Article

Assessing progress towards sustainable development over space and time

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To address global challenges[1–4], 193 countries have committed to the 17 United Nations Sustainable Development Goals (SDGs)[5]. Quantifying progress towards achieving the SDGs is essential to track global efforts towards sustainable development and guide policy development and implementation. However, systematic methods for assessing spatio-temporal progress towards achieving the SDGs are lacking. Here we develop and test systematic methods to quantify progress towards the 17 SDGs at national and subnational levels in China. Our analyses indicate that China's SDG Index score (an aggregate score representing the overall performance towards achieving all 17 SDGs) increased at the national level from 2000 to 2015. Every province also increased its SDG Index score over this period. There were large spatio-temporal variations across regions. For example, eastern China had a higher SDG Index score than western China in the 2000s, and southern China had a higher SDG Index score than northern China in 2015. At the national level, the scores of 13 of the 17 SDGs improved over time, but the scores of four SDGs declined. This study suggests the need to track the spatio-temporal dynamics of progress towards SDGs at the global level and in other nations.

To achieve these ambitious SDGs, the world needs to monitor progress towards all 17 SDGs by assessing past and current conditions at national and subnational levels[6]. However, no study has explored the spatio-temporal dynamics of progress towards the SDGs at both national and subnational levels. Such information is urgently needed, as many countries face the challenge of achieving sustainability in times of growing population, uneven development across regions within their borders and resource scarcity under rapidly developing economies. A spatio-temporal analysis of sustainable development can help countries to identify hotspot regions for targeted policy action and for tracking progress towards achieving the SDGs. Understanding the differences in sustainable development between developed and developing regions over time can help a nation to balance sustainable development across its regions.

In this study, we developed systematic methods to quantify the SDGs and provided a demonstration of quantification by performing a comprehensive spatio-temporal analysis of progress towards all 17 SDGs in China, the largest developing country both in areal extent and population. Over the past several decades, China has experienced rapid economic development, reflected in its exceptional growth in gross domestic product (GDP)[7] and becoming the world's second-largest economy. However, China also faces large socioeconomic challenges such as income and gender inequality[8], and environmental challenges such as water scarcity and pollution, energy shortages, and air and soil pollution[9]. These socioeconomic and environmental challenges within China vary substantially from region to region and have changed noticeably over time[10,11]. China is trying to achieve sustainability under complex environmental and socioeconomic challenges and policies[12]. To promote sustainable development, China has implemented a variety of policies such as the 'Western Development Strategy' and the 'Natural Forest Conservation Program'[11–13].

We tracked China's progress towards achieving the SDGs at the national and subnational (provincial) levels by quantifying (scoring) the SDGs over time (see details in the Methods). We addressed four major questions. First, how has sustainable development in China, as measured in terms of the SDGs, evolved at the national level? Second, how has sustainable development varied across China's provinces over time? Third, how have differences in sustainable development between more-developed and less-developed provinces in China evolved over time? Fourth, how has progress varied among the different SDGs?

To answer these questions, we used annual time series data relevant to the 17 SDGs from 2000 to 2015 at the national level and calculated the SDG Index score (0–100)[14], which consists of individual scores for the 17 SDGs and represents China's overall performance in achieving all 17 SDGs[14] (see details in the Methods). In total, 119 SDG indicators were used in this assessment (see data sources and indicator sources

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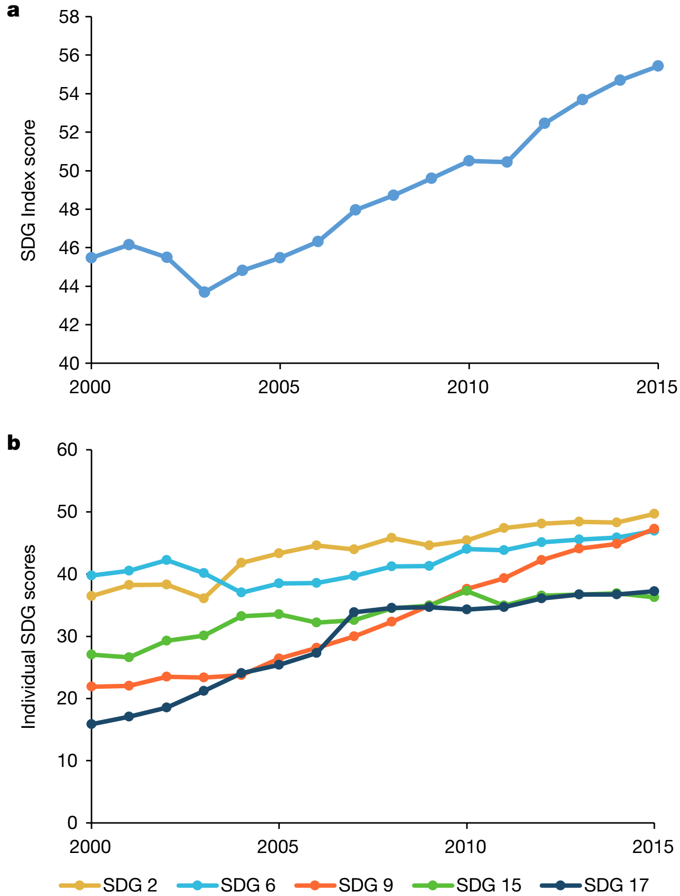

Fig. 1 | Change in China's SDG Index score and individual SDG scores. a, SDG Index score. **b**, Scores of selected SDGs (2, 6, 9, 15 and 17) at the national level from 2000 to 2015. For data sources, see Methods.

in Supplementary Table 1). We detected spatio-temporal changes in SDG Index scores across China's provinces based on data for the 17 SDGs at the provincial level in 2000, 2005, 2010 and 2015. We then compared the change in SDG Index scores over time between developed and developing provinces (determined by each province's average GDP per capita during 2000–2015; see details in the Methods) during the same period. Finally, by comparing scores for the individual SDGs we examined the relative progress toward achieving the different SDGs.

Results

Our results indicate that China has improved its SDG Index score at the national level over time (Fig. 1; Extended Data Fig. 1). Its national SDG Index score increased by approximately 21.9%, from a score of 45.5 in 2000 to 55.4 in 2015.

Notably, at the provincial level, eastern China had a higher SDG Index score than western China in the 2000s, while southern China had a higher SDG Index score than northern China in 2015, suggesting that substantial changes in sustainable development occurred across different regions (Fig. 2; see Supplementary Tables 2, 3). SDG Index scores at the provincial level ranged from 31.4 to 54.1 with a mean value of 42.2 in 2000, from 38.1 to 57.6 with a mean value of 45.2 in 2005, from 42.5 to 63.9 with a mean value of 49.8 in 2010, and from 47.0 to 66.1 with a mean value of 54.9 in 2015, reflecting a 30.0% increase in the mean value of the SDG Index score across provinces over time. The change in SDG Index score among provinces from 2000 to 2015 ranged from a 11.1% increase (Shanghai) to a 51.8% increase (Ningxia).

All provinces increased their SDG Index scores from 2000 to 2015 (Fig. 2; Supplementary Table 3). Developed provinces had higher SDG Index scores than developing provinces throughout our study period (Fig. 3; Supplementary Table 4). However, developing provinces experienced a greater growth rate in their average SDG Index scores than did developed provinces. These dynamics were also observed between the top five developed provinces and the bottom five developing provinces (Fig. 3; see details in the Methods).

At the national level, the scores of 13 of the 17 SDGs improved, while the scores of the remaining four SDGs decreased over time (Fig. 4). The four SDGs with declining scores, in order of greatest to least decline, were SDG 14 (life below water), SDG 12 (responsible consumption and production), SDG 5 (achieve gender equality) and SDG 13 (climate action) (Fig. 4). The three SDGs that improved the most, in order of greatest to least improvement, were SDG 9 (industry, innovation and infrastructure), SDG 10 (reduced inequalities), and SDG 17 (affordable and clean energy) . Generally, the changes in SDG scores at the provincial level showed similar dynamics as those at the national level (Supplementary Table 5). In terms of absolute SDG score, the bottom five SDGs, which lagged behind the other SDGs at the national level in 2015, included SDGs 15 (life on land), 14 (life below water), 17 (partnerships for the goals), 8 (decent work and economic growth) and 10 (reduced inequalities); see Supplementary Table 3.

Discussion

The spatio-temporal patterns of China's SDG Index scores may result from a number of factors, including the implementation of policies that have different regional impacts, geographical conditions, climate and infrastructure[13,15–17]. At the national level, factors such as governmental support for sustainability and investment in science and technology can strongly promote progress in national sustainable development (Supplementary Discussion). For the Chinese reform and opening-up policies that began in the late 1970s and early 1980s, the Chinese government focused on facilitating economic development more in eastern coastal regions than in inland regions, resulting in more advanced social services such as education and healthcare in eastern China[13]. Eastern China's relatively flat topography and favourable climate also make it more conducive for human habitation, as well as industrial and agricultural development[16]. Conversely, western China's rugged topography[11], combined with its distance from the coast, complicates transportation within the region and to and from other regions. As a result, in 2000, western China experienced limited urbanization and socioeconomic development and had the lowest industrialization level and highest poverty rate in China[16]. Western China's ecological assets have also historically limited its development (Supplementary Discussion). To alleviate this regional disparity, the Chinese government implemented the Western Development Strategy in 1999 to improve environmental and socioeconomic conditions in western China[13]. In 1999, only 29% of the Chinese government's fiscal transfers were allocated to western China, but this reached 39.4% in 2010[15]. Under the Western Development Strategy, both infrastructure development and ecological conservation in western China have greatly improved[17] (Supplementary Discussion). Meanwhile, after 2010 the growth rate of progress towards sustainable development (SDG Index score) in northeastern China fell behind other regions in socioeconomic development and environmental conservation because of low efficiency in resource use, unsustainable economic development and severe environmental pollution (Supplementary Discussion). Developed provinces experienced smaller increases in the SDG Index score than developing provinces mainly because they face problems associated with rapidly growing economies, such as a tendency for socioeconomic and gender inequality[18] to increase, as well as intensive resource consumption and severe environmental pollution (Supplementary Discussion).

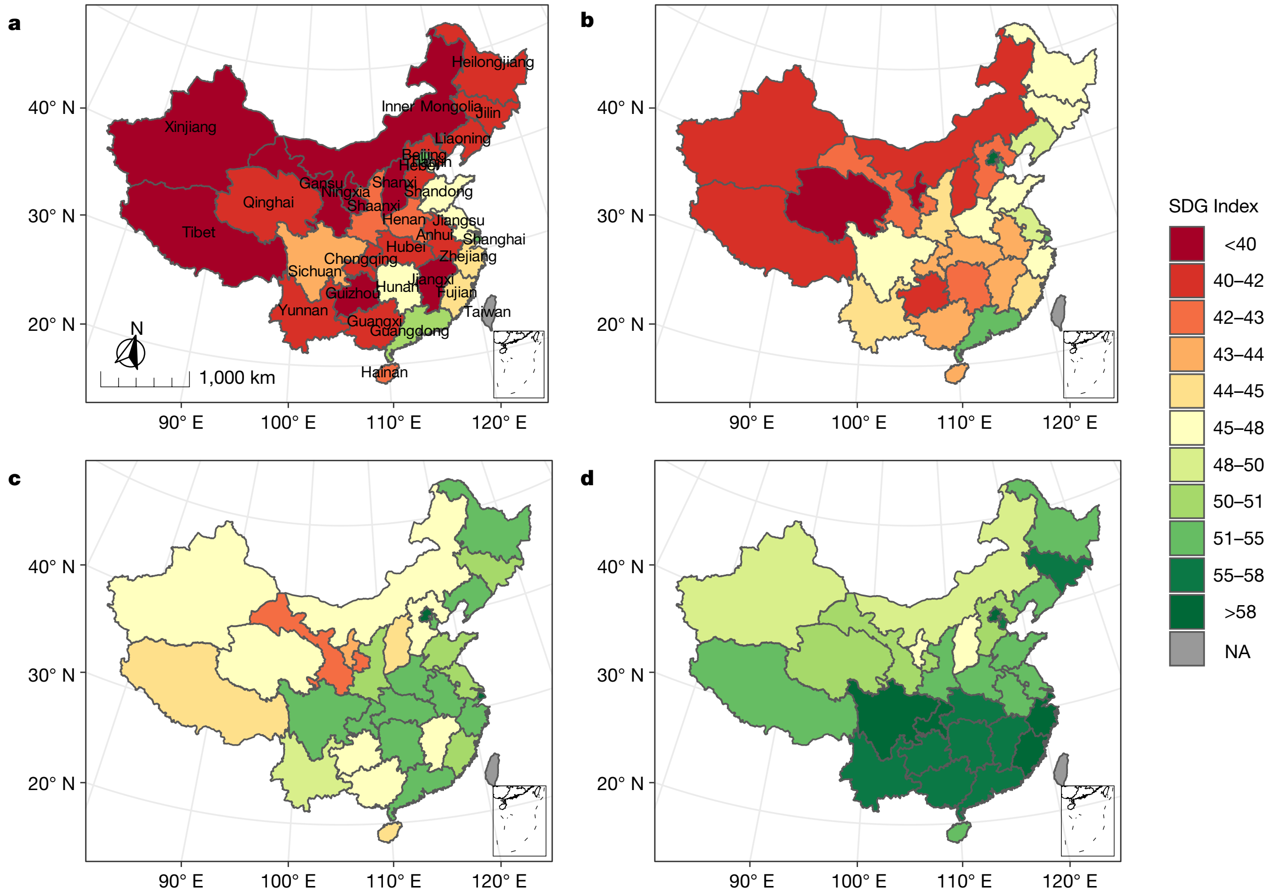

Fig. 2 | Spatial pattern of SDG Index scores in 2000, 2005, 2010 and 2015 for 31 Chinese provinces. a, 2000. **b**, 2005. **c**, 2010. **d**, 2015. The data for the base map was derived from the Resource and Environment Data Cloud Platform[39] and we generated the scores. For other data sources, see Methods. NA, not available.

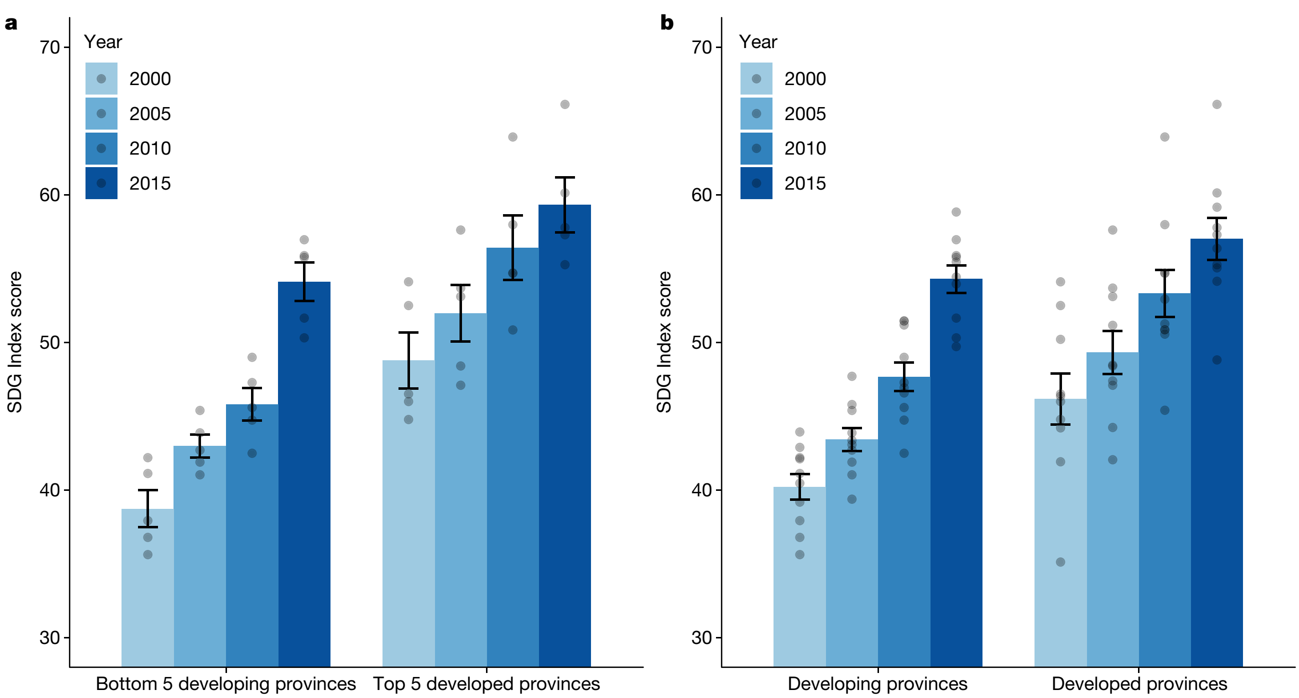

Fig. 3 | Comparison of average SDG Index scores for different groups of provinces in China. a, The top five developed (richest) provinces and the bottom five developing (poorest) provinces in China in 2000, 2005, 2010 and 2015 are compared. **b**, The developed provinces and developing provinces in China in 2000, 2005, 2010 and 2015 are compared. The vertical lines within the bar indicate the standard error in SDG Index scores ($n = 80$). For the data sources and a detailed definition for each category of province, see Methods.

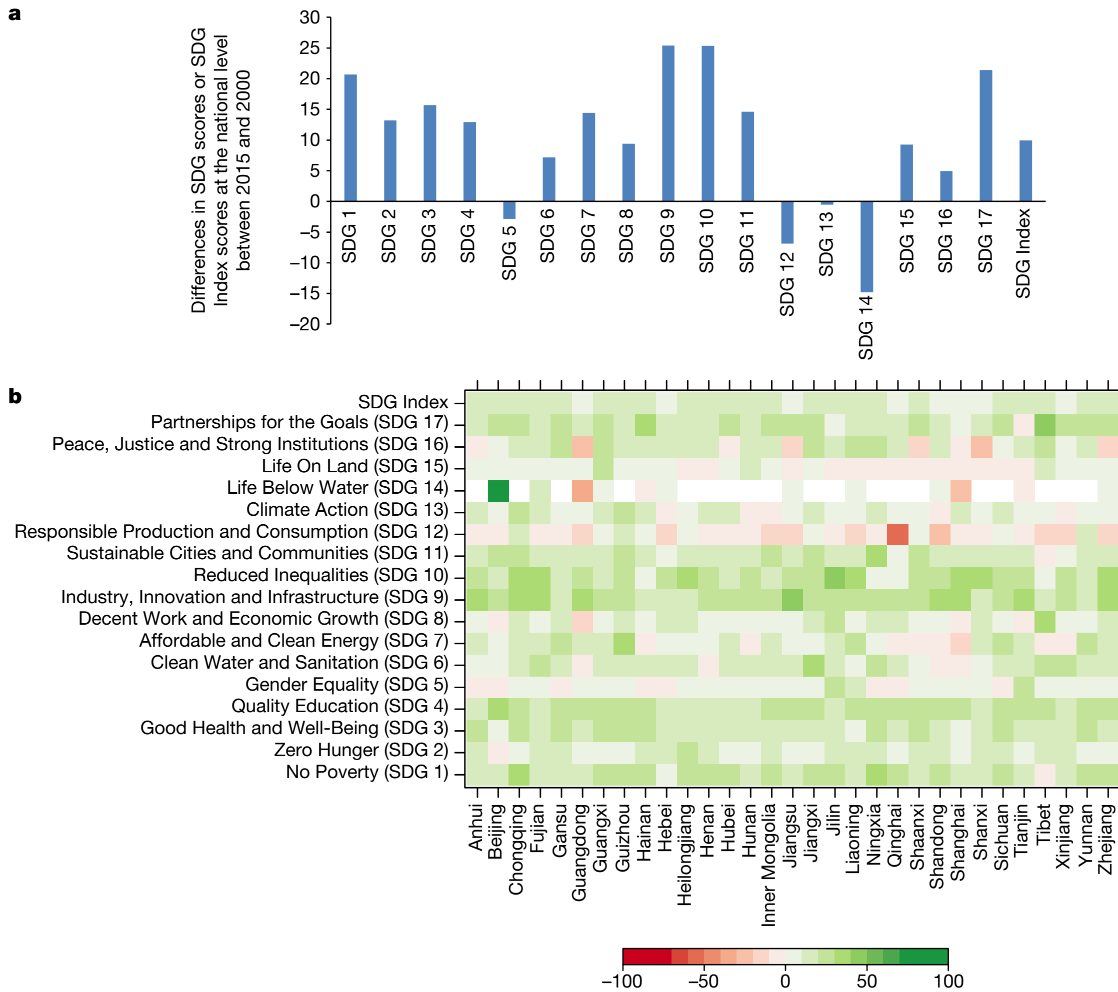

Fig. 4 | Differences in SDG scores or SDG Index scores between 2015 and 2000. a, At the national level. **b**, At the provincial level. The colour scale shows the change in the SDGs scores or SDG Index scores. A positive value (green) indicates an increase in the score from 2000 to 2015, while a negative value (red) indicates a decrease in the score from 2000 to 2015. For data sources, see Methods.

China's rapid technological advances, improved social services such as education and healthcare, and environmental conservation policies have all enhanced sustainability[10,11,13,19,20]. However, environmental problems such as water pollution and scarcity and land degradation still pose a great threat to China's sustainability because these burdens are often associated with other environmental problems such as biodiversity loss and severe droughts. Moreover, China's social problems, such as inequality, can be linked to other complex social problems (such as mental illness, violence, obesity, imprisonment, homicide, teen pregnancy, drug abuse and poor academic performance)[21] that make sustainability difficult to achieve. The Chinese government could therefore prioritize the SDGs that lag behind other SDGs, such as SDG 14 and SDG 15, while facilitating holistic sustainability through integrated policy action (Supplementary Discussion). In particular, for these SDGs more effective policies aimed at protecting life in water and on land are required. China can build on previous successes to deal with regional discrepancies. For example, policymakers could consider more strategies to promote development in northern China in order to reduce the gap in sustainable development between northern and southern China. Since the gap in sustainable development between western and eastern China has shrunk since the Western Development Strategy was implemented, lessons learned from the Western Development Strategy may help to close the gap in sustainable development between northern and southern China.

Future research could focus on the spillover effects of one region's actions on the sustainable development of other regions within China as well as on spillover effects across national borders[22] (Supplementary Discussion). Furthermore, exploring trade-offs and synergies between SDGs can help to reveal the complex mechanisms and consequences of sustainable development[23]. Research assessing the complex impacts of policies on sustainable development is also needed.

This study provides a temporal sustainability assessment of all 17 SDGs at national and subnational levels. China has mandated the monitoring of the progress toward the SDGs[24], but it has not developed systematic and comprehensive evaluation methods. Thus, the methods outlined in our paper are of value to China's monitoring efforts. Our approach might also lay a foundation for analysing spatio-temporal patterns of SDG progress for other countries and across local to global levels.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-019-1846-3.

1. Liu, J. et al. Systems integration for global sustainability. *Science* **347**, 1258832 (2015).
2. Mekonnen, M. M. & Hoekstra, A. Y. Four billion people facing severe water scarcity. *Sci. Adv*. **2**, e1500323 (2016).
3. International Energy Agency. *World Energy Outlook 2015* (IEA, 2015).
4. Larivière, V., Ni, C., Gingras, Y., Cronin, B. & Sugimoto, C. R. Bibliometrics: global gender disparities in science. *Nature* **504**, 211–213 (2013).
5. United Nations. *Sustainable Development Goals: 17 Goals to Transform Our World* http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (UN, 2015).
6. Schmidt-Traub, G., Kroll, C., Teksoz, K., Durand-Delacre, D. & Sachs, J. D. National baselines for the Sustainable Development Goals assessed in the SDG Index and Dashboards. *Nat. Geosci*. **10**, 547–555 (2017).
7. Rodrik, D. The past, present, and future of economic growth. *Challenge* **57**, 5–39 (2014).
8. Xie, Y. & Zhou, X. Income inequality in today's China. *Proc. Natl Acad. Sci. USA* **111**, 6928–6933 (2014).
9. Liu, J. G. et al. China's environment on a metacoupled planet. *Annu. Rev. Environ. Res*. **43**, 1–34 (2018).
10. Liu, J. & Diamond, J. China's environment in a globalizing world. *Nature* **435**, 1179–1186 (2005).
11. Ouyang, Z. et al. Improvements in ecosystem services from investments in natural capital. *Science* **352**, 1455–1459 (2016).
12. Bryan, B. A. et al. China's response to a national land-system sustainability emergency. *Nature* **559**, 193–204 (2018).
13. Ortuño-Padilla, A., Espinosa-Flor, A. & Cerdán-Aznar, L. Development strategies at station areas in Southwestern China: the case of Mianyang city. *Land Use Policy* **68**, 660–670 (2017).
14. Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G. & Fuller, G. *SDG Index and Dashboards Report 2018* https://www.sdgindex.org/reports/sdg-index-and-dashboards-2018 (Pica, 2018).
15. Lu, Z. & Deng, X. Regional policy and regional development: a case study of China's Western Development Strategy. *Ann. Univ. Apulensis Ser. Oeconomica* **15**, 250–264 (2013).
16. Gai, K. *Study on The Coordination between Ecological Environment and Economic Development in West China*. [in Chinese] https://www.sdgindex.org/reports/sdg-index-and-dashboards-2018, PhD thesis, Southwestern University of Finance and Economics (2008).
17. Yuan, N. *Study on the Sustainable Development of West China Economy.* [in Chinese] https://kns.cnki.net/KCMS/detail/detail.aspx?dbcode=CMFD&dbname=CMFD2008&filename=2008028325.nh&uid=WEEvREcwSlJHSldRa1FhdXNXaEhoOHRuWm1vU2REWU45b2ozL013SWRJTT0=$, Master's thesis, Sichuan University (2006).
18. Jayachandran, S. The roots of gender inequality in developing countries. *Ann. Rev. Econ*. **7**, 63 (2015).
19. Chen, Z. Launch of the health-care reform plan in China. *Lancet* **373**, 1322–1324 (2009).
20. Mok, K. H. & Wu, A. M. Higher education, changing labour market and social mobility in the era of massification in China. *J. Educ. Work* **29**, 77–97 (2016).
21. Wilkinson, R. G. & Pickett, K. E. Income inequality and social dysfunction. *Annu. Rev. Sociol*. **35**, 493–511 (2009).
22. Liu, J. An integrated framework for achieving Sustainable Development Goals around the world. *Ecol. Econ. Soc*. **1**, 11–17 (2018).
23. Nerini, F. F. et al. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nat. Energy* **3**, 10–15 (2018).
24. State Council of China. *China Implements the 2030 Agenda for Sustainable Development Country Programme* [in Chinese] https://www.fmprc.gov.cn/web/zyxw/t1405173.shtml (SSC, 2016).

Methods

Six interrelated steps for calculating and comparing SDG scores

Step 1: indicator selection and data sources. We selected indicators from a combination of the United Nations' official list of global Sustainable Development Goal indicators[25], the 2018 SDG Index and Dashboards Report[14] and a report of the United Nations titled "Indicators and a Monitoring Framework for the Sustainable Development Goals"[26]. The 2018 SDG Index and Dashboards Report and the Monitoring Framework Report were published by the Sustainable Development Solutions Network, which operates under the auspices of the United Nations to promote the implementation of the SDGs and the Paris Climate Agreement. The 2018 SDG Index and Dashboards Report provides a robust, quantitative and transparent method of measuring SDG baselines at the country level that has been used in a subsequent peer-reviewed paper[6]. In addition to the above indicators, we also constructed additional indicators based on our understanding of the SDG targets.

For each SDG, we chose as many SDG indicators as was feasible from the list of recommended indicators, based on data availability both at the provincial and national levels and the availability of the indicators across organizational levels and temporal scales (see Supplementary Methods for an example of indicator selection for SDG 6). This approach follows that of previous studies[27,28]. Our list of indicators included a total of 119 SDG indicators at both the national level and provincial level over time, which is greater than the number of indicators in the 2018 SDG Index and Dashboards Report (which used 88 indicators to assess China's SDGs performances for a single year).

Data for the selected indicators in this study were obtained from the following authoritative sources: the National Bureau of Statistics of the People's Republic of China, the China Statistical Yearbook[29], the Finance Yearbook of China[30], the China Statistical Yearbook on the Environment[31], the Educational Statistics Yearbook of China[32], the China Health Statistics Yearbook[33], the China Energy Statistical Yearbook[34] and the China Population Statistics Yearbook[35]. See Supplementary Table 1 for a list of SDGs and their corresponding indicators and the data sources used in this paper.

Step 2: bound selection. To ensure comparability across different SDGs, the indicator values for each SDG were normalized to a standard scale ranging from 0 (worst-performing indicator value towards achieving SDGs, or worst performance) to 100 (best-performing indicator value towards achieving SDGs, or best performance). 'Performance' refers to the progress of a nation or subnational unit towards achieving a single SDG or all 17 SDGs as a whole, measured in terms of SDG indicator values. A higher normalized SDG score indicates better performance towards achieving an SDG. For the national level analysis, we pooled the annual values for 2000–2015 for the selected indicator metrics of each SDG. Thus, the data for each SDG indicator includes 16 indicator values (one per year) that reflect the temporal dynamics of China's overall performance towards that SDG indicator. At the provincial level, we pooled, again separately for each SDG indicator, the values of the indicator metric for the 31 provinces for four years (2000, 2005, 2010 and 2015). In this case, the data reflect the temporal dynamics for each province towards meeting the individual SDGs.

We followed the methods proposed by the 2018 SDG Index and Dashboards Report[14] to normalize the national and provincial data arrays for each SDG indicator. These methods of establishing an upper and a lower bound minimize the potential effects of skewed data because they offset the effects of extreme values on both tails of the data distribution.

Similarly, we identified upper and lower bounds for each SDG indicator in order to minimize the potential effects of skewed data distributions on the standardized values during normalization. Our method for setting the upper bound is similar to the approach used in the 2018 SDG Index and Dashboards report in order to make it easier to compare China with other countries. The upper bound for each indicator was determined using a five-step decision tree. If the condition for an earlier step is met, then all of the later steps are skipped. First, for all indicators that are also used in the 2018 SDG Index and Dashboards report, we adopted the bound used in the 2018 SDG Index and Dashboards report. Second, we used relevant absolute quantitative thresholds for SDGs and targets, such as 'no poverty' and 'absolute gender equality'. Third, if no explicit SDG target was stated, we adopted the principle of 'leave no one behind' to determine the upper bound of zero deprivation or universal access for the following types of indicators: (1) public service coverage, and disease and pollution control, (2) measures of ending hunger (consistent with the SDG purpose to remove extreme hunger in all forms), and (3) access to basic infrastructure (for example, mobile phone coverage). Fourth, where they exist, we used science-based targets set for 2030 or later. Fifth, we set the upper bound for all other indicators equal to the average of the top five performers across the provincial and national levels together.

In terms of lower bound, for all indicators that were used in the 2018 SDG Index and Dashboards report, we adopted the lower bound used in the 2018 SDG Index and Dashboards report. For other indicators, the lower bound was defined as the SDG indicator value (one data point) located close to the value of the bottom 2.5th-percentile performer (across all provinces over four time steps (2000, 2005, 2010 and 2015) and entire China over time (2000–2015 annually)) of the sorted arrays, which was also similar to criteria in the 2018 SDG Index and Dashboard report for selecting the lower bound[14]. If the place of the bottom 2.5th percentile was located between two consecutive integers, the larger or smaller interger was used as the place for the lower bound when a larger indicator data value represented better or worse performance. We specified 'top-performing SDG indicator values' and 'bottom-performing SDG indicator values' rather than referring to the data points as simply high or low values, because a low value may represent high performance in some SDGs (for example, zero poverty) but poor performance in others (for example, amount of protected areas).

Step 3: normalization of indicator values. After establishing the lower and upper bound for each indicator, we used the following formula to normalize SDG indicator values towards meeting a SDG target at the national and provincial levels on a scale of 0 to 100 (ref. [14]):

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \times 100$$

where x is the original data value of each SDG indicator, max/min represents the upper/lower bounds for the best/worst performance, and x' is the normalized individual score for a given SDG indicator. All normalized values greater than the upper bound received a score of 100, and all normalized values less than the lower bound received a score of 0. Values between the upper and lower bounds were distributed along the spectrum from the worst performance (score 0) to the best performance (score 100). A province with a score of 50 is halfway towards achieving the best performance. The normalized scores can be used to evaluate relative performance over time and space towards achieving the SDGs. For example, if for a particular SDG indicator a province lagged behind all other provinces in both 2000 and 2015 but improved over time, its score for that SDG indicator in 2015 would be greater than its score in 2000, but in both years, its score would be lower than that of the other provinces. We normalized the data across provincial and national levels together, so that the SDG scores are comparable across China and its provinces.

Step 4: calculation of SDG Index scores. We calculated SDG Index scores at the national and provincial levels using arithmetic means, following the approach used in the 2018 SDG Index and Dashboards Report[14]. This is an aggregate score that consists of individual scores for all 17 SDGs and represents China's overall performance in achieving all 17 SDGs over time[14]. All SDGs were weighted equally in the SDG Index score to convey the importance of integrated solutions that equally address all 17 SDGs[14]. Consistent with previous research[6,14], there is no a priori reason to give one measure greater weight than another[6,14]. The equal weighting is also consistent with the spirit that all countries need to achieve all 17 SDGs through integrated strategies[6,14]. Within each SDG each indicator is equally weighted, which means that every indicator is weighted inversely to the number of indicators available for that SDG[14].

Step 5: calculation of SDG Index scores and individual SDG score over time and between organization levels. At the national level, we aggregated China's 17 SDG scores into one national SDG Index score for each year from 2000 to 2015, yielding 16 SDG Index scores. At the provincial level, we aggregated each province's 17 SDG scores for 2000, 2005, 2010 and 2015, separately, yielding four SDG Index scores per province. In addition, we calculated the change in SDG scores separately for each of the 17 individual SDG scores and for China and its provinces, by subtracting the normalized score in 2000 from the score in 2015. The SDGs with the bottom five scores in 2015 were considered to be the bottom five SDGs, lagging behind other SDGs.

Step 6: comparison of SDG Index scores between developing and developed regions. Ten developing provinces and ten developed provinces in China were selected to compare SDG Index scores between relatively more- and less-developed regions, based on each province's average GDP per capita from 2000 to 2015[36]. Provinces with the highest ten GDP values per capita were considered to be developed provinces, whereas provinces with the lowest ten GDP values per capita were considered to be developing provinces. We also designated provinces with the highest five GDP values as the top five developed provinces and provinces with the lowest five GDPs as the bottom five developing provinces. Finally, we compared the average SDG Index scores, calculated across all SDGs, between developed and developing provinces.

Uncertainty and sensitivity analysis for SDG scores

To explore the uncertainty introduced by the number of SDG indicators, we ran uncertainty analyses. For each SDG, we analysed all possible combinations of SDG indicators for all possible numbers of SDG indicators, which yielded a distribution of SDG scores for China in 2015. This allowed us to determine the impact of different numbers of indicators and different combinations of indicators on the SDG score. We found that as the number of indicators increased, the uncertainty (variation) in the SDG score decreased. When the number of indicators per SDG is two or larger, the median SDG score was almost constant (Extended Data Fig. 2). We performed an uncertainty analysis for SDG 9 as an example using all combinations of SDG indicators, under all possible numbers of SDG indicators. Given that the total number of indicators for SDG 9 is 14, the possible number of indicators to be selected for an uncertainty analysis ranges from 1, 2,... to 14. The number of possible combinations of indicators can be calculated based on the theory of combinations.

When we choose m indicators from a total of n indicators, the number of possible combinations is:

$$C_n^m = \frac{n!}{m!^{*}(n-m)!}$$

For example, when selecting one indicator, there are only 14 possible combinations (that is, 1, 2, 3,..., 14).

When we choose 2 indicators from 14 indicators, the number of possible combinations is

$$C_{14}^2 = \frac{1\times 2\times \ldots \times 12\times 13\times 14}{(1\times 2)\times(1\times 2\times \ldots \times 10\times 11\times 12)} = 91$$

When selecting 3–13 indicators, the numbers of combinations are 364, 1,001, 2,002, 3,003, 3,432, 3,003, 2,002, 1,001, 364, 91 and 14, respectively. When selecting all 14 indicators for analysis, there is only one combination.

Next we calculated the scores of SDG 9 for all these combinations of SDG indicators under different possible numbers of selected indicators. We obtained the distribution of SDG 9 scores for China in 2015 to determine the effect of the number of indicators under all potential combinations of indicators on the SDG score. We found that as the number of indicators for SDG 9 increased, the uncertainty (variation) decreased. When the number of indicators for SDG 9 was two or larger, the median SDG score remained almost constant (Extended Data Fig. 2).

We also ran a sensitivity analysis[37] to assess the sensitivity of the SDG scores to different values of variables that affect the SDG scores. We employed a widely used sensitivity index to measure the degree of sensitivity[38]: $S_x = (\Delta X/X)/(\Delta P/P)$ where X is the SDG score under the original condition for a performer of interest, ΔX is the difference of the SDG score for the performer of interest (for example, one province in a specific year) between the original and modified conditions due to changes in the performer's data value of a certain SDG indicator. P represents the value of an SDG indicator of the performer of interest under the original condition and ΔP is the difference in the data value of the SDG indicator of the performer between the original and modified conditions. S_x refers to the change in the SDG score of the performer due to the change in the data value of the SDG indicator. We decreased and increased (separately) the value for each indicator by 10% for China at the national level as well as for three randomly chosen provinces (Beijing, Henan and Gansu) from provinces at three sustainable development levels (average SDG Index scores in years 2000, 2005, 2010 and 2015: 1st to 10th-highest as high level, 11th to 20th as middle level, 21st to 31st as low level) as examples and recalculated their SDG score and obtained the sensitivity index S_x. We found that the sensitivity of SDG scores to changes in an indicator's data value is very small (less than 0.2) (Extended Data Fig. 3).

To assess where China stands relative to the rest of the world, we recalculated China's SDG Index score using the indicators that overlapped between our paper and the 2018 SDG Index and Dashboards report. China's SDG Index score over time relative to the rest of world in one year is shown (Extended Data Fig. 4).

To examine the spatio-temporal heterogeneity of SDGs at the provincial level, we calculated the coefficient of variation for each SDG score across provinces over time (Extended Data Fig. 5).

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this paper.

Data availability

All data are available from the corresponding authors upon reasonable request. Data that support the findings of this study are available within the paper and its Supplementary Information.

25. United Nations Statistics Division. *SDG Indicators* https://unstats.un.org/sdgs/indicators/indicators-list (UNSD, 2017).
26. Schmidt-Traub, G., De la Mothe Karoubi, E. & Espey, J. *Indicators and a Monitoring Framework for the Sustainable Development Goals: Launching a Data Revolution for the SDGs* https://ec.europa.eu/knowledge4policy/publication/indicators-monitoring-framework-sustainable-development-goals-launching-data-revolution_en (Sustainable Development Solutions Network, 2015).
27. Golding, N. et al. Mapping under-5 and neonatal mortality in Africa, 2000-15: a baseline analysis for the Sustainable Development Goals. *Lancet* **390**, 2171–2182 (2017).
28. Alia, D. Y. Progress toward the sustainable development goal on poverty: assessing the effect of income growth on the exit time from poverty in Benin. *Sustain. Dev.* **25**, 495–503 (2017).
29. National Bureau of Statistics of the People's Republic of China. *China Statistical Yearbook* [in Chinese] http://www.stats.gov.cn/tjsj/ndsj/ (China Statistics Press, 2001–2016).

30. Ministry of Finance of the People's Republic of China. *Finance Yearbook of China* [in Chinese] http://tongji.cnki.net/kns55/navi/HomePage.aspx?id=N2014020005&name=YZGCZ (China Financial & Economic Publishing House, 2001–2016).
31. National Bureau of Statistics & State Environmental Protection Administration of the People's Republic of China. *China Statistical Yearbook on Environment* [in Chinese] http://www.shujuku.org/china-environmental-statistics-yearbook.html (China Statistics Press, 2001-2016).
32. Ministry of Education of the People's Republic of China. *Educational Statistics Yearbook of China* [in Chinese] http://tongji.cnki.net/kns55/Navi/HomePage.aspx?id=N2012010030&name=YZKRM&floor=1 (People's Education Press, 2001-2016).
33. Ministry of Health of the People's Republic of China. *China Health Statistical Yearbook* [in Chinese] http://www.shujuku.org/china-health-statistical-yearbook.html (Peking Union Medical College Press, 2001-2016).
34. National Bureau of Statistics of the People's Republic of China. *China Energy Statistical Yearbook* [in Chinese] http://tongji.cnki.net/kns55/Navi/HomePage.aspx?id=N2016120537&name=YCXME&floor=1 (China Statistics Press, 2001–2016).
35. National Bureau of Statistics of the People's Republic of China. *China Population Statistics Yearbook* [in Chinese] http://tongji.cnki.net/kns55/navi/HomePage.aspx?id=N2007091124&name=YZGRL&floor=1 (China Statistics Press, 2001-2006).
36. Costa, L., Rybski, D. & Kropp, J. P. A human development framework for CO_2 reductions. *Plos One* **6**, e29262 (2011).
37. Turner, M. G., Wu, Y., Wallace, L. L., Romme, W. H. & Brenkert, A. Simulating winter interactions among ungulates, vegetation, and fire in northern Yellowstone Park. *Ecol. Appl*. **4**, 472–496 (1994).
38. Liu, J. & Ashton, P. S. FORMOSAIC: an individual-based spatially explicit model for simulating forest dynamics in landscape mosaics. *Ecol. Modell*. **106**, 177–200 (1998).
39. Institute of Geographic Sciences and Natural Resources Research of Chinese Academy of Sciences. *Resource and Environment Data Cloud Platform* [in Chinese] http://www.resdc.cn/data.aspx?DATAID=202 (2015).
40. Frigge, M., Hoaglin, D. C. & Iglewicz, B. Some implementations of the boxplot. *Am. Stat*. **43**, 50–54 (1989).
41. Krzywinski, M. & Altman, N. Visualizing samples with box plots. *Nat. Methods* **11**, 119–120 (2014).

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Author contributions Z.X. and J.L. designed the research. Yunkai Li and X.C. contributed and checked data. Z.X., S.N.C., J.L., T.D., Yunkai Li, Y.T., X.C., S.L., B.H., A.H., J.A.W. and D.H. provided comments on the manuscript. Z.X., J.Z., Yingjie Li and F.F. analysed the data. Yunkai Li and X.C. helped to analyse data related to SDGs 2 and 6. Z.X., S.N.C., J.Z., Yingjie Li and J.L. wrote the manuscript. All authors reviewed the manuscript.

Competing interests The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Yunkai Li or J.L.

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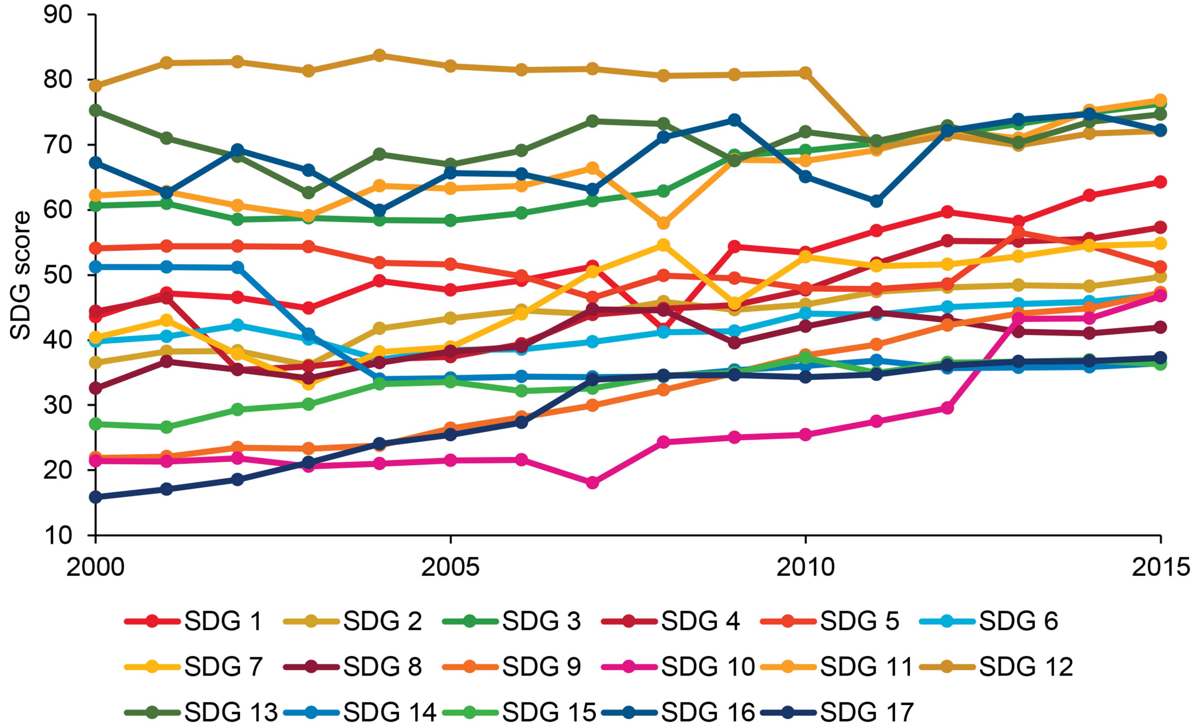
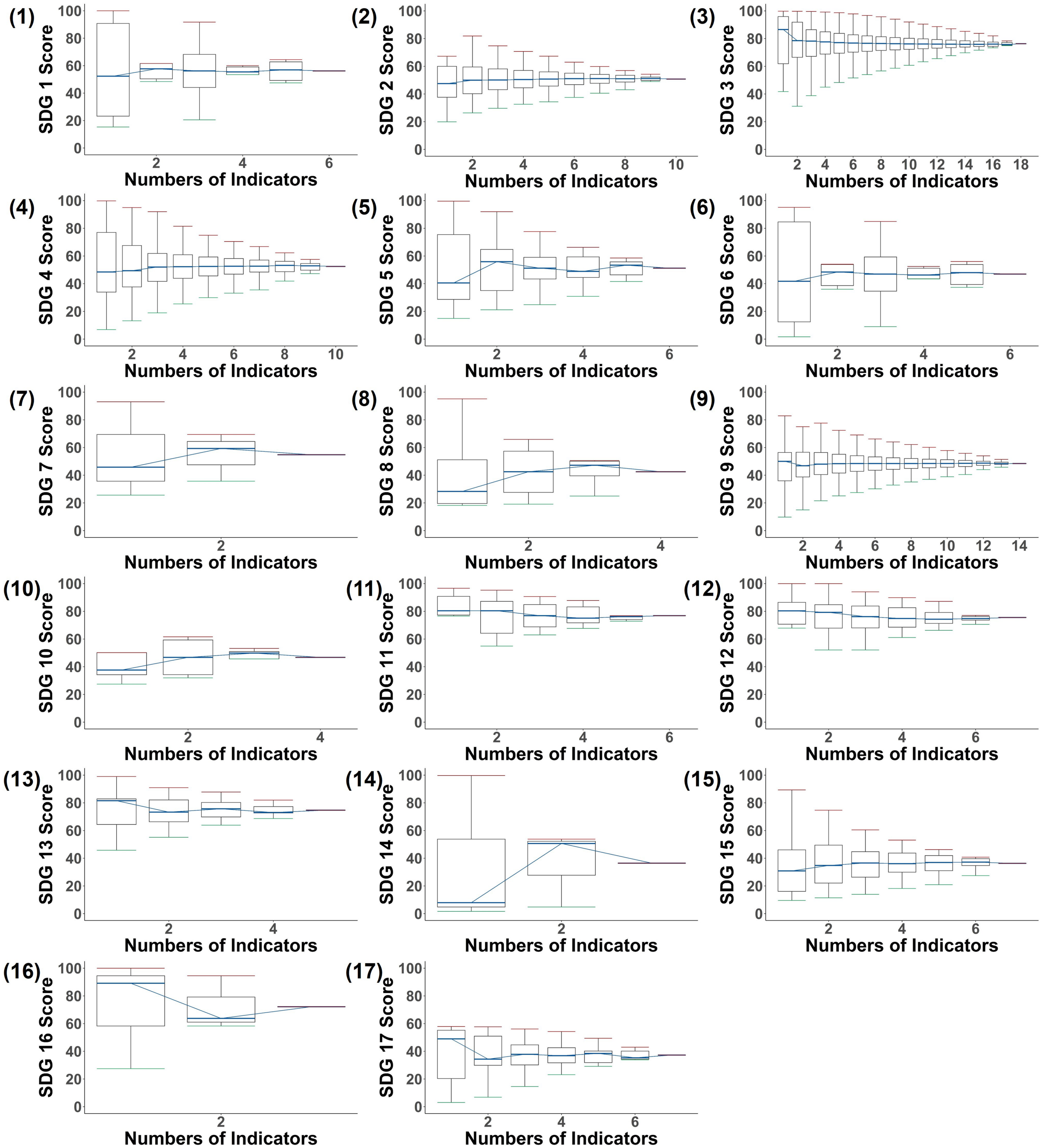
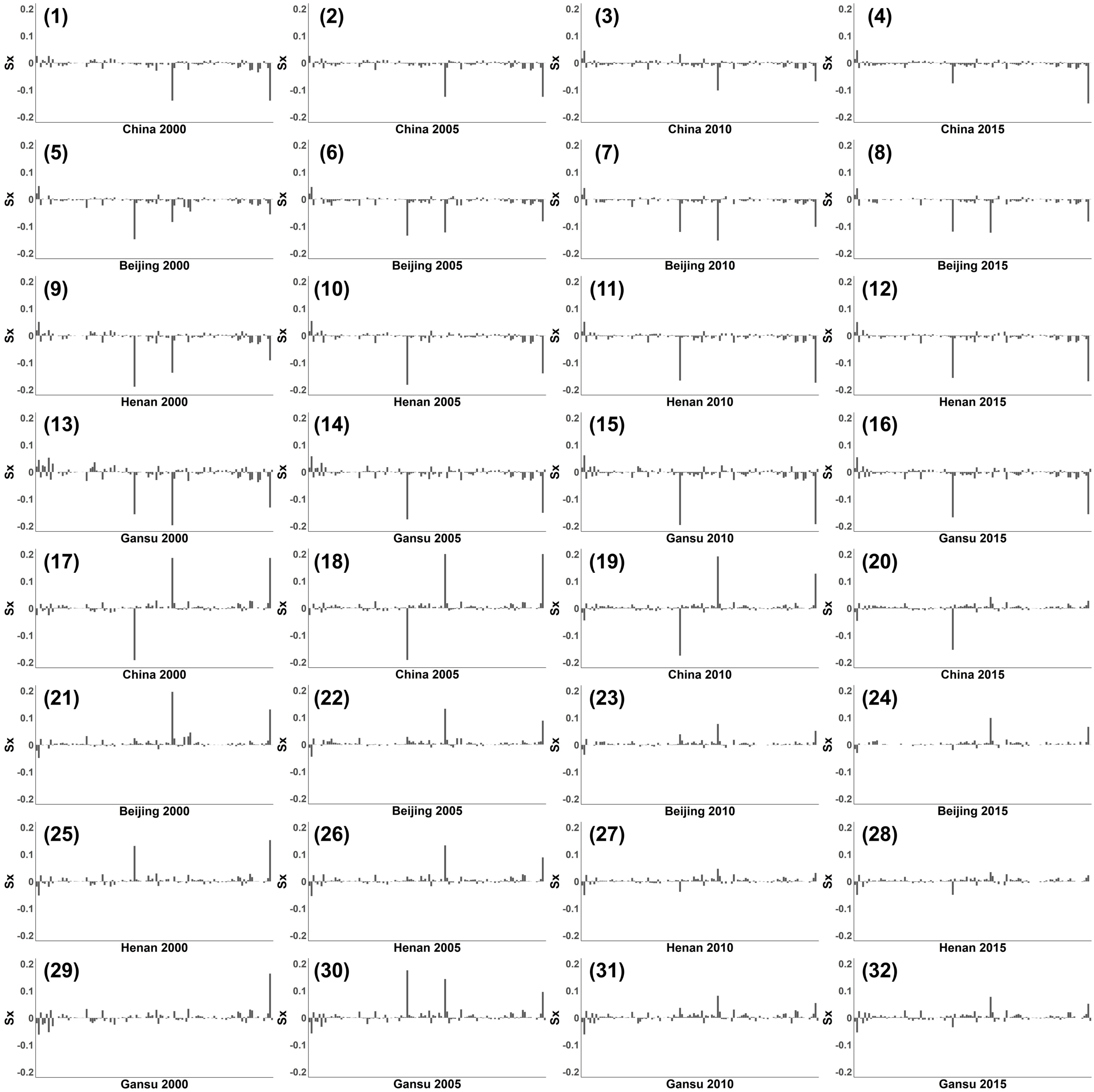


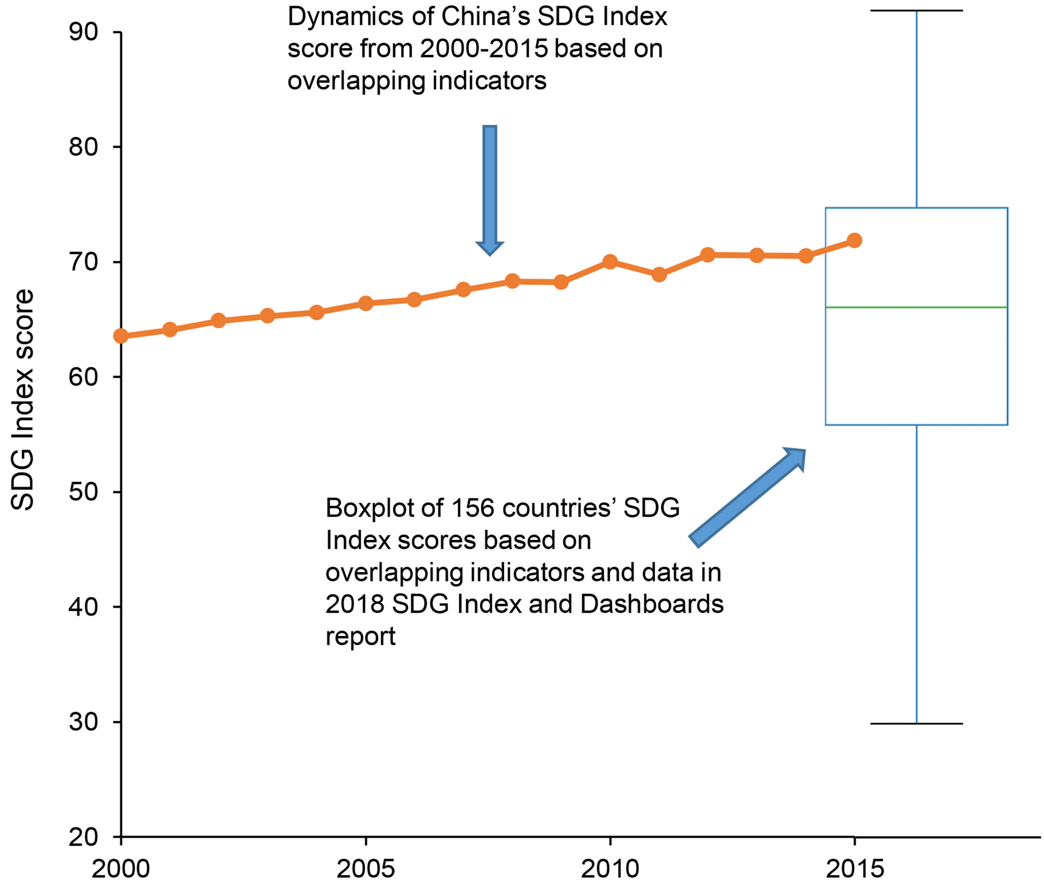
Extended Data Fig. 1 | Change in China's individual SDG scores at the national level from 2000 to 2015. For data sources, see Methods.



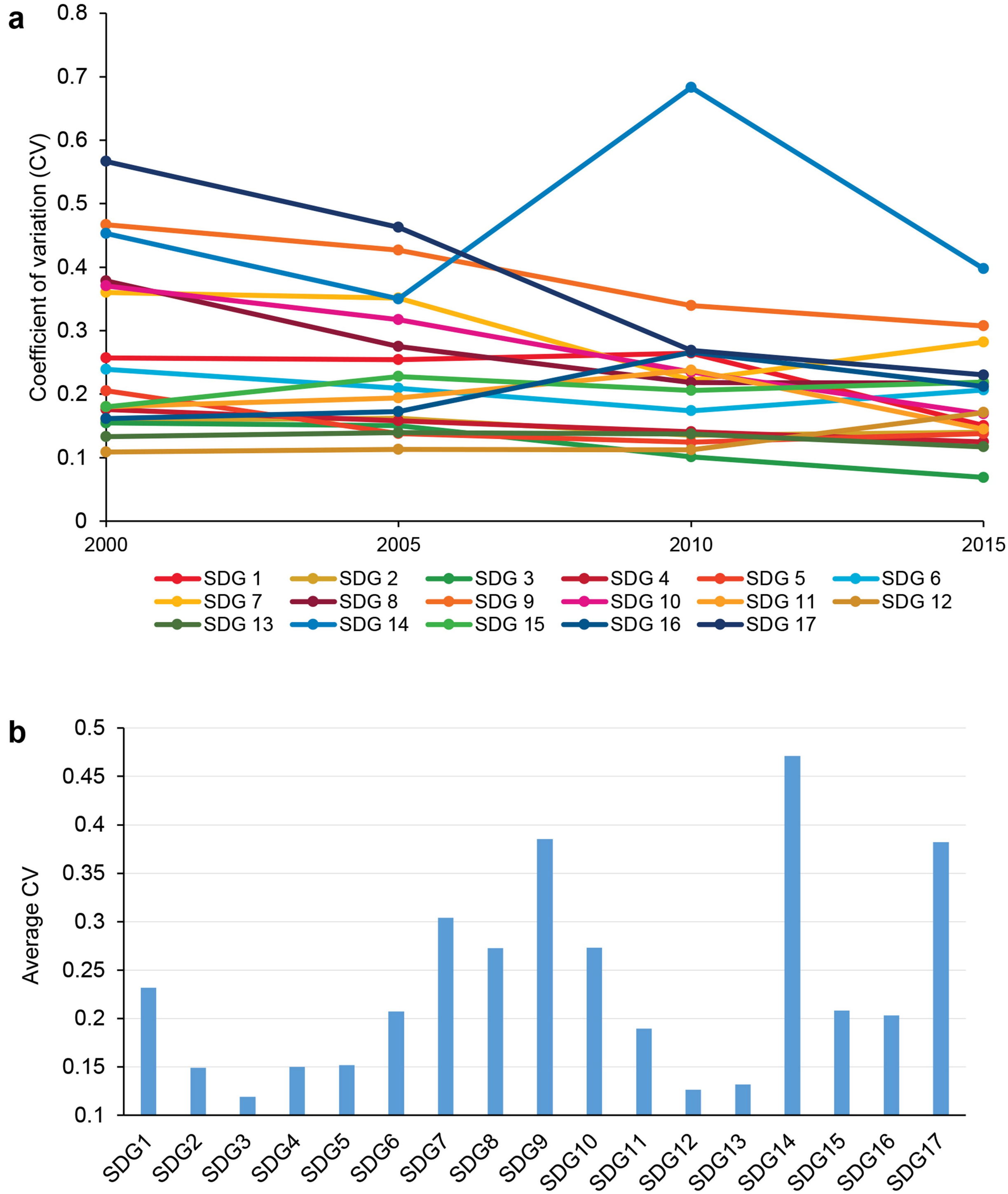
Extended Data Fig. 2 | Uncertainty analysis for SDG scores (n = 281,287) at the national level in 2015 for different numbers of selected indicators. 1–17 indicates uncertainty analysis for SDG 1–17. Sample sizes are 63, 1,023, 262,143, 1,023, 63, 63, 7, 15, 16,383, 15, 63, 127, 31, 7, 127, 7 and 127 for box plots of SDG 1–17. In each box plot, the central rectangle spans the first quartile Q1 to the third quartile Q3, which is the interquartile range (IQR)[40,41] (IQR = Q3 to Q1), while the line segment inside the rectangle shows the median. When the maximum observed SDG scores are greater than Q3 + 1.5 × IQR[40,41], the upper whisker (red) is Q3 + 1.5 × IQR[40,41]. Otherwise, the upper whisker is the maximum observed SDG score. When the minimum observed SDG scores are less than Q1 − 1.5 × IQR[40,41], the lower whisker (green) is Q1 − 1.5 × IQR. Otherwise, the lower whisker is the minimum observed SDG score[40,41].



Extended Data Fig. 3 | Sensitivity of SDG scores to changes in each indicator. The sensitivity index S_x of SDG scores is shown when each SDG indicator's original data value decreased by 10%, (1)–(16), or increased by 10%, (17)–(32), for China and for three example provinces (Beijing, Henan and Gansu) at three levels (high, middle and low) of the average SDG scores in 2000, 2005, 2010 and 2015. The sample size *n* for each figure is 119 indicators. The *x* axes display the SDG indicators arranged from 1 to 119. The *y* axis is the sensitivity index S_x of SDG scores due to the 10% decrease or increase in the original value of each indicator.



Extended Data Fig. 4 | China's SDG Index score compared with another 156 countries based on overlapping indicators. The box plot depicts the distribution of SDG Index scores (n = 156) for 156 countries in one year. The central rectangle spans the first quartile Q1 to the third quartile Q3, which is the IQR[40,41], while the line segment inside the rectangle shows the median. When the maximum observed SDG Index scores are greater than Q3 + 1.5 × IQR, the upper whisker is equal to Q3 + 1.5 × IQR[40,41]. Otherwise, the upper whisker is equal to the maximum observed SDG Index score. When the minimum observed SDG Index score is less than Q1 − 1.5 × IQR, the lower whisker is equal to Q1 − 1.5 × IQR[40,41]. Otherwise, the lower whisker is the minimum observed SDG Index score[40,41]. The green line segment within the box is the median value of SDG Index scores for the 156 countries.



Extended Data Fig. 5 | Coefficient of variation for SDG scores. a, Coefficient of variation (CV) for SDG scores of provinces in 2000, 2005, 2010 and 2015. **b**, Average value of the coefficient of variation for SDG scores at the provincial level in 2000, 2005, 2010 and 2015.

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Software and code

Policy information about availability of computer code

Data collection	Data for the selected indicators in this study were obtained from the following authoritative sources: National Bureau of Statistics of the People’s Republic of China, China Statistical Yearbook Finance Yearbook of China, China Statistical Yearbook on the Environment, Educational Statistics Yearbook of China, China Health Statistics Yearbook, China Energy Statistical Yearbook, China Population Statistics Yearbook etc. See Table S1 for a list of SDGs and their corresponding indicators and data sources used in this paper.
Data analysis	I use Microsoft Excel 2013 and Matlab 2017b to analyze data.

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April 2018

Data

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Data for the selected indicators in this study were obtained from the following authoritative sources: National Bureau of Statistics of the People's Republic of China, China Statistical Yearbook Finance Yearbook of China, China Statistical Yearbook on the Environment, Educational Statistics Yearbook of China, China Health Statistics Yearbook, China Energy Statistical Yearbook, China Population Statistics Yearbook etc. See Table S1 for a list of SDGs and their corresponding indicators and data sources used in this paper.

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Ecological, evolutionary & environmental sciences study design

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Study description

Global challenges such as hunger, water scarcity, energy shortage, environmental pollution, gender inequality and climate change pose threats to sustainability and human well-being worldwide. To address these and other challenges, nearly every country in the world has committed to the 17 United Nations Sustainable Development Goals (SDGs). Quantifying SDGs at the national and subnational levels can help track global progress towards sustainable development and identify priorities for policy-making and implementation, because nations and sub-nations are the basic units for implementing SDGs. However, there is no systematic spatio-temporal assessment of SDGs at national and subnational levels to guide policy development and implementation. To fill this gap, we used China, the largest developing country that increasingly shapes the world's future, as the first demonstration of examining the spatio-temporal dynamics of the 17 SDGs at both national and subnational levels. Our results indicate that China had an increasing SDG Index score (aggregated score representing China's overall performance in achieving all 17 SDGs) at the national level from 2000 to 2015. At the provincial level, east China had higher SDG Index score than west China in the 2000s, while south China had higher SDG Index score than north China in 2015. The SDG Index scores of all provinces increased over this period. Developed provinces had higher SDG index scores than developing provinces, but developing provinces experienced greater increases in SDG Index scores than did developed provinces. The Chinese government could consider prioritizing SDGs with low scores such as 15 (life on land), 14 (life below water) and 17 (partnerships for the goals). Also, since north China lags behind other areas it would warrant special attention. This study also suggests the need to track the spatio-temporal dynamics of progress toward SDGs in other nations to uncover significant shifts in sustainable development at national and subnational levels. Such insights can inform policy-making and implementation to achieve global sustainability.

Research sample

Data for the selected indicators in this study were obtained from the following authoritative sources: National Bureau of Statistics of the People's Republic of China, China Statistical Yearbook Finance Yearbook of China, China Statistical Yearbook on the Environment, Educational Statistics Yearbook of China, China Health Statistics Yearbook, China Energy Statistical Yearbook, China Population Statistics Yearbook etc. See Table S1 for a list of SDGs and their corresponding indicators and data sources used in this paper. At the national level, we aggregated China's 17 SDG scores into one national SDG Index score for each year from 2000 to 2015, yielding 16 SDG Index scores. At the provincial level, we aggregated each province's 17 SDG scores for 2000, 2005, 2010 and 2015 separately, yielding four SDG Index scores per province. In addition, we calculated the change in SDG scores separately for each of the 17 individual SDG scores and for China and its provinces, by subtracting the normalized score in 2000 from the score in 2015. The SDGs with bottom five scores in 2015 were considered as bottom five SDGs that lag behind other SDGs.

Sampling strategy

We study China and China's provinces over time, so the number of them is certain.

Data collection

Data for the selected indicators in this study were obtained from the following authoritative sources: National Bureau of Statistics of the People's Republic of China, China Statistical Yearbook Finance Yearbook of China, China Statistical Yearbook on the Environment, Educational Statistics Yearbook of China, China Health Statistics Yearbook, China Energy Statistical Yearbook, China Population Statistics Yearbook etc. See Table S1 for a list of SDGs and their corresponding indicators and data sources used in this paper.

Timing and spatial scale

We study China at national scale from 2000 to 2015, while study China's provinces in 2000, 2005, 2010 and 2015.

Data exclusions

No data was excluded

Reproducibility

We have followed the framework and guidelines in the 2019 report on reproducibility and replication by the National Science Foundation and the U.S. Department of Education (https://www.nsf.gov/pubs/2019/nsf19022/nsf19022.pdf). For instance, we have provided detailed, transparent, and clear descriptions of the methods (e.g., models, analysis procedures, data sources) that have led to the findings. We are committed to making all data, models, code, etc. used in our research available to those interested individuals so that they can be used by others to exactly reproduce our findings.

Randomization: No allocation. We study China and China's provinces.

Blinding: No blinding. We study China and China's provinces.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

Materials & experimental systems

n/a	Involved in the study
☒	☐ Unique biological materials
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology
☒	☐ Animals and other organisms
☒	☐ Human research participants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging