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Assessing the Spatiotemporal Development of Ecological Civilization for China’s Sustainable Development

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Abstract: The ecological civilization strategy in China has accelerated its national sustainability. However, few systematic evaluations of Chinese Ecological Civilization Construction (ECC) have provided detailed and timely information regarding estimations of the sustainable development levels. Here, we combined indicators and policies of the United Nations (UN) sustainable development goals (SDGs) with Chinese ecological civilization and built an integrated assessment system with mixed indicators for evaluating the sustainable development levels in five dimensions (i.e., economy, society, ecology, culture, and institutions). Based on the acquired sustainability index from the system, we revealed the spatiotemporal transitions at the national and provincial levels from 2005 to 2019 in China. Specifically, both the national and provincial ECC temporally increased in this period, while spatially, the development performance of ECC was differentiated across provinces and regions. In particular, sustainable trajectories in east China and coastal regions presented better than the west and inland. Moreover, we identified the different dimensional contributions between the top and bottom provinces in ECC development. The results showed that the institutional, social, and cultural dimensions created more effects than the economic and ecological dimensions. By analyzing the provincial development patterns, we recommend the comprehensive development of ECC across the five dimensions and suggest that addressing weak dimensions is a priority. The proposed system will elevate the sustainable development strategies and pave the way for the broadening of the framework’s application to other regions and countries in the future.

Keywords: ecological civilization; ecological civilization aggregated index; sustainable indicators; spatiotemporal analysis; hot spot of provinces

1. Introduction

Sustainable development alleviates the contradiction between ecological protection and economic development, represents particular global challenges, and prevents human activities from causing unacceptable environmental changes [1]. Sustainable development has been proposed as a way of resolving the environmental and resource crises that are gradually threatening the survival and economic development of humankind [2]. Since 2015, 193 United Nations (UN) member states have developed an extensive framework for coordinating and shaping government policies, and engaging the public with sustainability, relying on Agenda 2030 with its 17 Sustainable Development Goals (SDGs) [3]. However, in 2020 it became clear that the sustainable development processes were lagging behind: SDG 3 (Good health and well-being), SDG 8 (Decent work and economic growth), and even in SDG 4 (Quality education) are likely to fall short of the development goals by 2030, especially in developing countries [4].

It is noteworthy that the global building industry continues to explore and practice effective ways for sustainable development. Many countries have proposed appropriate
evaluation systems to estimate the sustainability performance of buildings, such as the British Building Research Establishment Environmental Assessment Method (BREEAM), the American Leadership in Energy and Environmental Design (LEED), and the French High Quality Environmental (HQE) [5]. Apparently, some Asian countries have developed evaluation systems, such as the Green Building Index Township (Malaysia), Green Mark for Districts (Singapore), and IGBC Green Township (India) [6].

BREEAM is a widely used green building assessment method across the whole world, which supports the designer to evaluate the performance of communities and building projects from local climate, ecology, culture, building materials, and so on [7]. BREEAM effectively evaluated the sustainable land development of all Lisbon city subsections [8]. However, researchers assessed the performance for three Chinese eco-villages (Huatao ECO-village, Sunshine Eco-village, and Southern Life), and they found that BREEAM had limitations (incomplete evaluation indicators: contribution to social benefits and farmland reclaiming) for evaluating the Chinese area [9]. LEED was developed on the basis of BREEAM to evaluate and examine the environmental impact of buildings in terms of site location and transportation, water conservation, indoor environmental quality, and so on [10,11]. Researchers appraised the green building performances in Sweden [12], the energy and atmosphere category in India [13], and the building of sustainable objects in Tallinn and Rakvere [14]. HQE is mainly responsible for evaluating the performance of green buildings in France in terms of sustainability. Researchers evaluated the type of renewable energy in buildings [15], the health and productivity of occupants in commercial buildings [16], and the indoor environmental quality of offices and hotels [17] in four aspects: energy, environment, comfort, and health. Researchers believe that the HQE evaluation system promotes the management of building waste and encourages the construction of waste management standards in France [18]. In conclusion, BREEAM, LEED, and HQE are models of green building evaluation, even in sustainable development assessment.

As the largest developing country, China is under pressure to meet global SDGs in the areas of biodiversity, low carbon, and climate change. Thus, the government has determined to enact a national “ecological civilization” plan by balancing economic development and the environmental protection [19]. In 1987, “ecological civilization” was proposed, followed by “Ecological Civilization Construction (ECC)” in 2007 [20–22]. The Chinese government is gradually strengthening the construction of ecological civilization from theory to practice (e.g., ecological demonstration construction) [23,24]. For example, China has made progress and improvements in the exploitation of renewable energy (wind, nuclear power, solar PV), ecological protection (greening of the planet), and low carbon emissions (CO₂ emissions from fossil fuels). Chinese ecological civilization laid the foundation and provided a reference for achieving the SDGs, especially for other developing countries. Therefore, understanding the processes, characteristics, and patterns of ECC is conducive to allay the sustainable development crisis while reaching global sustainable development unitedly.

The issue of ecological civilization has received considerable identified attention. Researchers believed that ecological civilization is a Chinese commitment to sustainability for the whole world, which keeps balance with national progress and environmental conservation [25]. Moreover, others argued that ecological civilization is a new way to solve social and ecological conflicts and change human beings to achieve sustainable development [26,27]. Most studies in ECC have focused on the evaluation index ranges, the spatial distribution, the temporal pattern, and evaluation methods and models. First, the choices of evaluation ranges reflected the differentiated influencing factors of national, provincial, and regional ECC. Researchers selected the evaluation index ranges from the national and provincial levels at society, economy, environment, and resource aspects [28,29]. Several studies adjusted the evaluation range in technology, physiological, psychological, human development, and so on [29,30]. Second, the evaluation of ECC at different levels displayed the spatial imbalance. Some researchers studied the spatial distribution at the national [31,32], provincial (Jiangsu and Xinjiang) [33,34], and regional levels, in particular 269 and 329 Chinese cities [26,32], resources cities [35,36], environment-based cities [37],
and coastal cities [38]. In addition, the scope of ecological civilization studies has gradually expanded to include oceans [39], mining regions [40], ecologically fragile regions [41], and ports [42]. Third, the ECC exhibited temporal characteristics. The temporal pattern analysis presented two main types: short periods (2015–2018) [26,28,43] and single-year (2015) [44]. Fourth, inconsistent models and methods increased the uncertainty of the evaluation results. Previous research has established evaluation models and methods such as TOPSIS, DEA, PSR, and GWR [22,31,33,36].

Previous studies have provided a preliminary understanding and experience of the performance of ECC through selecting and applying various evaluation dimensions and methods, and then presenting suggestions based on the development deficiencies. Of course, ECC faces challenges in relation to reaching the SDGs, and diverse regions variously promoted ECC in methods and effects. However, the comprehensive and balanced construction for regional development was crucial for ecological civilization [26]. Apparently, previous studies had certain restrictions and deficiencies:

1. The social, economic, institutional, cultural, and ecological dimensions were usually not applied in the same evaluation system. Among them, the social and economic dimensions were often adopted, while the ecological dimension was separated into the resource, energy, or environmental aspects, which were evaluated selectively based on evaluation contents. Significantly, the cultural dimension was always ignored [45]. Chinese ECC advocates for the “five-pronged approach to building socialism with Chinese characteristics” in relation to social, economic, political, cultural, and ecological progress. Notably, a long-term ECC connects with cultural and scientific engagement, social support, and cooperation between governments [43]. Therefore, a more comprehensive (five dimension) evaluation index system is beneficial to display the actual level of ECC accurately;

2. Short-term and localized spatial distribution studies do not necessarily show subtle changes over time. Most studies analyzed the spatiotemporal distribution of ecological civilization from the year 2015 when the local government proposed the “Opinions on Accelerating the Construction of Ecological Civilization” and in the spatial scale to select provincial and cities (counties, towns) mostly;

3. Although most studies showed spatial and temporal differences and imbalances in the construction of regional ecological civilization, some of them generalized the reasons for the differentiation. However, previous studies did not compare the characteristic changes and differentiation dimensions in typical provinces.

To address these restrictions and deficiencies, we first considered the SDGs and Chinese characteristics of ECC to establish a five-dimension evaluation index system based on society, economy, institution, culture, and ecology. Accordingly, the aggregated index (1–100) by 32 indicators across five dimensions reflected the spatiotemporal patterns of ecological civilization in China and 31 provinces (excluding Hong Kong, Macao, and Taiwan) in three stages from 2005 to 2019 (2005–2007 was the conceptualization stage, 2007–2010 was the national framework stage, and 2010–2019 was the experimental stage of national/provincial and county demonstration projects). We aimed to highlight ECC discrepancies at the national and provincial levels in great detail to trace the ECC process for China and its 31 provinces. We compared six typical provinces to identify the dimensional motivation, and we selected three typical provinces based on a hotspot analysis as a case study to analyze the dimensional contribution.

2. Methods
2.1. ECC Index System

We combined SDGs and the Chinese characteristics of ECC to establish a five-dimension (society, economy, institution, culture, and ecology) evaluation index system to quantify the ECC index at the national and provincial level, and then displayed the spatiotemporal patterns. Whenever possible, four-dimensional (i.e., social, environmental, economic, and institutional) indicators were taken from existing indicators published across international
documents (such as UN SDGs indicators, the 2018 SDG index and Dashboards Report 14, and Indicators of a Monitoring Framework for SDGs) [46,47]. Additionally, we picked the cultural dimensional indicators from the green development and resilient city assessment. Together, taking consideration of the SDGs and the compiled five-dimensional indicators above, we presented the evaluation framework of 32 indicators, including 8 indicators in the social dimension, 10 in the ecological dimension, 5 in the economic dimension, 4 in the institutional dimension, and 5 in the cultural dimension (Figure 1).

Figure 1. Ecological civilization evaluation index model based on SDGs. Note: Six geographical regions were introduced for special analysis, including central and south China (HA, HB, HN, GX, GD, HI, MO, HK); east China (SD, JS, SH, AH, ZJ, JX, FJ, TW); north China (IM, BJ, TJ, HE, SX); northeast China (HL, JL, LN); northwest China (XJ, QH, GS, SN, NX); and southwest China (Tibet, SC, CQ, GZ, YN).

The five-dimension indicators were selected as the ecological civilization index system:

1. Society: this mainly examined the practical applications and capabilities of the ECC in social development to evaluate the level of the public practice of ecological civilization;
2. Economy: this particularly displayed the various types of industries with GDP, such as industries related to green environmental protection and technological innovation;
3. Institution: this revealed the performance of the implementation and promotion of the work of the ECC in local government departments, and the spread of green government and office;
4. Culture: this reflected the level of cultural infrastructure construction, and the degree of ECC in both public and educational culture;
5. Ecology: this singled out the indicators of resources, energy, forest, and land, which were related to resource preservation, climate action, diversity, and land use (Table 1).
Table 1. Ecological civilization evaluation index.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Indicators</th>
<th>Attributes</th>
<th>Sources</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Society</td>
<td>1 Urban water supply penetration rate (%)</td>
<td>+</td>
<td>Sustainable development of communities—Indicators for city services and quality of life (GB/T 36749-2018)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>2 Urban gas supply penetration rate (%)</td>
<td>+</td>
<td>Indicators of green development (2016)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>3 Decontamination rate of urban garbage (%)</td>
<td>+</td>
<td>(GB/T 36749-2018)</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>4 Urban sewage centralized treatment rate (%)</td>
<td>+</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>5 Greening coverage rate in built-up areas (%)</td>
<td>+</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>6 Per capita green park areas (m²/person)</td>
<td>+</td>
<td>Indicators of green development (2016)</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>7 Public transportation vehicles per 10,000 people (vehicles)</td>
<td>+</td>
<td>Sustainable development goals (SDGs—goal 9)</td>
<td>13.13</td>
</tr>
<tr>
<td></td>
<td>8 Coverage rate of community service agencies (%)</td>
<td>+</td>
<td>Sustainable cities and communities—Indicators for resilient cities (ISO-37123-2019)</td>
<td>30</td>
</tr>
<tr>
<td>Economy</td>
<td>9 Unemployment rate (%)</td>
<td>−</td>
<td>Sustainable development goals (SDGs—goal 8)</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>10 Per capita annual disposable income of residents (yuan/person)</td>
<td>+</td>
<td>Indicators of green development (2016)</td>
<td>32,000</td>
</tr>
<tr>
<td></td>
<td>11 Proportion of tertiary industry of regional GDP (%)</td>
<td>+</td>
<td></td>
<td>54.5</td>
</tr>
<tr>
<td></td>
<td>12 Energy consumption growth rate (%)</td>
<td>−</td>
<td>Indicators of ecological civilization construction assessment (2016)</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>13 The proportion of waste gas treatment in industrial pollution treatment investment (%)</td>
<td>+</td>
<td>Indicators of National ecological civilization construction pilot demonstration area (2014)</td>
<td>68</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Indicators</td>
<td>Attributes</td>
<td>Sources</td>
<td>Target</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>------------</td>
<td>---------</td>
<td>--------</td>
</tr>
<tr>
<td>Institution</td>
<td>Local fiscal maintenance and construction tax accounting for the proportion of total fiscal revenue (%) +</td>
<td>Sustainable cities and communities—Indicators for resilient cities (ISO-37123-2019)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Income from the paid use of state-owned resources (assets) of local finance (One billion yuan¥)</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proportion of local fiscal expenditures on environmental protection (%)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resources tax (One billion yuan¥)</td>
<td>Indicators of National ecological civilization construction pilot demonstration area (2014)</td>
<td>30.1</td>
<td></td>
</tr>
<tr>
<td>Culture</td>
<td>Net primary enrollment rate (%)</td>
<td>Sustainable development goals (SDGs—goal 4)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Education rate (%)</td>
<td>Indicators of National ecological civilization construction pilot demonstration area (2014)</td>
<td>95.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of existing museums (%)</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of existing libraries (%)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proportion of local fiscal expenditure on education (%)</td>
<td>14.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecology</td>
<td>Proportion of days with air quality reaching and better than Class II (%)</td>
<td>Sustainable development goals (SDGs—goal 11)</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental noise level sound level (dB(A))</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comprehensively utilized rate of common industrial solid wastes (%)</td>
<td>GB/T 36749-2018</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>Indicators</td>
<td>Attributes</td>
<td>Sources</td>
<td>Target</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------</td>
<td>------------</td>
<td>--------------------------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>26</td>
<td>Per capita water consumption (m$^3$/person)</td>
<td>_</td>
<td>Provincial standard</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Soil erosion restoration area (km$^3$)</td>
<td>+</td>
<td>Indicators of green development (2016)</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Forest coverage rate (%)</td>
<td>+</td>
<td>Indicators of ecological civilization construction assessment (2016)</td>
<td>24.1</td>
</tr>
<tr>
<td>29</td>
<td>Proportion of wetland in urban area (%)</td>
<td>+</td>
<td>Indicators of green development (2016)</td>
<td>5.58</td>
</tr>
<tr>
<td>30</td>
<td>Proportion of nature reserves in the jurisdictional area (%)</td>
<td>+</td>
<td>Indicators of National ecological civilization construction pilot demonstration area (2014)</td>
<td>18</td>
</tr>
<tr>
<td>31</td>
<td>Forest pest and disease control rate (%)</td>
<td>+</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>32</td>
<td>Annual environmental emergencies (times)</td>
<td>_</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

+: it represents a positive attribute of the indicator, the higher index value obtains the positive evaluation; -: it means the indicator attribute is negative, the higher index value gets the negative evaluation.
2.2. Data Collection

The data were retrieved from official statistics, such as the China Statistical Yearbook (2006–2020) [48], the Bulletin of the State of the Ecological Environment (2006–2020) [49], the China Statistical Yearbook on the Environment (2006–2020) [50], the Educational Statistics Yearbook of China (2006–2020) [51], the China Energy Statistical Yearbook (2006–2020) [52], China City Statistical yearbook (2006–2020) [53], and the SDGs report [54–56] at the national and provincial levels (Table 2).

Table 2. Data sources for each indicator.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Indicators</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>China City Statistical Yearbook (2006–2020)</td>
</tr>
<tr>
<td>Economy</td>
<td>9</td>
<td>SDGs report</td>
</tr>
<tr>
<td>Culture</td>
<td>18–19</td>
<td>SDGs report</td>
</tr>
</tbody>
</table>

2.3. ECC Index Calculation

Based on the evaluation framework and the collected data, we calculated the aggregated and dimensional index at the national and provincial levels from 2005 to 2019.

2.3.1. Indicator De-Dimensionalization

According to the positive (+) and negative (−) attributes of the indicators, the original data needed to be de-quantified. The larger the positive indicator, the more significant the improvement to the ECC. In contrast, the smaller the negative indicator, the greater the improvement for the ECC (Equations (1) and (2)).

Positive indicators:

\[ y' = \frac{y}{TV(y)} \]  

(1)

Negative indicators:

\[ y' = 1 - \frac{y_{max} - y}{TV(y)} \]  

(2)

where \( y' \) represents the data [0, 1] after they have been de-quantified, \( y' \) is the data value, \( y_{max} \) is the upper value, and \( TV(y) \) is the target value.

2.3.2. Indicator Normalization

We used the following formula to normalize the indicator index towards meeting an ECC target at the national and provincial levels on a scale of 0 to 100. The specific target value of each indicator was strictly referenced as the developing goals of ecological civilization from the released planning files by the Chinese national administrations, such as the 13th Five-year plan (2016–2020), the water conservancy bulletin, the 13th Five-year Plan for energy (2016–2020), the 13th Five-year Plan for urban transportation (2016–2020), etc. (Equation (3)).

\[ Y = y' \times C \]  

(3)

where \( Y \) is the index [0, 20] of each dimension, and \( C \) is the coefficient of each indicator. Assuming each dimension has a full score of 20 points (the 100 points are equally distributed to the five dimensions), and according to the 8 indicators of social dimension, 5 indicators
of economic dimension, 4 indicators of institutional dimension, 5 indicators of cultural
dimension, and 10 indicators of ecological dimension, the final coefficient of each indicator
in the social indicator is 2.5, the economic indicator is 4, the institutional indicator is 5, the
cultural indicator is 4, and the ecological indicator is 2.

2.4. Aggregated Index Calculation

Summing each indicator value of economy, society, institution, culture, and ecology
obtained the advancement of each dimension. The individual index of each dimension was
calculated by all their indicators (Equation (4)).

\[
\begin{align*}
Y_S &= Y_1 + Y_2 + \cdots + Y_8 \\
Y_E &= Y_9 + Y_{10} + \cdots + Y_{13} \\
Y_I &= Y_{14} + Y_{15} + \cdots + Y_{17} \\
Y_C &= Y_{18} + Y_{19} + \cdots + Y_{22} \\
Y_{Eco} &= Y_{23} + Y_{24} + \cdots + Y_{32}
\end{align*}
\]  

where \( Y_S \) is the social dimensional index, \( Y_E \) is the economic dimensional index, \( Y_I \) is
the institutional dimensional index, \( Y_C \) is the cultural dimensional index, and \( Y_{Eco} \) is the
ecological dimensional index. \( Y_1 \) to \( Y_8 \) are indicators in five dimensions, \( Y_1 \) to \( Y_8 \) are social
indicators, \( Y_9 \) to \( Y_{13} \) are economic indicators, \( Y_{14} \) to \( Y_{17} \) are institutional indicators, \( Y_{18} \) to
\( Y_{22} \) are cultural indicators, and \( Y_{23} \) to \( Y_{32} \) are ecological indicators.

In this study, the weight of the indicators and index were assumed to be the same as
one, that means all the aspects showed by indicators were all significant. The aggregated
index of ecological civilization was generated by the overall index of five dimensions
(Equation (5)).

\[
X = Y_S + Y_E + Y_I + Y_C + Y_{Eco}
\]  

where \( X \) is the aggregated index, \( Y_S \) is the sum of 8 social indicators. \( Y_E \) is the 5 economic
indicators added together, \( Y_I \) is combined with 4 institutional indicators, \( Y_C \) is the total
index of 5 cultural indicators, and \( Y_{Eco} \) is the 10 ecological indicators’ summation.

2.5. Spatiotemporal Pattern Analysis of ECC Development

In this study, the spatiotemporal patterns were addressed from 2005 to 2019 in China
and 31 provinces to characterize the development trajectory of ecological civilization.

2.5.1. Temporal Patterns

In order to facilitate the observation of the developmental stage characteristics of ECC,
we divided the year 2005–2019 into three stages according to the developing spotlight
of ECC. The first stage from 2005 to 2007 was the conceptualization stage, during which
the government and researchers became interested in the definition and discussion of the
concept of ecological civilization; the second stage from 2007 to 2010 was the national
framework stage, during which guiding documents were issued for the construction
of ecological provinces (cities and counties); and the third stage from 2010 to 2019 was
the experimental stage of national/provincial and county demonstration projects, which
gradually began the construction of national ecological demonstration zones. The trajectory
of the national ecological civilization was aggregated and the dimensional indices over
14 years and three stages described the temporal patterns.

We calculated the percentage of each dimension through Equation (5), which was used
to observe the contribution of each dimension for ECC from 2005 to 2019.

\[
P = \frac{Y_{(S,E,I,C,Eco)}}{X_i} \quad (i = 2005, 2006, \ldots 2019)
\]  

where \( P \) is the percentage of each dimension. \( Y_{(S,E,I,C,Eco)} \) are the dimension indices of
society, economy, institution, culture, and ecology. \( X_i \) is the aggregated index from 2005
to 2019.
2.5.2. Spatial Patterns

The 2019 provincial aggregated index and each dimensional index were divided into four levels through the Jenks method: poor, medium, ideal, and good (Table 3), by ranking the aggregated index from low to high. Moreover, ArcGIS 10.6 was used to display the level from poor to good level in red, yellow, blue, and green.

Table 3. Provincial index and each dimension index level in 2019.

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Medium</th>
<th>Ideal</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Society</td>
<td>12.71</td>
<td>12.72–17.16</td>
<td>17.17–17.86</td>
<td>17.87–19.01</td>
</tr>
<tr>
<td>Economy</td>
<td>14.94–16.00</td>
<td>16.01–17.82</td>
<td>17.83–19.04</td>
<td>19.05–19.89</td>
</tr>
<tr>
<td>Institution</td>
<td>8.32–10.13</td>
<td>10.14–14.05</td>
<td>14.06–17.00</td>
<td>17.01–17.87</td>
</tr>
<tr>
<td>Aggregate</td>
<td>61.81–76.17</td>
<td>76.18–85.10</td>
<td>85.11–87.27</td>
<td>87.28–90.20</td>
</tr>
</tbody>
</table>

Analysis of the characteristics of the ranking changes of per capital GDP and ecological civilization.

The observation of the changing characteristics was based on per capital GDP and the ecological civilization aggregated index of the 12 provinces to express the developing features of the economy and ecological civilization. We selected five provinces at the poor level and seven provinces at the good level to observe their per capital GDP during 2019, and provinces with a per capital GDP ranked between 1 and 6 were considered to be provinces with a high economic level, while provinces with a per capital GDP ranked between 7 and 12 were considered to be provinces with a low economic level (Table 4). Finally, we compared the distribution of the aggregation index between 12 provinces with high and low economic levels in 2019.

Table 4. Per capital GDP for the ranking and values of 12 provinces in 2019.

<table>
<thead>
<tr>
<th>High Level</th>
<th>Province</th>
<th>Value (Yuan ¥)</th>
<th>Low Level</th>
<th>Province</th>
<th>Value (Yuan ¥)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BJ</td>
<td>164,220</td>
<td>7</td>
<td>XJ</td>
<td>54,280</td>
</tr>
<tr>
<td>2</td>
<td>SD</td>
<td>70,653</td>
<td>8</td>
<td>NX</td>
<td>54,217</td>
</tr>
<tr>
<td>3</td>
<td>AH</td>
<td>58,496</td>
<td>9</td>
<td>QH</td>
<td>48,981</td>
</tr>
<tr>
<td>4</td>
<td>LN</td>
<td>57,191</td>
<td>10</td>
<td>Tibet</td>
<td>48,902</td>
</tr>
<tr>
<td>5</td>
<td>HI</td>
<td>56,507</td>
<td>11</td>
<td>GZ</td>
<td>46,433</td>
</tr>
<tr>
<td>6</td>
<td>SC</td>
<td>55,774</td>
<td>12</td>
<td>HE</td>
<td>46,348</td>
</tr>
</tbody>
</table>

2.6. Identifying the Effectiveness of Provincial ECC Development at Five Dimensions

Based on the premise that the five dimensions jointly drove the development of ECC, we recognized and identified the key contributions of each dimension to ECC, and therefore two categories of representative provinces were selected. First, we separately chose the top and bottom three provinces based on the 2019 aggregated index ranking of 31 provinces and analyzed the performances and development changes in each dimension for a typical year (2005, 2010, 2015, and 2019). Second, we further considered the different development processes by three typical provinces (rank-rising, rank-falling, and rank-fluctuation) in a hotspot analysis. Among them, we elected the outstanding performance provinces (SD, SH, and XJ) for each type.

3. Results

3.1. Temporal Patterns of National and Provincial Ecological Civilization from 2005 to 2019

China has improved its aggregated index at the national level over time. The national aggregated index of ecological civilization increased by 36.4% from 2005 (index of 67.25) to 2019 (91.7). For the three stages, the aggregated index also rose by 7.61% and 2.56%, respectively, in stage I (2005–2007) and stage II (2007–2010). In particular, a significant
increase of 23.55% was observed in stage III (2010–2019). Behind the overall increase, some specific characteristics were identified at the dimensional level. For example, the social and cultural dimensions maintained an increase through all the stages, the institutional dimension had a marked growth in stage III, and the economic and ecological dimensions rose in volatility (Figure 2a).

Changes in the aggregated index at the provincial level showed similar dynamics as those at the national level. The maximum (Max) values were more densely distributed at the top, while the minimum (Min) values were more distributed in the middle. The maximum and minimum values of the provincial aggregated index separately improved by 22.32% (from 73.74 to 90.2) and 23.13% (from 48.77 to 65.61). The median values of the max and min values were 88.04 and 58.44, and they were separately distributed at the top and in the middle (Figure 3a). The median of the provincial aggregated index continued to rise; likewise, the median increased 23.05% from 2005 to 2019. Although the maximum value kept growing, the growth rate clearly decreased during the year. The aggregated index for the 31 provinces indicated a large disparity between the maximum and minimum values in 2010 and 2019. The differences between the maximum and minimum aggregated indices increased by 20.6% over time (Figure 3b).

Figure 2. The temporal patterns of national ecological civilization from 2005 to 2019; (a) the temporal pattern of the national aggregated index and each dimension index; (b) the contribution rate of each dimension.

Changes in the five-dimensional index also affected their contributions to ECC (Figure 2b). Explicitly, the contributions of social and economic dimensions slightly fluctuated by 1%, the institutional dimension increased by 8% from 2005 (11%) to 2019 (19%), and the cultural and ecological dimensions separately decreased by 3% and 5%. Although the main dimensional contributions of ECC were cultural (22%) and economic (21%), a more balanced trend was depicted with a remarkable increase in the institutional dimension by 2019.
The aggregated performance of the ECC was influenced by five dimensions, the high-level province obtained positive values in relation to the high-level dimensions, and the poor level dimensions had negative effects on poor level provinces. For example, the SD province displayed the ideal level in the social, cultural, and ecological dimensions, and a good level in the economic and institutional dimensions. The SD province had a good level performance on the aggregated index level. Comparably, the QH province exhibited a poor level on the aggregated index level, including a poor level in the cultural dimension, a medium level in the social, economic, and institutional dimensions, and even a good level in the ecological dimension. In conclusion, provinces with an obvious higher level in the five dimensions obtained a good level of aggregated performance, and conversely, poor
level provinces were affected from dimensions with a poor level, and significant disparities appeared in relation to the poor level dimensions (Figure 4).

Figure 4. Spatial patterns of the aggregated dimensions and the five dimensions for 31 Chinese provinces in 2019. (a) The spatial pattern of the provincial aggregated index level in 2019; (b) the ranking situations of the per capital GDP and ECC of 12 provinces; (c) the 31 Chinese provincial social, economic, institutional, cultural, and ecological dimension index level in 2019. Four levels based on the aggregated index and each dimension index related to poor, medium, ideal, and good are separated into red, yellow, blue, and green color. The five poor level provinces and seven good level provinces were selected to analyze the relationship between per capital GDP and ECC. The per capital GDP ranking from 1 to 6 (■) is shown by a purple box and ranking from 7 to 12 (■) is shown by a blue box. The ranking numbers are displayed in ball markers in Figure 4b.

3.3. ECC Performances and the Effectiveness of Six Typical Provinces

Provincial ECC displayed spatial differences (Figure 5a). Around 2005, the aggregated index in east and north China was higher than western and southern China. In particular, the most prominent development disparity and imbalance was estimated in the southwest, except SC which was located at the ideal level. However, in 2010, the number of provinces at the ideal and good level increased, and the number of poor level provinces decreased to five. Most of the good level provinces were located in the east; however, the northwest level declined (QH). In 2015, the number of good and ideal levels continued to increase. In particular, the ideal level of provinces rapidly increased to 16. The eastern coastal region was still leading, and the northeast region kept developing, synchronously, whilst the southwest and northwest regions also had growth. The number of good level provinces was raised to seven, and the number of poor levels stayed at five in 2019. The level of
sustainability; nevertheless, some provinces (HN, FJ, and CQ) dropped their levels from ideal to medium.

In order to identify the effectiveness of the five dimensions for ECC development, we further compared the top three (SD, AH, HE) and bottom three (QH, HI, Tibet) provinces. Six provinces revealed advances, each dimensional index had various degrees of enhancement, with the top three provinces in particular able to become close to the targets and tended to be comprehensive and jointly progressive until 2019. Among them, the top three provinces had a greater advantage in the cultural dimension, whereas the bottom three provinces paid more attention on the economic dimension in 2005. The distinctive difference appeared in the cultural dimension in 2005, and there was almost no difference in the economy. The institutional dimension reflected larger distances in 2010, and the economic dimensional difference narrowed further. The top provinces expanded their advantages in both the cultural and political dimensions; on the contrary, the bottom provinces had a small development in the social dimension. In 2015, the difference continued to reduce, the institutional and cultural dimensional differences remained obvious, besides economic dimension had increased. The differences in each dimension exhibited different degrees of expansion in 2019, and the bottom provinces regressed in the political dimension, followed by the cultural and social dimensions (Figure 5b). The top provinces had apparent advantages, while the bottom provinces had clear difficulties improving their levels. It is necessary to raise the comprehensive development of ECC following an orderly manner.

As shown in Figure 5b, each dimension in the top provinces had efficient advancement except ecological dimension. The political and social dimensions stayed at the lower level,
and conversely the cultural dimension had the best level in 2005. By 2019, the economic and cultural dimensions had the highest level, the political dimension had absolute progress, the social dimension gradually approached the development goal, and the ecological dimension was lagging behind compared with the other four dimensions. When we observed the trajectory of each dimensional level in the bottom provinces, it revealed a contrasting performance. The economic dimension was ahead of the other four dimensions in 2005, the social, ecological, and political dimensions had significant improvement in 2015, the political dimension broadened slowly, and one of the bottom provinces (Tibet) declined in relation to the social and ecological dimension in 2019.

3.4. Five Dimensional Contributions of Three Typical Provinces

The hotspot analysis summarized three varieties of provinces as rank-rising (HE and SD et al.), rank-falling (TJ and XJ et al.), and rank-fluctuation (IM and SH et al.) by the provincial aggregated index ranking (Figure 6a). The aggregated index of BJ had a fluctuation which relied on its improvement of the five-dimensional index. In particular, the significant increase in the institutional dimensional index because of BJ had good initiatives related to the implementation of ECC. IM had a large fluctuation in the ranking of the aggregated index from high to low, and each dimensional index had small increases. The ecological dimension obtained a good foundation; however, an obviously decline occurred in relation to the cultural and ecological dimensions from 2014. The ranking of JX displayed a large fluctuation from low to high with clear increases in the five-dimensional indices, particularly in the economic and institutional dimensions. The ranking of the aggregated index rose rapidly since the institutional dimension grew noticeably from 2011 to 2012. HE and NX were more stable in the leading and lagging provinces, respectively. HE maintained growth in the economic, institutional, and social dimensions, and the cultural dimension index kept full score. The aggregated index of NX continued to lag from 2005 to 2019. Due to the serious ecological pollution, the ecological dimensional index dropped lower than other provinces.

![Figure 6](image_url)

**Figure 6.** (a) Ranking changes of the aggregated index for 31 Chinese provinces from 2005 to 2019; (b) aggregated index and five-dimensional contributions for three typical provinces (SD, SH, XJ) from 2005 to 2019.

Although the change in the provincial aggregated index had no absolute influences on the ranking situation, the performance of the ECC can be effectively improved by the joint drive of the five dimensions. The aggregated index and each dimension in SD basically maintained growth; despite a minor decrease in 2014 and 2017, the ranking never changed obviously. SD increased its aggregated index by 27.49% from 2005 (70.75) to 2019 (90.2). In particular, SD was prominent in the cultural and ecological dimension,
and the institutional dimension was lagging relatively, forming a balanced pattern of all dimensions by 2019. By contrast, the aggregated index and five dimensions of SH were not stable, while a significant increase appeared in 2011, a major turning point of decrease in 2015, which led to the ranking dropping out of the top 20. SH mainly enhanced the aggregated index based on the economic, institutional, and social dimensions; however, the inefficient progress of the ecological and economic dimensions eventually generated an imbalance of ECC development. The third situation was the aggregated index and each dimension index which fluctuated widely in XJ, with sudden fluctuations in 2008 and 2011. Under the slight growth of social, cultural, and ecological dimensions, the economic and institutional dimensions’ disparities ultimately contributed to the fall behind other provinces (Figure 6b).

4. Discussion and Conclusions

This study estimated the spatiotemporal performance of ECC in the national and provincial levels through a five-dimensional evaluation index. At the national level, factors such as official support for ecological civilization investment and innovation in science provided a significant acceleration in the national ECC framework at each stage. In the conceptualization stage, the development of institutional and economic dimensions were the important influences that enhanced the ECC. In the national framework stage, the influence of the ecological dimension gradually appeared. Since 2010, China entered the national/provincial and county demonstration projects stage of ECC, and the aggregated index began to accelerate the promotion, whilst the government efficiently improved the policies and management procedures during this time [57–59].

This study also accords with previous observations, which reported that the level of eco-civilization in the eastern part of China was higher than most regions in the western part, and the southern part was higher than the northern part. The higher level of eco-civilization was concentrated in the coastal areas, while the lower level gathered in the western part [26,31,32,57]. Uneven spatial patterns of national ECC were driven by various variables, including developing and implementing policies with varying regional consequences, geographical circumstances, climate, and infrastructure [60]. The economic, technological, and institutional advantages of east China supported the leadership in ECC, and the differences in energy, resource, and environment between regions caused the uncoordinated performance of regional ECC in dimensions such as economy, society, and environment, which eventually influenced the differentiation of spatial ECC [61–63]. Taken together, the results of this study indicate that national ECC had general enhancement in temporal patterns; however, there were obvious regional disparities in spatial patterns.

Provincial ECC revealed the dynamic adjustment through a comparison with the development and ranking changes. Most provinces displayed an upward trend of ECC, and one unanticipated finding was that the existing demonstration provinces (SD, GZ, JX et al.) improved significantly, indicating that the path of demonstration construction is feasible. Therefore, the government should continue to encourage and promote the demonstration construction of ECC. The development advantage of top provinces was maintained in continuous progress, and conversely, relying on the basic advantage was unsustainable. The bottom provinces should never give up on innovation and breakthroughs. Meanwhile, support and cooperation between the backward and leading regions should be strengthened. In contrast, the development space of the backward provinces was sufficient; however, they principally improved their development capacity and efficiency by clarifying the development path. Because of the development differences of provinces in various dimensions, we suggest that the development of backward provinces is optimized in an orderly manner and that the development disparities are shortened by prioritizing the dimensional distinction from difficult to easy. For example, in this paper, the bottom provinces firstly developed the institution, then improved the social and cultural levels during the second step, and thirdly built up the economy and ecology.
The economic development had a significant enhancing effect on ECC based on the observation of per capita GDP and the ECC aggregated index. A strong positive relationship between the economy and ECC has been reported in the literature; however, several previous studies evaluating the association observed an inconsistent result. These findings cannot be extrapolated to all provinces, we also detected that several provinces had the opposite situation, and this inconsistency may have been due to the negative impact of economic growth on severe ecological damage and the increased consumption of energy and resources leading to imbalanced development [28,33,64–67]. The conclusion indicated that with economic development, the effect of ECC was not the same in each province. It is necessary to develop differentiated roadmaps and implementation plans for ECC. ECC should pay more attention to promote other dimensions such as society and culture [68,69], and emphasizing the coordination of multiple dimensions after a certain degree of economic development.

This study provided spatiotemporal patterns of aggregated and five dimensions at national and provincial level. We clarified the current development status and path characteristics of China and its 31 provinces, and at the same time, grasped the core of the promotion of ecological civilization. As one of the major developing countries, the Chinese experience in the construction of ecological civilization has shown significant progress in environmental protection and ecology. Therefore, China can act as a development reference and suggestion for other countries to provide a feasible solution for the world to solve environmental crises jointly and stay in the safe doughnut.

However, limitations exist and represent important future research needs. Being limited by the resource categories of the national resource database, we only selected five-dimensional indicators in this paper, and the conclusions drawn are not necessarily comprehensive. In addition, the selected indicators do not consider others available at this stage, and the evaluation method was relatively brief, so the results obtained may not be accurate. In the future, more comprehensive resource data and a better indicator system will produce more accurate and time-sensitive results. Subsequent studies could delve into the impact of each specific indicator under the five-dimensional model and establish a more multidimensional national and provincial evaluation system to explore and compare the reasonable scenarios of ECC in each province with a more systematic perspective.

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