ENVIRONMENTAL RESEARCH
LETTERS

OPEN ACCESS

RECEIVED
17 June 2021

REVISED
6 December 2021

ACCEPTED FOR PUBLICATION
10 March 2022

PUBLISHED
18 March 2022

LETTER

Bundling regions for promoting Sustainable Development Goals

Xutong Wu[1], **Jianguo Liu**[2], **Bojie Fu**[1,3,*], **Shuai Wang**[1], **Yongping Wei**[4] **and Yingjie Li**[2,5]

[1] State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, People's Republic of China
[2] Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48823, United States of America
[3] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, People's Republic of China
[4] School of Earth and Environmental Sciences, The University of Queensland, Brisbane 4067, Australia
[5] Environmental Science and Policy Program, Michigan State University, East Lansing, MI 48823, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: bfu@rcees.ac.cn

Keywords: sustainable development goals, sustainable development goal bundle, classification, China

Supplementary material for this article is available online

Abstract

The needs and capacities to achieve the 17 Sustainable Development Goals (SDGs) differ across regions and nations, but little research has been done to investigate their similarities and differences. Here, we proposed using SDG bundles (i.e. groups of regions with similar performances on all individual SDGs) to classify regions when assessing SDG progress and applied the method at the provincial level in China from 2000 to 2015. Five SDG bundles with distinct characteristics were identified. The dominant bundles changed from 'poor performance for all SDGs' in 2000 to 'high scores for environmental and some social SDGs and intermediate scores for others' and 'low scores for environmental SDGs but high scores for others' in 2015, indicating the overall improvement of China's sustainable development level. However, no bundle had relatively high scores in all SDGs, implying that China has much work left to do. Changes in the SDG bundles across space and time were related to regional socioeconomic development, climate, and geographic conditions. This study sheds light on identifying regions' strengths and weaknesses in achieving all SDGs, which can inform targeted sustainability actions for regions within certain SDG bundles and promote collaborations among regions with different bundles.

1. Introduction

To address the multiple and complex challenges faced by humankind, such as poverty, inequality, climate change, and environmental degradation, the United Nations (UN) proposed 17 interdependent Sustainable Development Goals (SDGs) to call for global action to promote prosperity while protecting the planet (United Nations 2015, Nilsson *et al* 2016, Pradhan *et al* 2017). Monitoring progress toward all of the SDGs by assessing past and current conditions and understanding the interactions among the SDGs are crucial to track the status of global sustainability and guide policy design and implementation (Nilsson *et al* 2016, Pradhan *et al* 2017, Schmidt-Traub *et al* 2017, Fu *et al* 2019, Xu *et al* 2020). Because of the interactions among the SDGs, one region may perform well on some SDGs (i.e. have a high score) while doing badly on others (Nilsson *et al* 2016, Pradhan *et al* 2017), leading to differences in needs and capacities to achieve SDGs across regions (Salvia *et al* 2019). Classification of the regions based on their different performances in SDGs can improve policy efficiency and promote joint action (Fu *et al* 2020).

Previous studies have developed different methods to analyze different dimensions of progress toward meeting the SDGs at different levels (Schmidt-Traub *et al* 2017, Liu *et al* 2021, Sachs *et al* 2020, Xu *et al* 2020). The aggregate SDG Index score was used to represent the overall performance toward achieving the 17 SDGs (Schmidt-Traub *et al* 2017, Sachs *et al* 2020, Xu *et al* 2020). Liu *et al* (2021) used an 'evenness score' to investigate whether all SDGs were being equally addressed in China at national and provincial levels, and the SDG dashboards highlight the strengths and weaknesses of each country in relation to each of the 17 SDGs and make regional comparisons by UN subregion and income group (Sachs *et al* 2020). However, the similarities and differences in the SDG performances among different countries or regions were not considered in these methods. Therefore, studies are needed to classify regions based on their performances on all individual SDGs and to show the progress of different regions, as well as reveal the potential factors that determine these different categories.

We propose the use of SDG bundles to identify the strengths and weaknesses of different regions when assessing SDG progress. Borrowed from the concept of 'ecosystem service bundles' used in ecosystem service studies (Raudsepp-Hearne *et al* 2010, Renard *et al* 2015), an SDG bundle is defined as a group of regions with similar performances on all individual SDGs. An SDG bundle can help identify which aspects of the SDGs a region performs better or worse, as well as reveal common synergy and trade-off characteristics in these clusters (e.g. which pairs of SDGs tend to have relatively higher or lower scores simultaneously and which do not). Identifying SDG bundles and their characteristics at the regional level and analyzing their changes across space and time can help better develop site-specific policies to mitigate trade-offs and improve synergies to achieve all 17 SDGs.

In this study, China was chosen as a case to demonstrate the use of SDG bundles at subnational level. Such information about regional differences is urgently needed as many countries face the challenge of achieving sustainable development in times of growing population, resource scarcity, and uneven development across regions within their borders (Liu *et al* 2021, Xu *et al* 2020). Understanding the subnational differences in sustainable development over time can help a nation to balance sustainable development across its regions (Xu *et al* 2020). To identify the SDG bundles, we used cluster analysis and a dataset (Xu *et al* 2020) that included the SDG scores of 30 provinces in China from 2000 to 2015 (SDG 14 was excluded in this study because some provinces do not have marine areas, see methods and section S1 available online at stacks.iop.org/ERL/17/044021/mmedia). We then examined the spatiotemporal dynamics of these bundles and explored the determinants of the SDG bundles. The policy implications of our findings were also discussed by analyzing how the bundles relate to the socioeconomic and environmental characteristics of the provinces.

2. Materials and methods

2.1. Data sources

The scores for each SDG at the provincial level in 2000, 2005, 2010, and 2015 were obtained from Xu *et al* (2020). In that study, 119 SDG indicators were used, based on a combination of list of recommended indicators from the UN (Sachs *et al* 2020), and 3–18 indicators were used for each SDG. Xu *et al* normalized SDG indicator values toward meeting an SDG target on a scale of 0–100, and then they calculated the scores for each SDG using the arithmetic mean of all corresponding indicators following the methods used in the 2018 SDG Index and Dashboards Report. The uncertainty and sensitivity of SDG scores was also addressed in their study, so the SDG scores were shown to be reliable and have been used in other studies (Liu *et al* 2021). SDG 14 was excluded because some Chinese provinces do not have marine areas and therefore lack data for indicators on this SDG. Also, Tibet was excluded because it lacks data for indicators of SDG 7. Therefore, a total of 16 SDGs for 30 provinces were analyzed in this study.

Previous studies reported that many factors such as economy, urbanization, geographic conditions, and climate affect SDG scores (Lu *et al* 2019, Xu *et al* 2020). To explore the determinants of SDG bundles, we selected several socioeconomic and environmental factors at the provincial level, including GDP per capita, urbanization rate, population density, distance of the provincial capital from the coastline, precipitation, temperature, elevation, and slope. The GDP, urbanization, and population data of each province in each year were obtained from the National Bureau of Statistics of China (www.stats.gov.cn). The distance of the provincial capital from the coastline was calculated based on the digital boundary shapefile. Annual precipitation and temperature data were obtained from the National Meteorological Administration of China (data.cma.cn). The average elevation and slope of each province were calculated based on Digital Elevation Model data of China, which were obtained from the Resource and Environment Science and Data Center (www.resdc.cn).

2.2. Identification and dynamics of SDG bundles

We used a K-means clustering analysis of the 16 SDG scores of 30 provinces on the entire time series to identify SDG bundles, that is, groups of regions with similar performances of all individual SDGs. Based on the elbow method (section S2 and figure S2), five was selected as the optimal number of clusters. Most of the provinces that were clustered together did not change when either four or six clusters were chosen in the cluster analysis instead of five (figure S2). After identifying the SDG bundles, we summarized the characteristics of each bundle based on the relative performance of each individual SDG. For clarity and conciseness, we divided the 16 SDGs into three categories, according to the three pillars of sustainable development: economy (SDGs 8, 9, 10, 12, and 17), society (SDGs 1, 2, 3, 4, 5, 7, 11, and 16), and environment (SDGs 6, 13, and 15). This division is consistent with the classification used in other studies

(Rockström and Sukhdev 2016, Vinuesa et al 2020). We then calculated the total number of provinces in each bundle in each year and used a Sankey diagram to visualize changes from one bundle to another over time and identify the main trajectories. Finally, we mapped the SDG bundles for each year to show their spatial distribution changes over time.

2.3. Comparisons of the individual SDG scores among years and bundles

To compare the differences of individual SDGs among years and SDG bundles, we used the Kruskal–Wallis test to analyze the 16 individual SDGs for the different years and different bundles, respectively. 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 on a continuous dependent variable (Kruskal and Wallis 1952).

2.4. Determinants of SDG bundles

We used a redundancy analysis (RDA) to analyze the relationship between SDG scores and the characteristics of provinces, such as GDP per capita, urbanization rate, population density, distance of the provincial capital from the coastline, precipitation, temperature, elevation, and slope. There may be multicollinearity among these factors. For example, western China's topography and distance from the coast make transportation difficult and have restricted urbanization and socioeconomic development. Considering the parsimony of model and multicollinearity of these explanatory variables, we selected the variables using the two-step procedure of forward selection proposed by Blanchet et al (2008). Five explanatory variables—GDP per capita, population density, precipitation, urbanization rate, and slope—were selected, and they explained 49.1% of the variance. The variance inflation factors of all the five variables are less than 4.0, indicating that the multicollinearity can be accepted.

3. Results

3.1. Five SDG bundles differ from each other

Cluster analysis divided the 30 provinces' SDG performances for the years 2000, 2005, 2010, and 2015 into five bundles (figure 1 and table S1). There are significant differences among these bundles in almost all SDGs except for SDG 5 and SDG 12 (figure 1(a)). Bundle 1 (B1) had the lowest mean value of all SDGs (mean SDG Index score = 41.2) and was characterized by poor performance on all SDGs. Bundle 5 (B5) had the highest mean SDG Index score (57.3), with relatively high scores in SDGs related to the economy and society but relatively low scores in environmental SDGs such as SDG 6 (clean water and sanitation) and SDG 15 (life on land). By contrast, bundle 2 (B2, mean SDG Index score = 45.2) had relatively low scores in economic and social SDGs but relatively high scores in environmental SDGs. Bundle 3 (B3, mean SDG Index score = 47.6) was characterized by relatively low scores for SDGs 6, 7, 13, and 15 and intermediate scores for the others. Bundle 4 (B4, mean SDG Index score = 54.3) was characterized by relatively high scores for SDG 2, 6, 7, 13, 15, and 16 and intermediate scores for the others.

3.2. The SDG bundles of provinces changed over time

The spatial distribution of the bundles across China changed over time (figure 2). Although B1 (low scores for all SDGs) and B2 (high scores for environmental SDGs but low scores for other SDGs) were the dominant bundles in 2000 and 2005, together accounting for 80% and 67% of provinces, respectively, there were no provinces in these bundles in 2015, indicating the overall improvement of China's sustainable development level. The dominant bundles changed to B4 (high scores for some social and environmental SDGs and intermediate scores for others) and B5 (low scores for environmental SDGs but high scores for others) in 2015, together accounting for 83% of provinces. The changes primarily followed three different trajectories (figure 2(b)). Provinces in B1 in 2000 advanced to B3, B4, and B5 in 2015, reflecting improvements in different SDGs to different degrees. All provinces in B2 in 2000 kept their high scores in environmental SDGs, improved in other SDGs, and changed to B4 in 2015. The number of provinces in B5 increased over time, and provinces in B3 and B4 in 2000 all changed to B5 in 2015.

3.3. SDG bundles were related to the socioeconomic and environmental characteristics of the provinces

The SDG bundles of provinces were related to socioeconomic and environmental attributes of the region (RDAs applied to all provinces, $R^2 = 0.49$, figure 3). Provinces with poor performance for all SDGs (B1) had low GDP per capita, low urbanization rate, and little precipitation. Provinces that had high scores for environmental SDGs but low scores for other SDGs (B2) had high precipitation, high slope, low GDP per capita, low urbanization rate, and low population density. Provinces in B3 (low environmental scores and intermediate scores for others) and B4 (high scores for some social and environmental SDGs and intermediate scores for others) had intermediate GDP per capita and intermediate urbanization rate. The precipitation and slope of B4 provinces were higher than those of B3, however, the population density was lower. Provinces with low scores for environmental SDGs but high scores for others (B5) had high GDP per capita, urbanization rate, and population density.

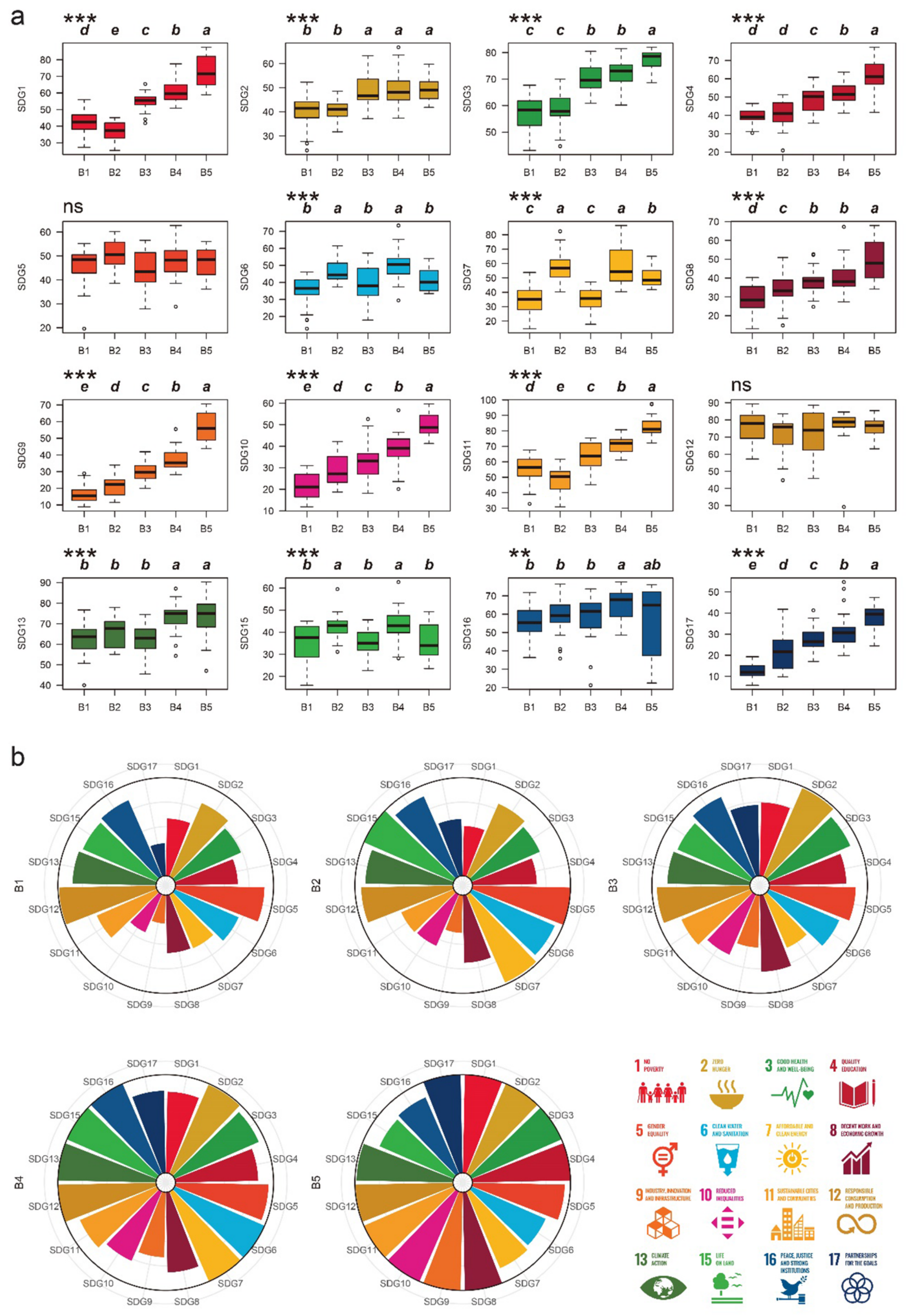

Figure 1. Characteristics of the five SDG bundles identified based on all 30 provinces in all four years (2000, 2005, 2010, and 2015). (a) Comparisons of the individual SDG scores among the five bundles. Boxplots with different letters at the top differ significantly among the bundles: ns, non-significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. (b) Relative SDG scores for the five SDG bundles (the outer circles represent 1 and the inner circles represent 0). To facilitate comparison among bundles, SDG scores were normalized by the maximum score of each SDG. Petals are comparable within the same SDGs.

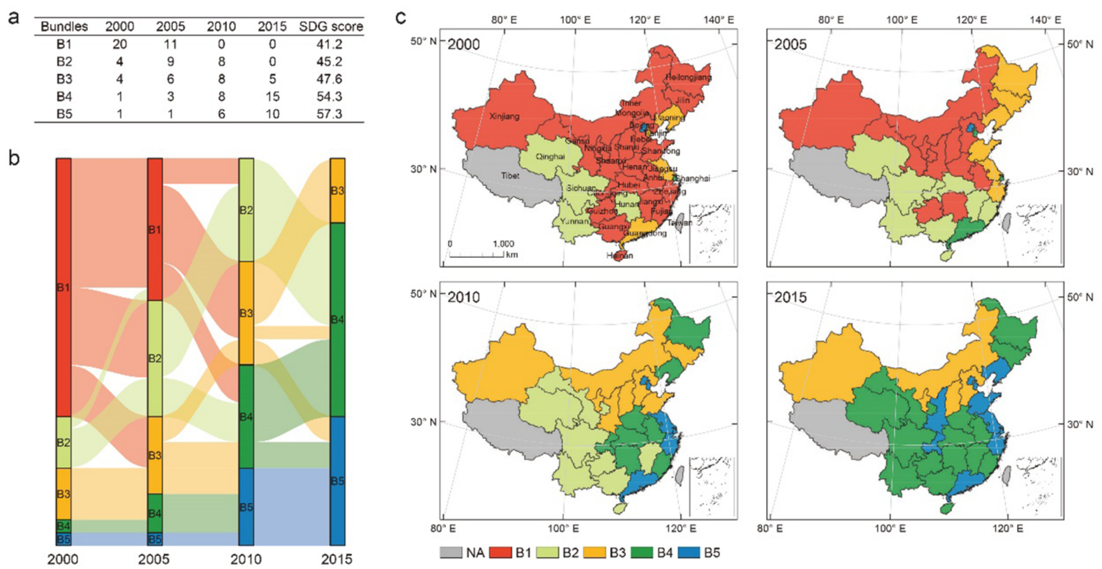

Figure 2. Dynamics of SDG bundles over time and across space. (a) The number of provinces in each bundle from 2000 to 2015. (b) Bundle change trajectories that provinces followed from 2000 to 2015. (c) Spatial distribution of each bundle in 2000, 2005, 2010, and 2015.

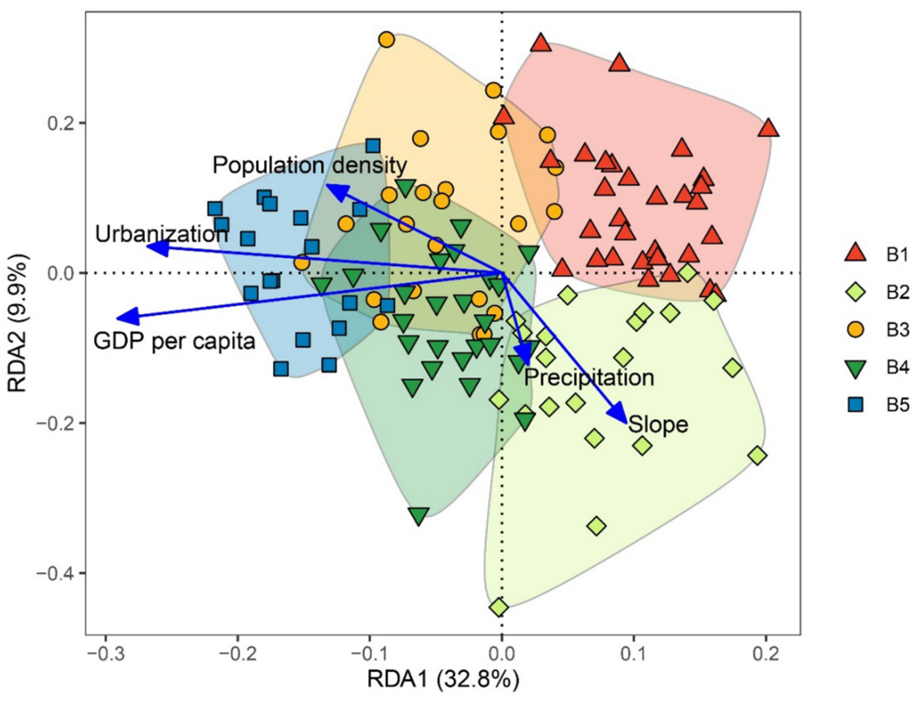

Figure 3. The relationships between the SDG bundles and provincial characteristics.

4. Discussion and conclusion

To our knowledge, this study is the first classification of regions based on their similarity in the performances of all individual SDGs. We empirically identified five SDG bundles and analyzed their changes across space and over time. The relative performances of most SDGs changed simultaneously (i.e. relatively high in one bundle but relatively low in the other), indicating there were more synergies than trade-offs among SDGs and presenting a promising future to successfully achieve all 17 SDGs simultaneously (Pradhan *et al* 2017). However, B5 had relatively high scores for economic and social SDGs but low scores for environmental SDGs, whereas B2 had the opposite grouping of low and high scores, suggesting the trade-offs between environmental SDGs and economic and social SDGs. These findings are consistent with those of other studies (Pradhan *et al* 2017, Hutton *et al* 2018, Mainali *et al* 2018, Scherer *et al* 2018, Zhao *et al* 2021), providing support for the classifications. No bundle had relatively high scores in all SDGs. Given the 'leave no one behind' objective of the SDG agenda (Nilsson *et al* 2016, Pradhan *et al* 2017), China has much work to do to achieve all of the SDGs and balance sustainable development across its regions.

The SDG bundles could assist in assessing and understanding the SDG progress. Regions with a higher mean SDG Index score did not necessarily perform better in all SDGs (Allen *et al* 2019, Liu *et al* 2021) (figures 1 and 2(a)). By revealing more details about the similarities and differences among regions, this study provides an effective complement to the SDG Index score and allows for better SDG assessments. In addition, analyzing the socioeconomic and environmental determinants of SDG bundles can help us to understand why provinces in the same bundle in one time period followed different trajectories (Renard *et al* 2015) and determine policy priorities for SDG achievement. Economic growth and urbanization in China could directly reduce poverty (SDGs 1 and 2), increase employment opportunities (SDGs 8 and 11), promote industry and infrastructure (SDG 9), indirectly improve health and welfare (SDG 3), reduce gender inequality (SDG 5), and achieve quality education (SDG 4) (Lu *et al* 2019). However, economic prosperity also causes environmental problems and loss of natural capital (Liu and Diamond 2005, Lu *et al* 2019), leading to the relatively low scores in the environmental SDGs in provinces in B5, such as Beijing. Provinces with higher precipitation and slope and lower population density (e.g. Qinghai, Sichuan, and Yunnan in B2 and B4) have sufficient water resources for socioeconomic development and healthier ecosystems (Konapala *et al* 2020), fewer human disturbances that impede the sustainability of terrestrial ecosystems (Wang *et al* 2001, MacDougall *et al* 2013), and abundant hydraulic resources and hydropower (Liu *et al* 2016), a dominant renewable source of energy production (Resch *et al* 2008). Therefore, they performed better in SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), and SDG 15 (life on land).

The use of SDG bundles can further inform targeted sustainability actions for regions in certain bundles and promote collaborations between regions with different bundles by identifying regions' strengths and weaknesses in achieving all SDGs. To fill their gaps in SDG progress, provinces with low scores for environmental SDGs but high scores for others (B5) need more environmental conservation policies to improve SDGs 6 and 15, while provinces with high scores for some social and environmental SDGs and intermediate scores for others (B4) should focus more on sustainable and inclusive economic growth and industrialization and address social needs including education, health, and equality. The trade-offs among SDGs need to be addressed and made structurally nonobstructive (Pradhan *et al* 2017) by cross-sectional integration policies to increase cooperation and reduce conflicts among SDGs (Liu *et al* 2018, Lu *et al* 2019). To balance sustainable development across different regions, regions in different SDG bundles may collaborate in complementary ways to holistically achieve sustainable development. Payments for ecosystem services, programs that incentivize landowners and other resource stewards for land management practices intended to provide or ensure ecosystem services while also have other goals related to human welfare and social equity (Salzman *et al* 2018, Wunder *et al* 2018), provide an innovative way of dealing with trade-offs between environmental and socioeconomic development goals and a paradigm for such regional integration and collaboration. For example, downstream B5 provinces like Shanghai benefit from ecosystem services generated in upstream provinces like Qinghai, which is rich in ecosystem assets but relatively poor in conventional economic measures (B4) (Ouyang *et al* 2020). Through investment in ecological conservation and reasonable ecological compensation, it is possible to conserve ecosystem assets and promote socioeconomic development simultaneously (Salzman *et al* 2018).

The SDG bundle method proposed in this study lays a foundation for classifying regions at different scales based on their SDG performances when assessing the progress toward sustainable development. Although the use of SDG bundle was demonstrated by subnational data of China, it can easily be applied at global scale and effectively complement the current measurement and comparison tools like the SDG Index and SDG Dashboard Report by the Sustainable Development Solutions Network (Sachs *et al* 2020). All countries could be clustered into several SDG bundles with distinct characteristics, and targeted policy recommendations or appropriate international support and assistance could be provided to countries in certain SDG bundles. Future research should focus on the complex mechanisms behind the trade-offs and synergies among SDGs (Fuso Nerini *et al* 2018) and find solutions to address conflicts among them (Nilsson *et al* 2018). Assessment of the complex impacts of different policies on SDG bundles and sustainable development is also needed.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (42041007), the Science-based Advisory Program of the Alliance of International Science Organizations, the China National Postdoctoral Program for Innovative Talents (BX2021042), and the China Postdoctoral Science Foundation (2021M700458).

Conflict of interest

The authors declare no competing interests.

ORCID iDs

Xutong Wu https://orcid.org/0000-0001-6124-0436
Yongping Wei https://orcid.org/0000-0002-4266-4433

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