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Article

Bleak prospects and targeted actions for achieving the Sustainable Development Goals

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A B S T R A C T

At the mid-point to 2030, progress towards achieving the Sustainable Development Goals (SDGs) varies significantly across countries. While the classification of countries can lay the foundation for improving policy efficiency and promoting joint action, bottom-up, SDG data-driven country classifications have largely remained unexplored. Here, we classified 166 countries based on their performances in the 17 SDGs and further used the classification to analyze SDG interactions and compare development aid distributions. The countries were classified into five groups, ranging from "lowest development with good environment" to "high development needing climate action". None of them scored highly in all SDGs, and due to trade-offs related to environment and climate SDGs, none of them can achieve all SDGs eventually. To maximize the potential for achieving the SDGs, all countries need to undergo a sustainable transformation, and prioritizing certain SDGs, such as SDG 9 (industry, innovation and infrastructure), can help countries with lower sustainable development levels achieve more with less. Furthermore, global development aid should be better aligned with country needs, particularly in areas of education, energy, environment, and water supply and sanitation. By better characterizing different countries, this study reveals the bleak prospects of achieving all SDGs and provides valuable insights into more targeted actions for national sustainable development and global collaboration.

1. Introduction

To end poverty, protect the planet, and ensure prosperity for all, the United Nations (UN) adopted 17 Sustainable Development Goals (SDGs) as a call to global action to transform our world [1]. These ambitious goals are integrated and indivisible, and recognize that development must balance the economic, social, and environmental dimensions [1,2]. Due to the complex interactions, the pursuit of one goal may reinforce or impair another [2,3]. These synergies and trade-offs among SDGs mean that one country may have good performance in some SDGs but worse performance in others [2,4]. In addition to the definition of a set of goals, targets, and indicators, the SDGs also commit to "leave no one behind" and thereby emphasize the achievement of sustainability for all segments of society and across all countries [1,5,6]. Classification of countries is an effective way to understand the common denominators of strengths and weaknesses in relation to SDGs for different countries, laying the foundation for improving policy efficiency and promoting joint action [7]. It also provides a starting point for analyzing and comparing the interactions among SDGs in different categories of countries, which can help to guide and prioritize SDG actions [8,9].

A number of studies have employed predefined classifications, such as income level, development stage, or geographic grouping, to assess and compare SDG progress and analyze the synergies and trade-offs among them [3,8,10–12]. By examining the current status and trend in relation to the 17 SDGs among countries in different regions and income groups, these previous studies have highlighted the advantages and disadvantages, and identified the efforts needed, for different categories of countries to achieve the SDGs [13–15]. Studies of the variations in SDG interactions have shown that these interactions differ by country income and region [3,8,10,11], and that only low-income countries are the most likely

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to achieve all of the 17 goals in tandem [3]. Based on analysis of SDG interactions and identification of the important individual SDGs, the key hurdles and opportunities for different groups of countries to achieve the SDGs have been further determined [3,11,16]. To date, the predominant categories used in SDG studies have mainly relied on the UN's national classifications based on geographical regions or the World Bank's income groups determined by gross national income per capita. Only few studies have classified countries based on their SDG performances and summarized their similarities [17]. However, in-depth analysis utilizing this kind of classification remains largely unexplored.

An SDG data-driven country classification would help to understand the commonalities between countries with similar performances towards achieving the SDGs, and promote more targeted sustainable development actions. Such a classification would avoid the heterogeneity of countries within regions and the differences in the development mode of countries within income groups, and better characterize the progress and identify the existing gaps in SDGs of different countries [17]. Analysis of SDG interactions based on this kind of classification would more accurately determine the hurdles and opportunities to maximize SDG implementation for different groups of countries [3,18]. Global coordination and collaboration for sustainability actions would also be promoted through the better characterization of different groups of countries using the bottom-up classification [7]. For example, it would help reveal whether the current distribution of global development aid, which plays a crucial role in helping developing countries achieve sustainable development and in fulfilling the commitment to "leave no one behind" [5,19], are in line with the needs of different countries.

Here, we conducted an SDG data-driven country classification and further used it to generalize the characteristics, analyze the SDG interactions, and compare the development aid distributions for different countries. First, we used the "SDG bundles" concept [20], i.e., groups of regions or countries with similar performances on all individual SDGs, to classify global countries and analyzed the strengths and weaknesses of different groups of countries in relation to SDGs. Subsequently, we estimated the synergies and trade-offs among the SDG goals and targets to identify the opportunities and barriers of sustainable development for each group. Finally, we analyzed the differences in development aid received by these groups and assessed whether the aid distribution aligned with the needs of different groups. Based on the findings, this study will provide valuable insights about more targeted actions for national sustainable development and global collaboration.

2. Materials and methods

2.1. Data sources

The identification of SDG bundles was based on the scores of the 17 SDGs for 166 countries, which were obtained from *Sustainable Development Report 2020* published by the Sustainable Development Solutions Network (SDSN) and the Bertelsmann Stiftung [12]. The SDSN has published the report annually from 2017 to 2022. However, because of changes to the indicators used and some methodological refinements, the SDGs scores cannot be compared between years [15]. The number of countries is greatest in *Sustainable Development Report 2020*; therefore, that was the report we used in the present study. *Sustainable Development Report 2020* provides a score for each SDG and an SDG Index score (measurement of overall sustainable development level) for each country, which together describe each country's progress towards achieving the SDGs. The SDG scores can be seen as a percentage of optimal performance. A total of 115 indicators, comprising 85 global indicators and 30 indicators specifically for the Organization for Economic Co-operation and Development (OECD) countries, were used to generate comparable scores. The raw data used for the indicators were collected mainly from international organizations that have extensive and rigorous data-validation processes, such as the World Bank, the Food and Agriculture Organization, the World Health Organization, and the OECD. To ensure comparability across all indicators, extreme values were censored from each indicator's distribution, and the data were then rescaled from 0 to 100. The scores for each goal were calculated as the arithmetic mean of the corresponding indicators. Collinearity between indicators under each SDG was assessed during SDSN's evaluation process. Although there were high correlation coefficients between five pairs of indicators belonging to SDG 1 and SDG 3, these indicators were retained due to their relevance and/or because they are specifically mentioned in the 2030 agenda [21].

To explore other characteristics of the identified groups of countries, we also collected socioeconomic and environmental data for each country from the World Bank's World Development Indicators. The economic variables included GDP and gross national income per capita, the ratios of value added of different industries (i.e., agriculture, forestry, and fishing; industry; services; and manufacturing) to GDP, the ratio of medium- and high-tech value added to manufacturing value added, the ratio of total natural resources rents to GDP, and the ratios of different natural resource rents (i.e., oil, natural gas, and forest) to GDP. The demographic variables used were population, population density, urbanization, and percentage of the population aged 0 to 14 years. The environmental variables were land area, precipitation, and the ratios of agricultural land, arable land, and forest area. For the regional characterization of the groups, we used three widely used classifications of countries: World Bank income group, United Nations continent and subregion, and the region used in the *Sustainable Development Report*.

We used a unified SDG database [22], which merged SDG indicator data provided by the United Nations, the World Bank Group, and the SDSN and the Bertelsmann Stiftung, to analyze SDG interactions at goal and target levels for each group of countries. The indicator data from different sources were assigned to the officially adopted global SDG indicator framework of 17 SDGs and 169 targets. The unified database consists of a unique list of 2584 disaggregated SDG indicators for 255 countries and areas between 2000 and 2019, covering more targets across more countries than the three original SDG databases, and can offer a more nuanced and reliable view of SDG interactions [22]. Due to data limitations, some indicators only have values available for specific years, making longitudinal analysis challenging. To include more indicators, we selected those with at least one value available for the period 2015–2019 and used the value from the nearest year for each indicator to conduct a cross-sectional analysis to understand SDG interactions [10].

Global development aid data were collected from an article by Toetzke et al. [5]. In their study, they used a dataset of global development aid activities provided by the Development Co-operation Directorate of the OECD. This dataset is considered the most comprehensive data on global development aid and includes textual descriptions of about 3.2 million aid activities conducted between 2000 and 2019 totaling US$2.8 trillion. The dataset comprises 160 recipient countries and over 750 different donor organizations, including 595 agencies from the 30 member states of the Development Assistance Committee (DAC) and 25 other non-DAC countries, 162 multilateral donor agencies (e.g., Global Environment Facility Trust Fund) and 28 private donors (e.g., Bill & Melinda Gates Foundation). Based on the textual descriptions from donors, Toetzke et al. [5] developed a machine-learning framework to generate a comprehensive and granular categorization of development aid activities and clustered the descriptions of these activities into 173 activity clusters representing the topics of the underlying aid activities. To summarize the scope, activity clusters were assigned to sectors of aid based on the official sector categories of the OECD [5]. The study of Toetzke et al. [5] provides a new and meaningful categorization of aid activities that can be used in analyses regarding the spatio-temporal distribution of aid across different countries, topics, and sectors.

2.2. Identification and comparison of different groups of countries

To identify SDG bundles, we conducted a hierarchical cluster analysis based on Euclidean distance and Ward's agglomerative method by using the scores of the 17 SDGs for the 166 countries in *Sustainable Development Report 2020*, which is a 166 $\times$ 17 ($i \times j$) matrix ($\boldsymbol{S}$) (Figs. S1 and S2 online). This approach has been widely used in previous studies to cluster different regions or countries based on their multidimensional characteristics [23,24]. The Euclidean distance between two countries, $i1$ and $i2$, was calculated as $\sqrt{\sum_j (S_{i1,j} - S_{i2,j})^2}$. The function dist in R package Stats was used to compute the distances. The function allows for missing values and excludes them from computations involving the rows within which they occur. If some columns are excluded in calculating a Euclidean distance, the sum is scaled up proportionally to the number of columns used [25]. The number of clusters to be retained was determined using the NbClust package in R [26]. Out of the 30 indices provided by NbClust, 11 indices suggested that five clusters would be the optimal choice when considering more than three clusters. This particular number of clusters was proposed more frequently than any other option. Therefore, we selected five clusters for the hierarchical cluster analysis. Due to data limitations, there are missing scores for SDGs 1, 4, 10, and 14 in 12, 2, 17, and 40 countries, respectively (Fig. S1 online). Although missing values are allowed in the hierarchical cluster analysis, we also compared our results with clustering results using completed data with imputed values for missing SDG scores. Four imputation methods were implemented using mice in R [27]. The clustering results exhibited similar patterns, and the classification groups for most countries remained unchanged when using different data (Fig. S3 online).

After clustering the countries, we used the Kruskal–Wallis and Chi-squared tests to summarize each group of countries in terms of their performances in the 17 individual SDGs and SDG Index and their socioeconomic and environmental characteristics and region. To compare the differences in development aid among different groups of countries, we calculated the ratio of aid for each sector to the total aid disbursement for each country, then performed the Kruskal–Wallis test. The Kruskal–Wallis test is a widely used non-parametric method for testing whether there are statistically significant differences between groups of an independent variable and a continuous dependent variable [28].

To validate the reliability of our classification, we conducted a comparison between the present SDG bundles and other commonly used country classifications. This was done by calculating the within cluster sum of squares (WSS) and between cluster sum of squares (BSS) for each type of classification. WSS measures the variability within each cluster/group, while BSS measures the separation of clusters/groups. A good clustering is characterized by a low total WSS and high BSS. Because WSS is often not directly comparable across clusters with different numbers of observations, we also calculated the average distance from centroid for each group in each classification. A group with a smaller average distance is more compact than that with a larger average distance. All statistical analyses were run within R.

2.3. SDG interactions and network analyses for different groups of countries

For each group of countries, we estimated pairwise interactions between SDGs and targets by conducting pairwise meta-analyses of the standardized coefficients of association between the relevant indicators [3]. Only the pairs of indicators consisting at least 10 data points for each group were used [10], and a total of 442 disaggregated indicators were selected (Table S1 online), covering 87 targets and 17 SDGs. The values of indicators were multiplied by −1 if a decline was required to achieve the SDGs, and multiplied by 1 if an increase was desirable. Subsequently, the values were standardized by subtracting the mean and dividing by the standard deviation of each indicator. The standardized coefficients of association between each pair of indicators were estimated using linear regression. We used these coefficients with their associated standard errors and meta-analyzed (using metafor in R [29]) the associations for each target pair given the target membership of each indicator, and then used the coefficients of association of each target pair with their associated standard errors and meta-analyzed the associations for each SDG pair given the SDG membership of each target [3]. The estimated association coefficients that significantly ($P < 0.05$) differ from zero were retained for further analysis: positive values represent synergies whereas negative values represent trade-offs, and the absolute values of the coefficient represent the strength of the interaction.

Using igraph in R [30], the pairwise association coefficients between SDGs and targets for each group of countries were converted to network graph objects. In these networks, the nodes represent the interactive SDGs/targets, and links between nodes represent positive or negative associations between two SDGs/targets and their weights. We used simulations to estimate the probable fate of goals/targets when we intervened on a specific goal/target, given the observed interactions. If the interactions remain unchanged, the vector of SDG/target states at time t + 1 ($\boldsymbol{a}_{t+1}$) can be estimated by the vector at time t ($\boldsymbol{a}_t$) and the association matrix $\boldsymbol{A}$ [3,31,32], that is, $\boldsymbol{a}_{t+1} = \boldsymbol{A} \cdot \boldsymbol{a}_t$. We used intervention and no intervention scenarios to simulate the vector of SDG/target states through time (1000 steps), starting with all entries of $\boldsymbol{a}_0$ at a value of 1 [3]. In the intervention scenario, we intervened on a single goal/target, i, by a small increment (0.1) at each time step ($\boldsymbol{a}_{i,t} = \boldsymbol{a}_{i,t} + 0.1$) before estimating $\boldsymbol{a}_{t+1}$ [3]. We repeated the simulation 17 times for SDGs and 87 times for targets to cover every SDG/target involved. The effects on all SDGs/targets when intervention takes place for a specific SDG/target were calculated as the differences in all SDGs/targets at the end between simulation with intervention on the given SDG/target and simulation without intervention. Although this simulation method is simple and not highly precise, it is an attempt to capture the interaction effects [31] and can help determine the antagonistic clusters in the networks [3].

To analyze the structural importance of SDGs/targets in the interaction networks, we calculated the eigenvector centrality and weighted node degree for each node. Eigenvector centrality takes account the influence of a node across the entire network structure [32]. A node with high eigenvector centrality has significant indirect effects on other nodes, not only those with which it connects, but also effects propagating through its neighbors [3,32]. Eigenvector centrality was calculated for the synergy and trade-off networks, respectively [22]. Weighted node degree (i.e., the average strength of connection to other nodes, calculated as the product of the degree of a node and the mean of the absolute association coefficients of all connections [16]) was used to calculate the positive and negative connectivity of each node separately and identify the most positively and negatively connected nodes. Given the uncertainties surrounding the estimation of associations

[3], we assessed whether the observed eigenvector centrality and connectivity of each SDG occurred by chance. To do so, we randomly shuffled the existing associations of SDGs for each group of countries 1000 times while maintaining the symmetry of the matrix. For each of the 1000 randomized networks, we calculated the eigenvector centrality and connectivity for each SDG. This process allowed us to estimate the likelihood of obtaining the observed eigenvector centrality and connectivity values for each group among the 1000 random estimates.

3. Results

3.1. Five groups of countries with different gaps in achieving SDGs

We performed a hierarchical cluster analysis to classify 166 countries based on their performances on the 17 individual SDGs as published in *Sustainable Development Report 2020* [12]. Using NbClust in R [26] (see Materials and methods for details), we determined the number of clusters to be five, which resulted in the classification of the 166 countries into five distinct groups (i.e., SDG bundles [20]) with significant differences in SDG performances (Fig. 1a and Figs. S1 and S2 online). None of the groups had high scores in all SDGs, with different gaps observed in achieving the SDGs (Fig. 1b and Fig. S1 online). Group 1 "lowest development with good environment" was characterized by countries with the lowest level of sustainable development (SDG Index) and the lowest performance in almost all social and economic SDGs, but the highest performance in SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water), and SDG 15 (life on land). In contrast, Group 5 "high development needing climate action" was characterized by countries with the highest level of sustainable development and the highest ranks in the social and economic SDGs and SDG 15, but the lowest ranks in SDGs 12–14. Group 2 "low development with degraded environment" was characterized by countries with the second lowest sustainable development level; compared with Group 1, it showed better performance in eight SDGs and similar performance in seven SDGs, a slightly worse performance in SDG 13, and a markedly worse performance (one of the lowest among the five groups) in SDG 15. Group 3 "middle development needing environment and climate action" was characterized by countries with an intermediate sustainable development level and the worst performance in SDG 14 and the second worst performance in SDG 13; compared with Groups 1 and 2, it had better performance in most individual SDGs except for SDGs 12–14. Group 4 "middle development with inequality and degraded environment" was characterized by countries with mid-level sustainable development but the lowest rank in SDG 10 (reduced inequalities) and one of the lowest ranks in SDG 15. Table 1 provides a summary of the general SDG performances and characteristics of the five groups of countries, taking into account socioeconomic and environmental information and regional contexts; related analysis results are provided in Fig. S4 and Table S2 (online).

3.2. Opportunities and hurdles for each group revealed by SDG interactions

We used a unified SDG database [22] to analyze SDG interactions for each group at goal and target levels based on associations between SDG indicators (see Materials and methods for details). The interactions reflected by the weighted and undirected networks show that both synergies and trade-offs exist among goals and targets in all groups, with drastic differences among groups (Fig. 2 and Fig. S5 online). To describe the dynamics of these networks, we estimated the probable fate of goals and targets under the observed interactions as we intervened on a goal or target, and found that each network contained antagonistic SDG clusters (Figs. S6 and S7 online). These antagonistic clusters behave in different ways from one another, indicating that progress towards some goals or targets will lead to movement away from others, and that no group of countries can achieve all of the SDGs if the interactions remain unchanged (Figs. S6 and S7 online).

Some SDGs emerge as clear structural priorities in the interaction networks (Fig. 3 and Figs. S8 and S9 online); their interactions with other SDGs are dominant features of the networks and will affect many other SDGs directly and indirectly. Such observations were not attributable to chance when compared with random networks (Figs. S10–S13 online). SDGs 4 (quality education), 6 (clean water and sanitation), and 9 (industry, innovation and infrastructure) for Group 1; SDGs 2 (zero hunger), 9, and 16 (peace, justice and strong institutions) for Group 2; SDGs 9, 11 (sustainable cities and communities), and 14 for group 3; SDGs 3 (good health and well-being), 7 (affordable and clean energy), and 9 for Group 4; and SDGs 4, 5 (gender equality), and 6 for Group 5 were the top three highly positively connected goals for each group (Fig. 3). These goals also showed relatively high eigenvector centrality in the synergy networks (Fig. S8 online). Because an association network cannot infer causality, these findings mean that many other SDGs will disproportionately improve as progress is made towards the above goals (and *vice versa*) for the corresponding groups of countries. Regarding negative connections, SDGs 13 and 14 for Group 1; SDG 14 for Group 2; SDGs 4 and 13 for Group 3; SDGs 13 and 14 for Group 4; and SDGs 9, 12, and 13 for Group 5 were highly connected with other SDGs (Fig. 3) and had high eigenvector centrality in the trade-off networks (Fig. S9 online). These conflicts indicate that actions for these SDGs will impair the ability to address many other SDGs (and *vice versa*).

The interactions at the target level are more complex (Fig. S5 online). Dominant targets in the interactions differ widely across the five groups (Figs. S14–S16 online). However, for all groups, Target 3.2 (reducing child mortality) was highly positively connected with other targets (Fig. S14 online) and had relatively high eigenvector centrality in the synergy networks (Fig. S15 online), indicating that focus on child mortality will have beneficial effects for many other targets (and *vice versa*) in all groups of countries. Target 3.5 (prevention and treatment of substance abuse) for Groups 1–4 and Target 12.c (rationalizing inefficient fossil-fuel subsidies) for Groups 2, 4, and 5 are the common barriers for corresponding groups, as they were highly negatively connected with other targets (Fig. S14 online) and had high eigenvector centrality in the trade-off networks (Fig. S16 online). The differences between target interactions and their respective interactions at the goal level reflected the importance of scale selection in the interpretation of SDG interactions: goal-level analysis provides insights for broader governance while target-level analysis help reveal potential interventions [3].

3.3. Development aid for different groups needs to be better aligned

A database about categorization of development aid activities [5] was used to determine whether the distribution of development aid aligned with the needs of different groups of countries, as indicated by their gaps in achieving SDGs. We observed that total and sectoral disbursements of development aid varied across different groups between 2000 and 2019 (Fig. 4). All countries in Groups 1, 2, and 4, and 32 out of 35 countries in Group 3, received some form of financial support from donor organizations. Each of these groups received a total of approximately US$500 billion during the analysis period (Fig. 4). In contrast, only 7 out of 45 countries in Group 5, the group with the best overall performance in SDGs, received a total of around US$160 billion. Since most of

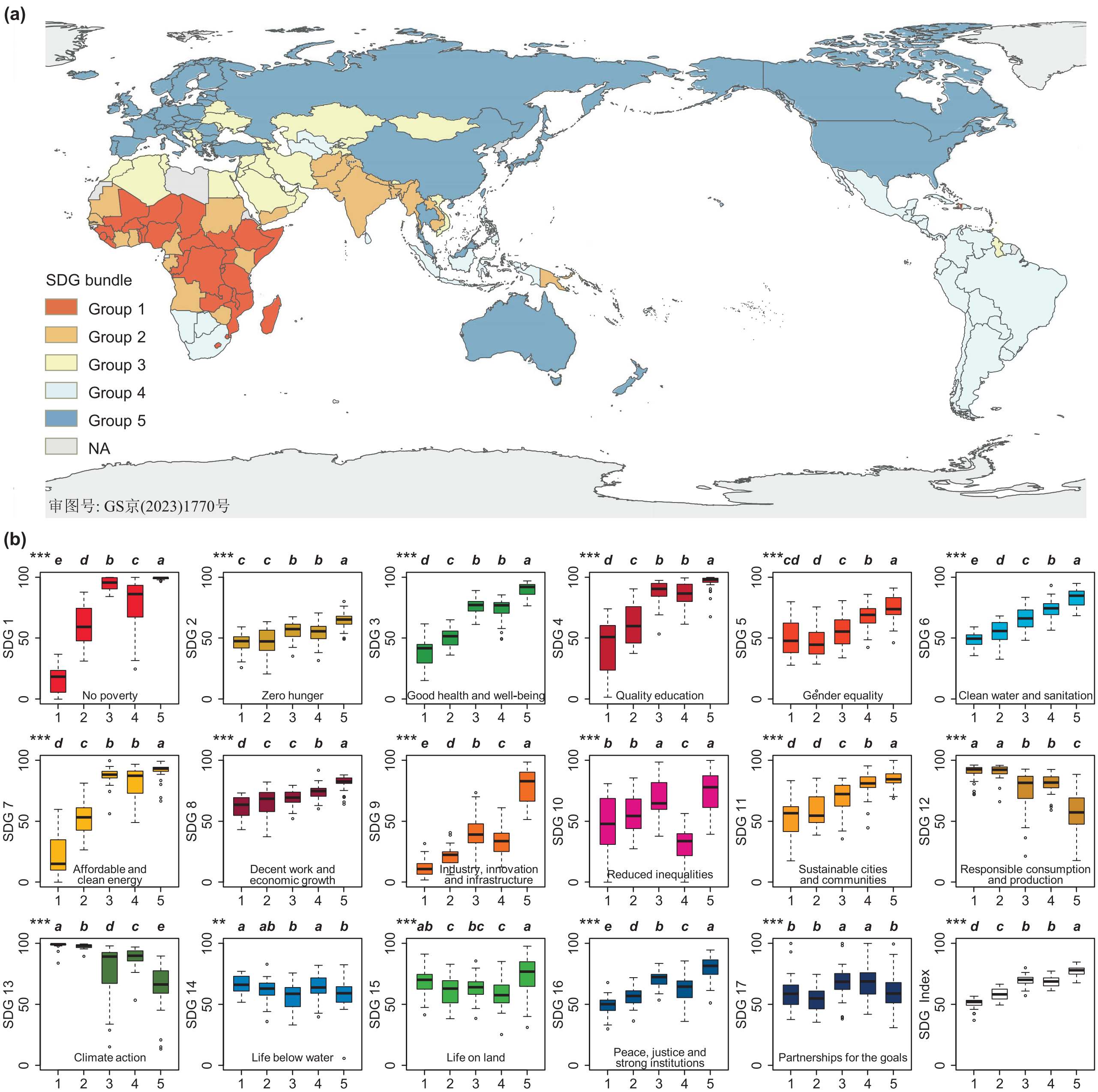

Fig. 1. The five identified groups of countries. (a) Spatial distribution of the five identified groups of countries. (b) Comparisons of individual SDG scores and SDG Index score among the five groups of countries based on data obtained from *Sustainable Development Report 2020* [12]. The characteristics of different groups of countries were summarized based on their individual SDG scores. Boxplots with different letters at the top differ significantly among the groups: **, $P < 0.01$; ***, $P < 0.001$.

the countries in Group 5 are donor countries, we excluded this group from subsequent analysis.

We further conducted a sector-wise analysis of aid distribution for each country and compared the results across the different groups (Fig. 5). The proportion of aid received in most sectors varied significantly across the groups and somewhat aligned with the specific needs of each group. For instance, Group 1 countries performed the worst in SDG 1 (no poverty) (Fig. 1b) and received the highest proportion of aid in debt relief and general budget support (Fig. 5), which together accounted for over 20% of their total aid (Fig. 4). Groups 1 and 2 countries had poor performance in SDG 2 (zero hunger) and received a significantly higher proportion of aid in agriculture and food assistance compared to the other groups. Similarly, Groups 1 and 2 also performed poorly in SDG 3 (good health and well-being) and received significantly more aid in the health sector, accounting for 16.7% and 10.9% of their total aid, respectively. Group 4, which had the worst performance in SDG 10 (reduced inequalities), received about 30% of its development aid in the government and civil society sector and social infrastructure and services sector, with significantly higher proportions of aid in these sectors than the other groups.

However, there were some mismatches between the proportions of aid received in certain sectors and the needs of different groups of countries. Although Group 1 countries exhibited the worst performance in SDGs 4 (quality education) and 7 (affordable and clean energy) among the four groups, they received

Table 1
Comparison of general SDG performances and the characteristics of the five identified groups of countries. The characteristics of the different groups of countries were summarized by using the Kruskal–Wallis and chi-squared tests.

	Group 1	Group 2	Group 3	Group 4	Group 5
Number of countries	27	25	35	34	45
Location	Mostly in eastern, middle, and western Africa	Mostly in Africa and southern Asia	Mostly in western and central Asia and northern Africa	Mostly in central and south America and southern Africa	Mostly in Europe, northern America, eastern Asia, and Australia and New Zealand
Performances in SDGs	Lowest overall sustainable development level (SDG Index). Lowest performances in almost all social and economic SDGs, but highest performances in SDGs 12 (responsible consumption and production), 13 (climate action), 14 (life below water), and 15 (life on land)	Second lowest overall sustainable development level. Better performance in eight SDGs and similar performance in seven SDGs, a slightly worse performance in SDG 13, and a markedly worse performance in SDG 15 compared with Group 1. One of the lowest performances in SDG 15	Intermediate overall sustainable development level. Lowest performance in SDG 14 and second-lowest performance in SDG 13. Performance in most individual SDGs is better than that in Groups 1 and 2, except for SDGs 12–14	Intermediate overall sustainable development level. Lowest performances in SDGs 10 (reduced inequalities) and one of the lowest performances in SDG 15. Performances in the other SDGs are intermediate, better or worse than those of Group 3	Highest overall sustainable development level. Best performance in social and economic SDGs and SDG 15, but worst performance in SDGs 12–14
Socioeconomic characteristics	Countries with the lowest gross domestic product (GDP) and gross national income (GNI) per capita. Countries most reliant on natural resources, especially forest. Agriculture, forestry, and fishing responsible for a high share of the GDP; shares of industry, services, and manufacturing lowest among the five groups	Countries mostly with lower-middle income, and higher GDP and GNI per capita compared with Group 1. GDP share structure is similar to that of Group 1 but is less reliant on natural resources	Countries with intermediate GDP and GNI per capita, varying from lower-middle to high income. GDP share of industry is the largest among the five groups, and these countries are most reliant on oil and natural gas rents. GDP shares of other industries are intermediate among the five groups	Countries with similar intermediate GDP and GNI per capita compared with Group 3, but mostly including upper-middle and lower-middle income countries. GDP shares of various industries are intermediate among the five groups	Countries with high or upper-middle income, with the highest GDP and GNI per capita. GDP of these countries relies least on agriculture and natural resources and most on services and manufacturing, especially medium and high-tech manufacturing
Demographic characteristics	Lowest urbanization rate and youngest population	Lowest urbanization rate and second-youngest population	Medium urbanization rate and second-oldest population	Medium urbanization rate and intermediate proportion of young population	Highest urbanization rate and oldest population
Environmental characteristics	Higher precipitation than Group 3; non-significant differences in other selected characteristics	High forest proportion; higher precipitation than Group 3; non-significant differences in other selected characteristics	Lowest precipitation; low arable land proportion and forest proportion	Highest precipitation; high forest proportion and low arable land proportion	Medium precipitation; relatively high forest proportion and high arable land proportion compared with other groups

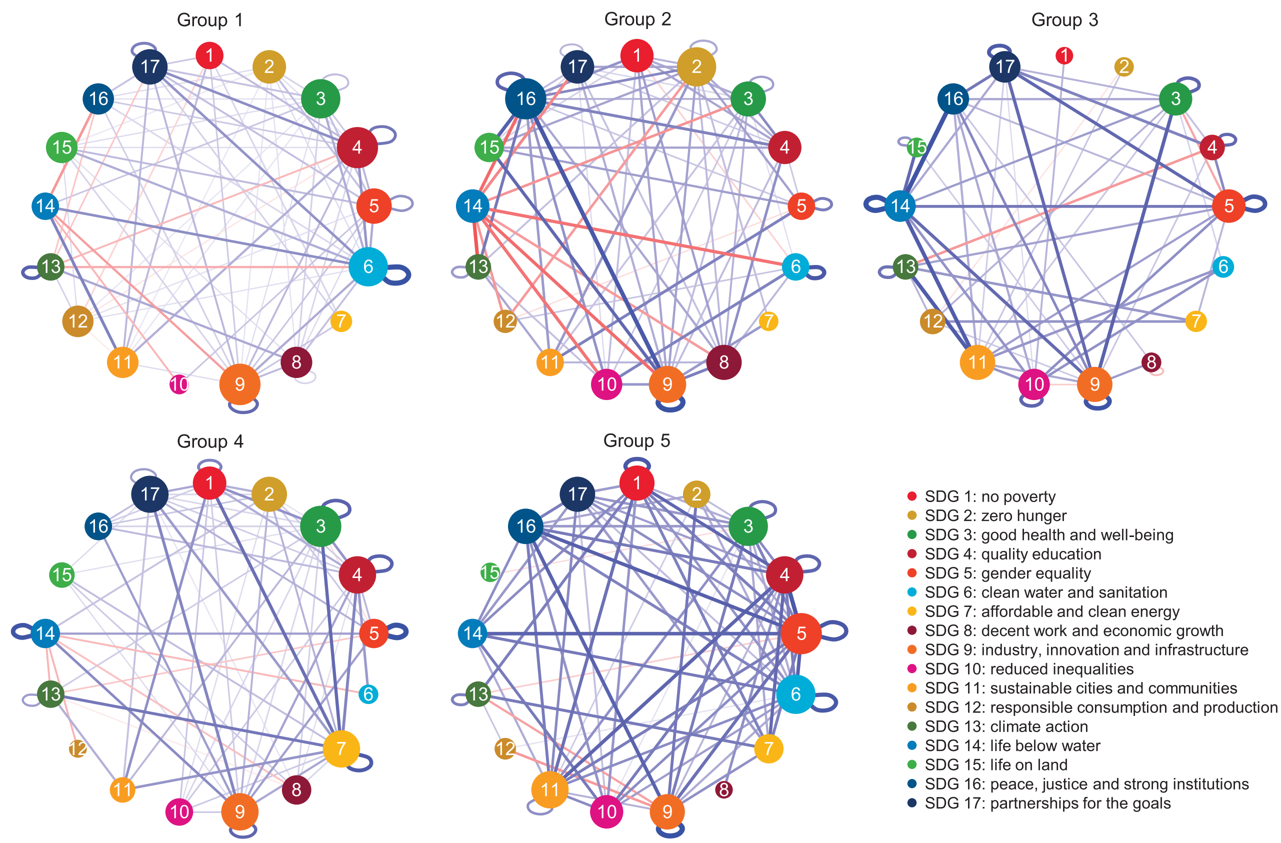

Fig. 2. SDG interaction networks for the five identified groups of countries. The lines are associations that significantly ($P < 0.05$) differ from zero, of which the width represents the association strength. Blue lines indicate positive associations; red lines indicate negative associations. Node sizes correspond to the number of both positive and negative connections to other nodes.

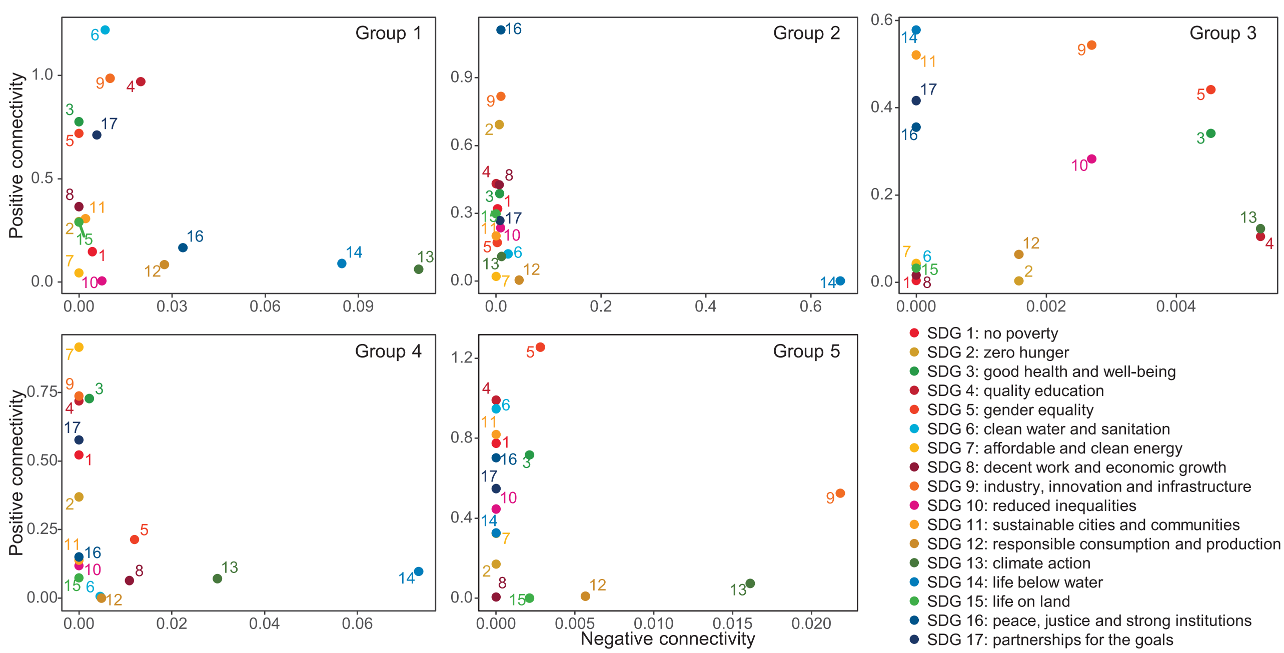

Fig. 3. Positive and negative connectivity of individual SDGs for the five identified groups of countries.

the smallest proportion of aid for education and energy (Figs. 1b and 5). The performance in SDG 6 (clean water and sanitation) decreased in order from Group 4 to Group 1; however, the corresponding ratio of development aid in water supply and sanitation showed no significant difference among the four groups. Group 4 countries, which had one of the worst performances in SDG 15

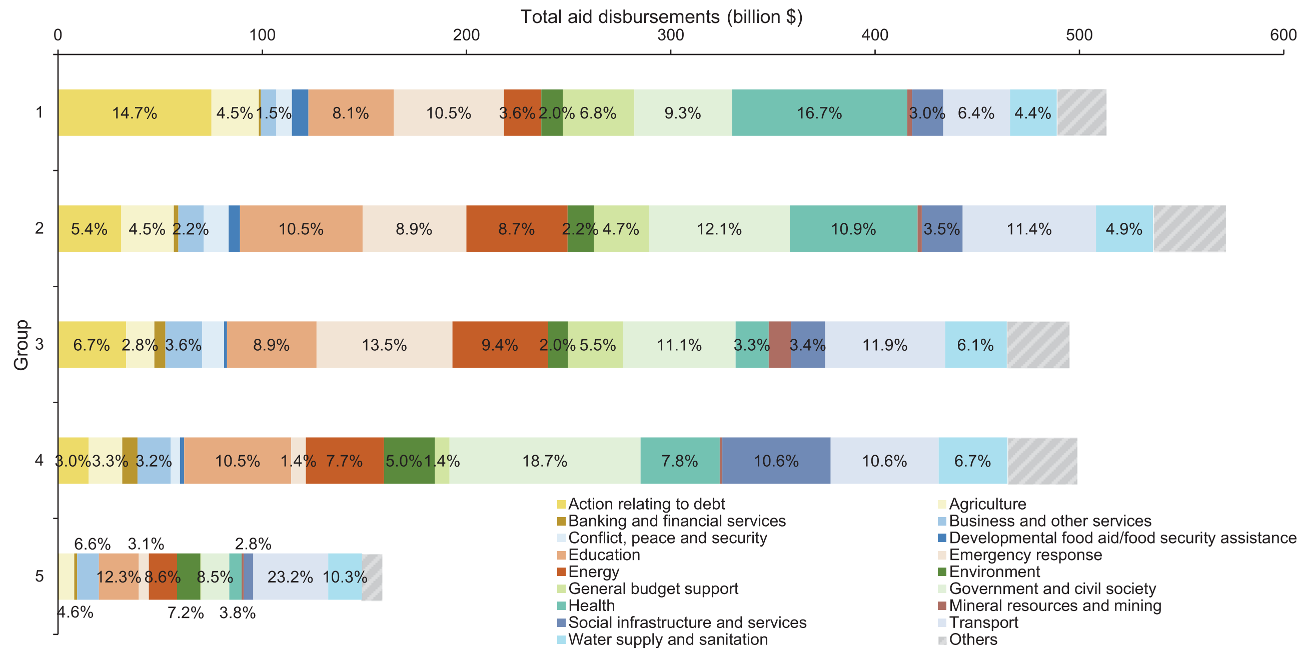

Fig. 4. Aid disbursements spent on different sectors from 2000 to 2019 for the five identified groups of countries. Percentage on each bar represents the ratio of respective sector aid to total disbursement. Only sectors with a ratio to total disbursement higher than 1% are shown. The data were collected from an article by Toetzke et al. [5].

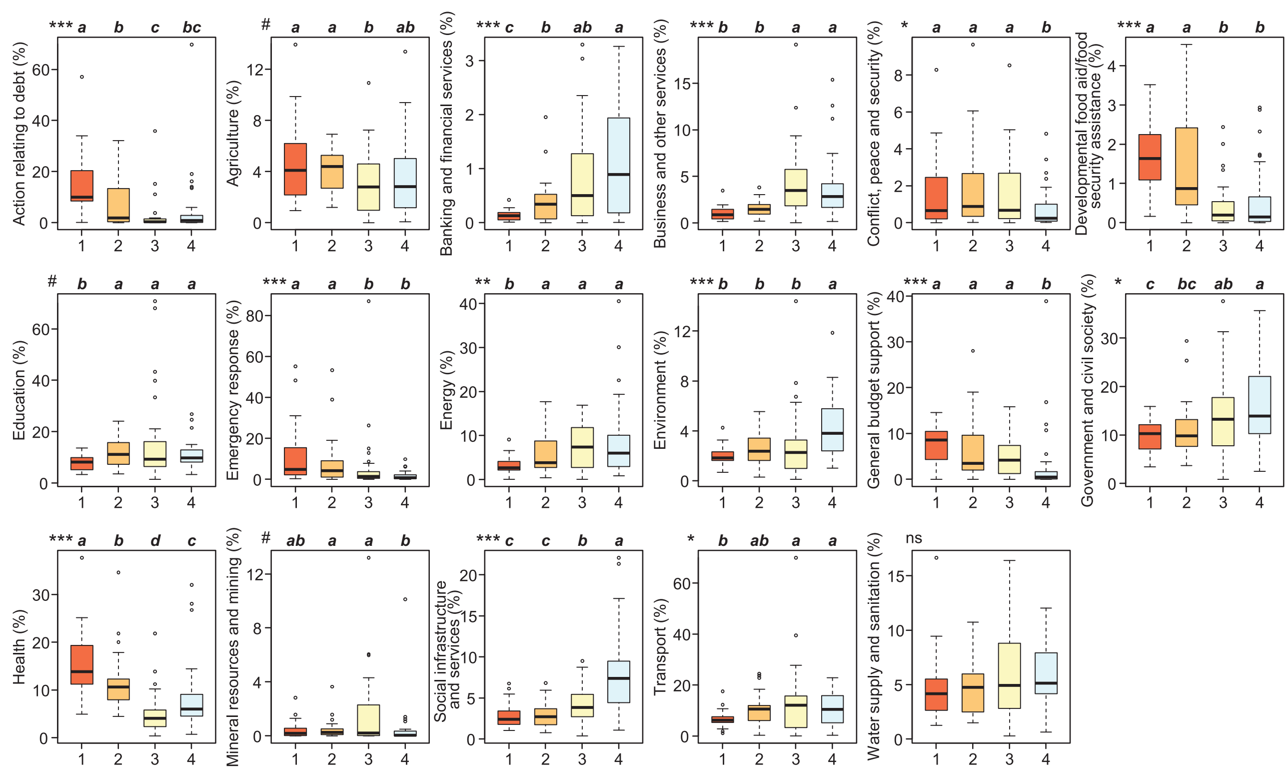

Fig. 5. Comparisons of the ratios of sector aid to total disbursement among Groups 1–4. Boxplots with different letters at the top differ significantly among the groups: ns, non-significant; #, $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

(life on land) and relatively poor performances in SDGs 12 (responsible consumption and production) and 13 (climate action), received the highest ratio of environmental aid, but the ratios were not significantly different among Groups 1–3, even though Groups 2 and 3 countries also performed poorly in SDG 15 and SDGs 12–15, respectively. Together, these findings suggest that while development aid in some sectors is aligned with the needs of the different groups of countries, greater alignment is required in the areas of education, energy, environment, and water supply and sanitation.

4. Discussion and conclusion

This study provides a classification of global countries according to their individual SDG performances. By clustering 166 countries into five distinct groups, we found that no country or group had relatively high scores for all SDGs (Fig. 1 and Fig. S1 online). Furthermore, SDG interaction networks for the five groups revealed that no group of countries can achieve all the SDGs due to antagonism associated with the environment and climate SDGs. Consequently, the prospects of achieving global sustainability seem bleak. Nevertheless, this classification can serve as a useful starting point to develop more targeted actions for national SDG implementation and global development aid to maximize the potential for achieving the SDGs, taking into account the current SDG characteristics and synergy and antagonism contexts of the identified groups of countries.

4.1. A potential complement to geographical region and income groupings

Since our classification was based on the SDG scores of each country, the identified SDG bundles exhibit the lowest intra-group variability and the highest separation of groups in terms of SDG performance when compared with other commonly used country classifications (see Table S3 online). This provides a more reasonable basis for sustainable development actions, which we expect will complement groupings by geographical region and income. Although the present SDG bundles were concentrated in certain regions or income groups, this does not mean that all countries in the same region or income group should be assumed to have similar SDG performances (and *vice versa*). For example, Group 5 mainly consisted of high-income countries, but some upper-middle-income countries with similar patterns of the 17 SDG scores, like China and Thailand, also fell under this Group (Fig. S1 online). Conversely, some high-income countries, like Kuwait, Qatar, and Saudi Arabia, were classified in Group 3 due to their poorer scores in certain SDGs (e.g., SDGs 5, 6, and 11) when compared to the high-income countries in Group 5.

Using this new classification, our analysis of SDG interactions yielded different results compared to a previous study that analyzed SDG interactions based on income groups [3]. The previous study had concluded that the 17 SDGs do not conflict and are more likely to be achieved simultaneously by low-income countries. However, our analysis, which considers the different sustainable development statuses of countries within an income group by using SDG bundles, indicates that no group of countries can achieve all SDGs due to the observed interactions. Another study on estimation methods for SDG networks suggested that when time series analysis is infeasible, pooling data from a group of countries with structural similarity (such as demonstrated through statistical cluster analysis) are a second-best alternative [18], further supporting the validity of our findings. This difference in results suggests that the prospect of global sustainability is less promising than previously thought and highlights the need for all countries, regardless of their group classification, to adapt sustainability strategies to their specific social, economic, and environmental circumstances.

4.2. Development paths behind the identified groups of countries

The significant differences in SDG performances among the different groups of countries reflect the development paths examined by previous studies [33]. Scores of most socioeconomic SDGs and the overall sustainable development level increase from Group 1 to Group 5, accompanied by decreasing scores in responsible consumption and production (SDG 12) and climate action (SDG 13) and decreasing then increasing scores in reduced inequalities (SDG 10) and life on land (SDG 15), with the exception of Group 3 countries whose GDP relies mostly on oil and natural gas. These trends coincide with the inverted U-shaped relationships between economic development and income inequality and between economic development and environmental degradation revealed by Kuznets Curve [34] and Environmental Kuznets Curve [35,36] and the unsustainable development paradigm in which economic growth is pursued to generate human welfare at the expense of environmental sustainability (e.g., large environmental and material footprints and high greenhouse gas emissions [4,37,38]). These previous studies also explain why the environmental SDG, SDG 14, for Groups 1, 2, and 4, and the climate SDG, SDG 13, for Groups 1, 3, 4, and 5 are the main barriers to achieving other SDGs. The trade-offs among the environment and climate SDGs and other SDGs may result from current approaches that have tended to rely on diverting resources from other socioeconomic activities to protect the environment [3] or of the unsustainable development paradigm mentioned above [33].

4.3. More targeted sustainable development actions based on the findings

Improvements in the understanding of the commonalities and SDG interactions of different groups of countries will provide practical and actionable evidence that support national implementation of SDGs for policy makers and stakeholders [39–41]. Different countries need to contextualize and prioritize SDGs by the group they are in. Combining the existing gaps in achieving SDGs and the opportunities revealed by SDG interactions of different groups, we found that, besides the specific actions for the less progressed SDGs, prioritizing certain SDGs is a way of doing more with less in countries with lower sustainable development levels. SDGs with greater potential for systematic impact (e.g., SDGs 4, 6, and 9 for Group 1; SDGs 2, 9, and 16 for Group 2; SDGs 9, 11, and 14 for Group 3; and SDGs 3, 7, and 9 for Group 4) showed relatively poor performances in the corresponding groups. Therefore, actions taken to promote these SDGs, such as building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation, will not only address the respective weaknesses of different groups of countries but also have simultaneous compounding positive effects on other SDGs. The analysis at target level showed that the structurally important targets were not necessarily associated with structurally important SDGs. Given that target interactions are more complex, maintaining flexibility on targets while remaining focused on SDGs may offer more opportunities to achieve overall sustainability across countries [3].

Despite the opportunities, our analysis of SDG interactions also revealed trade-offs related to environment and climate SDGs in different groups, emphasizing the necessity and importance of sustainable transformation. The transformation is urgently needed for countries in Groups 3–5, especially Group 5, which, despite having considerable resources to find solutions [42], generally had the worst performances in these SDGs. As previous studies have highlighted, sustainable transformation aims to make trade-offs among SDGs structurally non-obstructive and facilitate new synergies by cross-sectional integration policies [43–45]. In the context of this study, this points to a need to "rewire" the antagonism related to SDGs 12–14 and find solutions to remediate resource overuse, climate change, and environmental deteriorations while creating socioeconomic stimuli [3,16]. The concepts of circularity and decoupling without compromising human well-being provide potential ways to achieve such sustainable transformation [46]. Through circularity that promotes the reuse and recycling of materials [47], decarbonization that sustainably reduces and compensates for greenhouse gas emissions [46], and economic innovations and technological advances that dissociate the net release of pollutants from human well-being [48], the climatic and environmental issues and the uses of freshwater, land, and non-renewable resources can be decoupled from social and economic progress [49]. Enabling such transformation depends on the development of new technologies and types of governance, as well as the collaborations and actions of government, business, and civil society [46,47]. Some initiatives, such as China's carbon peaking and carbon neutrality goals [50], and the European Union's Green Deal [51], offer hope for this fundamental transformation. These initiatives aim to create a green path to achieve net-zero emissions and are expected to trigger comprehensive top-down reforms in all aspects of the economy and society, promoting sustainable and high-quality development [50].

Besides prioritized actions and sustainable transformation, a more reasonable distribution of global development aid is also crucial to fulfilling the "leave no one behind" commitment [1,5], as the lack of adequate financing is hindering progress towards achieving the SDGs in developing countries [15]. Our analysis of the distribution of sectoral development aid among different groups of countries highlights the need for adjustments to better align aid with the needs of different groups in certain areas, such as education, energy, environment, and water supply and sanitation. For instance, the countries in Group 1, which performed worst in SDGs 4 (quality education) and 7 (affordable and clean energy), but received the smallest proportions of aid in these sectors, require a greater ratio of aid activities in education and energy, including development projects, financial assistance, technological support and training. Similarly, the proportion of water supply and sanitation aid needs to increase for some groups (e.g., Groups 1 and 2) based on their performances in SDG 6 (clean water and sanitation). While the highest ratio of environment aid for Group 4 is reasonable, countries in Groups 2 and 3 also require a similar level of attention, with a particular focus on greenhouse gas emission reduction, climate change adaptation, and ecosystem conservation for Group 3 and conservation of terrestrial ecosystems for Group 2.

4.4. Limitations and future prospects

Our present study has some limitations. First, the five groups of countries were identified based on the SDG scores obtained from *Sustainable Development Report 2020*, which only used 115 of the UN's 231 indicators [12]. While the dataset is a well-recognized and widely used global dataset at the level of whole goals [16,17], it should be noted that the selection of different SDG indicators, measuring methods of SDG performance, or clustering methods may lead to different findings [52]. Second, the selection of SDG data will also change the understanding of SDG interactions [22]. Although we used a unified SDG database [22] for more nuanced and reliable views of SDG and target interactions of different groups, our understanding of these interactions of different groups will evolve as more indicators and time-series data become available. Third, the analysis of development aid and the needs of different groups of countries were mainly conducted from the view of development aid distribution, without delving into the temporal relationships between aid and SDG progress due to the lack of long time-series SDG data. However, the effects of different development aid on sustainable development and the amount of aid needed to achieve SDGs in different countries deserve more explorations in future studies. Given the complex interactions among aid and SDGs, the needs of improving one goal may be satisfied or exacerbated by development aid targeted at other goals [53]. To achieve a comprehensive understanding, these studies demand more data to track SDG progress and consider the complex SDG interactions, along with other influencing factors such as background conditions, international trade, and investment, simultaneously [54,55].

In conclusion, this study clustered 166 countries into five groups comprising countries that share commonalities in SDG progress, synergies, and conflicts. These groups have different strengths and weaknesses with respect to SDGs, and none can achieve all SDGs due to observed interactions. Prioritized actions and sustainable transformation are crucial for national sustainable development, and global development aid needs to be better aligned. This study highlights the value of an SDG data-driven classification of countries and lays the foundation to extend the approach to address various SDG issues at different scales.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Bojie Fu and Xutong Wu designed the research. Xutong Wu, David Lusseau, and Shuang Song performed the analyses. Xutong Wu drafted the manuscript. All authors contributed to the interpretation and manuscript revisions.

Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.scib.2023.09.010.

Data availability

All of the data used in this paper can be obtained from the Sustainable Development Report (https://www.sustainabledevelopment.report/), the World Bank World Development Indicators (https://databank.worldbank.org/reports.aspx?source=world-development-indicators), the paper by Warchold et al. (https://doi.org/10.1002/sd.2316), and the paper by Toetzke et al. (https://doi.org/10.1038/s41893-022-00874-z). All computer code used in conducting the analyses summarized in this paper is available from the corresponding author upon reasonable request.

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