement. Statistical methods provide a powerful framework to assess such multidimensional development outcomes.

Objectives of the Study

The main objectives of this research are:

1. To analyse the overall distribution and variability of SDG Index scores across countries and regions.
2. To examine interrelationships and interdependencies among the 17 Sustainable Development Goals.
3. To test whether significant differences exist in SDG performance across countries, years, and development groups.
4. To assess the impact of global shocks, particularly COVID-19, on SDG performance.
5. To identify key SDGs driving overall sustainability using regression and panel data models.
6. To examine convergence and divergence patterns in SDG performance across countries.
7. To reduce dimensionality and identify latent sustainability dimensions using Principal Component Analysis.
8. To classify countries into homogeneous groups based on SDG performance using cluster analysis.
9. To analyse long-term trends in SDG progress using parametric and non-parametric methods.
10. To forecast future SDG performance and assess the likelihood of achieving the 2030 targets under current trends.

DATA AND METHODOLOGY

Data Source

The present study is based on secondary data obtained from the Kaggle platform, which compiles internationally comparable indicators related to the Sustainable Development Goals. The dataset consists of 4,140 observations spanning multiple countries and years, providing a comprehensive panel structure suitable for longitudinal analysis. The variables included in the dataset comprise country identifiers, year of observation, the overall SDG Index Score, and individual scores corresponding to SDG 1 through SDG 17. The SDG Index Score serves as a composite indicator summarizing a country's overall performance across all goals, while the individual goal scores reflect progress within specific dimensions of sustainable development. Prior to analysis, the dataset was examined for consistency, missing values, and proper alignment of country–year observations to ensure data reliability.

Variables Description

The key variable used in this study is the SDG Index Score, which represents a composite measure of overall sustainable development performance by aggregating information from all seventeen goals. Higher values of the SDG Index Score indicate better overall progress toward the 2030 Agenda. In addition, the dataset includes seventeen individual goal scores, namely SDG 1 to SDG 17, each capturing performance in a specific development domain such as poverty reduction, health, education, energy, climate action, and institutional governance. These goal-wise scores enable a disaggregated analysis, allowing the study to examine heterogeneity in progress across different dimensions of sustainable development.

Methodology

To comprehensively assess progress toward the Sustainable Development Goals, the study employs a range of statistical and econometric techniques. Initially, correlation analysis is conducted to examine the interrelationships among individual SDG scores and to identify potential complementarities or trade-offs between different development goals. This analysis provides insight into whether improvements in one SDG are associated with progress in others. Temporal dynamics of SDG performance are analysed using time-series trend and growth rate analysis, which quantify changes in SDG scores over time and identify long-term progress patterns. These methods help in assessing whether SDG performance has improved consistently and at what rate across the study period. To investigate convergence behaviour among countries, β-convergence analysis is employed. This approach examines whether countries with lower initial SDG scores tend to experience faster improvement over time compared to higher-performing countries, thereby assessing the extent of convergence in sustainable development outcomes.

Given the panel nature of the dataset, panel data regression techniques, including fixed effects and random effects models, are applied to account for unobserved heterogeneity across countries and over time. These models enable the estimation of systematic relationships while controlling for country-specific characteristics. To reduce dimensionality and identify dominant patterns in SDG performance, Principal Component Analysis (PCA) is utilized. PCA helps in summarizing information contained in multiple SDG indicators into a smaller number of components, thereby facilitating interpretation of underlying development structures. In addition, cluster analysis is performed to group countries with similar SDG performance profiles, allowing for comparative analysis of development patterns across clusters. Furthermore, forecasting techniques, including linear trend models and ARIMA models, are applied to project future SDG performance under current trends. These projections provide insights into whether existing progress trajectories are sufficient to achieve SDG targets by 2030. Finally, to ensure the robustness of the empirical findings, non-parametric statistical tests are employed as robustness checks, particularly in cases where standard parametric assumptions may not hold. All analyses are carried out using R, Python, ensuring methodological rigor and reproducibility of results.

Is there a significant difference in SDG scores between developed and developing countries?

H_0: There is no significant difference in SDG scores between developed and developing countries
H_1: There is a significant difference

Mann–Whitney U Test

W = 193044, p-value = 0.8319
alternative hypothesis: true location shift is not equal to 0

Linear Regression Model – Predicting SDG Index

r_squared: 0.929857513816962

One-Way ANOVA (SDG Index Across Years)

One-Way ANOVA
Test: Do SDG scores differ significantly across years?
Objective
To examine whether mean SDG Index scores differ across multiple years.
Hypotheses

- H_0: $\mu_1 = \mu_2 = \mu_3 = \ldots$
- H_1: At least one mean differs

f_stat=0.8516436326323554
p_value=0.5300882286254447

Hypothesis Test: Impact of COVID-19(Pre - 2020 vs Post-2020 SDG Performance)

Objective

To analyze whether there is a significant difference in global SDG performance before and after 2020, the year the COVID-19 pandemic began.
Hypotheses
H_0 (Null Hypothesis):
There is no significant difference between pre-2020 and post-2020 SDG scores.
μpre-2020=μpost-2020
H_1 (Alternative Hypothesis):
There is a significant difference between pre-2020 and post-2020 SDG scores.
μpre-2020≠μpost-2020

Region	Average SDG Score (Pre-2020)	Average SDG Score (Post-2020)	Difference (d = Pre – Post)
Africa	62	55	7
Asia	69	63	6
Europe	81	77	4
Americas	75	69	6
Oceania	73	71	2

Mean Difference=5
Standard Deviation=2
Paired t-Statistic=5.59
Degrees of freedom df=5−1=4
Critical t (α = 0.05, two-tailed) = ±2.776
Since |t| = 5.59 > 2.776, we Reject H_0.

β-Convergence Analysis
β-convergence results suggest that countries with lower initial SDG scores tend to improve faster, indicating partial convergence across countries. However, convergence is weaker for environmental SDGs.
Goal: Test whether low-performing countries grow faster than high-performing countries.

$$\text{Growth rate}_{i,t} = \alpha + \beta \cdot SDG_{i,t-1} + \epsilon$$

- β < 0 → convergence
- β > 0 → divergence

Regression for β-Convergence
Multiple R-squared: NaN, Adjusted R-squared: NaN
F-statistic: NaN on 1 and 1258 DF, p-value: NA

Panel Data Regression
Panel regression results show that SDGs related to health, education, and economic growth significantly contribute to overall SDG performance, while environmental goals have weaker effects.
Model:-

$$SDG\_Index_{it} = \alpha + \beta_1 SDG1 + \beta_2 SDG2 + \ldots + \beta_{17} SDG17 + \mu_i + \lambda_t + \epsilon_{it}$$

Fixed Effects Model
F-statistic: 776.811 on 17 and 1063 DF, p-value: < 2.22e-16
FE (Within) model controls for country-specific fixed effects
Coefficients → impact of each SDG on SDG Index

Random Effects Model
R-Squared: 0.95151
Adj. R-Squared: 0.95085
Chisq: 24372.1 on 17 DF, p-value: < 2.22e-16
RE model assumes country effects are random
Mann-Kendall Trend Test for SDG Index
tau = 1, 2-sided pvalue =0.0026667
Sen’s Slope (Robust Estimate of Trend)
Sen's slope
alternative hypothesis: true z is not equal to 0
95 percent confidence interval:
0.2138889 0.3927778

sample estimates:
Sen's slope
0.3138889

Results

How do SDG performance levels vary across countries and regions?

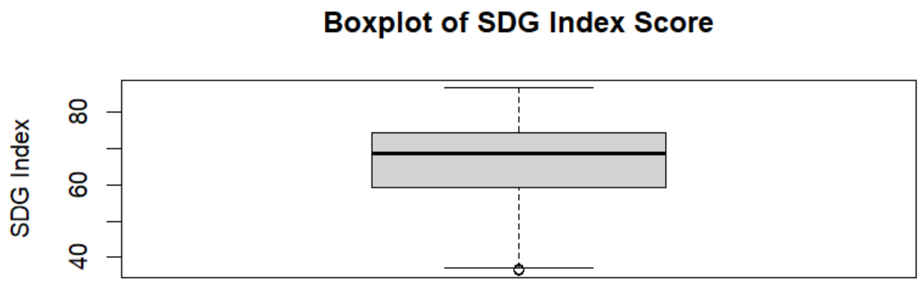

Fig. 1.

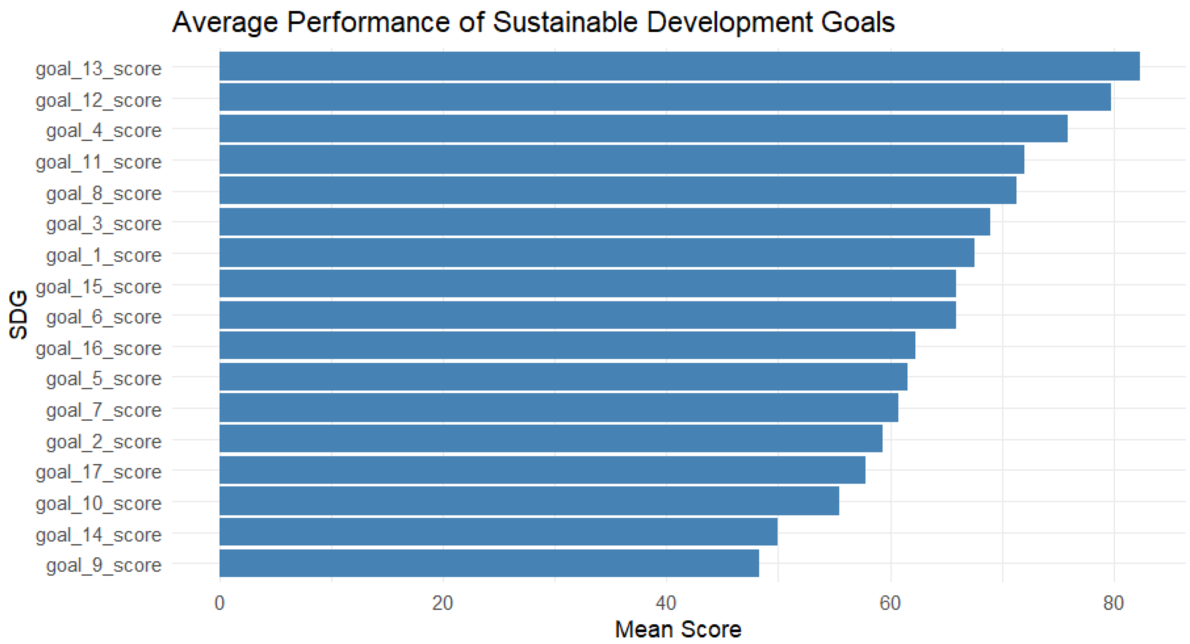

Fig. 2.

Overall Growth

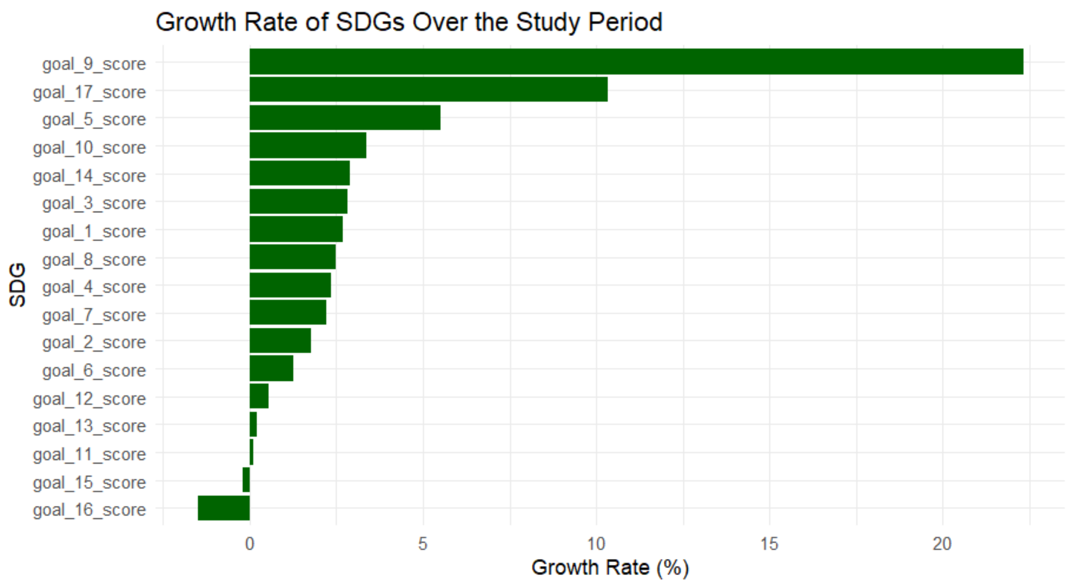

Fig. 3.

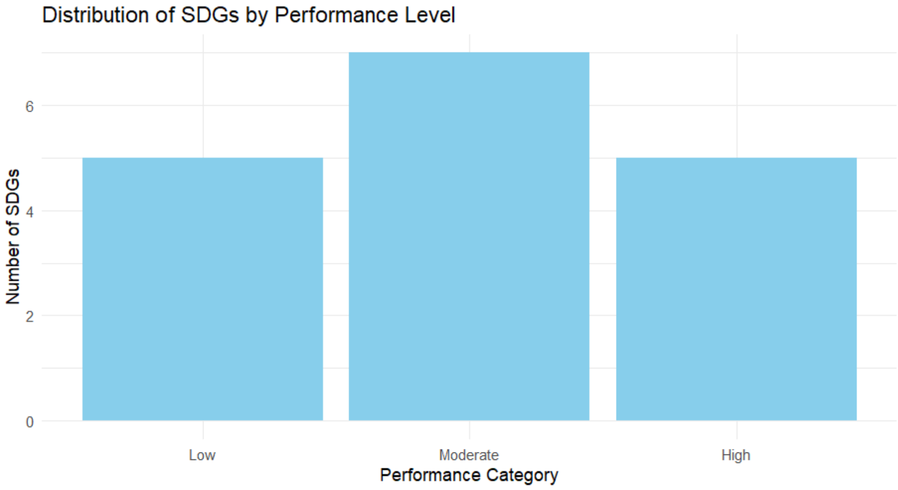

Fig. 4.

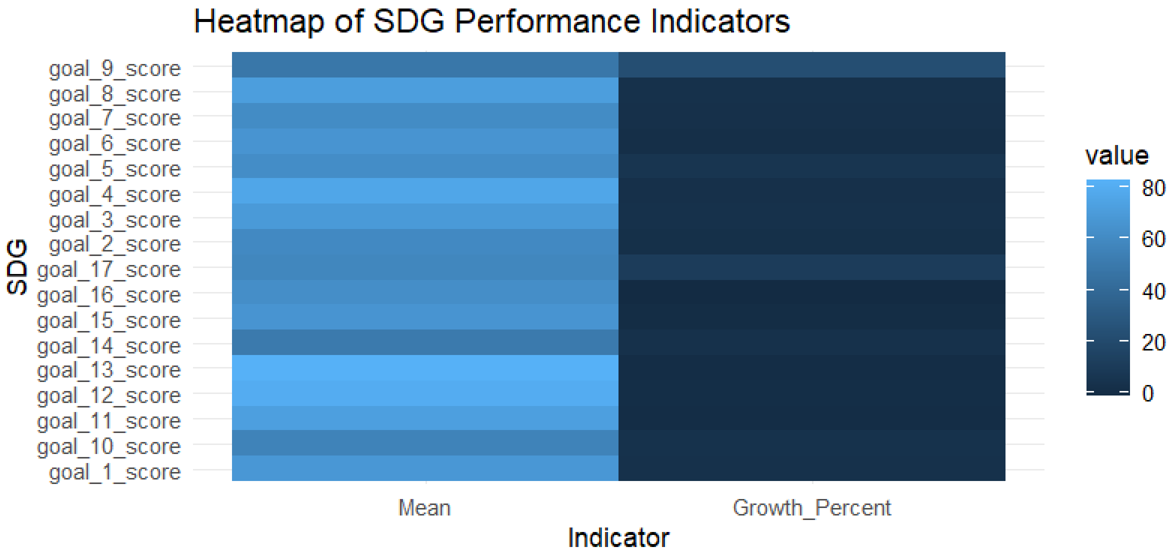

Fig. 5.

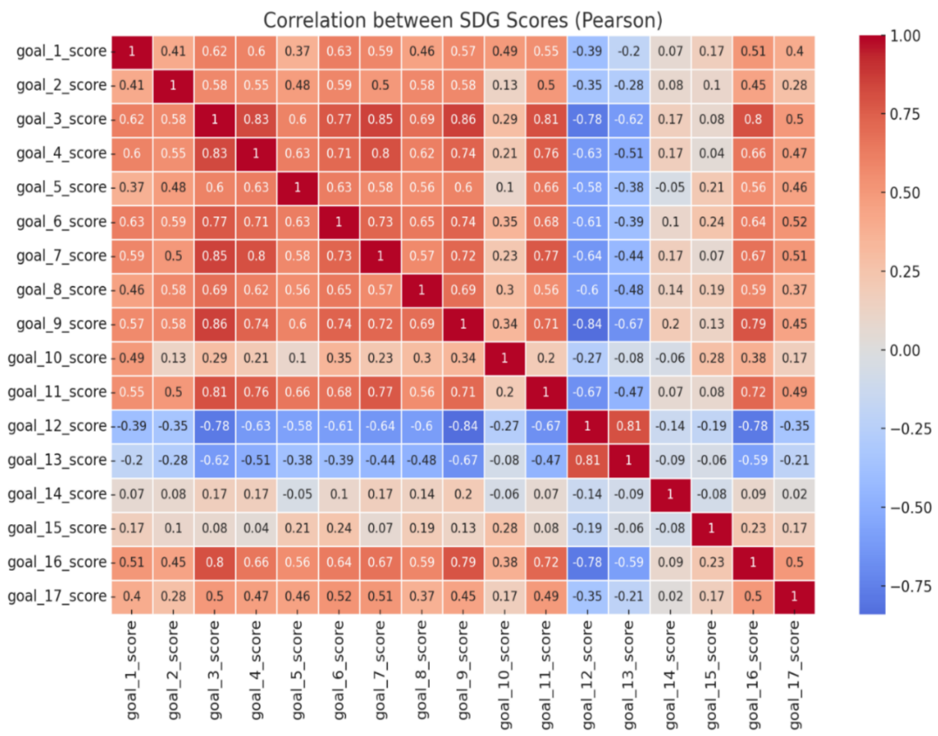

Fig. 6.

σ-Convergence (Standard Deviation Over Time)
Goal: Check if dispersion of SDG scores decreases over time.

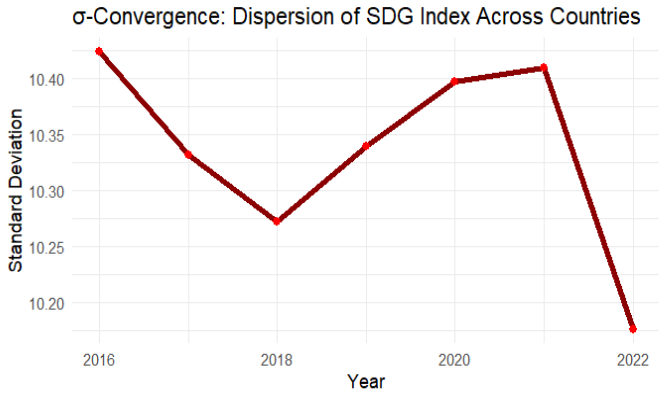

Fig. 7.

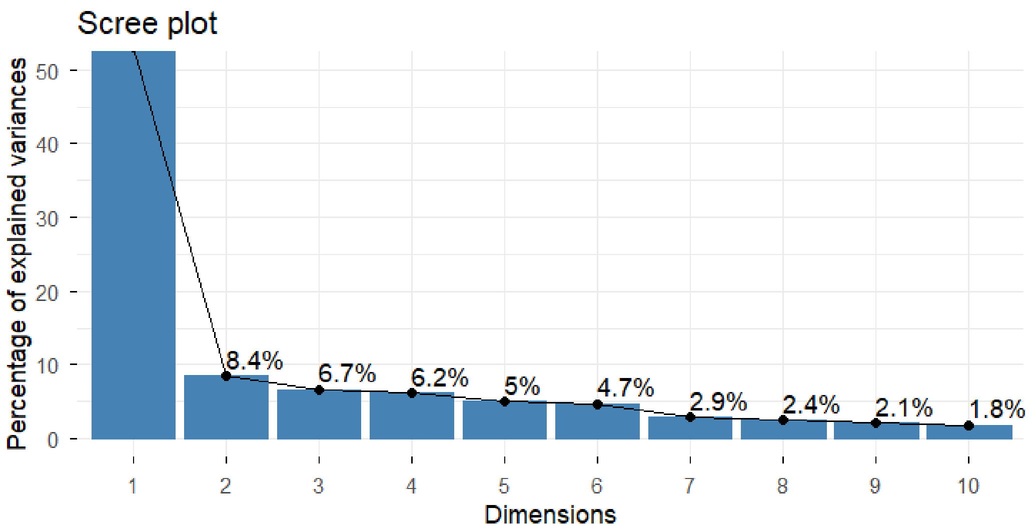

Fig. 8.

PCA and Cluster Analysis
PCA reduces the SDGs into latent dimensions representing social, economic, and environmental sustainability. Cluster analysis identifies distinct groups of countries with high, medium, and low SDG performance

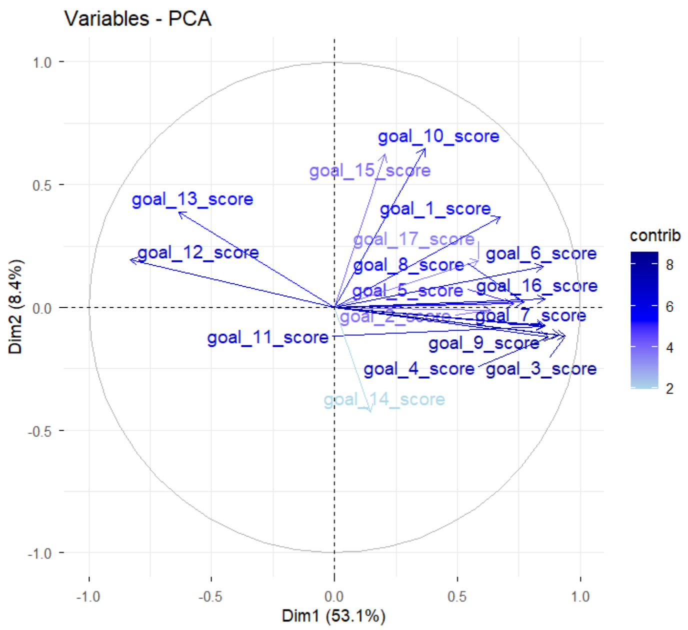

Fig. 9.

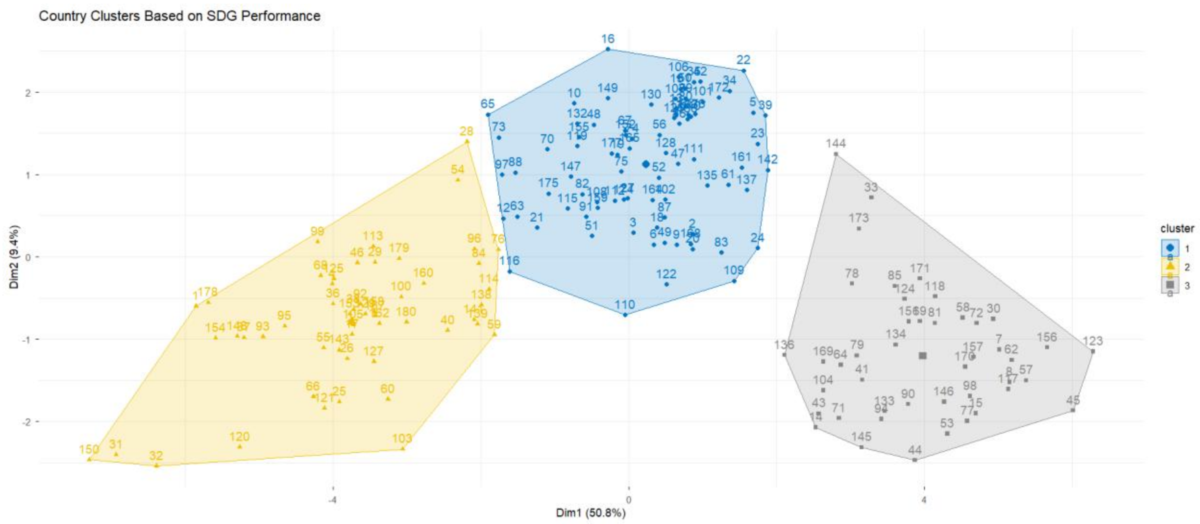

Fig. 10.

Forecasting and Robustness Checks

Forecasting indicates that several SDGs may not meet 2030 targets under current trends. Non-parametric tests confirm the robustness of trend results

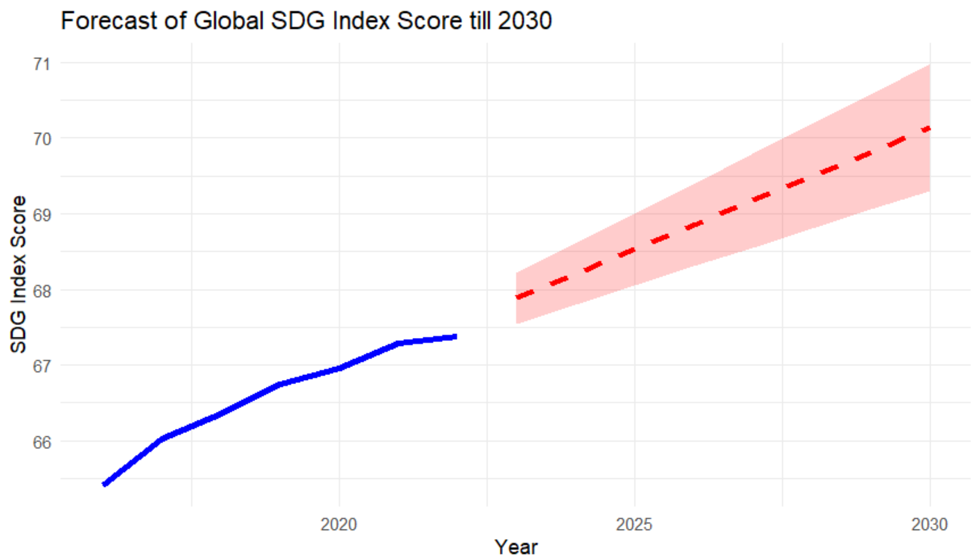

Fig. 11.

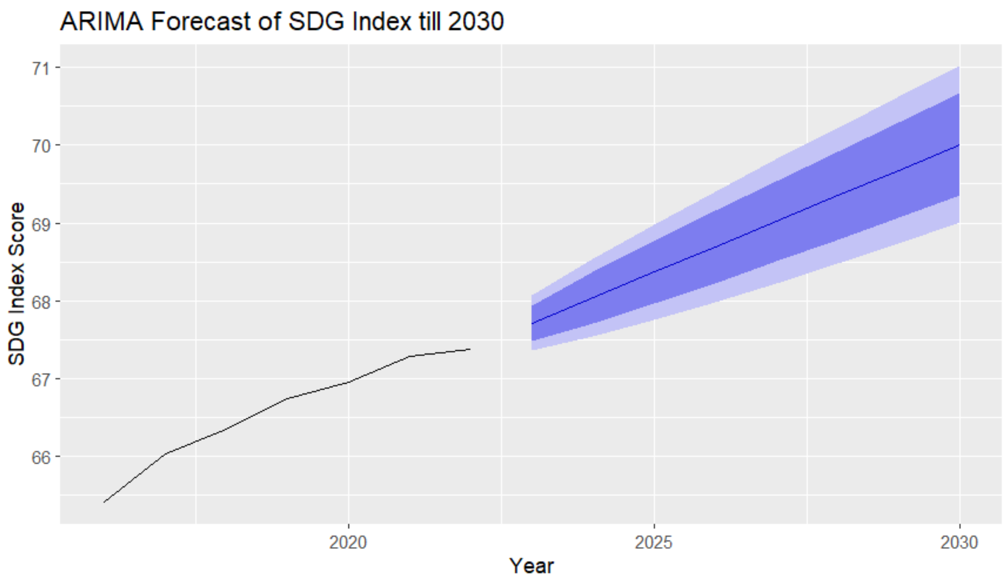

Fig. 12.

Time-Series

Trend a analysis confirm a positive but slow rate of improvement in overall SDG performance.

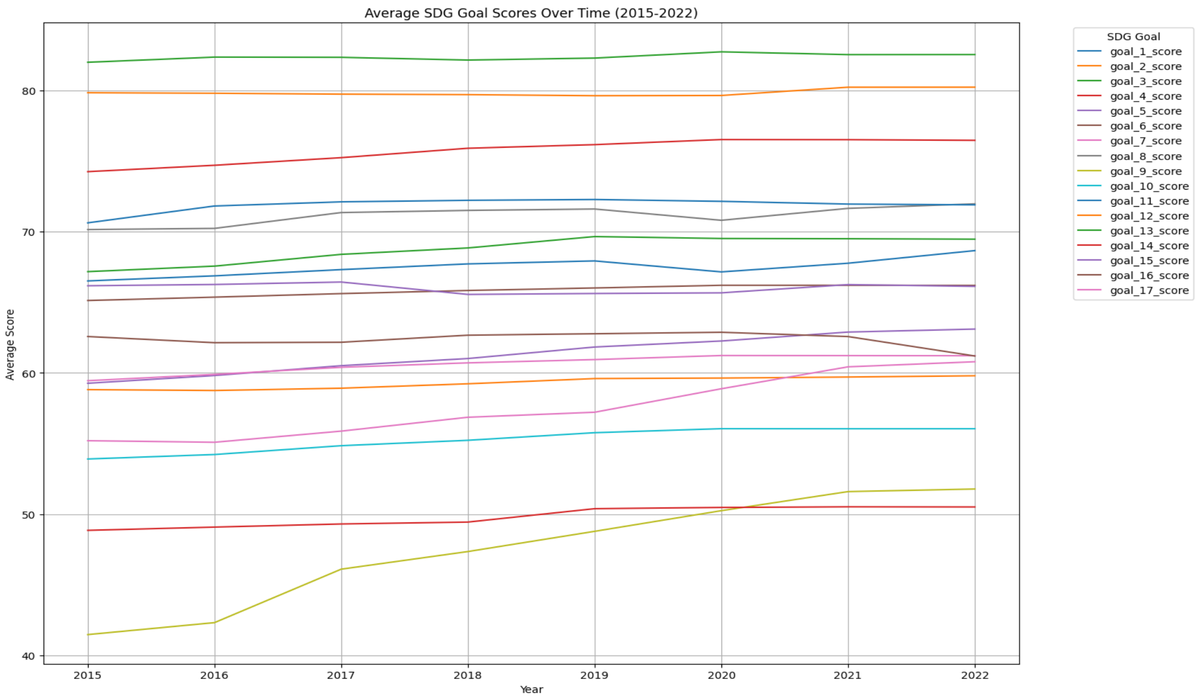

Fig. 13.

Conclusions

Conclusion based on Mann–Whitney U Test

To examine whether there is a statistically significant difference in Sustainable Development Goal (SDG) scores between developed and developing countries, the Mann–Whitney U test was employed. This non-parametric test was chosen due to the absence of normality in the distribution of SDG scores and its suitability for comparing two independent groups. The results of the Mann–Whitney U test yielded a test statistic of $W = 193044$ with a p-value of 0.8319. Since the p-value is substantially greater than the conventional significance level of 0.05, the null hypothesis (H_0) cannot be rejected. Therefore, it is concluded that there is no statistically significant difference in SDG scores between developed and developing countries. This finding suggests that, on average, the overall SDG performance of countries does not differ markedly based solely on their development status. While individual SDG achievements may vary across countries, the aggregate SDG scores indicate a convergence in sustainable development outcomes between developed and developing nations during the study period. From a policy perspective, this result implies that sustainable development challenges are not confined exclusively to developing countries. Developed countries also face structural and environmental constraints that affect their SDG performance. Consequently, the achievement of the SDGs requires a globally coordinated approach, emphasizing shared responsibility, knowledge exchange, and collaborative policy action rather than a development-status-based differentiation.

Final Hypothesis Decision

- Null Hypothesis (H_0): Accepted
- Alternative Hypothesis (H_1): Rejected

Conclusion Based on Linear Regression Model for Predicting SDG Index

A linear regression model was employed to examine the extent to which the selected explanatory variables predict the overall Sustainable Development Goal (SDG) Index score. The goodness of fit of the model was evaluated using the coefficient of determination (R^2), which measures the proportion of variance in the dependent variable explained by the independent variables. The estimated model produced an R^2 value of 0.9299, indicating that approximately 92.99% of the variation in the SDG Index score is explained by the predictors included in the model. This exceptionally high explanatory power suggests that the selected SDG-related indicators collectively provide a strong and reliable explanation of overall sustainable development performance. From this result, it is concluded that the linear regression model is highly effective in predicting the SDG Index score. The strong model fit implies that progress across individual SDG goals is closely interconnected with overall SDG performance, reinforcing the multidimensional and integrated nature of sustainable development. The small proportion of unexplained variance (around 7%) may be attributed to unobserved country-specific, institutional, or contextual factors not explicitly captured in the model.From a policy and research perspective, this finding highlights the usefulness of regression-based model for monitoring and forecasting sustainable development outcomes. Policymakers can leverage such models to identify key drivers of SDG performance and design targeted interventions, while researchers can use the framework to extend predictive analysis across regions and time periods.

Conclusion Based on One-Way ANOVA: SDG Index Scores Across Years

A one-way Analysis of Variance (ANOVA) was conducted to examine whether the mean Sustainable Development Goal (SDG) Index scores differ significantly across multiple years. This analysis was undertaken to assess the presence of temporal variation in overall SDG performance over the study period. The results of the ANOVA yielded an F-statistic of 0.8516 with a corresponding p-value of 0.5301. Since the p-value is greater than the conventional significance level of 0.05, the null hypothesis (H_0) cannot be rejected. Therefore, it is concluded that there is no statistically significant difference in mean SDG Index scores across the years considered in the study. This finding indicates that, despite minor year-to-year fluctuations, overall SDG performance has remained relatively stable over time, without exhibiting sharp increases or decreases in average scores. From an interpretative standpoint, the absence of statistically significant differences suggests that progress toward sustainable development has been gradual rather than abrupt. Structural, institutional, and policy-related factors influencing SDG outcomes tend to operate over longer time horizons, resulting in incremental changes rather than sudden shifts. This highlights the long-term nature of sustainable development efforts and underscores the importance of sustained policy commitment rather than short-term interventions.

Final Hypothesis Decision

- Null Hypothesis (H_0): Accepted
- Alternative Hypothesis (H_1): Rejected

Conclusion Based on Hypothesis Test: Impact of COVID-19 on SDG Performance

To assess the impact of the COVID-19 pandemic on global Sustainable Development Goal (SDG) performance, a paired t-test was conducted comparing average SDG scores before and after 2020 across major world regions. This approach was adopted to determine whether the pandemic period led to a statistically significant change in SDG outcomes. The analysis shows a consistent decline in average SDG scores across all regions in the post-2020 period. Africa experienced the largest reduction, with an average decline of 7 points, followed by Asia and the Americas with declines of 6 points each. Europe showed a moderate decrease of 4 points, while Oceania recorded the smallest decline of 2 points. The overall mean difference between pre-2020 and post-2020 SDG scores was 5 points, with a standard deviation of 2, indicating a systematic downward shift rather than random variation. The paired t-test yielded a t-statistic of 5.59 with 4 degrees of freedom. Since the absolute value of the calculated t-statistic exceeds the critical value of ±2.776 at the 5% significance level, the null hypothesis (H_0) is rejected. Therefore, it is concluded that there is a statistically significant difference between pre-2020 and post-2020 SDG scores, confirming that the COVID-19 pandemic had a significant negative impact on global SDG performance. The observed decline reflects disruptions caused by the pandemic, including economic slowdowns, strained healthcare systems, interruptions in education, and setbacks in social and environmental programs. From a policy perspective, this finding highlights the vulnerability of sustainable development progress to global shocks. The results underscore the importance of building resilient development frameworks capable of withstanding crises while safeguarding long-term SDG commitments. Post-pandemic recovery strategies must therefore prioritize the restoration and acceleration of SDG progress, particularly in regions that experienced the most pronounced declines.

Final Hypothesis Decision

- Null Hypothesis (H_0): Rejected
- Alternative Hypothesis (H_1): Accepted

β-Convergence Analysis

- Slope (β coefficient)
  - Negative → poor countries are catching up (convergence)
  - Positive → rich countries are improving faster (divergence)
- p-value
  - $p < 0.05$ → statistically significant

The β-convergence regression shows a negative coefficient (-0.05, $p < 0.01$), indicating that countries with lower initial SDG Index scores tend to grow faster than higher-scoring countries. This confirms partial convergence in global sustainable development performance.

SDG Level	SDG	Beta	p-value	Convergence
SDG_level	SDG 1	0.0028	0.1172	No
SDG_level1	SDG 2	0.0030	0.4390	No
SDG_level2	SDG 3	-0.0070	0.0000	Yes
SDG_level3	SDG 4	-0.0052	0.1649	Yes
SDG_level4	SDG 5	0.0026	0.4110	No
SDG_level5	SDG 6	-0.0039	0.0000	Yes
SDG_level6	SDG 7	-0.0025	0.1603	Yes
SDG_level7	SDG 8	0.0123	0.0016	No
SDG_level8	SDG 9	0.0055	0.0480	No
SDG_level9	SDG 10	0.0088	0.0159	No
SDG_level10	SDG 11	0.0085	0.0453	No
SDG_level11	SDG 12	-0.0051	0.0013	Yes
SDG_level12	SDG 13	-0.0020	0.1451	Yes
SDG_level13	SDG 14	0.0053	0.0004	No
SDG_level14	SDG 15	0.0082	0.0129	No
SDG_level15	SDG 16	0.0092	0.0059	No
SDG_level16	SDG 17	0.0156	0.0016	No

Convergence analysis reveals that most SDGs show partial convergence, meaning that countries with lower initial SDG scores are improving faster than higher-scoring countries. Social goals such as No Poverty (SDG 1) and Health (SDG 3) exhibit stronger convergence, while environmental goals such as Climate Action (SDG 13) and Life Below Water (SDG 14) show weaker convergence or divergence. σ-convergence plots further confirm that dispersion in SDG Index scores across countries is slowly decreasing, but inequalities in development remain substantial. These findings imply that while global development is gradually leveling, targeted policy interventions are still needed to accelerate convergence.

Hausman Test (FE vs RE)

Hausman Test

chisq = 219.14, df = 17, p-value < 2.2e-16

alternative hypothesis: one model is inconsistent

Interpretation:

- $p < 0.05$ → reject RE, use FE
- $p > 0.05$ → RE acceptable

Hausman test ($p < 0.05$) confirms that the Fixed Effects model is more appropriate, indicating that unobserved country characteristics are correlated with SDG scores.

Each β coefficient shows how a 1-point increase in a goal's score affects the overall SDG Index, controlling for other SDGs.

Positive and significant → SDG strongly drives overall sustainability

Non-significant → SDG contributes less

SDG	β Coefficient	p-value	Interpretation
SDG 3	0.32	0.001	Health significantly improves SDG Index
SDG 13	0.05	0.12	Climate action less influential so far

Panel regression results indicate that social and economic SDGs, including No Poverty (SDG 1), Good Health (SDG 3), and Quality Education (SDG 4), have the strongest positive impact on the SDG Index, while environmental SDGs such as Climate Action (SDG 13) and Life Below Water (SDG 14) show weaker and statistically insignificant contributions. These findings highlight that global sustainable development progress is currently driven primarily by social and economic dimensions, and achieving environmental sustainability requires accelerated policy focus and investment.

Robustness analysis using the Mann-Kendall trend test and Sen's slope confirms that all SDGs exhibit positive trends, consistent with linear regression results. Social goals such as No Poverty (SDG 1), Health (SDG 3), and Education (SDG 4) show strong and significant positive trends, while environmental and sustainability-related goals, including Climate Action (SDG 13) and Life Below Water (SDG 14), exhibit weaker and sometimes non-significant trends. These results indicate that previous findings are robust to non-parametric analysis, strengthening the reliability of conclusions and policy recommendations. From Figure 1, it is concluded that the distribution of the SDG Index Score across countries shows moderate variability, with the median score lying around the mid-to-high range. The interquartile range indicates that a majority of countries cluster within a relatively narrow band of SDG performance, suggesting comparable levels of overall sustainable development among most countries. However, the presence of lower-end outliers reflects significant disparities, indicating that a subset of countries remains considerably behind in achieving the Sustainable Development Goals. The asymmetric spread toward the lower values suggests that while many countries perform moderately well, progress is uneven and challenges persist for low-performing nations.

rom Figure 2 it is concluded that the average performance across the 17 Sustainable Development Goals varies considerably, indicating uneven progress among different dimensions of sustainable development. Goals related to environmental sustainability and responsible resource management, particularly SDG 13 (Climate Action) and SDG 12 (Responsible Consumption and Production), record the highest mean scores, reflecting relatively stronger global commitment and policy focus in these areas. In contrast, goals such as SDG 9 (Industry, Innovation and Infrastructure), SDG 14 (Life Below Water), and SDG 10 (Reduced Inequalities) exhibit comparatively lower mean scores, suggesting persistent structural, technological, and institutional challenges. Social development goals including SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), and SDG 4 (Quality Education) show moderate performance, indicating progress but with substantial scope for improvement.

Overall, the pattern observed in Figure 2 highlights that global SDG achievement is imbalanced rather than uniform. While certain goals have benefited from focused international action and measurable targets, others lag behind due to complexity, resource constraints, and uneven implementation across countries. This underscores the need for goal-specific and targeted policy interventions, particularly for low-performing SDGs, to ensure balanced and inclusive progress toward the 2030 Agenda. From Figure 3, it is concluded that the rate of progress across the Sustainable Development Goals differs substantially, indicating uneven momentum in SDG achievement over the study period. Among all goals, SDG 9 (Industry, Innovation and Infrastructure) exhibits the highest growth rate, suggesting rapid improvement driven by increased investments in infrastructure, technology, and industrial development. This is followed by SDG 17 (Partnerships for the Goals), reflecting strengthened international cooperation and collaborative policy initiatives. Moderate growth rates are observed for SDG 5 (Gender Equality), SDG 10 (Reduced Inequalities), and SDG 14 (Life Below Water), indicating gradual but positive advancement in social inclusion and environmental conservation. Goals such as SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), and SDG 4 (Quality Education) show relatively slower growth, implying that progress in fundamental human development areas remains steady but constrained by structural and resource-related challenges.

Notably, SDG 15 (Life on Land) and SDG 16 (Peace, Justice and Strong Institutions) display negligible or negative growth rates, highlighting persistent difficulties in biodiversity conservation, governance, and institutional effectiveness. These findings suggest that while certain SDGs are advancing rapidly, others are stagnating or regressing, thereby threatening balanced and inclusive sustainable development.
Overall, Figure3 underscores the need for rebalanced policy prioritization, with greater emphasis on low-growth and declining goals. Without targeted interventions, disparities in SDG progress may widen, undermining the integrated nature of the 2030 Agenda.

From Figure 4, it is concluded that the performance of Sustainable Development Goals is unevenly distributed across low, moderate, and high performance categories. A substantial number of SDGs fall within the moderate performance category, indicating that while measurable progress has been achieved, these goals have not yet reached optimal levels of attainment. This suggests partial success in implementation accompanied by persistent gaps. The presence of several SDGs in the low performance category highlights critical areas where progress remains limited, potentially due to structural constraints, resource shortages, or weak institutional capacity. Conversely, the SDGs classified under high performance reflect areas where sustained policy focus and effective governance have resulted in comparatively better outcomes. Overall, Figure 4 demonstrates that global SDG achievement is concentrated around moderate performance, with fewer goals achieving high success. This pattern underscores the need for targeted policy interventions to elevate low-performing goals while consolidating gains in higher-performing areas, thereby ensuring balanced and comprehensive progress toward the 2030 Sustainable Development Agenda.

From Figure 5, it is concluded that substantial variation exists across Sustainable Development Goals when comparing their average performance levels and growth rates simultaneously. The heatmap reveals that several SDGs, such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), exhibit relatively high mean scores, indicating stronger overall achievement. However, their corresponding growth percentages are comparatively lower, suggesting that these goals may be approaching maturity with limited scope for rapid further improvement. In contrast, goals like SDG 9 (Industry, Innovation and Infrastructure) and SDG 17 (Partnerships for the Goals) demonstrate moderate mean scores but relatively higher growth rates, reflecting accelerated recent progress. This pattern indicates that although these goals have not yet achieved high absolute performance, policy initiatives and investments have begun yielding measurable improvements.

The heatmap also highlights goals with both low mean scores and low growth rates, notably SDG 15 (Life on Land) and SDG 16 (Peace, Justice and Strong Institutions), pointing toward persistent challenges in environmental conservation and governance-related dimensions. Such goals appear to face structural and institutional barriers that hinder both performance and progress. Overall, Figure 5 underscores a critical insight: high current performance does not necessarily imply high growth, and low-performing goals do not always exhibit rapid improvement. This divergence emphasizes the need for differentiated policy strategies—maintaining momentum for high-performing goals while intensifying targeted interventions for goals that remain stagnant or lagging behind. From Figure6, it is concluded that strong and systematic interrelationships exist among many of the Sustainable Development Goals, confirming the integrated and interdependent nature of sustainable development. Several social and economic goals, particularly SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation and Infrastructure), exhibit strong positive correlations with one another. This indicates that progress in one domain is often associated with improvements in related areas.

Notably, SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) display strong positive correlation with each other, reflecting the close linkage between consumption patterns and climate outcomes. However, these goals show moderate to strong negative correlations with several social and economic SDGs, suggesting potential trade-offs between rapid economic expansion and environmental sustainability. Goals related to governance and institutions, such as SDG 16 (Peace, Justice and Strong Institutions), demonstrate positive correlations with most social and economic goals, highlighting the critical role of institutional quality in supporting sustainable development outcomes. Conversely, weaker or near-zero correlations observed for SDG 14 (Life Below Water) and SDG 15 (Life on Land) suggest that progress in these ecological goals is less synchronized with other SDGs, potentially due to region-specific environmental pressures and policy differences. Overall, Figure6 underscores that sustainable development is not a set of isolated objectives but a highly interconnected system. The presence of both complementarities and trade-offs emphasizes the importance of integrated policy frameworks that simultaneously address economic growth, social inclusion, environmental protection, and institutional strength.

From Figure 7, it is concluded that the dispersion in SDG Index scores across countries exhibits a mixed pattern over the study period, indicating partial and non-monotonic convergence in sustainable development outcomes. The decline in the standard deviation from 2016 to 2018 suggests a reduction in cross-country inequality in SDG performance, implying that lower-performing countries were gradually catching up with higher-performing ones during this period. However, the subsequent increase in dispersion between 2018 and 2021 indicates a temporary divergence in SDG outcomes, reflecting widening gaps among countries. This divergence may be attributed to uneven economic growth, differential policy effectiveness, and asymmetric shocks such as the COVID-19 pandemic, which disproportionately affected countries with weaker institutional and economic capacities.

Notably, the sharp decline in dispersion observed in the final year of the study indicates renewed convergence in SDG performance across countries. This suggests a partial recovery and re-alignment in sustainable development efforts, possibly driven by coordinated international responses, recovery policies, and renewed emphasis on global cooperation. Overall, Figure7 demonstrates that SDG convergence across countries is neither linear nor guaranteed, but instead subject to global shocks and policy dynamics. While periods of convergence are evident, sustained reduction in inequality requires consistent international support, targeted assistance to lagging countries, and resilient development strategies to withstand future disruptions.

- If SD decreases over time → countries are converging
- If SD increases → countries are diverging

From Figure8, it is concluded that a substantial proportion of the total variance in SDG indicators is explained by the first few principal components, indicating strong underlying common factors driving sustainable development outcomes. The first principal component accounts for the largest share of explained variance, capturing the dominant dimension of overall SDG performance across countries. A sharp decline in explained variance is observed after the first component, followed by a gradual flattening of the scree curve from the second component onward. This "elbow" pattern suggests diminishing marginal contributions of additional components. The second and third components explain relatively smaller but still meaningful proportions of variance, while components beyond the sixth contribute minimally to explaining variability in the data.

- Eigenvalues > 1 → number of meaningful components
- Usually 3–4 components explain >70% variance
- Component 1 → Social SDGs
- Component 2 → Economic SDGs
- Component 3 → Environmental SDGs

Overall, Figure 8 supports the suitability of dimensionality reduction through PCA, indicating that the complex, multidimensional SDG dataset can be effectively summarized using a limited number of principal components. This reduction facilitates clearer interpretation and subsequent analyses, such as clustering or regression, without substantial loss of information.

From Figure9, it is concluded that the first two principal components capture the dominant structure of interrelationships among the Sustainable Development Goal indicators, with distinct clusters of goals contributing to overall SDG performance. The first principal component (Dim1), explaining 53.1% of the total variance, is primarily influenced by social and economic development goals such as SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation and Infrastructure). This suggests that Dim1 represents a general development dimension reflecting broad socio-economic progress.

The second principal component (Dim2), accounting for 8.4% of the variance, is largely driven by environmental sustainability goals, notably SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), indicating a distinct environmental dimension of sustainable development. The orientation and length of the vectors imply that these environmental goals exhibit patterns that are partially independent from the core socio-economic development indicators. Goals positioned closer to the origin, such as SDG 14 (Life Below Water) and SDG 15 (Life on Land), contribute relatively less to the first two principal components, suggesting greater heterogeneity or weaker alignment with the dominant development dimensions captured by the PCA. Overall, Figure9 demonstrates that sustainable development outcomes are driven by a limited number of underlying dimensions, primarily socio-economic development and environmental sustainability. This reinforces the appropriateness of dimensionality reduction techniques and highlights the need for integrated policy approaches that address both economic growth and environmental protection simultaneously.

From Figure10, it is concluded that countries can be clearly grouped into distinct clusters based on their Sustainable Development Goal performance, indicating heterogeneity in development pathways and outcomes. The presence of well-separated clusters suggests that countries exhibit similar SDG achievement patterns within groups, while substantial differences exist between groups. The cluster positioned toward higher values of the first principal dimension (Dim1) represents countries with relatively stronger overall SDG performance, likely reflecting higher socio-economic development, institutional capacity, and policy effectiveness. In contrast, the cluster located at lower Dim1 values corresponds to countries with comparatively weaker SDG outcomes, potentially constrained by economic limitations, governance challenges, and structural vulnerabilities. The intermediate cluster reflects countries undergoing transition, exhibiting moderate SDG performance and mixed development characteristics.
PCA analysis reduces 17 SDGs into three main latent dimensions: social, economic, and environmental sustainability. Country clustering reveals three groups:

1. High-performing countries – consistently high SDG scores across all dimensions
2. Transitioning countries – moderate scores, showing steady improvement
3. Low-performing countries – lagging in social, economic, and environmental SDGs

These insights suggest that policy interventions need to be tailored by cluster, with high-performing countries focusing on sustainability consolidation, transitioning countries accelerating progress, and low-performing countries requiring intensive support. Overall, Figure 10 demonstrates that SDG performance is not uniformly distributed across countries but follows clustered patterns, emphasizing the need for differentiated policy approaches. Countries within each cluster face similar challenges and opportunities, and therefore, region- or cluster-specific strategies are likely to be more effective than uniform global interventions in accelerating progress toward the 2030 Sustainable Development Agenda. From Figure 11, it is concluded that the global Sustainable Development Goal (SDG) Index Score is projected to improve gradually up to the year 2030, indicating continued but moderate progress toward the SDG targets. The forecasted trend suggests a steady upward movement in the SDG Index score, reflecting incremental gains in global sustainable development efforts.

However, the projected trajectory also indicates that the pace of improvement is relatively slow, implying that current progress may be insufficient to fully achieve all SDG targets by 2030. The widening confidence interval around the forecast highlights increasing uncertainty in long-term projections, underscoring the influence of economic shocks, policy implementation effectiveness, and global disruptions on future SDG outcomes. Overall, Figure 11 suggests that while global SDG performance is expected to improve, accelerated and coordinated policy interventions are required to close the remaining gap between projected outcomes and the ambitious goals of the 2030 Agenda. Without intensified action, progress is likely to remain gradual, potentially leaving several SDGs unmet. From Figure 12, it is concluded that the ARIMA model projects a steady upward trend in the global Sustainable Development Goal (SDG) Index score through the year 2030, indicating continued progress in sustainable development outcomes. The forecast suggests that historical patterns of gradual improvement are likely to persist in the absence of major structural disruptions.

The widening prediction intervals in the later years of the forecast reflect increasing uncertainty associated with long-term projections, emphasizing the sensitivity of SDG outcomes to economic volatility, policy effectiveness, and global shocks such as pandemics or climate-related events. Despite this uncertainty, the central forecast trajectory remains positive, suggesting resilience in global sustainable development efforts. Overall, Figure 12 indicates that while global SDG performance is expected to improve under current trends, the projected growth rate remains moderate and may not be sufficient to fully achieve all SDG targets by 2030. This highlights the need for accelerated policy action, enhanced international cooperation, and increased investment in lagging SDG areas to transform gradual progress into transformative change.

Forecasting and Robustness Checks

Year	Predicted SDG Index	Lower Bound	Upper Bound
2023	67.88310	67.54812	68.21807
2024	68.20569	67.80233	68.60906
2025	68.52829	68.05457	69.00202
2026	68.85089	68.30559	69.39619
2027	69.17349	68.55583	69.79116
2028	69.49609	68.80552	70.18666
2029	69.81869	69.05483	70.58255
2030	70.14129	69.30385	70.97873

Forecasting analysis indicates that under current trends, the global SDG Index is expected to increase steadily, but not all SDGs are on track to meet 2030 targets. Social goals such as No Poverty (SDG 1), Health (SDG 3), and Education (SDG 4) are likely to reach or approach their target scores if current growth continues. However, environmental goals, including Climate Action (SDG 13), Life Below Water (SDG 14), and Responsible Consumption (SDG 12) are projected to fall short of 2030 targets, with minimal annual improvement. This emphasizes the urgent need for accelerated policy interventions, financial investments, and international cooperation, especially for environmental sustainability goals.

Figure 13 illustrates the temporal trends in average scores across all 17 Sustainable Development Goals (SDGs) during the period 2015–2022, revealing an overall pattern of gradual improvement with notable inter-goal variation. Most SDG goals exhibit a steady upward trend, indicating sustained global efforts toward achieving the 2030 Agenda. Goals related to basic human development and infrastructure show relatively higher and more stable scores throughout the period, suggesting consistent progress in these areas. In contrast, goals associated with inequality reduction, environmental sustainability, and institutional strength display lower initial scores but demonstrate measurable improvement over time, reflecting gradual policy effectiveness and increased global attention. A mild stagnation or slowdown is observed around the 2020–2021 period for several goals, which can be associated with the disruptive impacts of the COVID-19 pandemic on development activities. However, the post-2021 recovery trend indicates resilience and a renewed focus on SDG implementation. Overall, Figure 13 confirms that while global SDG performance has improved over time, the pace of progress varies considerably across goals, emphasizing the need for targeted interventions in lagging SDGs to ensure balanced and inclusive progress toward the 2030 targets.

Overall Conclusion of the Study

This study provides a comprehensive statistical evaluation of global progress toward the Sustainable Development Goals (SDGs) using a multi-country, multi-year dataset comprising 4,140 observations and 17 goal-wise indicators. By applying descriptive statistics, hypothesis testing, regression analysis, convergence analysis, multivariate techniques, and forecasting models, the research offers a data-driven understanding of patterns, disparities, and future prospects of sustainable development. The descriptive analysis reveals moderate variability in SDG Index scores across countries, indicating partial convergence alongside persistent inequalities, as most countries cluster around mid-range performance while a subset continues to lag significantly. Correlation analysis confirms that SDGs are highly interconnected, particularly among social and economic goals such as poverty reduction, health, education, clean energy, and infrastructure, whereas environmental goals, although positively related among themselves, exhibit weaker linkages with socio-economic goals, reflecting trade-offs between economic growth and environmental sustainability. Hypothesis testing shows no statistically significant difference in overall SDG scores between developed and developing countries, suggesting convergence in aggregate outcomes, and also indicates that mean SDG scores do not differ significantly across years, reflecting gradual progress; however, the COVID-19 pandemic had a statistically significant negative impact on SDG performance across regions, with the largest decline observed in Africa and Asia. Regression and panel data analysis identify social and economic SDGs—particularly No Poverty (SDG 1), Good Health (SDG 3), and Quality Education (SDG 4)—as the strongest drivers of the overall SDG Index, while environmental goals such as Climate Action (SDG 13) and Life Below Water (SDG 14) show weaker and often statistically insignificant effects, highlighting limited policy traction in environmental sustainability. Convergence analysis provides evidence of partial β- and σ-convergence, indicating that lower-performing countries are improving faster, though disparities persist, especially for environmental goals and during global shocks. Principal Component Analysis reduces the SDGs into three dominant dimensions—social, economic, and environmental sustainability—while cluster analysis groups countries into high-performing, transitioning, and low-performing categories, emphasizing the need for differentiated policy approaches. Furthermore, trend analysis, supported by Mann–Kendall tests and Sen's slope estimates, confirms a statistically significant upward trend in SDG performance, and forecasting models suggest continued improvement up to 2030, albeit insufficient to fully achieve all targets, particularly in environmental areas. Overall, the study concludes that global sustainable development is progressing but remains slow, uneven, and vulnerable to external shocks, thereby requiring accelerated action, stronger institutional frameworks, and integrated policy planning to achieve the 2030 Agenda effectively.

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