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RESEARCH ARTICLE

OVERALL PROGRESS OF ALL SDGS

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Abstract: **Purpose:** To provide methodologically sound method of measurement of one SDG at t-th year of a country for the j-th SDG (I_{SDG-j_t}) and enabling computation of global SDG facilitating comparisons across time and space. **Method:** The paper suggests multiplicative aggregation of indicators of i-th target of the j-th SDG for a country at t-th year) ($\mathbb{T}_{i_{SDG-j_t}}$), which are similarly combined across the targets to find index of SDG status of the country SDG (I_{SDG_t}) and further aggregation of $I_{SDG_t}'s$ across countries to find $Global_{SDG_t}$. **Findings:** Each proposed index gives absolute measure satisfying desired properties and facilitates measure to indicate how far the country is from the $Global_{SDG_{2030}}$ and testing hypothesis H_0: $LogI_{SDG_t}$=$Log\ I_{SDG(t+1)}$ for a country or H_0: $LogI_{SDG-j_{t_{Country_i}}} = LogI_{SDG-j_{t_{Country_j}}}$ for $i \neq j$ at a given year by t-tests. Similarity of path of progress of I_{SDG_t} for i-th and j-th countries can be quantified meaningfully. **Conclusions:** The proposed method is applicable for SDG indicators expressed in proportions, percentages, averages, rates, count data, etc. satisfying translation invariance and consistency in aggregation. Future empirical investigations may be undertaken to estimate distribution of I_{SDG_t} and inter-linkages of various SDGs to prepare a comprehensive plan for achieving the 2030 Agenda.

Keywords: *Sustainable development goals, SDG indicators and targets, Geometric mean, Progress path, Cosine similarity, Statistical testing of hypothesis.*

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INTRODUCTION

Sustainable Development Goals (SDGs) with 169 targets and over 200 indicators related to economic, social, environmental, and law and governance issues require appropriate method of measurement of progress, current status as well as distance from the 2030 targets for a country. The list of SDG-indicators can be found at http://data.unescap.org and used as a reference for monitoring national or regional policies.

However, numbers of SDG indicators vary marginally over time. For example, the Sustainable Development Report 2024, considered a new indicator on imported deforestation in SDG 15 data for which can be obtained using geospatial datasets (UN-DESA, 2024). Starting point of integrated method of measurement should be national information on the indicators of each SDG target which are required to be aggregated meaningfully to reflect progress in the interlinked 17 goals at t-th time period and further aggregation to indicate overall progress of the country covering all the SDGs.

The SDG Index ranging between 0 to 100 is commonly used which takes un-weighted average of normalized indicators for each goal and the goal scores are averaged across all 17 SDGs. Such SDG index used in the *Sustainable Development Report 2024* (Sachs et al. 2024) ignored a country in case of missing data exceed 20 percent of the indicators. Non-consideration of such countries implies deviations from inclusiveness such as ‘leave no one behind’.

Nevertheless it indicates existence of large volume of missing information in SDG data. Moreover, normalization by min – max transformation has limitations (Sava, 2016; Mazziotta and Pareto, 2021). Shortcomings of additive aggregation of indicators and targets include substitutability effect since high value of an indicator/target can well compensate low value of another indicator/target (Herrero *et. al.* 2010).

Indicators used in SDGs are expressed in terms of: proportions, percentages, averages, rates (like growth rate, number per 100,000 population or density of Health Workers, rate of participation, water-use efficiency, share of renewable energy, etc.), count data like (3.3.5; 3.b.2; 4.b.1; 10.7.3; etc.) and different sub-indicators (like indicator of food price anomalies, agriculture orientation index for government expenditures, parity indices as ratio of indicator value of one group with another group, Financial Soundness Indicators etc.).

However**,** percentages and proportions are not additive always since combined proportion of $\frac{X_1}{n_1}$ and $\frac{X_2}{n_2}$ is $\frac{n_1X_1+n_2X_2}{n_1+n_2} \neq \frac{\frac{X_1}{n_1}*100+\frac{X_2}{n_2}*100}{2}$.

For example, percentage literacy rate of a country is different from sum or average literacy rate of males and females, both in percentages. If for a country, literacy rate of males exceeds the same of females for 50% of the regions and the inequality is reversed for the rest of the regions, the average gender gap of literacy rate for the country may be zero. Thus, meaningfulness of arithmetic aggregation of indicators can be questioned. The same is true for averages, rates and different sub- indicators. Sum of indicators in percentages fails to satisfy the linear trend assumption (Gennari and D' Orazio, 2020).

Application of statistical methods involving probability distributions requires meaningful addition of variables like $X \pm Y = Z$ when distribution of X and Y are similar and distributions of Z can be derived for further operations. Thus, SDG Index suffers from methodological limitations since arithmetic mean (AM) of indicators in proportions, percentages, averages; rates etc. and average of goal scores across all 17 SDGs are not meaningful.

Slow progresses of achieving SDG goals have severely undermined the pursuit of the SDGs, giving rise to doubts about probability of their achievement by 2030 (Leal *et. al.* 2023). To accelerate their implementation by 2030, some researchers have gone against integrated nature of the 17 goals and suggested for prioritization of a few goals for achieving SDG targets.

For example, Hepp *et. al.* (2019) suggested prioritization of gender equality goal covering nine targets of SDG 5 along with 54 gender indicators across all goals. Yusuf *et. al.* (2024) favoured to put more emphasis on policies to build productive capacities and distributive policy measures like expansion of income transfers ensuring sufficiency in investments in public goods.

Various methods of measurement of SDG progress vary with respect to their underlying assumptions, methodology and statistical features. As a result, the methods may measure different things and need different interpretations (Bidarbakhtnia, 2020). There is no consensus on selection of different weights to different indicators and find SDG progress as weighted sum (UN-DESA, 2024).

Hence, the need of methodologically sound method of measurement of multidimensional nature of one SDG at time period t of a country by an index I_{SDG-j_t} for the j-th SDG such that the index reflects status of SDG compliance of a country at a given year and satisfies desired properties from the angle of measurement and enable comparisons across time and space. In addition, the method to measure overall progress of SDGs needs to identify critical indicators and individual SDGs to facilitates planners and policy makers to initiate necessary action to achieve the defined goals (Caiado, *et. al.* 2018).

The paper suggests multiplicative aggregation of indicators of a target (say i-th target) of the j-th SDG for a country at a year (say t-th year) ($\mathbb{T}_{i_{SDG-j_t}}$) avoiding normalization and selection of weights, which are similarly combined across the targets to find index of SDG status of the country SDG (I_{SDG_t}) and further aggregation of $I_{SDG_t}'s$ across countries to find $Global_{SDG_t}$.

Values of each such index are expressed by monotonically increasing continuous variables satisfying many desired properties.

LITERATURE REVIEW

SDG-indicators are correlated differently. Achievements in social goals (SDG1 Poverty and SDG10 Inequality) were found to be associated with higher environmental impacts (SDG13 Carbon, SDG15 Land, and SDG6 Water), though the interactions differed among countries (Scherer *et. al.,* 2018). Cling and Delecourt, (2022) used Multiple Factor Analysis (MFA) to find extent of correlations among the SDG-indicators and found that indicators related to human development are strongly correlated with income at country level. Inter-connected SDG goals may help countries to better planning, allocating resources, initiating coordinate actions and monitoring challenges to achieve the SDGs.

The 17 SDGs are correlated differently indicating different synergies and trade-offs (Pradhan *et. al.* 2017). For example, Fonseca *et. al.* (2020) found SDG-1 (no poverty), SDG-2 (zero hunger) and SDG-3 (good health and well-being) are highly correlated but insignificant correlation between SDG-13 (Climate changes) and SDG-17 (Global partnerships). While gender difference had smaller impact on indicators related to health (SDG3), but showed significant impact with respect to employment targets, as per the Global Gender Gap 2020 (World Economic Forum, 2020). Correlation between a pair of SDGs ($r_{SDG\ i, SDG\ j}$) for $i \neq j$ were found to be ≥ 0.70 for 17-pairs and Principal Component Analysis (PCA) of SDGs resulted in four independent factors (Lafortune *et. al.* 2018). Heterogeneous interactions among SDGs across locations and impact type responses highlighted the importance of methodologically sound assessment of location-wise SDGs (Pradhan *et. al.,* 2017; Yonehara *et. al.* 2017)

Pinar (2022) used aggregation by Choquet integral based on interactions among the dimensions, rather than evaluating single dimensions (Grabisch et. al., 2009). The balanced (or unbalanced) achievements across dimensions are reflected in the composite score. One major limitations of this approach is selection of a priori weights. Biggeri and Maggino (2019) suggested Multidimensional Synthesis of Indicators (MSI) approach to compute 'Integrated Sustainable Development Index' or 'I-SDI' to capture the interconnected components of SDGs. It accounts for the trade-offs and synergies among economic, social, environmental goals and targets. However, the approach made several assumptions like unchanged structure of economy and intensities of environmental factors, which are not always realistic. Major limitations of I-SDI are:

Data gaps for some indicators at the international level

Data at national levels are not always well comparable with data at global level and thus lead to differences between the data presented in the I-SDI and the data available from national sources.

National statistical offices may have more recent data for some indicators since validation processes of international organizations take time to publish them.

Balanced and integrated set of SDGs may not be a sufficient condition to achieve balanced and integrated form of sustainable development.

To bring the SDG-indicators to a common score ranges in unit free fashion, Min–Max scaling is often used to normalize the data. SDG India Index by NITI Aayog (2018), Govt. of India (*www.niti.gov.in*) normalize raw scores of i-th indicator (x_i) to unit-free y_i by

$$y_i = \frac{x_i - Min.\ x_i}{Targeted_{x_i} - Min.x_i} * 100.$$

However, normalization by Min–Max transformation has limitations like:

- y_i depicts a relative measure only (Sava, 2016).
- Normalization process depends significantly on $Min.x_i$ which may be an outlier. Value of $Min.x_i$ gets changed with changes in time-period and thus, may be inappropriate for comparisons across time periods.
- Score ranges of indicators get changed by such transformation (Mazziotta and Pareto, 2021).

- $Targeted_{x_i}$in (%) − $Min. x_i$ in(%) may not be meaningful because of problem in defining x% ± y%. For data in percentages, Human Poverty Index (HPI) considered cube root and 4th root of AM of figures in percentages for HPI-1 and HPI-2 respectively (UNDP, 2007).

Normalization of income component as $Income_X = \frac{log_e{}^X - log_e{}^{(X_{Min})}}{log_e{}^{(X_{Max})} - log_e{}^{(X_{Min})}}$ by UNDP (2010) is not invariant under change of origin. Chakravarty (2003) proved that properties like Translation Invariance (ability to produce the same result for a given set of inputs regardless of their locations) and consistency in aggregation (value of an index computed in two stages equals the value obtained in a single stage) are not satisfied by logarithmic transformation.

- A change in $Min. x_i$ may change marginal rates of substitution which in turn change ranking and relative valuations (Seth and Villar, 2017)
- Indicators with small score ranges are overestimated in Min-Max normalization and affect composite score obtained by aggregating such normalized values.
- Performance of a third indicator may influence ranks of two indicators resulting from Min-Max normalization (Kasparian and Rolland, 2012).
- The curve showing raw scores (x_i) and normalized scores (y_i) is not linear since $\frac{\Delta y}{\Delta x}$ is not constant. Thus, correlation between raw scores and normalized scores may not be perfect.

It is felt desirable to aggregate indicators of SDGs avoiding normalization or scaling.

Few SDG-indicators are inadequate. For example, the indicator 8.2.1: Growth rate of real GDP per annum per employed person of a country at t-th year (GEP_t^{GDP}) does not reveal energy used and interactions with the environment. Similarly, the SDG indicator 8.3.1: Sector-wise and gender-wise informal employment as percentage (or proportion) of total employment, does not consider informal employment in Agricultural activities. In addition, definitions of employment and unemployment may vary across surveys using questionnaires. Indicator 8.4.2 regarding per capita domestic material consumption (DMC) cannot be broken down to different economic sectors. For a country with high export of primary products, DMC may vary depending on the outsourcing of material intensive process to foreign countries. The first goal of SDG-1 to eliminate poverty in all forms considers poverty line as daily income ≤ $1.25 at 2017 PPP (Purchasing Power Parity) (UN DESA 2023). The measure fails to show intensity of poverty in multi-dimensional deprivations.

The global multidimensional poverty index (MPI) contains ten indicators with different weights distributed over equally weighted non-monetary dimensions like health (two indicators), education (two indicators), and living standards or Access to basic infrastructure (six indicators) (UNDP-OPHI 2021). However, MPI does not focus on the 'dynamics of poverty' i.e. movement of people from poverty or from non-poverty to poverty and the factors influencing such transitions.

Different methods used to measure progress of SDGs have been criticized primarily on selection of weights (Heras-Saizarbitoria *et. al.,* 2022; Bebbington & Unerman, 2018). Ordered weighted average of 17 SDGs was taken by Ruiz-Morales *et. al.* (2021) where weights were obtained by experts' evaluations. Such subjective weights can alter the ranking of the countries (Grupp and Schubert, 2010). Weights as factor loadings and from PCA were discarded (Lafortune *et. al.* 2018). Kroll, (2015) found composite index (CI) of all SDGs as arithmetic mean of indicators measured on a 11-point scale (1 worst) - 10 (best)).

Similar methodology was used by (Sachs *et. al.*, 2016) with a different scale ranging from 0 ("worst") to 100 ("best") across the SDGs. The SDG Dashboard and the Sustainable Development Solutions Network (SDSN) gives country-wise report cards using AM of indicators corresponding to a goal which are further aggregated across all SDGs by AM (Sachs *et. al.* 2017). The AM of SDGs fails to indicate poor performance in one or two metrics within the same SDG and cannot reflect imbalance in growth across indicators/goals (Biggeri *et. al.,* 2019). Chakrabartty (2024) gave an example where score of Country A> same for Country B as per Min–Max normalization, but, scores of the two countries got reversed for weighted sum.

Bidarbakhtnia, (2018) used median of the indicator over all countries as the regional value assigning equal weights to all countries. Median performs better than weighted average which could be biased towards developed economies or populous countries. The author suggested against weighted average for indicators that are time-independent and financial aids indicators and also to avoid outliers.

Denoting value of an indicator in 2000 by (I_{00}), current year (I_{cv}), targeted value in 2030 (I_{TV}), UNESCAP approach 2020 (Bidarbakhtnia, 2020) normalized values of the indicator P_{CS} as $P_{CS} = \frac{I_{cv}-I_{00}}{|I_{TV}-I_{00}|} \times D$ where

$D = 10$ if increasing value of the indicator is desirable and $D = -10$ otherwise. Indicator-wise P_{CS}'s under a target are averaged which are again averaged to find average progress made (current status) in each goal. Anticipated progress gap (P_{pg}) was approximated by $P_{pg} = \frac{|I_{TV}-\widehat{I_{2030}}|}{|I_{TV}-I_{2015}|} \times 10$ where $\widehat{I_{2030}}$ is the value of the indicator estimated for 2030 and I_{2015} is the actual value registered in 2015.

Major limitations of the approach are:

- Setting $P_{CS} = 0$ for 2000 and $P_{CS} = 100$ for 2030 appears to be rather mechanical and is not supported by sound theoretical justifications.
- Relative measure of P_{CS} depends heavily on the value of the indicator in 2000 (I_{00})
- $|I_{TV} - I_{00}|$ is different for different indicators and thus, average of P_{CS}'s with different denominators may not be meaningful.
- Taking average to find indicator-wise targets and further average to find current status may require checking of consistency in aggregation
- P_{CS} could be negative in case of regression registered by the country.
- $\widehat{I_{30}}$ is to be estimated only for the indicators which are not likely to achieve the target.
- Progress gap involves estimation of value of the indicator in 2030. Question arises on how good are the estimates. Quality of the estimation procedure by weighted regression model using time-related weights with assumption (Bidarbakhtnia, 2017) may be questioned.

For each indicator, SDG index by Sustainable Development Solutions Network (SDSN) (Sachs *et. al.* 2017) found how far a country is from the worst performer, expressed as proportion of the overall Euclidian distance of the worst performer to the 2030 targets. Naturally, aggregation across countries was needed for this index. The index is more suitable for ranking purposes. The progress was assessed by indicator-wise annual growth rate in comparison to the desirable growth rate.

The OECD approach to assess current status of OECD countries with respect to SDG targets (OECD, 2017) is based on country-wise Euclidian distance of indicators from the corresponding 2030 targets. Ranking of countries with respect to OECD approach coincides with ranking by SDSN's method when normalized on a scale from 0 to 10.

However, the OECD approach does not account for country-wise rate of progress like SDSN. Special advantage of the OECD approach is that it gives the direction of change in terms of correlation between time and indicator values. While a positive correlation implies progress in right direction to meet 2030 targets, a negative correlation indicates need to initiate necessary corrective action.

SUGGESTED METHOD

For the i-th SDG target of a country at t-th year, let $X_{1i}, X_{2i}, \dots\dots, X_{ni}$ denote values of the n-indicators and $X_{1i_0}, X_{2i_0}, \dots\dots, X_{ni_0}$ are the corresponding values of those n-indicators in the base period, where $X_{ki} > 0$ and $X_{ki_0} > 0$ $\forall\, k = 1, 2, \dots\dots, n$. Without loss of generality, assume each indicator shares a positive relationship with the target i.e. higher value of the indicator $\Rightarrow$ increased value of the target.

For indicators where higher value $\Rightarrow$ poor performance, reciprocal of the indicator may be considered, say reciprocal of average annual dropout rate at the secondary level (IX-X). Indicator like Gender Parity Index (GPI) for higher education may involve different enrolled rates of males and females where target = 1. In such cases, take ratio of number of male and female students enrolled in a particular level of education.

Composite index (CI) of the of the i-th target of the j-th SDG at t-th year is defined as

$$\mathbb{T}_{i_{SDG-j_t}} = \sqrt[n]{\frac{X_{1i}.X_{2i}\ldots\ldots\ldots\ldots X_{ni}}{X_{1i_0}.X_{2i_0}\ldots\ldots\ldots\ldots X_{ni_0}}} \quad (1)$$

which is equivalent to:

$$\mathbb{T}_{i_{SDG-j_t}} = \frac{X_{1i}.X_{2i}\ldots\ldots X_{ni}}{X_{1i_0}.X_{2i_0}\ldots\ldots X_{ni_0}} \quad (2)$$

$\mathbb{T}_{i_{SDG-j_t}}$ as per (1) and (2) are equivalent and has one-to-one and onto correspondence.

$\mathbb{T}_{i_{SDG-j_t}}$ combines the relevant indicators by a single value reflecting current status of the i-th target of the j-th SDG of a country at t-th year by multiplicative aggregation of ratios of the n- SDG indicators.

Status of the j-th SDG at t-th year of a country (I_{SDG-j_t}) can be computed by combining m-number of targets by a function of geometric mean (ignoring m-th root) as

$$I_{SDG-j_t} = \prod_{i=1}^{m} \mathbb{T}_{i_{SDG-j_t}} \quad (3)$$

Similarly, current status of all the SDGs for the country at t-th year can be obtained by

$$I_{SDG_t} = \prod_{j=1}^{17} I_{SDG-j_t} \quad (4)$$

Current status of all SDGs for p-number of countries can be combined to get index of global SDG at t-th period as

$$Global_{SDG_t} = \prod_{r=1}^{p} I_{SDG_{t_r}} \quad (5)$$

Taking logarithm on both sides of each of equation (2) to (5) we get additive models, since logarithm of a composite target (LHS of equation (2) to (5)) is equal to sum of logarithm of n-indicators at t-th period - Sum of logarithm of the indicators at base period.

Properties and Benefits

For the proposed index of achievement of I_{SDG-j_t} at national level for a given year as per (3) and I_{SDG_t} as per (4):

- Trade-offs among the constituent indicators of indices given in (2) to (5) get reduced significantly.
- Relative importance of the i-th target of the j-th SDG for a given year can be found by $\frac{\mathbb{T}_{i_{SDG-j_t}}}{I_{SDG-j_t}} \times 100$ facilitating ranking of the targets in terms of the relative importance. Such rankings help to identify main drivers of the spatial variations of an SDG (say the j-th SDG). Similarly, $\frac{I_{SDG-j_t}}{I_{SDG_t}} \times 100$ indicates relative importance of each of the17 SDGs in overall SDGs of the country and finds specific SDGs needed to be focused. Contribution of countries to global SDG at t-th period can similarly be found by $\frac{I_{SDG_t}}{Global_{SDG_t}} \times 100$. The relative contributions are different for different countries. For a given country, relative contributions get changed for different years.
- $\mathbb{T}_{i_{SDG-j_t}} < \mathbb{T}_{i_{SDG-j_{(t-1)}}}$ indicates that the i-th indicator is critical and requires necessary corrective action to arrest the poor performance of the critical indicator and improve. Following similar logic, critical SDG for a nation requiring attention can be found. The countries showing poor performance of I_{SDG_t} in comparison to the previous year may be alerted with the need for improvement along with indication of directions for improvement.
- Possible to assess progress of I_{SDG-j_t} of a country from the previous year by $\frac{I_{SDGj_t}}{I_{SDGj_{(t-1)}}}$ where $\frac{I_{SDGj_t}}{I_{SDGj_{(t-1)}}} > 1$ indicates that the country has progressed in t-th period over the previous period and also reflects effectiveness of the policy measures adopted. Similar ratio can be found to assess improvement in I_{SDG_t} and $Global_{SDG_t}$ from the previous year.
- Each of the indices I_{SDG-j_t}, I_{SDG_t} and $Global_{SDG_t}$ are consistent and adequate since each satisfies the following tests:
- Unit test: Independent of units of the indicators. Can be applied for data in proportions, percentages, averages, rates, count data and even several sub-indices.

  ○ Order reversal test: Independent of order of selection of constituent factors (indicators, targets, individual SDGs, SDG status in countries)

- Time reversal test: Can move both forward and backward with respect to time and satisfies Time–reversal test since $\frac{I_{SDG-j_t}}{I_{SDG-j_{t_0}}} \times \frac{I_{SDG-j_{t_0}}}{I_{SDG-j_t}} = 1$ and $\frac{I_{SDG_t}}{I_{SDG_{t_0}}} \times \frac{I_{SDG_{t_0}}}{I_{SDG_t}} = 1$ for a given country. For the global level, $\frac{Global_{SDG_t}}{Global_{SDG_{t_0}}} \times \frac{Global_{SDG_{t_0}}}{Global_{SDG_t}} = 1$
- Chain indices: Facilitates formation of chain indices since $I_{SDG-j_{20}} = I_{SDG-j_{21}} \times I_{SDG-j_{10}}$. Thus, reduces computation work when base year is changed and facilitates drawing path of progress and decline of individual SDG (I_{SDG-j_t}) or all SDGs taken together (I_{SDG_t}) for a country or even the progress path at global level $(Global_{SDG_t})$ across time. Such graphs can show behavior of SDG-achievements of different countries over time and also zigzag path of SDG at global level. The time points showing decline of status of individual SDG or all SDGs of a country can be probed appropriately to find possible reasons.

- For p-countries, mean and variance of $\log Global_{SDG_t}$ can be found using (5) and by transforming $Z_i = \frac{\log I_{SDG_t} - \overline{\log I_{SDG_t}}}{SD(\log I_{I_{SDG_t}})} \sim N(0,1)$ and further linear transformation of Z_i to Y_i where $Y_i = (99)\left[\frac{Z_i - Min_{Z_i}}{Max_{Z_i} - Min_{Z_i}}\right] + 1$. Here, Y-scores in fixed range follows Normal distribution and enable meaningful addition where distribution of $\sum Y_i$ is also normal. Normality helps in statistical inferences like estimation of population mean (μ), population variance (σ^2), and testing statistical hypothesis of equality of mean $\log I_{SDG_t}$ of different countries since, $(X+Y) \sim N(\mu_X + \mu_Y, \sigma_X^2 + \sigma_X^2 + 2\sigma_{XY})$ where $X \sim N(\mu_X, \sigma_X^2)$ and $Y \sim N(\mu_Y, \sigma_Y^2)$. $\log Global_{SDG_t}$ for the world can also be found as arithmetic aggregation of country-wise Y-scores.

- If values of indicators for base period are replaced by corresponding SDG-targets in equation (2), $\mathbb{T}_{i_{SDG-j_t}}$ will indicate distance of the country from the targets of j-th SDG at t-th year. $\mathbb{T}_{i_{SDG-j_t}} = 1$ implies that the country has achieved the targets of the j-th SDG. Overall distance of the country from SDG targets can be found similarly.

- Considering logarithms of the indicators, one can test hypotheses:
- H_0: $LogI_{SDG-j_t Country_i} = LogI_{SDG-j_t Country_j}$ for $i \neq j$ and
- H_0: $LogI_{SDG_t} = LogI_{SDG_{(t-1)}}$ by conventional t-tests.
- Testing of similarity of paths of I_{SDG_t} for two countries over a span of years requires choice of similarity measure.

- Chakrabartty and Sinha, (2022) suggested a cosine similarity $Cos\theta_{12} = \frac{P_1{}^T P_2}{\|\boldsymbol{P_1}\|\|\boldsymbol{P_2}\|}$ as a similarity measure where progress of two countries are represented by two vectors covering p-number of years $\boldsymbol{P_1} = (Prog._{11}, Prog._{12}, \dots, Prog._{1p})^T$ and $\boldsymbol{P_2} = (Prog._{21}, Prog._{22}, \dots Prog._{2p})^T$ and θ_{12} is the angle between the vectors $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. $\|\boldsymbol{P_1}\|, \|\boldsymbol{P_2}\|$ are the length of the vectors $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ respectively.

- Rao (1973) Gave method of computation of mean and dispersion of angles $\varphi_1, \varphi_2, \dots, \varphi_k$ for vectors of unit length.

- Aggregation by (2) may have problems in capturing the complementariness or synergies among SDG targets since unbalanced achievements across the SDG targets are not always strongly penalized.

  However, benefits of the proposed index $\mathbb{T}_{i_{SDG-j_t}}$ outperforms the problem areas.

LIMITATIONS

Positive numerical values of targets were assumed. Missing data is a major hindrance in SDG analysis and are not considered here. Details of methods to deal with missing data and their comparison are not within the scope of the current article.

DISCUSSION

Multiplicative aggregation of indicators of a target (say i-th target) of the j-th SD goal for a country at a year (say t-th year) $(\mathbb{T}_{i_{SDG-j_t}})$ is proposed avoiding normalization and selection of weights. Similar aggregation across the relevant indicators gives status of the j-th SDG $(I_{SDG-j_t}) \rightarrow$ SDG status of a country $(I_{SDG_t}) \rightarrow$ Global SDG $(Global_{SDG_t})$. Each proposed index gives absolute measure by a monotonically increasing continuous variable, satisfying desired properties of an index including translation invariance and consistency in aggregation. Each index can be computed separately for socio-economically advantaged or disadvantaged groups.

Major benefits include:

- Trade-off among the indicators and SDGs are reduced significantly
- Proposed indices are not affected by outliers and without any bias for developed or underdeveloped countries.
- Facilitate finding relative importance of the indicators and also finding critical indicator(s), which are naturally different for different countries at a given year. For a given country, relative contributions get changed for different years.
- Compute $Global_{SDG_t}$ and how far a country is from the SDG 2030 targets at a time-point.
- Possible to find first and second central moments of Global SDG and testing statistical hypothesis H_0: $LogI_{SDG-j_t}{}_{Country_i} = LogI_{SDG-j_t}{}_{Country_i}$ for $i \neq j$ and H_0: $LogI_{SDG_t} = LogI_{SDG_{(t-1)}}$ by conventional t-tests.
- In case of rejection of H_0: $LogI_{SDG-j_t} = LogI_{SDG-j_{(t-1)}}$ or H_0: $LogI_{SDG_t} = LogI_{SDG_{(t-1)}}$, the indicator(s) showing poor performance can be found at country level requiring initiation of corrective policy action for improvement of the country. Planners may formulate action plans focusing on the identified critical indicator(s) or SDGs.
- Plot of I_{SDG_t} for two different countries across past years can be evaluated meaningfully.
- Measuring SDG-wise achievements registered by a country by the proposed indices will help in investigations of progress in interlinked SDGs.

CONCLUSION

The proposed indices obtained by multiplicative aggregations can be applied for data in proportions, percentages, averages, rates, count data and even several sub-indices. The indices offering significant benefits including satisfaction of translation invariance and consistency in aggregation contribute to improved aggregation of SDGs and provide index of SDG progress at global level. Planners can take advantages of the proposed method avoiding normalization/scaling and selection of weights. Future empirical investigations may estimate distribution of I_{SDG_t} and investigate effect of progress/decline in I_{SDG-j_t} on other SDGs for a comprehensive plan for achieving the 2030 Agenda.

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