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Assessing the sustainability of socio-economic boundaries in China: a downscaled "safe and just space" framework

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This study constructs a downscaled "safe and just space" framework consisting of 13 processes to evaluate China's sustainability status of socio-economic sphere in 2020, with a focus on the impact of COVID-19. To minimize subjectivity in threshold setting, the study adopts the expected targets outlined in the national and sectorial official documents of China's 13th Five-Year Plan. The results show that while overall employment and income have achieved satisfactory thresholds without deprivation, issues such as youth unemployment and wealth disparity have deteriorated. Social inequality and lack of trust remain prevalent despite high levels of self-reported life satisfaction. Developed areas exhibit a significantly higher average life expectancy than developing areas do, and gender imbalance persists as a chronic issue. The severity of energy deprivation compared with water is highlighted. In addition, this study confirms the validity of Hu Huanyong Line in dividing the spatial pattern of socio-economic sustainability status in China, as all the provinces meeting more than eight thresholds are located in the eastern part of the country. Based on these findings, the interactions between the socio-economic processes as well as their resilient behaviors to climate change under the COVID-19 impact are discussed. Finally, the study suggests future research directions to enhance the theoretical and methodological defects of the framework.

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INTRODUCTION

The socio-economic transition, guided by the "safe and just space" framework, represents a new approach to combat climate change and safeguard the global commons for present and future generations[1,2]. This analysis takes into account the resilience thinking of China's socio-economic system under the impact of COVID-19, assessing the adaptability and transformation abilities to rebuild and reorganize in ways that minimize harm and enhance human wellbeing[3,4]. In this context, two specific questions are posed: (1) How can subjectivity in threshold setting be reduced and a reliable downscaled "safe and just space" framework be established for China? (2) How has the pandemic affected socio-economic processes and what are its implications for climate change? To address these questions, a downscaled socio-economic sustainability evaluation framework is constructed that focuses on China and encompasses 13 processes. The thresholds are based on the expected 2020 targets outlined in the national and sectorial 13th Five-Year Plan (FYP) (2016–2020). The framework facilitates the identification of the "safe and just space"[5,6] and allows for the presentation of China's socio-economic processes' sustainability status.

The planetary boundaries (PB) framework, emerging as a crucial tool for sustainability evaluation[7], was formulated by Rockström et al.[8]. The framework encompasses nine bio-physical boundaries with predefined thresholds. Operating within these thresholds ensures the existence of "safe and just spaces" where irreversible damage and adverse impacts on human well-being can be avoided. Recognizing the importance of integrating socio-economic dimensions into PB, this approach aims to achieve "the global sustainability vision with a plurality of bottom-up realisations of sustainability."[7] [1] Raworth[9,10] proposes a socio-economic sphere with 11 boundaries based on practical experiences of Sustainable Development Goals (SDGs)[11] and national social development priorities in 80 government submissions to the UN Rio+20 Conference in 2012[12]. This model gave rise to the so-called Doughnut, which visualizes a safe and just operating space between the bio-physical and socio-economic thresholds, aiming to achieve environmental protection, social equity, and justice, along with inclusive and sustainable economic growth[10]. Therefore, Doughnut is at the core of Doughnut economics (DE): the former denotes the visualization accounting process whereas the latter refers to the sustainability evaluation framework with solid theoretical bases[13]. In other words, the Doughnut presents a vision of human thriving, while DE explores the mindset and ways of thinking required to get us there. Moreover, the interrelatedness of multiple bio-physical and socio-economic processes reveals resilience thinking, which means that changes in one aspect may affect others[9,14], such as the water–food–energy–climate change–land nexus[15].

Figure 1 illustrates the Doughnut socio-economic processes based on existing empirical studies. O'Neill et al.[6] conducted a comprehensive cross-national analysis to examine sustainability status in more than 150 countries/regions in (or around) 2011. Only Germany, the Netherlands, and Australia achieved sustainability for all 11 socio-economic processes. Seven countries achieved 10 thresholds, and 35 countries failed to achieve more than one. The authors argue that, due to the resource distribution disparities, meeting additional targets (e.g., life satisfaction and social support) would require resource consumption at 2–6 times the globally sustainable level. Therefore, the existing inequitable resource allocation mechanism serves as the main obstacle to sustainable development, and a fundamental institutional change is needed. Fanning et al.[16] expanded the research period to 1992–2015 and examined the historical dynamics of the same 11 indicators. The results reveal an overall positive trend, with the number of countries reaching the thresholds increasing for five socio-economic indicators, decreasing for two, and remaining relatively stable for the remaining four.

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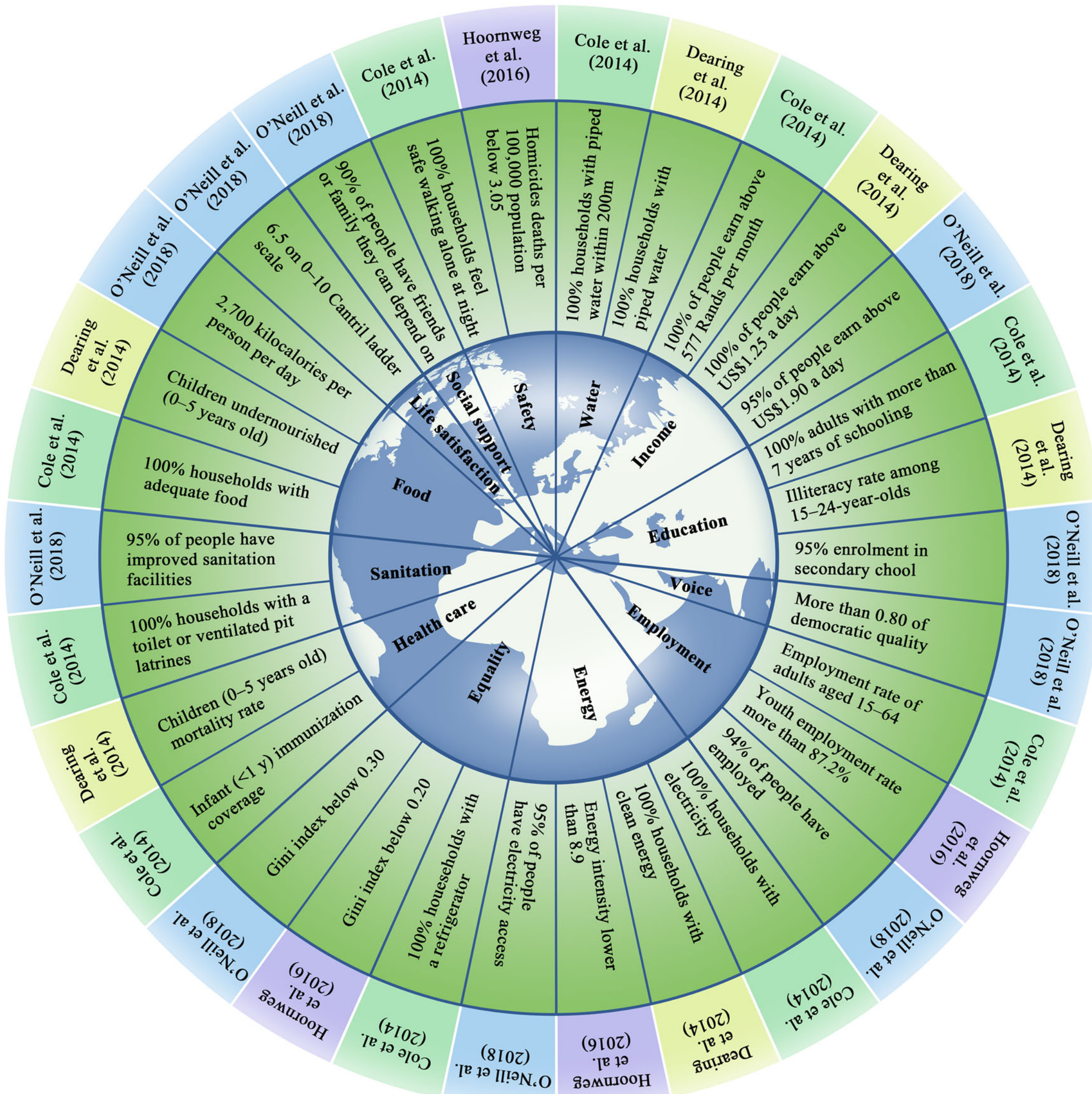

Fig. 1 Overview of Doughnut socio-economic processes. This figure provides an overview of socio-economic indicators derived from established Doughnuts and showcases various definitions proposed in existing empirical studies. The inner ring depicts the 13 socio-economic indicators put forth by researchers. The middle ring presents the specific definitions, with corresponding authors displayed in the outer ring (each study represented by one background color). Please refer to the research conducted by Cole et al.[5], Dearing et al.[12], Hoornweg et al.[17], and O'Neill et al.[6]. The work of Fanning et al.[16] is excluded because they use the same indicator system as O'Neill et al.[6] (both studies share the same group of main contributors).

Cole et al.[5] were pioneers in downscaling the framework to the national level, enabling the identification and quantification of PB to measure sustainability in South Africa. Their findings reveal that safety exhibits the worst performance, with a deprivation rate of 63.5%, thus highlighting the severe social security issues. This is followed by income level and job opportunities, which stand at 52.5% and 36.3%, respectively, indicating the presence of significant vulnerable groups and a high unemployment rate. These findings are in line with Raworth's[9] observations, further suggesting that the gap between the rich and the poor is a prevalent global issue.

At the sub-national level, Hoornweg et al.[17] assessed the sustainability of seven socio-economic boundaries with 24 specific indicators. Their findings indicate that Toronto performs the best, with all indicators falling within the "safe and just space." However, Shanghai exceeds the safety red line in the economic field due to low per capita income and a high Gini coefficient. São Paulo and Dakar exceed the thresholds in four and six boundaries, respectively, and Mumbai performs the worst, failing to achieve any of the thresholds. In a separate study by Dearing et al.[12], the focus shifts to the social-ecological sphere within two Chinese localities: the Erhai Lake catchment area and Shucheng County. By using local statistical data and conducting a questionnaire survey, they found that Shucheng has effectively guaranteed food safety, health security, and minimum income, thanks to the government's successful poverty alleviation efforts. However, the provision of drinking water and sanitation facilities remains insufficient, indicating an urgent need for improved water management in rural China. Additionally, intensive agriculture in both areas has reduced poverty but also resulted in environmental damage, illustrating a clear trade-off between economic development and environmental pollution.

Compared with the bio-physical thresholds, whose scaling standards are established by authoritative institutions or academia, the setting of socio-economic thresholds is inherently subjective. Existing studies have identified four categories of

Table 1. China's regional performances on Doughnut socio-economic processes in 2020.

Socio-economic indicator	Threshold	Definition	Regions without deprivation (%)
Life satisfaction	6.5	0–10 Cantril ladder scale for self-assessment of life satisfaction	80.00
Social support	61.78	Percentage of people who believe that most people can be trusted	33.33
Voice	28.95	Percentage of people who vote in elections	66.67
Life expectancy	77.3	Years of life expectancy at birth	13.33
Employment	95	Percentage of people employed	100
Income	100	Percentage of people with disposable income higher than RMB 10,000	100
Education	2591.55	Number of students in higher education per 100,000 residents	90
Gender equity	98.35	Percentage of average world female-to-male population ratio	13.33
Social equality	60	0–100 scale (Gini Coefficient of 0.4)	36.67
Sanitation	6	Number of beds in medical institutions per 1,000 residents	70.00
Access to water	95	Percentage of people with access to water	83.33
Access to energy	95	Percentage of people with access to gas	40.00
Safety	1.3	Number of disaster-related deaths per million of the population	83.33

(1) Tibet is excluded due to data inaccessibility, leaving a total of 30 provinces, municipalities, and autonomous regions.
(2) There is no missing data for this Doughnut, resulting in 30 value numbers for each indicator.

methods for determining these thresholds: commonly accepted rules, accumulated experience, reference to typical samples, and desired targets set by the government. First and foremost, the World Bank uses an income of US$ 1.9 per day as the poverty criterion, which serves as a threshold for income indicators[6]. Second, in the case of the *World Happiness Report*'s 0–10 Cantril ladder scale[18], most studies consider a level above 7 as a measure of high happiness. However, O'Neill et al.[6] found that the data from the Cantril ladder were, on average, 0.5 lower than other happiness statistics based on personal experience. Therefore, a threshold of 6.5 was set. Similarly, in the case of *Nutrition*, considering the unequal distribution of food in different countries, researchers increased the average daily consumption of 2500 calories (according to the Food and Agriculture Organization[19]) by 200, resulting in a threshold of 2700 calories. Third, concerning sample reference, O'Neill et al.[6] used the UK and the US as reference samples and set a threshold of 0.8 for the *Voice* indicator. Fanning et al.[16] followed a similar approach and further rescaled the values to 0–10. Lastly, certain thresholds proposed by Cole et al.[5] align with the standards of the *Reconstruction and Development Programme*[20], a policy framework implemented by the South African government. Therefore, it is difficult to find a unified standard generally accepted by all parties, which hinders the development of socio-economic boundaries.

Using China's provincial-level data to bridge this gap, this study introduces an innovative method for determining thresholds, aiming to avoid subjectivity. Specifically, this study mainly adopts the 2020 target values of relevant indicators as stated in the official documents of the 13th FYP as the threshold value. It then investigates whether the actual occurrence value in 2020 reached the expected goals, using this as a standard to evaluate the degree of sustainability. This method is not only simple and straightforward in operation but also authoritative in its reliance on the official documents of the 13th FYP. As a result, it eliminates subjective flaws in the threshold setting of socio-economic processes and enhances the reliability of the findings.

RESULTS

This study assesses the sustainability status in China's socio-economic boundaries. Thirteen representative indicators are selected to construct the Doughnut model, drawing on empirical research by Cole et al.[5], Dearing et al.[12], Hoornweg et al.[17], O'Neill et al.[6], and Fanning et al.[16] (Table 1). Detailed discussions on the criteria for selecting indicators and the methods used to set their corresponding thresholds are presented in Supplementary Information. Additionally, sources of data are provided.

Sustainability evaluation from the perspective of socio-economic deprivation

Figure 2 presents the sustainability evaluation results of the 13 socio-economic processes in China in 2020. Specifically, the indicators of *Employment* and *Income* both reach 100% and are classified within the "safe and just space." This indicates that the registered employment rate in urban areas across the 30 regions has exceeded 95%. Furthermore, the average annual disposable income surpasses China's 2020 national poverty line of RMB 10,000. These findings underscore the government's successful efforts in raising employment and eradicating poverty. In addition to direct payments, the government has invested in skills training and infrastructure development in impoverished areas, contributing to a reduction in the unemployment rate[21]. Consequently, a sustainable and resilient virtuous circle between income and employment has been established. However, it is important to note that China's youth unemployment, specifically the monthly surveyed urban unemployment rate for individuals aged 16–24, fluctuated between 12.5% and 16.8% throughout 2020[22]. Actually, the youth unemployment rate already surpassed 10% in 2018 and reached its peak of 21.3% in June 2023[22]. Therefore, except for the exacerbation of pandemic-induced strict social-distancing measures[23] and the regulatory crackdown on private companies operating in the internet, real estate, and education sectors[24], high youth unemployment is also attributed to structural issues stemming from rapid economic growth over the past few decades, such as the producer-biased and export-led growth model[25]. In this light, it is crucial to implement employment policies for the youth in order to maintain a low overall unemployment rate within acceptable thresholds. These policies should involve subsidizing small- and medium-sized businesses that hire college graduates and directing state-owned enterprises to create more job opportunities for entry-level positions.

Except for the border areas of Xinjiang, Inner Mongolia, and Qinghai, all regions have achieved sustainability in terms of higher education enrollment. However, owing to the lack of higher education institutions, they cannot compare with regions like Beijing and Tianjin, which boast abundant higher education resources and policy support. In particular, climate change

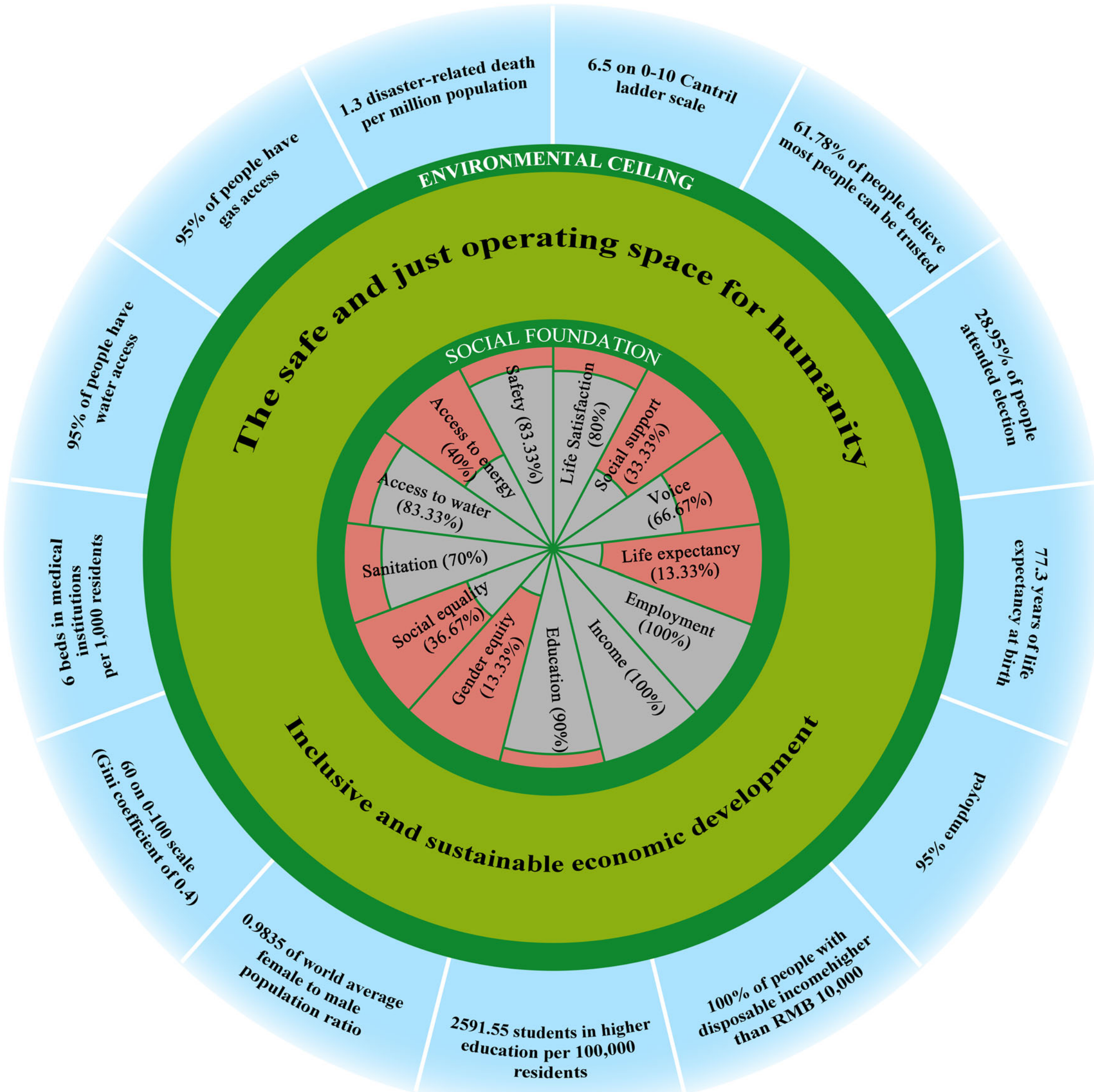

Fig. 2 Sustainability evaluation results of the 13 socio-economic processes in China for 2020. The gray wedge-shaped areas depict the sustainability status of each process in 2020, with proximity to 100% indicating a higher degree of sustainability. The green ring represents the "safe and just space," symbolizing the inclusive and sustainable development that humankind strives for. The fan-shaped red sector between the two signifies socio-economic deprivation, representing the unacceptable loss of human well-being. A larger gray area indicates a higher level of sustainability. The material outside the green ring represents the threshold for each process.

education is essential in enabling people to make informed decisions regarding adaptation strategies[26], which is worth promoting throughout society[27]. The five regions beyond the *Safety* threshold are all located in impoverished western areas that frequently experience severe geological and climate disasters, resulting in numerous disaster-related deaths. Natural disasters in China can have indirect, long-term effects on society and the economy. In the years following a disaster, the economic situation in the affected areas can improve significantly thanks to government investment. Over time, however, there is often a notable downturn caused by a decline in investment and mounting debt[28]. Therefore, local governments should maximize the opportunities for reconstruction to facilitate industrial upgrading, thereby minimizing losses caused by disasters.

Regions like Tianjin, Shandong, and Beijing, which have the highest level of *Life Satisfaction*, also exhibit a correspondingly high level of *Social Support*. Apart from Shaanxi, all regions with a trust degree above the threshold have achieved sustainable life satisfaction. Social trust, as the core of social capital, is considered crucial in promoting physical health (e.g., self-reported good health; see Lu et al.[29]) and psychological well-being (e.g., good personal relationships and higher social cohesion; see Sztompka[30]). In addition, six regions have life satisfaction values below the threshold. Among these, except for Jiangxi Province, which has the lowest income level in East China, the remaining regions are impoverished areas in the northwest (Shaanxi, Ningxia, and Xinjiang) and southwest China (Guangxi and Guizhou). This aligns with the findings of Awaworyi Churchill and Mishra[31], who argue that, in China, income has a greater impact on life satisfaction than social trust.

The severity of the deprivations of energy sources among Chinese residents is much greater than that of water. In 2020, natural gas accounted for only 8.4% of China's total primary energy consumption, significantly lower than the average global value of 24.72% (see Our World in Data[32]), despite the implementation of policies like the "coal-to-gas" transition some years ago[33,34]. Areas with gas supply popularizing rates above the threshold of 95% are all located on the eastern seaboard, reflecting a preferential supply strategy that prioritizes limited natural gas resources to economically developed areas, especially metropolitan cities like Beijing, Shanghai, and Tianjin. These cities have achieved a gas supply popularization rate of 100%. However, this policy preference exacerbates the energy divide between urban and rural areas, as well as between affluent and impoverished communities, leading to more severe energy poverty[35].

Metropolitan cities and heavily populated eastern coastal provinces face significant challenges in terms of inadequate sanitation facilities, due to their large population bases. Among these areas, Guangdong, the most economically developed province in China, has the lowest score. With a population exceeding 126 million, medical resources are mainly concentrated in the provincial capital of Guangzhou. This remarkably inequitable distribution of resources is also reflected in the *Social Equality* indicator. Guangdong is one of the most unequal regions in China in terms of income[36,37]. In 2020, the combined GDP of Shenzhen and Guangzhou accounted for nearly half of the province's total GDP. The nine cities comprising the Pearl River Delta alone account for ~80% of the province's economic output among all 21 cities. Shandong and Guizhou score the lowest and, thus, show the highest Gini coefficients. In Shandong, nine of the 16 cities had a per capita disposable income lower than the national average in 2020. By contrast, the per capita disposable income of urban residents in Guizhou is more than three times that of rural residents, making it the province with the largest urban–rural income gap in China. Despite China's economy experiencing continued growth during the COVID-19 pandemic in 2020, which reduced population-weighted inequality[38], the results show the wealth gap between the rich and the poor remains wide. This situation highlights the seriousness of the income disparity problem.

In 20 regions in China, the voting rate for villagers' or residents' committee elections exceeded the threshold of 28.95%. In China's most common form of political participation[39,40], Shanghai ranked first with a voting rate of 55.44%, thereby showcasing its exceptional grassroots political governance ability[41]. In addition, Shanghai boasts the highest life expectancy (i.e., 80.26 years), followed by the three developed regions of Beijing, Tianjin, and Zhejiang. This aligns with the findings of Wang and Ren[42], who highlighted a significant positive effect of per capita income on lifespan expectancy at birth. Therefore, the sustainability resilience of the relationship between high per capita disposable income and life expectancy in these four regions is revealed.

Equity holds fundamental importance in climate research as it can undermine collective action in addressing common challenges[43]. However, gender equity in China performs the worst, with only four regions surpassing the world average value. The impact of the one-child policy before 2016, coupled with the male-dominated loss of population in the northeast, has placed the three northeastern provinces in the top rankings in terms of sex ratio, with more women than men in Liaoning and Jilin. Guangdong had the largest gender gap, with a ratio of 100 males to 88 females, primarily due to a net population inflow of more men than women[44]. Over the past decade, gender equity in China has deteriorated due to decreasing educational attainment and job participation of women[45]. In addition to the new three-child policy to stimulate population growth[46], future strategies should ensure equal access to education and employment opportunities for women while encouraging men's full participation in caregiving[47].

Sustainability evaluation from the perspective of regional heterogeneity

Figure 3 illustrates the spatial distribution of sustainability status in China for 2020. None of the regions achieved all 13 thresholds. Among them, Shanghai performed the best by meeting 11 thresholds and falling short in *Social Support* and *Gender Equity*. This suggests a low level of trust among Shanghai residents and a significant gender imbalance. Trust levels are usually low in megacities, especially in Shanghai, an international metropolis with complex population structures, including local urban residents, migrants from all parts of China, and hundreds of thousands of foreigners[48]. The abundance of job opportunities in megacities attracts many migrants, most of whom are male, thus exacerbating the gender imbalance.

Three other municipalities (Beijing, Tianjin, and Chongqing), along with Shandong and Hebei, achieved sustainability in ten socio-economic thresholds. Similar to Shanghai, these five regions also exhibit significant gender imbalances, highlighting the widespread nature of this issue that needs urgent resolution. Moreover, Beijing lags behind in terms of grassroots political participation and the availability of hospital bed numbers relative to the local population. Tianjin and Hebei lack medical resources; in addition, the former has a considerable wealth gap, and the latter has a comparatively short life expectancy. Similar circumstances can be observed among the residents of Chongqing and Shandong, with Chongqing displaying lower levels of trust than Shandong. However, the gap between the rich and the poor is relatively small in Chongqing.

A total of 21 regions, making up the overwhelming majority of the sample at 70%, achieved socio-economic sustainability for seven to nine thresholds. Among them, the affluent areas along the eastern coast achieved sustainability in nine thresholds. Regions achieving eight thresholds were typically found in the central and western parts of China. Regions that met seven thresholds were distributed in underdeveloped frontier regions like the northeast and southwest, aligning with their perceived level of social and economic development. These regions should make greater efforts to improve social trust, extend life expectancy, eliminate gender discrimination, reduce income inequality, and alleviate energy poverty. The regions of Guizhou, Ningxia, and Xinjiang performed the worst, achieving sustainability in only five dimensions. They attained sustainability status solely in the employment rate, income level, and water supply thresholds.

In addition, as Fig. 3 shows, a clear divide is evident along the Hu Huanyong Line, representing a robust east–west division based on population density[49] and the relationship between human settlements and the natural environment (i.e., the man–land relationship) in China[50,51]. Specifically, all three regions with the lowest sustainability status (meeting five thresholds) are located west of the line, while the six regions with the highest sustainability status (achieving 10–11 thresholds) are situated east of the line. Moreover, all regions achieving sustainability for nine thresholds are located in the east, and among the regions meeting eight thresholds, only Gansu is located in the west. Among the eight regions attaining seven thresholds, only Inner Mongolia and Qinghai are in the west, while Sichuan lies between the east and the west. Overall, there is a clear trend, indicating a gradual increase in the degree of sustainable socio-economic development from west to east in China, with Xinjiang being the least developed and Shanghai being the most developed. The validity of the Hu Huanyong Line in dividing the spatial pattern of socio-economic sustainability status in China is confirmed, except when considering population density and the man–land nexus.

DISCUSSION

Resilience, which refers to the capacity of a system with alternative attractors to maintain a particular state when subjected to disturbances[52], is essential in facilitating a sustainable socio-economic transition and is fundamental to building a "safe and just space" framework[53]. Downing et al.[7] noted the need to

Fig. 3 The spatial pattern of socio-economic sustainability status of provincial-level China in 2020. This graph depicts the sustainability status in terms of the socio-economic processes based on the Doughnut in the 30 provinces, municipalities, and autonomous regions of mainland China. Different colors indicate varying levels of sustainability. Notably, the Hu Huanyong Line, running approximately at a 45-degree tilt from Heihe City in Heilongjiang Province in the northeast to Tengchong City in Yunnan Province in the southwest, divides China into two parts with distinctly different attributes.

incorporate resilience thinking into the "safe and just space" framework, as it is key to understanding the varying processes and their interactions at sub-global scales[7]. Despite the omission of resilience thinking in previous PB research, this study recognizes the significance of adopting a systematic approach to gain a better understanding of the interactions between the socio-economic processes as well as their resilient behaviors to climate changes under the COVID-19 impact.

In general, the findings reveal worsening climate change impacts for China in certain aspects, partly influenced by the pandemic. Evidence shows that greenhouse gas emissions have a significant impact on mortality rates due to the increased concentration of fine particulate matter[54,55]. This finding is particularly meaningful for China, where air pollution is responsible for nearly one million deaths annually[56]. Furthermore, deaths related to the pandemic[57] and extreme climate events such as heat waves[58], floods[59], and droughts[60] can also cause tens of thousands of excess deaths in China each year[61]. These findings are in line with the results that indicate life expectancy as the socio-economic process with the greatest deprivation, having the lowest value of 13.33%.

Similar levels of deprivation are observed in relation to gender imbalance. The COVID-19 pandemic has had a devastating impact on women[62]. According to a recent survey conducted by Peking University, 7.4% of Chinese women were unemployed, and 10% had dropped out of the labor market by November 2020, whereas the corresponding figures for men were only 2.4% and 5.7%, respectively[63]. The evidence further illustrates the essential role of gender equality in fostering a resilient economic recovery from the pandemic[64,65]. Moreover, a society with a wide gender gap usually lacks the resilience required to adapt to climate change: Shaped by local gendered ideologies and cultures, women are typically more vulnerable to the impacts of climate change than men[66], especially in developing countries[67]. As such, policy packages should be designed to integrate gender equality targets in order to build a climate-resilient society[68,69].

The COVID-19 pandemic and subsequent implementation of social-distancing and border-restriction policies exacerbated the inequalities[38,70] and contributed to the lack of trust among various socio-economic groups[71,72]. These factors reveal the interaction between the processes within the framework. Social inequality and lack of trust further undermine climate efforts by driving emissions-intensive consumption among the wealthy and eroding the social foundations of collective climate action[69,73]. In the context of China, inadequate social trust and the resulting social inequality often form a "vicious cycle" with climate change: Initial inequality and weaker social bonds of trust increase the vulnerability of socio-economically disadvantaged groups to the adverse effects of climate change, making them more susceptible to climate-related damages and reducing their ability to cope and recover. Consequently, this cycle leads to an increased lack of trust and further inequality[74,75]. Moreover, socio-economic inequality weakens social trust between different groups, diminishing people's willingness to make sacrifices and fight for the common climate challenges[69]. In practice, the implementation of climate policies, while aimed at adapting and mitigating climate hazards[76], often has unintended side effects such as poverty and socio-economic inequality. Unfortunately, these side effects are often overlooked or not adequately addressed by governments[77].

The implementation of anti-pandemic confinement measures changed the energy structure, with increased household energy consumption and reduced commercial and industrial demand, leading to an overall reduction in energy demand[78]. However, these changes have disproportionally affected certain societal groups in China and have had a negative impact on the climate. Essentially, energy access and climate mitigation are mutually-affected: Ensuring adequate and equal access to energy is essential for mitigating climate challenges[79], and well-designed climate mitigation schemes could lift millions of households out of energy poverty[80]. To reverse the current energy poverty situation in China, it is important to design a just portfolio of climate policies with a balanced mix of instruments to jointly combat climate change[80,81].

The "safe and just space" framework represents a shift in the development goal, moving away from solely focusing on GDP growth toward the co-development of a set of processes. This shift is in line with related theoretical frameworks such as "De-growth/A-growth"[82] and "Prosperity without Growth."[83] The core concept of this framework is maximizing welfare within boundaries, which is also in line with the traditional Chinese philosophy of "harmony between humans and nature" (*tian-ren-he-yi*)[84]. However, compared with the practice of DE in Amsterdam, where climate goals are put ahead of GDP[85,86], it is clear that there is a lag in theoretical and methodological advancements in other cities. Particularly in the post-pandemic era, there is a need to view cities as opportunities for socio-economic transitions and the construction of a climate-resilient society.

This study proposes two future research directions. Firstly, there is a need to improve resilience by integrating multiple socio-economic processes and analyzing their interaction mechanisms. In reality, these processes are interdependent, but because they are expressed in different units, it becomes challenging to represent them on an equal footing and compare them. Current solutions, such as converting units to a single scale or averaging different indicators into one index, are inadequate for capturing the many diverse facets of complex social-ecological systems[7]. Secondly, the "safe and just space" framework is based on a "top-down" global perspective and, therefore, faces the problem of "localization" when it is downscaled, requiring adjustments in indicator selection and threshold setting to account for local conditions. However, there is currently a lack of widely accepted methodological theories to regulate, guide, and identify rationality. As such, it is important to establish a resilient methodological system that is suitable for sustainability evaluation at multiple scales. This will help enhance the scientific foundation of the "safe and just space" framework.

METHODS

This section provides an overview of how we collect data, select indicators, and set the thresholds. A full discussion of indicator-specific methods for the socio-economic processes is presented in the Supplementary Information.

Establishing socio-economic boundaries through a downscaling approach

We select socio-economic indicators and set thresholds by referring to the works of Cole et al.[5], Dearing et al.[12], Hoornweg et al.[17], O'Neill et al.[6], and Fanning et al.[16], which operationalize the "safe and just space" framework at multiple scales. We adhere to two basic principles in selecting the indicators and setting the thresholds: Firstly, we use as many processes as possible to build a comprehensive socio-economic sphere, and second, we rely on reliable data from official documents and authoritative institutions. To ensure relevance to the current situation in China, the thresholds are set in alignment with the prevailing conditions. A final selection of 13 indicators is made, and the corresponding thresholds are determined.

Using the authoritative survey dataset, China Family Panel Studies (CFPS)[87], we estimate the three qualitative indicators of *Life Satisfaction, Social Support*, and *Voice* based on the three corresponding questions extracted from CFPS; the detailed estimation methods can be found in the Supplementary Information. Since qualitative data are difficult to measure directly from official documents, we rely on the nationwide reliable survey data, which is considered accurate and representative. After scaling the responses of *Life Satisfaction* from 0–10, we chose 6.5 as the threshold, following the approach of O'Neill et al.[6]. As for *Social Support* and *Voice*, we scale the negative and positive responses from 0/1 and calculate the percentage of positive responses for each province. The thresholds for these two indicators are identified by using social trust and voting data from the seventh wave of the World Values Survey (WVS, 2017–2020)[88], which is a rigorous and high-quality sub-global dataset. Therefore, the national standards from the WVS are downscaled to assess sub-national data from CFPS.

The definition criteria for four indicators (*Life Expectancy*, *Income*, *Education*, and *Access to Energy*) are downscaled based on the current situation in China. (1) The study uses overall life expectancy data instead of the "healthy life expectancy" data employed by O'Neill et al.[6]. We regard life expectancy as a more comprehensive process comprising people's living standards, lifestyle, and access to quality health services. The choice aligns with the study by Fanning et al.[16], who also used this data, and their threshold of 74 years is similar to the threshold of 77.3 years used in this study. (2) For *Income*, the World Bank standard of US$ 1.9 per day used by O'Neill et al.[6] is considered too low and not suitable for the current situation in China. Instead, this study adopts China's national poverty line in 2020 (i.e., disposable income of RMB 10,000, a higher standard than US$ 1.9 per day). (3) Unlike the studies of O'Neill et al.[6] and Fanning et al.[16], this study does not use the percentage of gross enrollment in secondary schools as an indicator for *Education*. Since enrollment rates for secondary schools in China are already very high, distinguishing regional differences becomes challenging and does not produce convincing results. Instead, student enrollment in higher education institutions is used to represent *Education*, as higher education resources in China are scarce and limited. (4) While Cole et al.[5], O'Neill et al.[6], and Fanning et al.[16] use population electricity access as a measure of *Access to Energy*, this approach is not applicable in China because the country solved the problem of electricity shortages in 2015. By comparison, natural gas as an important clean energy has significant development potential but shows obvious regional heterogeneity, making it suitable for measuring energy accessibility.

In contrast to the research conducted by O'Neill et al.[6] and Fanning et al.[16], this study excludes *Nutrition* and *Democratic Quality* as indicators and instead includes *Voice*, *Access to Water*, *Gender Equity*, and *Safety* because there is insufficient data on food nutrition and democratic quality in China. *Voice* data are sourced from CFPS. Considering the serious issue of water shortage in China, which has much lower per capita water resource possession than the global average, the inclusion of *Access to Water* aligns with the approach taken by Cole et al.[5] and Dearing et al.[12]. *Gender Equity* is included in this study in accordance with Hoornweg et al.[17] because gender equity remains a serious problem in China, where the male population greatly outnumbers the female population. This imbalance has implications for social stability and poses challenges in addressing aging issues. Hoornweg et al.[17] use homicide rates and other data to represent *Safety*. In present-day China, however, the homicide rate is low. By contrast, natural disasters pose a significant threat to humans. Therefore, we use the number of disaster-related deaths to estimate social safety.

On the whole, apart from the data sourced from CFPS for the first three qualitative indicators, the actual data for *Life Expectancy*, *Employment, Income, Education, Gender Equity, Sanitation, Access to Water, Access to Energy*, and *Safety* in 2020 are extracted from the 2021 statistical yearbooks for China. The thresholds for *Life Expectancy*, *Employment, Education, Sanitation*, and *Safety* are derived from the 2020 expected targets outlined in the national and sectorial official documents of the 13th FYP. This method of setting thresholds is both simple to operate and authoritative.

Reporting summary

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

DATA AVAILABILITY

The data used in this analysis are included in the Supplementary Information accompanying this article. The analysis incorporates data from multiple sources, mainly the 2021 statistical yearbooks for China (which report 2020 data) in different fields and the CFPS[87], which reports the first three indicators (i.e., *Life Satisfaction*, *Social Support*, and *Voice*). The rules for setting thresholds are mainly derived from the expected 2020 targets of the national and sectorial official documents of the 13th FYP (2016–2020). Therefore, they are authoritative, which addresses the problem of thresholds being set too subjectively. All the data used pertains to the year 2020.

CODE AVAILABILITY

Code can be accessed under reasonable request.

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The author declares no competing interests.

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