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RESEARCH ARTICLE

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Green growth as a pathway toward sustainable development: A systems thinking on the Qinghai-Tibet Plateau in China

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Abstract

Green growth gained traction as a global climate change strategy and pathway toward sustainable development. China's green growth has been on the rise since the turn of the century, yet it is little understood in the context of its provinces. Previous studies focus on ranking green growth across countries and regions, not on assessing individual provinces over time. This study employs systems thinking and constructs an index framework to assess the environmental, economic, and social dimensions of green growth as a pathway toward sustainable development in Qinghai on the Qinghai-Tibet Plateau. The study finds that green growth has steadily increased between 2000 and 2021 despite a volatile growth rate. The 10th–13th Five-Year Plans showed similar trends. Short-term green growth performance fluctuated in its dimensions and pillars, while long-term performance increased steadily. Qinghai is well-positioned to achieve sustainable development and build a circular economy. The study further discusses sustainable policy implications.

KEYWORDS
circular economy, green growth, index framework, Qinghai-Tibet Plateau, sustainable development, systems thinking

1 | INTRODUCTION

Green growth has emerged as a global policy for sustainable economies (Belmonte-Ureña et al., 2021; Herman, 2023; Lee, 2019). It pursues economic growth without imperiling natural resources and ecosystem services that societies depend on (OECD, 2011). More inclusive to the economy, environment, and social sustainability than growth driven by gross domestic product (GDP) (Sun et al., 2020), green growth is an integral approach to achieve sustainable development. At its core, green growth promotes decoupling between economy and greenhouse gas emissions by expanding green industry to foster sustainable production and consumption practices (UNIDO, 2011). The development of green industry and green finance for instance, is vital in the transition toward a modern, high-quality, low-carbon, and sustainable economy (Nyangchak, 2022).

The literature indicates that while growth-driven greenhouse gas emissions are rising rapidly in emerging nations, green growth effects and performances are less understood in the Global South (Herman, 2023). In its "new normal" era, China promoted green industrial policies and adjusted industrial structures to enhance nationwide green growth (OECD, 2017b). However, green growth varies across provinces in China (Zhao et al., 2023). Provinces in its western region experienced extensive growth, primarily dependent on natural resources, while the eastern region experienced intensive growth with more advanced technology and efficient infrastructure (Jin, 2020). Notably, green growth of provinces on the Qinghai-Tibet Plateau are seldom studied. The plateau has distinct trajectory of natural capital and economic growth than the rest of the country that has unique implications for sustainable development. The Qinghai-Tibet Plateau, China's ecological barrier, features the greatest tectonic landform and climate-sensitive glaciers. Extreme climate changes inhibited alpine meadow flora, exacerbated desertification, threatened food, water, and energy security, and substantially affected global climate energy and water cycles (Immerzeel et al., 2020; Zou et al., 2020). In addition, the rapidly increased industrialization, urbanization, mining, and agricultural production in the past two decades has added to the climate change effect on the regional ecosystem (Yu et al., 2022). Despite its extensive growth, Qinghai, a major portion of the plateau region, is economically far behind the rest of China. Expanding resource-based economy would be costly, uncompetitive, and an economic and ecological cul-de-sac owing to the region's ecological fragility.

In recent years, both national and provincial governments have made headway in safeguarding the delicate resources of the plateau and fostering green growth as pathways to achieve sustainable development. This progress is notably evident in the emergence of pilot industrial parks for circular economy, renewable energy, green and organic agriculture, destination for ecotourism, and other distinctive green industries. Since the mid-2000s, Qinghai has championed the circular economy, advocating for the reduction, reuse, and recycling of resources. From the 11th Five-Year Plan onwards, the province has emphasized green and low-carbon industries. While the sparsely populated Qinghai-Tibet Plateau has abundant resources, Qinghai has carefully sidestepped the potential pitfalls of a resource curse by tapping into renewable sources such as hydro, solar, and wind energy. The foundation for sustainable development has been firmly established through green industrial initiatives. Local governments are fervently endorsing these green industries, positioning the region to potentially become a prominent center for sustainable development. These advancements offer valuable insights that may be applicable at regional, national, and international levels. However, Qinghai's green growth-driven sustainable development remains critically under-researched. Global, regional, and national green growth indices, which serve as barometers for sustainable development, have been highlighted in studies such as the World Bank (2012), OECD (2023), Jha et al. (2018), and Acosta et al. (2019). Yet, the nuances of green growth in individual provinces remain largely unexplored. In this light, it is imperative to develop a holistic understanding of sustainable development by evaluating the progress and performance of green growth in specific provinces, utilizing sufficient time-series data.

The distinct natural capital and socio-economic features of the plateau merit an exploration of sustainable development in its own context. The Qinghai-Tibet Plateau stands out as a study area due to its unique regional, geographical, cultural, political, and economic characteristics within China. In this context, Qinghai functions as a distinct administrative and provincial entity, offering a well-defined and recognizable area for study. Moreover, Qinghai's capacity in conserving its natural resources, coupled with its ability to drive robust economic growth, positions it as a potential model for the rest of the nation and other developing countries. The insights garnered from this region can be referenced, at least, to the six provinces and regions of the Qinghai-Tibet Plateau, as well as to other regions and nations with comparable conditions.

This study assesses the performance and progress of green growth as a pathway for sustainable development in Qinghai from 2000 to 2021. The study also assesses the prospect scenarios of sustainable development based on green growth through 2040. A systems thinking approach is employed to evaluate the green growth dimensions of environmental sustainability, circular economy, and social inclusion, as well as their implications for sustainable policies. The approach helps to gain a holistic understanding of the complex nature of sustainable development by accounting for multiple dimensions, concepts, and sectors. Anchored in systems thinking, a green growth index framework was developed using a sequence of methods in composite indicators. Composite indices aggregate and measure economy-wide indicators to capture the environmentally and socially interrelated factors influencing sustainable development. Green growth has been recognized as a highly effective method for monitoring progress toward sustainable development (Alrasheedi et al., 2021). Indicators serve as instrumental tools for measuring the development of green growth (Lyytimäki et al., 2018). However, the index framework can be misleading in the absence of transparent indicator development methods (Acosta et al., 2021). Thus, best practices for developing composite indicators from OECD and JRC (2008), Acosta et al. (2019); Acosta, Mamiit, et al. (2020), and Becker et al. (2017, 2022) were used and adapted to normalize and aggregate relevant but diverse and complex indicators into a common unit for measurement and assessment.

This study contributes the existing literature on green growth practices and offers insights for enhancing green growth performance in emerging economies. Specifically, the contributions of this research can be summarized in four areas. First, green growth index in a regional province provides deeper insights in sustainable development with sufficient time-series data and contributes to previous studies that prioritize global and national perspectives over subnational and local ones. Second, province-specific performance and progress in sustainable development are assessed across time, adding to studies ranking green growth across countries, regions, and provinces. Third, Qinghai, as an economically insignificant and resource-rich province, demonstrates potential lessons that can be learned regionally, nationally, and globally by safeguarding natural capital and fostering green industries. Fourth, a system thinking is used to integrate social factors on a par with the economic and environmental dimensions, corresponding to the three pillars of sustainable development to build a sustainable and circular economy. This adds to previous studies that prioritize environment-economic issues over social ones.

2 | LITERATURE REVIEW

Sustainability of economic growth has always been contested. In the face of climate change, growth skeptics that trace back to the "Malthusian trap" and *Limits to Growth* are becoming more vehement. Call for green growth, degrowth, and circular economy is gaining ground (Belmonte-Ureña et al., 2021). There is a growing literature on green growth, circular economy, and degrowth contributing to the United Nations Sustainable Development Goals (Capasso et al., 2019; Hickel & Kallis, 2020). The emergence of green growth discourse demonstrates the ambition of nations exploring green economic opportunities in quest for sustainable development (Capasso et al., 2019). It allies with green development, low carbon, circular economy, green economy, and green industry to foster sustainable development (Hu, 2014; Jänicke, 2012; UNIDO, 2011). Like these concepts, green growth is a holistic and eclectic approach to sustainable development (Belmonte-Ureña et al., 2021). It is ecologically friendly as innovation in clean technology and substitution aims for absolute decoupling between economic growth and resource use (Hickel & Kallis, 2020).

Green growth is influenced by a myriad of mechanisms. Economic growth and advancements in green technology bolster green growth, whereas increased energy consumption and emissions detract from it (Hussain et al., 2022). Concurrently, the transfer of green technologies and sustainable innovations fuel green growth, which in turn has a favorable impact on economic growth (Fernandes et al., 2021). However, while economic growth and the adoption of renewable energy facilitate green growth, factors like trade openness and energy consumption hinder it (Tawiah et al., 2021). When Foreign Direct Investment (FDI) contribute to pollution, such as through road construction or natural resource extraction, green growth suffers, but it flourishes with investments in environmentally friendly imports, like solar panels, highlighting the importance of directing FDIs toward environmentally sustainable endeavors to further sustainable development (Chen et al., 2023; Tawiah et al., 2021). Moreover, addressing the environmental implications of corruption is paramount for green growth. Countries with prevalent corruption, regardless of their development stage, tend to struggle in fostering green growth (Tawiah et al., 2023). Consequently, curbing corruption is a crucial factor in achieving sustainable development. The effects of these factors vary between developed and developing nations, underscoring the need for different strategies at different stages of economic development to meet the Sustainable Development Goals.

Green growth, if pursued without necessary constraints, may inadequately address the intricate issues of inequality, capitalist accumulation, and competition, which underpin the market dynamics of capitalism (Parr, 2016). Some argue that green growth simply redefines “nature” to derive profit, perpetuating traditional capitalist growth paradigm (Lohmann, 2016). Consequently, the green growth concept may be inherently paradoxical, as it does not rigorously seek a transformative departure from conventional economic growth models (Ha & Byrne, 2019). A paradigmatic shift toward a renewed “green growth” perspective is imperative to revitalize discussions and to reshape the prevailing narrative on climate change and green growth (Zhang, 2014). The green growth paradigm possesses both theoretical and empirical limitations, failing to deliver its anticipated outcomes, and the need to reassert societal oversight over economic activities, and exploration of alternatives should be underscored (Mathai et al., 2018).

As absolute decoupling from carbon emissions at a global scale is unlikely to be achieved in time to avert global warming over 1.5 or 2°C, alternatives are imperative (Hickel & Kallis, 2020). In this context, the notion of degrowth has evolved as a radical analysis to reject all forms of growth (Kallis et al., 2020; Liegey et al., 2020). Degrowth holds that slower economic growth makes it manageable to reduce emissions as growth-based production of renewable energy increases total energy consumption (Mastini et al., 2021). In projected scenarios, green growth significantly reduces greenhouse gas emissions but increases income inequality and unemployment, whereas degrowth reduces emissions, inequality, consumption, and exports with a bigger public deficit (D'Alessandro et al., 2020).

Despite facing pushback, green growth embodies the rapid growth of green sectors and the “de-growth” of less efficient sectors, both driven by green investments and rapid green innovation toward sustainable development (Jänicke, 2012). The proliferation of green sectors and finances directly aid in mitigating the greenhouse effect (Zhao et al., 2023). Although short-term environmental regulation can be expensive, the rationale for green growth becomes increasingly persuasive over the long term (Jacobs, 2013). While emerging economies require further growth, developed nations can afford to moderate theirs. Beyond a certain threshold, growth does not necessarily improve human well-being and affluent countries might thrive without prioritizing growth, opting instead to replace it with sustainability (Hickel et al., 2022; Jackson, 2016). Beyond environmental considerations, unrestrained growth in wealthier nations can also challenge quality of life, happiness, and health (Mathai et al., 2018). Transitioning from a fossil fuel-centric economy to a sustainable one is complex, necessitating structural economic shifts that will inevitably produce both beneficiaries and those adversely affected (Jacobs, 2013). Notwithstanding the debates around growth, green growth, and degrowth, the realization of sustainable, regenerative, equitable, and circular economies remains both feasible and imperative (Hickel et al., 2022; Jackson, 2016; Stoknes, 2021).

In China, green growth has been on the rise, bolstered by the national vision of ecological civilization and sustainable development (Lin & Zhou, 2022; SCIO, 2023; Zhang, 2015, 2023). China knows that the fossil fueled economic growth model cannot support its massive industrialization as its demands rise (Mathews, 2014; Zhang, 2015, 2023). A greener model is necessary, and China, by forging a green industrial revolution, envisions a sustainable development alternative to the fossil fuel-based economy (Nyangchak, 2022). This revolution is a greening process that begins in strategic productions of certain sectors and diffuses throughout the industrial production system, transforming into a green growth system (Hu, 2014; Mathews, 2014). As the largest greenhouse gases emitter since 2005, it has built massive renewable energy technology, resource-efficient industrial models, and increased green growth efficiency in manufacturing sectors (Mathews, 2014, 2017; Qu et al., 2017; Wang & Yan, 2022). China's green growth is attributable to a range of factors, with environmental regulatory policies, particularly in the field of renewable energy development, standing out prominently (Zhao, Mahendru, et al., 2022). Furthermore, the digital economy plays a significant role in driving green growth (Wang et al., 2022). Specifically, digital technology stands as a pivotal driver behind urban green growth, underscoring China's strategy for high-quality development (Liu et al., 2022). In a similar vein, green trade and green energy are instrumental in bolstering China's green growth trajectory (Li et al., 2022).

Today, China has emerged as a pioneer in green growth, making significant investments in green industries to revitalize its energy-intensive sectors (Chen et al., 2017). Meanwhile, regional disparities persist. The northeastern and eastern regions of China have witnessed pronounced green growth, largely fueled by innovative initiatives, while provinces such as Qinghai in the western region have trailed behind (Zhao, Ma, et al., 2022). However, green growth has demonstrated efficacy in curtailing CO_2 emissions primarily in the central and western regions while the eastern and central regions appear to be more receptive to green finance as a mechanism to promote carbon reduction (Zhao et al., 2023).

While green growth is gaining ground, theoretically and practically, as vital pathways toward sustainable development, its measurement also makes headway. In the last decade, green growth indices, which use composite indices to assess, rank, and compare complex multidimensional concepts that are not immediately measurable, have gained popularity (OECD & JRC, 2008; Becker et al., 2017, 2022). Prominent international organizations developed a plethora of green growth index as sustainable development indicators (Acosta et al., 2019; AfDB, 2014; GGKP, 2013; Jha et al., 2018; OECD, 2017a, 2023; PAGE, 2017; Tamanini & Valenciano, 2016; UNESCAP, 2013; World Bank, 2012). Others introduced a green growth-ranking system for countries based on their capacity to competitively export intricate green products (Mealy & Teytelboym, 2022); gauged the green growth productivity gap utilizing the Sustainable Society Index (Luukkanen et al., 2019); devised a ranking system and evaluation methodology for green growth indicators in the manufacturing sector by integrating the Combined Compromise Solution (Alrasheedi et al., 2021); monitored the transition toward green growth in developing countries using a set of distinct indicators (Kararach et al., 2018); and evaluated policy-relevant key indicators crucial to the advancement of green growth (Lyytimäki et al., 2018). These indicators mainly evaluate green growth at the global, regional, and national levels, less on subnational levels. Meanwhile, a continuing discourse attempt to develop a common green growth index across countries (Acosta et al., 2021; GGKP, 2013; Narloch et al., 2016). However, owing to diverse conditions and data availability of different countries, developing a uniform global green growth index with sufficient data has proven formidable. Assessing green growth practices theoretically remains a challenge due to the absence of a proper evaluation framework (Guo et al., 2018). In addition, green growth has evolved with diverse definitions and subcomponents prioritized by different institutions (Acosta et al., 2021).

In China, several sustainable development indicators, grounded in composite indices, are employed to rank, score, and assess an array of factors pertaining to green growth across all provinces (CCIEE, 2022; Guan & Han, 2019; Han, 2021; Yi, 2020). Additional research has formulated a holistic evaluation system for green growth using the plan-do-check-action cycle method (Guo et al., 2018); investigated provincial green growth levels using diverse indicators, shedding light on the relationship between green growth, green trade, and green energy (Li et al., 2022); and analyzed the impact of labor market distortions on inclusive green growth by exploring factors of economic growth, social equity and welfare, and environmental sustainability (Li et al., 2023). While these indicators are instrumental for national comparisons, yielding macro-level policy insights, they often obscure the intricacies of green growth performance and progress within the unique context of individual provinces. Given the stark disparities in economic, social, cultural, and environmental aspects across regional provinces, it is imperative that studies are focused to account for the unique context of each province.

3 | METHODS

3.1 | Conceptual framework

Systems thinking is a holistic approach to complex and interconnected issues (Arnold & Wade, 2015; Voulvoulis et al., 2022). It elucidates the intricate web of interrelations that underlie sustainable development (Voulvoulis et al., 2022). The globalized and complex world requires systems thinking due to unprecedented interdependency. Grounded in the green growth theory and systems thinking, this study constructed a green growth index framework as a sustainable development indicator (GGGI, 2017; OECD, 2011; Sun et al., 2020; Voulvoulis et al., 2022). As green growth is a multidimensional concept with diverse subcomponents, the index framework is useful for aggregating and measuring complex factors that are equally important independent of measurement units. The conceptual framework for this index framework is primarily based on the models by Acosta et al. (2019, 2021), OECD (2017a, 2023), Jha et al. (2018), Guan and Han (2019), Han (2021), and CCIEE (2022).

The index framework integrates environmental, economic, and social dimensions of sustainable development to foster environmental sustainability, circular economy, and social inclusion as objectives of green growth. Each dimension has three pillars or categories that are objectives in themselves. At its pillar level, environmental sustainability aspires for greater natural capital, less environmental pressure, and less resource use. The aim of the circular economy is increased economic growth, green investment, and resource efficiency. The social inclusion aims to expand access to basic services, social security, and social equity. Each of these nine pillars has 10 distinct but associated indicators, totaling 90. As such, multidimensionality of the green growth is reflected in its dimensions, pillars, and indicators. Figure 1 demonstrates the green growth index framework where all indicators are aggregated into a single index score and each dimension and pillar has its own index score. The index scores reveal the performance and progress for a given year.

Table A1 in appendix lists all indicators and pillars under the environmental sustainability, circular economy, and social inclusion dimensions and their relationship to green growth index.

3.2 | Data

Time-series data from 2000 to 2021 were collected from these sources: China Statistical Yearbook, Qinghai Statistical Yearbook, China Environment Statistical Yearbook, China Energy Statistical

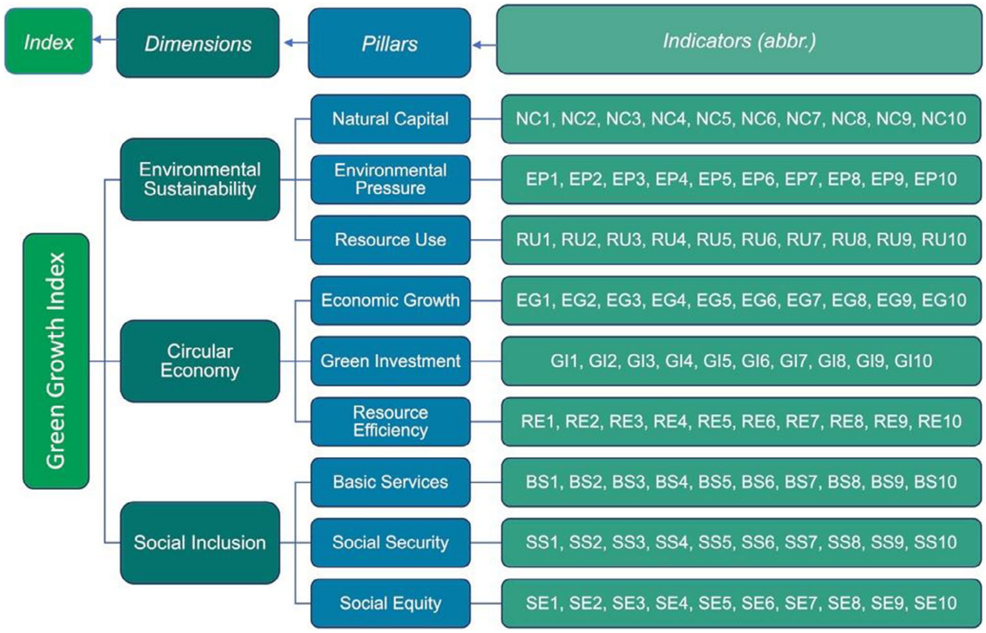

FIGURE 1 Green growth index framework.

Yearbook, China Forestry and Grassland Statistical Yearbook, and CEADs (2020). Baseline data is from 2000 since half the relevant indicator values before this year are missing.

3.3 | Indicator selection

Criteria for data selection were from existing literature (Acosta et al., 2019, 2021; Acosta, Maharjan, et al., 2020; Guan & Han, 2019; Han, 2021; Jha et al., 2018; OECD, 2017a, 2023). This study has equally selected 10 indicators for each green growth pillar. Table 1 shows a set of criteria applied during the selection process to be consistent with the purpose of developing the index framework.

3.4 | Data imputation

Common methods addressing missing data include mean imputation, single imputation, multiple imputation, linear interpolation, maximum likelihood, and regression analysis; nevertheless, they are based on implausible assumptions and some of them underestimate variance, correlation, and standard errors (Acosta et al., 2021; Acosta, Maharjan, et al., 2020; He, 2010; OECD & JRC, 2008). Removing missing data is the simplest method while it may reduce sample size (Kang, 2013; OECD & JRC, 2008). ADB Inclusive Green Growth Index and Global Green Growth Index excluded indicators with values missing more than 25% (Acosta et al., 2021; Jha et al., 2018). This study omitted indicators with missing values for more than three consecutive years, except for one indicator highly relevant to the study. Comparable, relevant, and compensable indicators replaced omitted ones. This study employed the simplest method by imputing data from the closest year, as applied by the Happy Planet Index of the New Economics Foundation and the Global Green Growth Index (Acosta et al., 2021).

TABLE 1 Criteria and definitions.

Criteria	Detail
(1) Relevance	Data interrelated to the dimensions and pillars of the green growth index guided by the conceptual framework
(2) Accessibility	Data in published statistics
(3) Availability	Data between 2000 and 2021
(4) Association	Data related to each other within indicator pillars
(5) Compensability	Indicators within indicator pillars

Two data imputations used closest three-year trend estimations. Table B1 shows, in 2000–2021 dataset, 30 values (1.52%) out of 1980 values were imputed. Table B2 shows, in Five-Year Plans dataset, 15 values (0.83%) out of 1800 values were imputed.

3.5 | Outlier treatment

Outliers need to be treated as they distort statistical properties, normalized values, the covariance structure of the indicator, and the correlation between indicators (Acosta et al., 2021; OECD & JRC, 2008). Outliers are identified using boxplot, as demonstrated in Figure 2, to visualize the distribution of indicator values. Based on data distribution, winsorization is used, as applied by Acosta et al. (2021), to reassign and cap outlying values at the next highest or lowest threshold value of fences, depending on their level in a boxplot. However, this approach reduces outliers to the same threshold value at the upper or lower bounds, eliminating their real value that is higher/lower than the dataset. This study capped outliers slightly above/below the fence threshold values in boxplot to account for their real values without affecting data distribution. High outliers are capped at +0.05 over the upper fence threshold value and low outliers at −0.05 over the lower fence. Second and third outliers in the same indicator are capped at 0.01 and 0.02, respectively. When these capping values affect the shape of data distribution, they are further decreased to 0.005, 0.001, and 0.002. Three indicators used this latter method. Table C1 shows 23 outliers in 2000–2021 dataset, while Table C2 shows 21 outliers in 2001–2020 dataset adjusted for FYP periods.

3.6 | Data validation

Pearson's correlation coefficient was used to assess the correlation between indicators within each pillar. Its coefficient values range from −1 to +1, indicating a linear negative to a linear positive relationship, while 0 indicates no linear relationship. The absolute values or linearity of the coefficients are more important for the green growth index than their signs or positive/negative relationships (Acosta et al., 2019). The correlation analysis helped detect redundant indicators, levels of association between indicators within each pillar, and the significance level of the indicators. As interpretation of coefficient values varies, this study adjusted the coefficient value ranges set by Acosta et al. (2019). The levels of significance range among 10%, 5%, and 1%. The *p*-value indicates correlation coefficient significance. *p*-Value <.01 represents 99% confidence or 1% significance. *p*-Value .01–.05 represents 95% confidence or 5% significance. *p*-Value .05–.10 represents 90% confidence or 10% significance. Table 2 summarizes the percentage of correlation coefficients with significance levels of 10%, 5%, and 1%. These values are summarized from the findings of correlation analysis presented in Table D1.

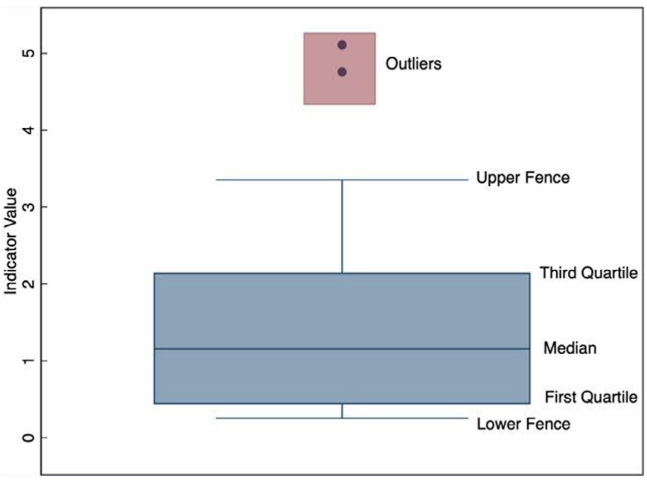

FIGURE 2 Boxplot for the labor productivity of the primary sector indicator with outliers.

Majority of the indicators fall within the range of ideal coefficient values, except for 37% values in the circular economy and 27% values in the social inclusion in the high range. These high correlations indicate high association and significance levels of coefficients, not redundancy. The correlation analysis validates the model since the coefficient values are within the interpreted coefficient range.

The relationship between dimensions and pillars are further analyzed in scatterplots to validate the indicators. Figure 3 shows strong linear relationship between the scores of pillars and dimensions. Most scores cluster around the mean represented by the fitted value lines and within 95% confidence intervals represented by the gray area.

3.7 | Data normalization

Data normalization is the most essential technique in developing a composite index for preparing data and enhancing the comparability of multidimensional concepts and indicators (Acosta et al., 2021; Han, 2021; OECD & JRC, 2008). Normalization, using min–max rescaling, scale indicators with diverse units and ensure data consistency. Normalization equation rescales variables to 0–1 based on a minimum and maximum:

$$X^i_{\text{norm}} = \frac{x_i - X_{\min}}{X_{\max} - X_{\min.}}$$

where X^i_{norm} = normalized *i*th indicator.

$$X = (X_1, X_2 \ldots X_n)$$

Introducing lower bound *a* and upper bound *b* into Equation (1) reduces extreme values and partially corrects for outliers (Acosta et al., 2021). This study replaces the minimum bound 0 with 1 and maximum bound 1 with 100 to avoid misrepresenting low green growth performance by a lack of green growth performance with 0. Adjusted equation:

$$X^i_{\text{norm}} = a + \left(\frac{x_i - X_{\min}}{X_{\max} - X_{\min}}\right)(b - a)$$

where a = lower bound; b = upper bound.

An inversed equation addresses indicators with a negative link to green growth:

TABLE 2 Summary of correlation coefficient and statistical significance in percentage.

Coefficient range	Environmental sustainability	Circular economy	Social inclusion
High (less than 1)	7	37	27
Ideal (0.89–0.1)	93	63	73
Low (less than 0.1)	0	0	0

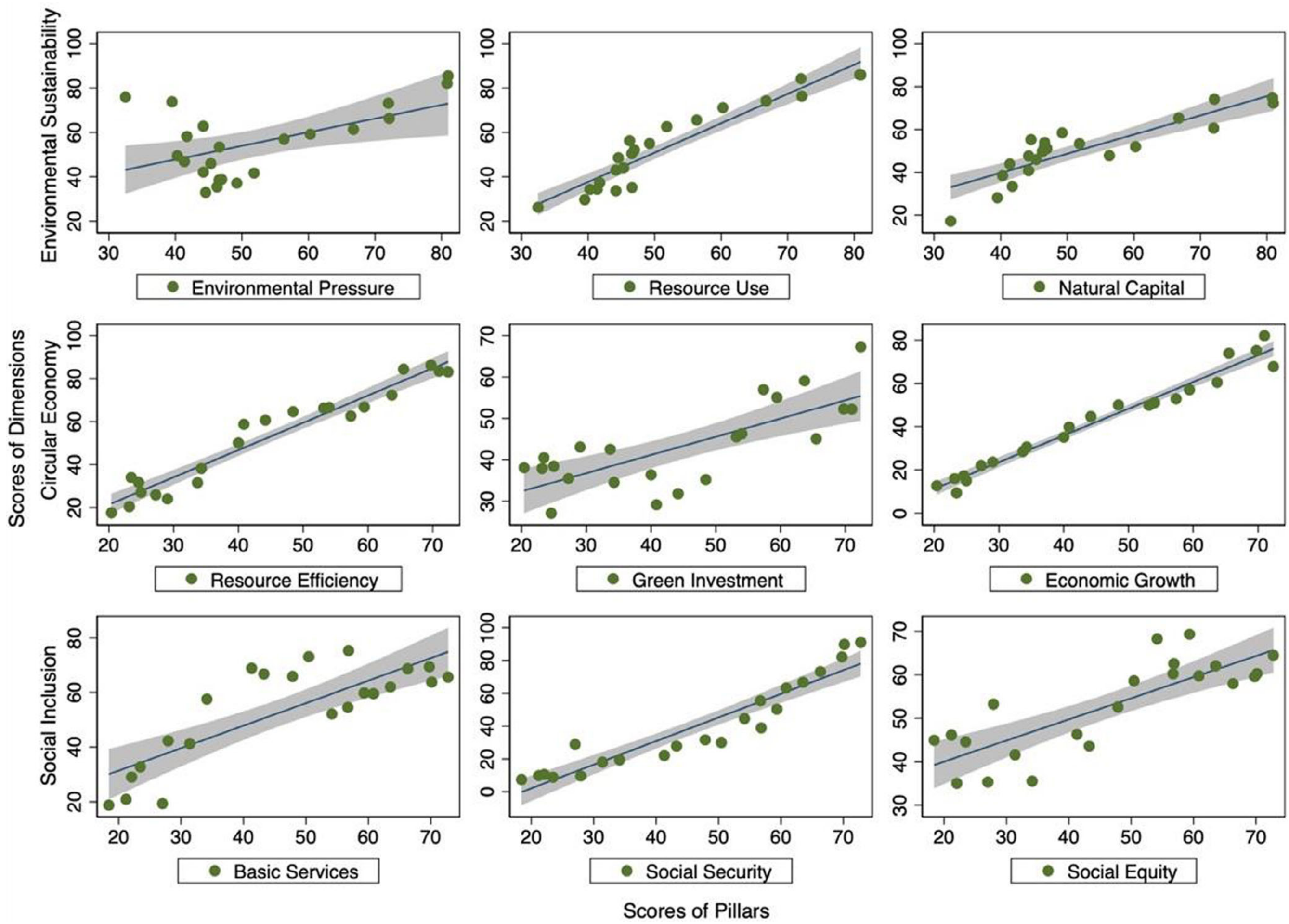

FIGURE 3 Scatters of pillars and dimensions with mean line and 95% confidence interval.

$$X^i_{\text{norm}} = a + \left(\frac{x_i - X_{\max}}{X_{\min} - X_{\max}}\right)(b - a)$$

where a = lower bound; b = upper bound.

3.8 | Aggregation and weights

Green growth is measured by aggregating multidimensional indicators into a single inclusive value. Linear aggregation is used for full compensability and geometric aggregation is used for partial compensability (Acosta et al., 2021; OECD & JRC, 2008). Each indicator pillar was compensated by linearly aggregating the normalized indicators. The indicator pillars were geometrically aggregated to partially compensate between dimensions. Geometric aggregation was applied again at the dimension level to generate the final green growth index scores.

Composite indices are often weighted equally (Acosta et al., 2021; Gan et al., 2017; OECD & JRC, 2008). This study also uses equal weighting since each green growth pillar and dimension has equal indicators.

3.9 | Robustness check

As assumptions must be made in developing the index framework, evaluating model confidence is an essential method. Sensitivity and uncertainty analysis determine robustness of the methods and improve construction transparency (Acosta et al., 2021; OECD & JRC, 2008). The uncertainty analysis used 10,000 Monte Carlo simulations to evaluate the output effects of uncertainty on changing aggregation method assumptions to linear in one and geometric in another, capping outliers by upper/lower fences with (±) 0.05/0.005% threshold values, and equal weighting and unweighting in developing the index framework. Figure 4a shows the result of uncertainty analysis of original and simulated mean green growth index. The method assumptions have negligible uncertainty. Figure 5 shows effect variance of each method. Geometric aggregation has the largest effect, followed by linear aggregation, and other methods have minor variations. The application of both geometric and linear aggregations minimized their individual variance effect. Sensitivity analysis using 10,000 Monte Carlo simulations has evaluated changes in indicator input variables by tempering them with intervals of (±) 20%–100% relative to baseline values. Figure 4b shows that

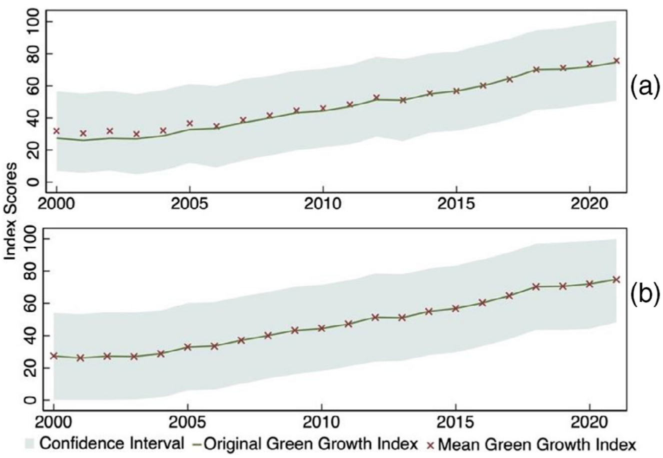

FIGURE 4 Uncertainty analysis (a) and sensitivity analysis (b) with 95% confidence interval.

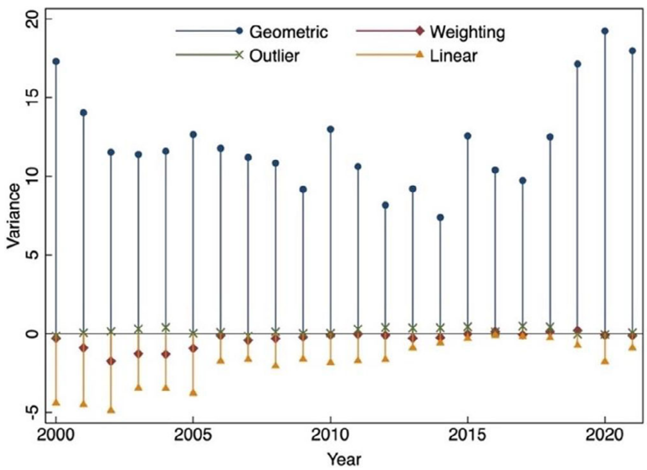

FIGURE 5 Variance of effect by method assumptions.

sensitivity of input assumptions is minimal when comparing original and simulated mean green growth index.

4 | RESULTS AND DISCUSSION

4.1 | Sustainable development at national level versus provincial level

Green growth, as a holistic measure of progress toward sustainable development within the framework of systems thinking, encapsulates the intricate interplay of social, economic, and environmental dimensions (Alrasheedi et al., 2021; Voulvoulis et al., 2022). While many prevalent green growth indicators predominantly concentrate on global and national perspectives (Acosta et al., 2019; AfDB, 2014; Jha et al., 2018; OECD, 2023; World Bank, 2012), sustainable development indicators through green growth and green development in China yield divergent results. Nationally, the China Sustainable Development Indicator ranked Qinghai 25th out of 30 provinces (CCIEE, 2022), while

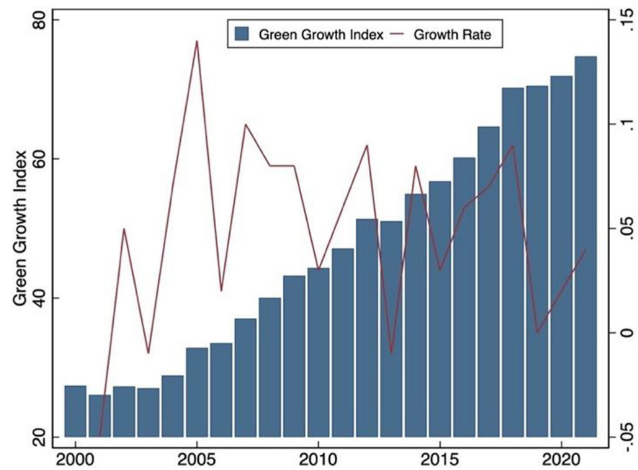

FIGURE 6 Green growth index and growth rate.

the China Green Development Index ranked Qinghai 27th (Guan & Han, 2019). Qinghai's rich natural capital boosts its environmental carrying capacity but scores low on economic and investment dimensions. After a year, the China Low Carbon Development Index, with slightly different dimensions, placed Qinghai 13th out of 30 provinces, ranking first in natural capital and fifth in green growth policies and social wellbeing but far behind on economic growth and resource use and efficiency (Han, 2021). Despite their striking discrepancies in ranking owing to different structure and components, both studies largely share identical indicators and corroborate a pattern of strong natural capital and weak economic growth of Qinghai relative to the rest of the country. National index rankings may provide a broader overview of each province, but they cannot offer deeper insights into each province. Time-series data analyses of specific provinces give insights into past performance and progress in the province's unique setting.

Nationally, most high-performing provinces on green development index are concentrated in eastern regions with high growth and population density, whereas low-performing provinces are in western regions striving to move away from resource-based economy (Han, 2021). Qinghai is economically dwarfed by other provinces as its nominal GDP and income per capita rank 30th and 27th, respectively, out of 31 provinces (NBSC, 2022). The western region, particularly Qinghai, performs poorly in green growth compared with rest of the country (Zhao, Ma, et al., 2022). However, when this national picture is amplified on Qinghai, there is a high performance of both extensive growth and green growth. Qinghai has experienced significant growth since the Western Development Program in 2000. The GDP per capita of Qinghai grew 11-fold from 5138 RMB in 2000 to 56,398 RMB in 2021 at 12% average annual growth (QSB, 2022). This period has been marked by fast infrastructure expansion, urbanization, and industrialization with unforeseen environmental and social effects. Meanwhile, the economic growth of Qinghai since 2000 has been highly correlated with a shift in industrial structure and a persistent increase in green growth. Agriculture, manufacturing, and services make up 10%, 40%, and 50% of the industrial structures, respectively (QSB, 2022). Figure 6 indicates that the performance of green growth was lowest between 2000 and 2003 but has progressed significantly since 2004 and almost tripled by 2021. Importantly, Qinghai's carbon emissions peaked as early as in 2016 (Guan et al., 2021; Shan et al., 2020) or 2018, 14–12 years earlier than the national target, and it is expected to attain net zero carbon emissions by 2037, whereas the national target is 2060 (Zhang, 2022). These trends demonstrate that Qinghai is experiencing high green growth, concurrently with decreasing carbon emissions and increasing economic growth. This aligns with the literature that robust economic growth contributes to enhanced green growth (Hussain et al., 2022; Tawiah et al., 2021). Additionally, Qinghai has a distinct trajectory that contrasts with the national growth of increasing fossil fuel production and green growth (Mathews, 2014, 2019).

4.2 | Performance and progress of green growth dimensions and pillars

The green growth index has three equally weighted dimensions. Figure 7a indicates that environmental sustainability and social inclusion mostly outscored circular economy. All of them had an impact during the Covid-19 pandemic, salient in their subcomponents, although they recovered quickly by 2021. Since 2000, the environmental sustainability has outperformed the other two dimensions, except for social inclusion between 2010 and 2016. From 2017 to 2021, environmental sustainability outperformed the other two dimensions again, with circular economy performing marginally better in 2018. It scored 81 in 2021, whereas circular economy and social inclusion scored 71 and 73. Overall, environmental sustainability outperformed the green growth index, apart from 2011 to 2015. Since 2001, the circular economy dimension has also risen continuously. After a little decline in 2019 and 2020, it rebounded to pre-pandemic levels in 2021 and surpassed the other two dimensions several times. Qinghai's commendable achievements in environmental sustainability and the circular economy stem from its commitment to preserving its abundant natural capital and investing in green industries, notably renewable energy. This observation aligns with the literature indicating that renewable energy fosters green growth, whereas excessive energy consumption and emissions hinder it (Hussain et al., 2022; Tawiah et al., 2021; Zhao, Ma, et al., 2022). Finally, social inclusion dimension declined from 2000 to 2002, but has risen consistently since 2003. It exceeded the circular economy from 2005–2007, 2009–2014, 2016 and 2019–2021. Overall, green growth has risen in all three dimensions.

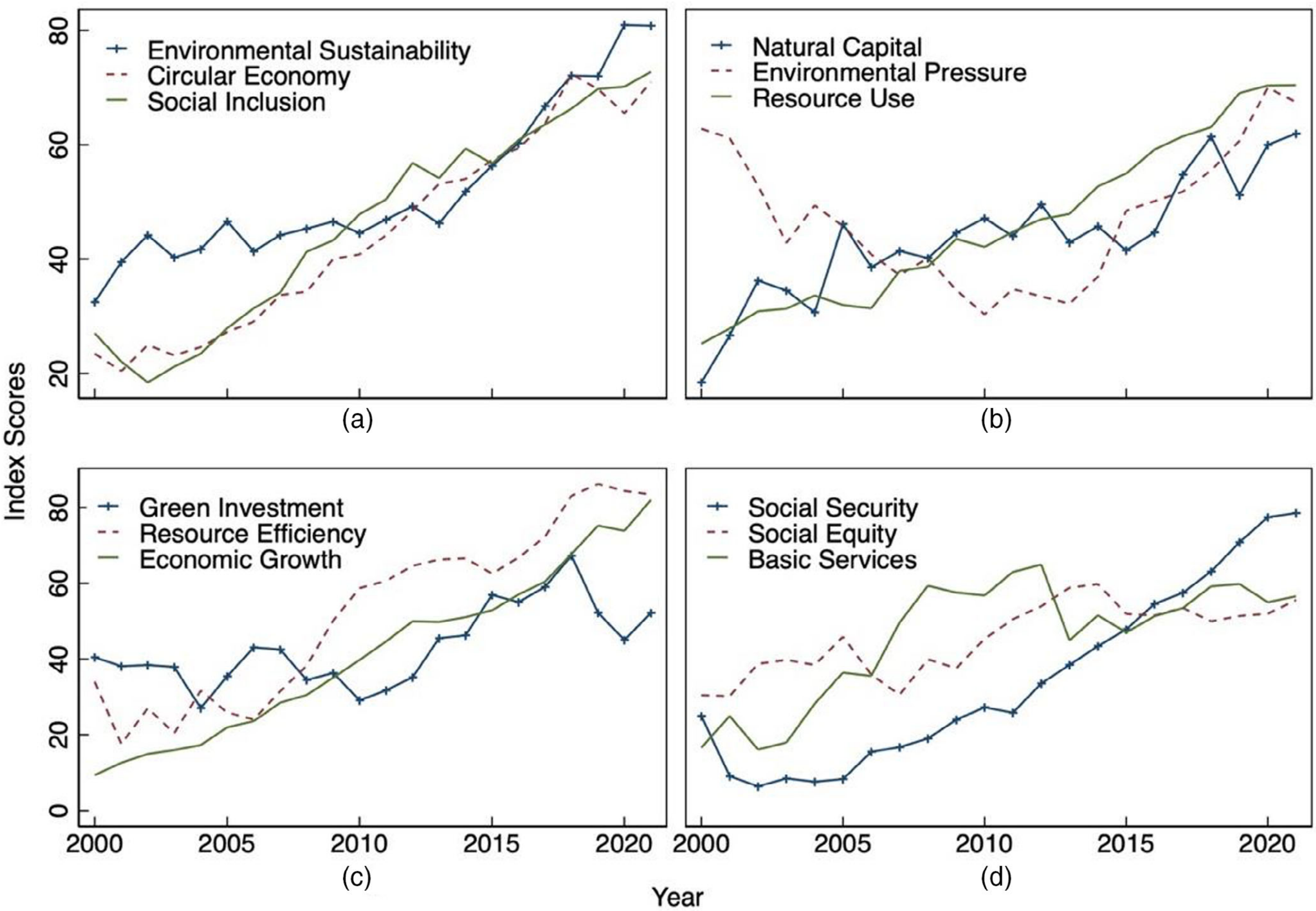

FIGURE 7 (a-d) Performance of green growth dimensions and pillars from 2000 to 2021.

Figure 7b shows the performance of three pillars under the environmental sustainability dimension. Green growth performance in natural capital is dynamic and continuous. It scored 17 in 2000 and 75 in 2021, with four low and six high performances. Due to limited investment and incapacity to transform natural resources into economic drivers, many natural capital-rich provinces fare less than others with even less natural capital (Han, 2021). Despite its struggles to divorce off natural resources, Qinghai's rich natural capital has contributed to the green growth index. Green growth in environmental pressure scored 76 in 2000, 33 in 2010, 86 in 2020, and 82 in 2021. This trend reflects the environmental effect of rapid economic growth in Qinghai over the last two decades and the efficacy of its green industrial policies since the 2010s. Among the three pillars, green growth in resource use has been the most consistent, except for 2005 and 2006. It scored 26 in 2000 and 86 in 2021, highest of all three pillars. In 2020 and 2021, the Covid-19 pandemic slowed the performance of three pillars.

Figure 7c depicts the green growth index of three pillars under circular economy dimension. The steady economic growth of Qinghai had a hitch during the Covid-19 pandemic. It has rapidly recovered in 2021 to a score of 82, exceeding the circular economy index of 71. As economic growth is closely associated with the government, government investment, and support results in greater green growth (Han, 2021). Government investments in innovation and renewable energy have catalyzed green growth. This reaffirms the established understanding that advancements in innovation and green technology lead to enhanced green growth, which subsequently bolsters economic growth (Fernandes et al., 2021; Hussain et al., 2022). Green investment in the circular economy has been volatile until 2010. It scored 27 in 2004, 29 in 2010, and 67 in 2018. It dropped sharply in 2019 and 2020 due to the Covid-19 pandemic before recovering to 52 in 2021. This swift rebound is a credible positive sign of green investment and green growth in the post-pandemic period. Resource efficiency was the best-performer among the three pillars. It scored 38 in 2008 and 84 in 2021. It grappled with volatility between 2000 and 2008, but it made significant progress that left the other two pillars well behind, except for a new low score of 63 in 2015, which is still higher than the other two. It scored 84 in 2021, placing it closer to but above the economic growth pillar. Between 2000 and 2021, resource efficiency has performed markedly, and economic growth has performed steadily despite green investment fluctuations.

Some green growth studies overlook social dimension (Nyangchak, 2022; Tamanini & Valenciano, 2016). The emergence of inclusive green growth, inclusive growth, and inclusive development (Jha et al., 2018; Narloch et al., 2016; Rauniyar & Kanbur, 2010; Sun et al., 2020; World Bank, 2012) highlights the absence of social dimension in previous studies addressing sustainable development. This research incorporated social factor into the green growth index on a par with the other two dimensions. Figure 7d shows the progress and performance of three social inclusion pillars. Basic services scored 19 in 2000 and 66 in 2021, with volatility. It outperformed social equity and social security between 2006 and 2012 and outperformed social security between 2001 and 2015. However, its low points were in 2002, 2006, and 2010, with a sharp drop in 2013 and a slow subsequent rise. In contrast, social security, the highest-scoring pillar in all dimensions, scored 29 in 2000 and 91 in 2021. However, this phenomenal performance declined first in 2001 and stagnated until 2005. After a little blip in 2011, it performed steadily until 2021. In 2000, social equity scored 35; in 2021, 64. This journey has been marked by a high score in 2005, a decline in 2007, and a peak score of 69 in 2014. It then decreased to a score of 60 in 2015, plateaued until 2020, and then rose to 64 by 2021.

4.3 | Green growth performance and progress during the 5-year plans

The green growth index has consistently improved over the previous four Five-Year Plan (FYP) periods. The green growth index was 28 for the 10th FYP (2001–2005) and 70 for the 13 (2016–2020). However, the performance of the three dimensions varied as shown in Figure 8a. Environmental sustainability outperformed the other two dimensions by a wider margin in the 10th, 11th, 13th periods, except for a lower performance in the 12th FYP. Circular economy and social inclusion dimensions showed a similar trend with modest variances between FYPs. Each of the two dimensions outperformed the other twice. All dimensions performed remarkedly during the four FYP periods.

In each dimension, the performance varies across pillars. Figure 8b illustrates that natural capital in the environmental sustainability dimension performed well consistently until the 11th FYP period. It then slowed in the 12th FYP and underperformed in the 13th. The green growth of environmental pressure began with a score of 63, higher than the dimension score, and declined to 43 in the 11th and 45 in the 12th FYP. It returned to a score of 71 at the end of the 13th FYP. The performance of resource use is comparable to that of natural capital, except for it starting with the lowest score of 33 in the 10th FYP period and ranking second in the 11th FYP. It then led in the 12th and 13th FYP periods. The resource use pillar outperformed its dimension index in the last two FYPs.

Figure 8c shows the performance of three circular economy pillars. The pillars performed markedly in the 10th and 13th FYP periods. The economic growth pillar outperformed green investment in the 12th and 13th FYPs, while it lagged in the 10th and 11th FYPs. The green investment performance peaked at 35 in the 10th FYP and dropped to 60 in the 12th and 13th FYPs. Resource efficiency outperformed in the 11th, 12th, and 13th FYP periods, but ranked second among the three pillars in the 10th FYP. Economic growth and resource efficiency pillars have comparable performance, while resource efficiency fared well above the other.

Figure 8d shows the performance of three social inclusion pillars. Basic services performed in the second rank in the 10th FYP period, first in the 11th FYP, and practically plateaued in the 12th and 13th. It outperformed the social inclusion dimension index in the 10th, 11th, and 12th FYPs. In the 10th FYP, social equity performed well, but in the 11th FYP, it performed poorly. However, the 12th and 13th FYP

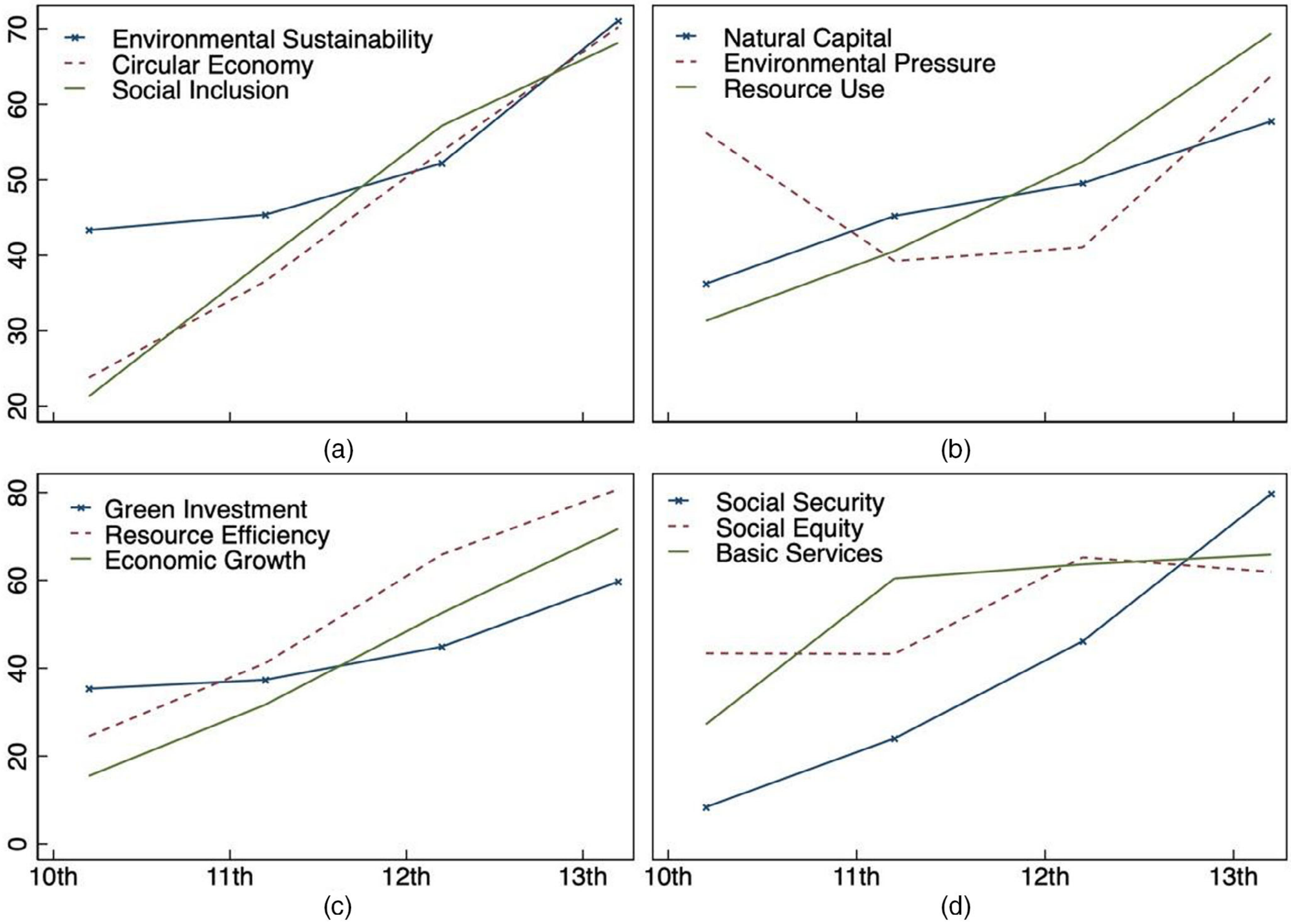

FIGURE 8 (a-d) Performance and progress of green growth dimensions and pillars during FYPs.

reversed this trend. Social security underperformed the other two pillars in the 10th, 11th, and 12th FYPs. It scored eight, the lowest of all pillars in all dimensions, and only overcame the others in the 13th FYP. Social security has constantly grown while basic services and social equity have plateaued. It outgrew the green growth index of social inclusion dimension in the 13th FYP.

4.4 | Green growth prospects and implications

The green growth trajectory in Qinghai provides insights into its sustainable development over the last and next two decades. Figure 9 depicts 2021–2040 green growth projections based on 100,000 Monte Carlo simulations. With the assumption that Qinghai would maintain its present performance, its green growth index is projected to reach 100 by 2030 in the ideal scenario and 2027 in the best-case scenario. However, if concerted efforts are not made, especially in emerging green industries fostering clean technology, cleaner production, and consumption, performance will deteriorate, and a worst-case scenario of low and sluggish performance may occur in the following decade with index scores plateauing at 86 and start to decline by 2037.

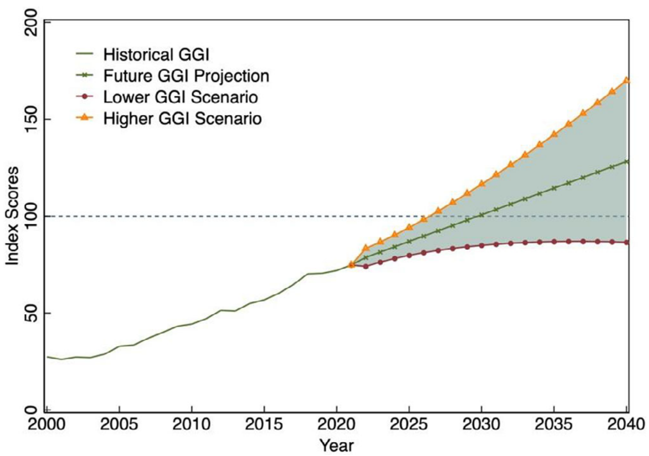

FIGURE 9 Green growth index (GGI) projection.

Moreover, policy implications can be drawn from the growing trajectory of green growth due to the fragility of natural capital and ecosystem services in regional socio-economic life that have risen to the forefront of conservation strategies. Environmental regulations have taken precedence and polluting industries are increasingly challenged.

As the resource-based economy becomes more restricted and the natural resources becomes more valuable, the conundrum of achieving economic growth without compromising the environment persists. Stranded between the polarities of natural capital that is susceptible to climate change and economies that are peripheral, Qinghai must pursue sustainable development pathways. As a late industrializer, it may reap the benefits of the "economic backwardness" advantage (Gerschenkron, 1992) and leapfrog to a cleaner future. Qinghai has less risk and cost in adopting clean technology, cleaner industrial production, and environmental management than more advanced regions of China and industrialized nations, where the wheel has already been invented. In this transition, the province must make consistent effort to develop innovative green industries to stay on track of an ideal green growth scenario as a pathway toward sustainable development. Further, as evidence around the world demonstrate, investing in human capital, clean technology, institutions, upgrading industrial structure, and diversifying sustainable production and consumption patterns reduces natural resource dependency (Barbier, 2020; Jia et al., 2021; Lin & Ma, 2022; Nyangchak, 2022; Rodrik, 2014).

5 | CONCLUSION AND IMPLICATIONS

This study assessed the performance, progress, and prospect of green growth as a pathway toward sustainable development on the Qinghai-Tibet Plateau in China. Grounded in systems thinking, it holistically developed an index framework to account for environmental, economic, and social dimensions of sustainable development. The study finds that as one of the provinces with insignificant economy in China, the performance of green growth in Qinghai has steadily risen with a volatile growth rate. Based on its historical performance, Qinghai is well positioned to achieve sustainable development and build a green and circular economy. It demonstrates that even a resource-reliant province can decarbonize the economy and embrace sustainable development, indicating potential regional, national, and global lessons.

Sustainable development in Qinghai might be strengthened and accelerated on several policy fronts through the green growth framework. First, the natural capital pillar needs more attention due to its instability and a glitch during the Covid-19 pandemic. It could be more stable and consistent with further economic incentives and conservation programs, such as ecological compensation mechanisms, emissions trading schemes, carbon pricing, and ecological restoration programs, and strengthening the capacities of grassland and forest in carbon sink and carbon sequestration. Second, Qinghai must scale up green investment in innovative industries to shift from extensive growth toward intensive and greener growth while alleviating pressure on natural resources. By leveraging the clean energy sector, it might expand energy storage systems, batteries, transmission, solar and wind power equipment, carbon capture and storage, digital services, and other clean technology in energy-intensive sectors like steel and cement. In addition, green industries could be created in all prefectures and counties, each with its own specializations, to foster a synergistic environment for a sustainable and circular economy. Third, disparities in sustainable development demand coordinated development between regions. As a latecomer, Qinghai may benefit from the eastern regions' clean technology, cleaner production processes, green skills, markets, supply chains, green investments, and other resources without having to reinvent the wheel. Fourth, the pillars of basic services and social equity need more improvement as the performance of these two pillars have practically plateaued since early mid-2010s.

As such, future research could delve deeper into the pillars of natural capital, basic services, social equity, and green investment, as well as the potential for innovative industries across all prefectures and counties within the province. These areas represent the greatest potential for Qinghai to further its green growth trajectory. Additionally, subsequent studies could refine the green growth index framework introduced in this research to better explore and align the relationship between green growth and sustainable development.

There are two limitations to this study. First, the insufficiency of literature on green growth specific to the study area positions this research as a pioneering endeavor, setting a basis for subsequent studies. Second, although transparent methodology is provided, the inherent complexity of composite indicators, which condense multidimensional concepts of green growth, may be challenging to grasp without a deep dive into the methodological specifics.

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APPENDIX

TABLE A1 Green growth index framework with dimensions, pillars, and indicators.

Index	Dimensions	Pillars	Indicators		Unit	Relationship
Green Growth Index	Environmental Sustainability	Natural Capital	NC1	Water resources per capita	100 million cu. m/10,000 persons	Positive
			NC2	Forest area per capita	10,000 hectares/10,000 persons	Positive
			NC3	Forest coverage rate	Percentage	Positive
			NC4	Wetland area per capita	10,000 hectares/10,000 persons	Positive
			NC5	Grassland area per capita	1000 hectares/10,000 persons	Positive
			NC6	Area of natural reserves per capita	10,000 hectares/10,000 persons	Positive
			NC7	Green coverage rate of built-up areas	Percentage	Positive
			NC8	Ratio of days of air quality equal to or above grade II in provincial capital	Percentage	Positive
			NC9	Proportion of total monthly precipitation between 30 and 300 mm	Percentage	Positive
			NC10	Proportion of average monthly temperature between 15 and 25°C	Percentage	Positive
		Environmental Pressure	EP1	SO_2 emissions per unit of built-up areas	10,000 tons/sq km	Negative
			EP2	COD emissions per unit of built-up areas	10,000 tons/sq km	Negative
			EP3	Consumption of chemical fertilizers per unit of cultivated land area	10,000 tons/1000 hectares	Negative
			EP4	Consumption of pesticides per unit of cultivated land area	Tons/1000 hectares	Negative
			EP5	Number of forest fire	Quantity	Negative
			EP6	Proportion of raw coal in total energy production	Percentage	Negative
			EP7	Proportion of crude oil in total energy production	Percentage	Negative
			EP8	Production output of cement	10,000 tons	Negative
			EP9	Proportion of thermal power in total installed power generation capacity	Percentage	Negative
			EP10	Damage area by grassland rats and pests	1000 hectares	Negative
		Resource Use	RU1	Energy consumption per unit of GDP	10,000 tons/100 million yuan	Negative
			RU2	Electric power consumption per unit of GDP	100 million kwh/100 million yuan	Negative
			RU3	Coal consumption per unit of GDP	10,000 tons/100 million yuan	Negative
			RU4	Total consumption of water	100 million cubic meter	Negative
			RU5	Total consumption of water in agriculture	100 million cubic meter	Negative
			RU6	Utilization amount of industrial solid waste	10,000 tons	Positive
			RU7	Energy consumption per unit of value added by industrial enterprises	10,000 tons/100 million yuan	Negative
			RU8	Area of built-up areas per capita	Square kilometers	Negative
			RU9	Area of cultivated land per capita	1000 hectares/10,000 persons	Negative
			RU10	Area of fenced grassland per capita	1000 hectares/10,000 persons	Positive

TABLE A1 (Continued)

Index	Dimensions	Pillars	Indicators		Unit	Relationship
	Circular Economy	Economic Growth	EG1	GDP per capita	Yuan/person	Positive
			EG2	Labor productivity of the primary sector	Percentage	Positive
			EG3	Labor productivity of the secondary sector	Percentage	Positive
			EG4	Labor productivity of the tertiary sector	Percentage	Positive
			EG5	Growth rate of investment in fixed assets (year-on-year)	Percentage	Positive
			EG6	Rate of urbanization	Percentage	Positive
			EG7	Gross value of agricultural production per capita	Yuan/person	Positive
			EG8	Gross value of production by industrial enterprises above designated size	100 million yuan	Positive
			EG9	Actual utilization of foreign direct investment	10,000 US dollars	Positive
			EG10	Number of patents applications granted	Piece	Positive
		Green Investment	GI1	Ratio of environmental spending to government expenditure	Percentage	Positive
			GI2	Ratio of comprehensive environmental governance and construction investment to GDP	Percentage	Positive
			GI3	Area of park green land per capita in urban areas	Square meters	Positive
			GI4	Forested area at year-end	Hectare	Positive
			GI5	Area of artificial grassland reserved	1000 hectares	Positive
			GI6	Ratio of renewable energy (wind, hydro, solar) to total installed power generation capacity	Percentage	Positive
			GI7	Share of technology market transaction by GDP	Percentage	Positive
			GI8	Area of cumulative soil erosion per capita	1000 hectares/10,000 persons	Positive
			GI9	Prevented area of grassland rats and pests	1000 hectares	Positive
			GI10	Share of contribution by the tertiary sector	Percentage	Positive
		Resource Efficiency	RE1	CO_2 emissions per unit of GDP	Million tons/100 million yuan	Negative
			RE2	CO_2 emissions of raw coal per unit of GDP	Million tons/100 million yuan	Negative
			RE3	SO_2 emissions per unit of GDP	10,000 tons/100 Million yuan	Negative
			RE4	COD emissions per unit of GDP	10,000 tons/100 Million yuan	Negative
			RE5	Disposal and utilization rate of industrial solid waste	Percentage	Positive
			RE6	Rate of energy self-sufficiency	Percentage	Positive
			RE7	Growth of the proportion of renewable energy power generation	Percentage	Positive
			RE8	Treatment rate of urban wastewater	Percentage	Positive
			RE9	Land productivity	Percentage	Positive
			RE10	Consumption of water per capita	Cubic meter/person	Negative
	Social Inclusion	Basic Services	BS1	Ratio of spending on science, education, culture, and public health to government expenditure	Percentage	Positive

(Continues)

TABLE A1 (Continued)

Index	Dimensions	Pillars	Indicators		Unit	Relationship
			BS2	Coverage rate of water supply in urban areas	Percentage	Positive
			BS3	Area of effective irrigation per capita	1000 hectares/10,000 persons	Positive
			BS4	Access to public transportation per 10,000 urban population	Quantity	Positive
			BS5	Density of highway network	km/10,000 sq km	Positive
			BS6	Access to public libraries per million urban population	Quantity	Positive
			BS7	Access to urban public toilet per capita	Quantity	Positive
			BS8	Popularization rate of telephone	Set/100 persons	Positive
			BS9	Number of enrolled students in higher education per 10,000 population	Persons	Positive
			BS10	Number of kindergartens per 10,000 population	Quantity	Positive
		Social Security	SS1	Share of social security and employment spending to government expenditure	Percentage	Positive
			SS2	Pension insurance participants of employees per 10,000 population	Persons	Positive
			SS3	Number of urban employees participated in medical care insurance per 10,000 population	Persons	Positive
			SS4	Number of participants in maternity insurance per 10,000 population	Persons	Positive
			SS5	Outstanding amount of RMB saving deposits in urban and rural areas per capita	100 million yuan	Positive
			SS6	Number of participants in unemployment insurance per 10,000 population	Persons	Positive
			SS7	Rate of registered urban unemployment	Percentage	Negative
			SS8	Number of health technicians per 10,000 population	Persons	Positive
			SS9	Number of medical beds per 10,000 population in health institutions	Quantity	Positive
			SS10	Ratio of kindergarten teacher and student	Percentage	Negative
		Social Equity	SE1	Difference of male–female employment in rural area (male>)	Percentage	Negative
			SE2	Difference of actual unemployed male–female at year-end (male>)	Percentage	Negative
			SE3	Difference of urban–rural residents receiving minimum living allowance (rural>)	Percentage	Negative
			SE4	Number of leadership seats held by women at all levels of government	Persons	Positive
			SE5	Difference of urban–rural per capita disposable income (urban>)	Percentage	Negative
			SE6	Growth rate difference of urban–rural per capita disposable income (urban>)	Percentage	Negative
			SE7	Difference of urban–rural per capita consumption expenditure (urban>)	Percentage	Negative
			SE8	Growth rate difference of urban–rural per capita consumption expenditure (urban>)	Percentage	Negative

TABLE A1 (Continued)

Index	Dimensions	Pillars	Indicators		Unit	Relationship
			SE9	Engle's coefficient of urban per capita consumption expenditure	Percentage	Negative
			SE10	Engle's coefficient of rural per capita consumption expenditure	Percentage	Negative

TABLE B1 Imputed indicators, value counts, and methods between 2000 and 2021.

Indicators	Values	Years	Imputation methods
NC1	2	2000, 2001	Closest year
NC4	2	2000, 2001	Closest year
NC5	1	2021	Closest year
NC8	2	2000, 2001	Closest year
EP3	1	2021	Closest year
EP4	1	2021	Closest year
RU4	2	2000, 2001	Closest year
RU5	2	2000, 2001	Closest year
RU9	1	2021	Closest year
GI1	6	2000, 2001, 2002, 2003, 2004, 2005	Three closest years
GI2	3	2000, 2001, 2002	Three closest years
RE1	1	2021	Closest year
RE2	1	2021	Closest year
RE8	2	2000, 2001	Closest year
RE10	3	2000, 2001, 2002	Closest year

TABLE B2 Imputed indicators, value counts, and methods between 2001 and 2020.

Indicators	Values	Years	Imputation methods
NC1	1	2001	Closest year
NC4	1	2001	Closest year
NC8	1	2001	Closest year
RU4	1	2001	Closest year
RU5	1	2001	Closest year
GI1	5	2001, 2002, 2003, 2004, 2005	Three closest years
GI2	2	2001, 2002	Three closest years
RE8	1	2001	Closest year
RE10	2	2001, 2002	Closest year

TABLE C1 Summary of outliers in 2000–2021 indicators.

Indicators	Outliers	Years	Fence	Capping value
NC6	1	2000	Lower	−0.05
EP4	1	2021	Lower	−0.05
RU9	3	2000, 2001, 2002	Upper	+0.05, +0.06, +0.07
EG2	1	2001	Upper	+0.05
EG10	2	2020, 2021	Upper	+0.05, +0.06
GI5	2	2000, 2001	Upper	+0.05, +0.06
GI8	2	2020, 2021	Upper	+0.005, +0.006
GI10	2	2010, 2020	Lower	−0.05, −0.06
RE5	1	2000	Upper	+0.05
BS2	2	2000, 2006	Lower	−0.05, −0.06
SS6	1	2000	Upper	+0.05
SS7	1	2021	Lower	−0.05
SE1	3	2000, 2001, 2002	Lower	−0.005, −0.006, −0.007
SE6	1	2000	Lower	−0.005

TABLE C2 Summary of outliers in 2001–2020 indicators.

Indicators	Outliers	Years	Fence	Capping value
NC2	4	2017, 2018, 2019, 2020	Upper	+0.05, +0.06, +0.07, +0.08
EP4	1	2020	Lower	−0.05
EP7	3	2000, 2001, 2002	Upper	+0.05, +0.06, +0.07
RU9	2	2000, 2001	Upper	+0.05, +0.06
EG2	1	2020	Upper	+0.05
EG10	1	2020	Upper	+0.05
GI4	1	2020	Upper	+0.05
GI5	1	2000	Upper	+0.05
GI8	2	2019, 2020	Upper	+0.005, +0.006
GI10	2	2010, 2020	Lower	−0.05, −0.06
BS2	1	2006	Lower	−0.05
SE1	2	2000, 2001	Lower	−0.005, −0.006

TABLE D1 Pearson's correlation coefficients.

Natural capital										
	NC1	NC2	NC3	NC4	NC5	NC6	NC7	NC8	NC9	NC10
NC1	1.000	0.585***	0.566***	0.25	−0.287	−0.171	0.567***	0.593***	0.175	−0.224
NC2	0.004	1.000	0.789***	0.692***	−0.581***	−0.667***	0.673***	0.514**	0.286	−0.256
NC3	0.006	0.000	1.000	0.841***	−0.56***	−0.572***	0.884***	0.554***	0.261	−0.281
NC4	0.261	0.000	0.000	1.000	−0.678***	−0.735***	0.755***	0.199	0.148	−0.124
NC5	0.195	0.005	0.007	0.001	1.000	0.665***	−0.654***	−0.258	0.066	−0.022
NC6	0.447	0.001	0.005	0.000	0.001	1.000	−0.41*	−0.108	0.045	0.204
NC7	0.006	0.001	0.000	0.000	0.001	0.058	1.000	0.577***	0.191	−0.067
NC8	0.004	0.014	0.008	0.373	0.247	0.631	0.005	1.000	0.022	−0.298
NC9	0.435	0.197	0.240	0.511	0.771	0.844	0.395	0.923	1.000	−0.016
NC10	0.317	0.250	0.205	0.581	0.921	0.362	0.768	0.178	0.945	1.000
Environmental pressure										
	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8	EP9	EP10
EP1	1.000	0.934***	0.667***	0.846***	0.128	0.835***	−0.335	−0.062	0.135	0.485**
EP2	0.000	1.000	0.574***	0.645***	−0.048	0.87***	−0.437**	0.033	−0.105	0.558***
EP3	0.001	0.005	1.000	0.732***	0.252	0.583***	−0.435**	0.492**	0.084	0.145
EP4	0.000	0.001	0.000	1.000	0.375*	0.664***	−0.167	−0.079	0.326	0.247
EP5	0.570	0.832	0.257	0.086	1.000	0.081	−0.353	0.178	−0.098	−0.166
EP6	0.000	0.000	0.004	0.001	0.722	1.000	−0.446**	0.118	−0.005	0.643***
EP7	0.127	0.042	0.043	0.458	0.107	0.038	1.000	−0.731***	0.659***	−0.132
EP8	0.785	0.884	0.020	0.725	0.428	0.601	0.000	1.000	−0.519**	−0.079
EP9	0.550	0.643	0.710	0.139	0.665	0.984	0.001	0.013	1.000	0.158
EP10	0.022	0.007	0.520	0.267	0.460	0.001	0.558	0.727	0.483	1.000
Resource use										
	RU1	RU2	RU3	RU4	RU5	RU6	RU7	RU8	RU9	RU10
RU1	1.000	0.829***	0.896***	0.666***	0.511**	0.9***	0.743***	−0.901***	0.435**	0.874***
RU2	0.000	1.000	0.765***	0.658***	0.807***	0.667***	0.395*	−0.886***	0.43**	0.757***
RU3	0.000	0.000	1.000	0.499**	0.506**	0.85***	0.778***	−0.911***	0.682***	0.949***
RU4	0.001	0.001	0.018	1.000	0.737***	0.639***	0.159	−0.713***	−0.097	0.436**
RU5	0.015	0.000	0.016	0.000	1.000	0.408*	−0.045	−0.733***	0.213	0.487**
RU6	0.000	0.001	0.000	0.001	0.060	1.000	0.751***	−0.852***	0.29	0.823***
RU7	0.000	0.069	0.000	0.481	0.844	0.000	1.000	−0.581***	0.595***	0.759***
RU8	0.000	0.000	0.000	0.000	0.000	0.000	0.005	1.000	−0.481**	−0.912***
RU9	0.043	0.046	0.000	0.666	0.342	0.190	0.004	0.023	1.000	0.669***
RU10	0.000	0.000	0.000	0.042	0.022	0.000	0.000	0.000	0.001	1.000
Economic growth										
	EG1	EG2	EG3	EG4	EG5	EG6	EG7	EG8	EG9	EG10
EG1	1.000	0.959***	0.99***	0.992***	−0.589***	0.997***	0.988***	0.919***	−0.666***	0.928***
EG2	0.000	1.000	0.962***	0.919***	−0.685***	0.952***	0.96***	0.825***	−0.651***	0.945***
EG3	0.000	0.000	1.000	0.973***	−0.646***	0.982***	0.966***	0.862***	−0.676***	0.964***
EG4	0.000	0.000	0.000	1.000	−0.546***	0.991***	0.975***	0.937***	−0.674***	0.895***
EG5	0.004	0.000	0.001	0.009	1.000	−0.581***	−0.541***	−0.336	0.439**	−0.735***
EG6	0.000	0.000	0.000	0.000	0.005	1.000	0.987***	0.925***	−0.651***	0.915***
EG7	0.000	0.000	0.000	0.000	0.009	0.000	1.000	0.934***	−0.615***	0.892***
EG8	0.000	0.000	0.000	0.000	0.127	0.000	0.000	1.000	−0.603***	0.714***

(Continues)

TABLE D1 (Continued)

Economic growth

	EG1	EG2	EG3	EG4	EG5	EG6	EG7	EG8	EG9	EG10
EG9	0.001	0.001	0.001	0.001	0.041	0.001	0.002	0.003	1.000	−0.667***
EG10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	1.000

Green investment

	GI1	GI2	GI3	GI4	GI5	GI6	GI7	GI8	GI9	GI10
GI1	1.000	−0.359	−0.925***	−0.674***	0.512**	−0.616***	−0.578***	−0.68***	0.28	0.17
GI2	0.101	1.000	0.399*	0.194	−0.336	0.064	0.53**	0.098	−0.121	0.25
GI3	0.000	0.066	1.000	0.798***	−0.463**	0.591***	0.535**	0.831***	−0.244	−0.081
GI4	0.001	0.386	0.000	1.000	−0.516**	0.598***	0.238	0.919***	−0.289	−0.111
GI5	0.015	0.126	0.030	0.014	1.000	−0.323	0.011	−0.359	0.226	0.501**
GI6	0.002	0.776	0.004	0.003	0.142	1.000	0.22	0.638***	−0.479**	−0.086
GI7	0.005	0.011	0.010	0.286	0.962	0.326	1.000	0.207	−0.121	0.319
GI8	0.001	0.663	0.000	0.000	0.100	0.001	0.354	1.000	−0.199	0.018
GI9	0.208	0.592	0.274	0.193	0.312	0.024	0.592	0.375	1.000	0.119
GI10	0.450	0.263	0.720	0.622	0.017	0.705	0.148	0.936	0.598	1.000

Resource efficiency

	RE1	RE2	RE3	RE4	RE5	RE6	RE7	RE8	RE9	RE10
RE1	1.000	0.98***	0.752***	0.876***	0.66***	0.041	0.185	0.983***	0.97***	0.81***
RE2	0.000	1.000	0.649***	0.833***	0.607***	0.125	0.256	0.962***	0.931***	0.736***
RE3	0.000	0.001	1.000	0.898***	0.715***	−0.183	−0.097	0.785***	0.843***	0.874***
RE4	0.000	0.000	0.000	1.000	0.6***	−0.175	0.009	0.906***	0.924***	0.861***
RE5	0.001	0.003	0.000	0.003	1.000	0.125	0.111	0.658***	0.689***	0.662***
RE6	0.855	0.579	0.414	0.436	0.580	1.000	0.15	0.006	−0.081	−0.264
RE7	0.409	0.251	0.666	0.969	0.624	0.504	1.000	0.155	0.082	0.019
RE8	0.000	0.000	0.000	0.000	0.001	0.977	0.491	1.000	0.972***	0.836***
RE9	0.000	0.000	0.000	0.000	0.000	0.719	0.716	0.000	1.000	0.903***
RE10	0.000	0.000	0.000	0.000	0.001	0.236	0.932	0.000	0.000	1.000

Basic services

	BS1	BS2	BS3	BS4	BS5	BS6	BS7	BS8	BS9	BS10
BS1	1.000	−0.33	0.126	0.148	0.757***	0.639***	0.235	0.697***	0.802***	0.582***
BS2	0.133	1.000	0.205	0.419*	−0.471**	−0.404*	0.285	−0.449**	−0.474**	−0.557***
BS3	0.575	0.361	1.000	0.299	0.001	0.015	0.425**	−0.011	−0.025	−0.145
BS4	0.512	0.053	0.176	1.000	−0.196	−0.124	0.849***	−0.266	−0.156	−0.514**
BS5	0.000	0.027	0.996	0.383	1.000	0.893***	−0.067	0.978***	0.984***	0.915***
BS6	0.001	0.062	0.949	0.584	0.000	1.000	−0.017	0.919***	0.859***	0.849***
BS7	0.293	0.199	0.049	0.000	0.766	0.939	1.000	−0.145	−0.069	−0.391*
BS8	0.000	0.036	0.962	0.232	0.000	0.000	0.520	1.000	0.962***	0.945***
BS9	0.000	0.026	0.913	0.487	0.000	0.000	0.759	0.000	1.000	0.885***
BS10	0.005	0.007	0.518	0.014	0.000	0.000	0.072	0.000	0.000	1.000

Social equity

	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10
SE1	1.000	0.348	0.665***	−0.387*	−0.33	−0.653***	−0.758***	−0.324	−0.335	−0.717***
SE2	0.113	1.000	0.192	−0.786***	−0.297	−0.279	−0.456**	0.373*	−0.332	−0.524**
SE3	0.001	0.393	1.000	−0.011	−0.806***	−0.466**	−0.824***	−0.198	−0.708***	−0.803***

TABLE D1 (Continued)

Social equity										
	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10
SE4	0.075	0.000	0.962	1.000	0.132	0.369*	0.463**	−0.125	0.206	0.492**
SE5	0.134	0.179	0.000	0.557	1.000	0.437**	0.798***	−0.03	0.863***	0.779***
SE6	0.001	0.208	0.029	0.091	0.042	1.000	0.685***	0.336	0.302	0.617***
SE7	0.000	0.033	0.000	0.030	0.000	0.000	1.000	0.237	0.693***	0.936***
SE8	0.141	0.088	0.378	0.578	0.895	0.126	0.289	1.000	−0.173	0.05
SE9	0.127	0.132	0.000	0.358	0.000	0.172	0.000	0.441	1.000	0.811***
SE10	0.000	0.012	0.000	0.020	0.000	0.002	0.000	0.824	0.000	1.000
Social security										
	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
SS1	1.000	0.184	0.337	0.001	0.185	0.033	−0.02	0.079	0.081	0.24
SS2	0.413	1.000	0.878***	0.926***	0.972***	0.654***	0.766***	0.975***	0.953***	0.932***
SS3	0.125	0.000	1.000	0.855***	0.938***	0.397*	0.498**	0.845***	0.889***	0.797***
SS4	0.998	0.000	0.000	1.000	0.964***	0.693***	0.789***	0.958***	0.975***	0.86***
SS5	0.410	0.000	0.000	0.000	1.000	0.645***	0.738***	0.971***	0.985***	0.906***
SS6	0.883	0.001	0.067	0.000	0.001	1.000	0.911***	0.726***	0.698***	0.734***
SS7	0.931	0.000	0.018	0.000	0.000	0.000	1.000	0.833***	0.765***	0.767***
SS8	0.726	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.971***	0.902***
SS9	0.720	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.907***
SS10	0.281	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Note: The right-side values are correlation coefficients, and the left-side are the level of significance. ***, **, * represent correlation significance at the 1%, 5%, 10%, respectively.