



# Global Sustainable Development Evaluation Methods With Multiple-Dimensional: Sustainable Development Index

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Sustainable development has become a new goal of world development, and the measurement of sustainable development level is an important issue. This article introduces indicators of land ecology and allocation to establish a sustainable development index (SDI) including two levels of indicators. Based on the data research of SDI 2019 of 188 countries (regions), we conclude as follows: 1) the ranking of oil-producing countries fell sharply because of land ecological deterioration and single industrial structure; 2) the ranking of Southeast Asian and East African countries (regions) progressed because of ecological protection; 3) most developing countries (regions) have excellent performance on ecological protection, and the main reason for changing their ranking is the inequality of land allocation. Emerging countries, such as China and Russia, also have these problems in their rapid development. We suggest that countries (regions), especially countries (regions) that rely heavily on resource extraction, should pay attention to land ecological protection, and developed and emerging countries (regions) should optimize land allocation. The main contribution of this article is to provide a new solution and ideas for the measurement of sustainable development by improving the indicator system.

**Keywords:** sustainable development index, land ecological protection, inequality, balanced development, sustainable development assessment

## 1 INTRODUCTION

Sustainable development has been an important issue in today's world, but there is still no recognized method to measure the level of sustainable development. The United Nations issued Sustainable Development Goals (SDGs) in 2015 (United Nations Sustainable Development Summit, 2015), and it contains 17 sustainable development goals in three dimensions: environment, economy, and society (17 Goals to Transform Our World, 2021). Each goal contains some indicators to show the completion of countries (regions) around the world. Unfortunately, the United Nations only published these data and failed to form a sustainable development index. The most important reason is that most indicators are incomplete and lack data from many countries (regions).

The United Nations still use the Human Development Index (HDI) as a primary reference to measure the national development level. As time goes by, the defects of HDI become more and more obvious. On the one hand, the HDI seems to be a redundant index because it is no comparison in time and space (Srinivasan, 1994) and is significantly positively correlated with each component variable (Kelley, 1991; McGillivray, 1991; McGillivray and White, 1993; Islam, 1995; Anand and Sen,

2000; Cahill, 2005; Klugman et al., 2011). On the other hand, the HDI does not consider the contributions to sustainable development (Lind, 1992; Ivanova et al., 1999; Morse, 2003a; Moran et al., 2008; Togtokh, 2011; Bilbao-Ubillos, 2013; Biggeri and Mauro, 2018).

Scholars dedicate to improving HDI from three directions to measure sustainable development. Regarding the first direction, scholars introduced per capita carbon emission, a new indicator, to the HDI, which is called the Human Sustainable Development Index (HSDI) (Togtokh, 2011; Bravo, 2014). It is found that the HSDI rankings of the United States, Australia, Canada, and oil-producing countries have greatly regressed compared with HDI. However, HSDI still has a strong correlation with HDI (Bravo, 2014), probably because HSDI lacks more indicators of environmental sustainability. Environmental sustainability contains not only climate factors but also land ecology, air quality, and other factors.

Regarding the second direction, scholars introduce a comprehensive environmental index combined with HDI (Costantini and Monni, 2005; Hickel, 2020), such as the Ecological Footprint Human Development Index (EFHDI) (Morse, 2003a) and the Environmental Human Development Index (EHDI) (Maccari, 2014). Ecological Footprints (EF) (Wackernagel and Rees, 1997) and the Environmental Performance Index (EPI) (EPI, 2012) are comprehensive environmental indicators, in addition to per capita carbon emission, including land ecological indicators such as forest coverage and nature reserves area. This method makes up for the defects of HSDI, but it also brings more problems. First, indicators of EPI and EF are difficult to collect and cover too few countries, which is not conducive to the promotion. Second, both HDI and HSDI consider that all indicators have equal weight and nonlinear substitution. But the weight of each indicator of EPI is different, and the indicators of EF are a linear summation. Therefore, the calculation methods of EF and EPI conflict with the concept of HDI (HSDI). Third, EF and EPI are comprehensive indicators, while health, education, and per capita income are only single indicators, and this combination will lead to the problem of index level mismatch. Index level mismatch would make it more difficult to improve the score of the environmental dimension over the social and economic dimensions. In other words, the country can easily improve on the score of the economic dimension solely by adjusting per capita income, but the score of the environmental dimension needs to be improved with multiple indicators, which may reduce the country's motivation for environmental construction.

Regarding the third direction, scholars directly select some indicators and combine them into an index (Ranis et al., 2006; Distaso, 2007; Bilbao-Ubillos, 2013; Liang et al., 2019; Singh et al., 2021). Although this method enriches the number of indicators, it is easy to raise problems of overweighting certain factors in the economy, environment, and society. For example, there is only one environmental indicator in the index established by Distaso, which is inappropriate for countries (regions) with good environmental construction (Distaso, 2007). In addition, as the number of indicators increases, the number of countries (regions)

that meet the requirement decreases. The sustainable development index which covers only dozens of countries (regions) is not conducive to popularization (Liang et al., 2019; Singh et al., 2021).

The purpose of this study is to establish a multidimensional global sustainable development evaluation system. A multidimensional evaluation system can make up for the shortcomings of the existing index and accurately measure the sustainable development level of countries around the world. Meanwhile, the sustainable development index can make countries pay more attention to sustainable development than economic growth, and the ranking of the index and indicators can provide policy suggestions for improving the level of sustainable development. We will also study the differences between countries at different stages of development, identify common problems in sustainable development in these countries, and provide inspiration and references for countries that are about to enter a certain stage.

In general, we should not just add indicators or composite indexes to establish a new index; rationality, comparability, popularization, and representativeness also need to be considered. Therefore, we have collected and compared more than one hundred indicators and finally selected 15 indicators to establish a new Sustainable Development Index (SDI) with two levels of indicators. The contributions of this article can be summarized as follows: 1) we have improved the measurement of sustainable development by adding several indicators, which provide a new solution and ideas for the measurement of sustainable development. 2) We have added a land resource allocation factor to the Sustainable Development Index. 3) The existing sustainability index is either insufficient in the number of indicators or insufficient in the number of countries. We have considered comparability and balance in the establishment of SDI and ensured that SDI could cover 188 countries while increasing the number of indicators.

In the rest of this article, the second section introduces the selection of indicators; the third section introduces index calculation methods and data normalization; the fourth section shows the performance of SDI; and the fifth section gives the conclusion and prospects.

## 2 LITERATURE REVIEW

The key to establishing a sustainable development index is how to select the sustainable development assessment dimensions. We combined existing research studies on the dimension of sustainable development and added some indicators collected by ourselves. To evaluate the country's sustainable development level more comprehensively and realistically, we propose to establish an indicator system. The new system contains two levels of indicators (Huan et al., 2021). The first-level indicators contain society, economy, and environment, as recognized by studies (Carlucci and Pisani, 1995; Barrera-Roldán and Saldívar-Valdés, 2002; Lamichhane et al., 2021). The purpose of establishing two-level indicators is to ensure that

the weight of each dimension is equal. This section mainly discusses the basis for the selection of second-level indicators.

## 2.1 Environmental Dimension

Climate is critical to environmental sustainability (Guest, 2010; Peeters et al., 2013; Gough, 2015); urgent action to tackle climate change and its impacts is one of the UN SDGs, and 75 countries (regions) commit to zero emissions by 2050 (Climate Action Summit, 2019). Therefore, we introduce per capita carbon emissions as a second-level indicator, which is the same as the improvement of HSDI (Togtokh, 2011; Bravo, 2014). However, it is not enough for environmental sustainability to consider only climate factors; we also need to consider land ecological factors such as water, soil, forests, and biodiversity in the SDI (Neumayer, 2001; Beça and Santos, 2010). Sustainable utilization of land resources is an important method to maintain land ecological stability (Brulé, 2022). The sustainable use of land resources requires the coordinated development of the environment, resources, population, and economy, which all determine that land ecological indicators are an indispensable part of the sustainable development index (Gupta and Bharat, 2022). Regarding the water resource, we replace “water quality evaluation indicators” with a relatively complete indicator of “maximum water extent” because the existing “water quality evaluation indicators” are seriously deficient, and water coverage is more important to the land ecosystem. Regarding biodiversity, it is inappropriate to measure biodiversity by the number of species, which has a great correlation with the national area. We chose “proportion of land protected area” to encourage countries (regions) to protect species diversity. As of 2016, 90 percent of urban residents breathed unsafety air, and 4.2 million people died from air pollution (Goal 11, 2021), indicating air quality has a major impact on human health. Therefore, we choose “mean population exposure to PM<sub>2.5</sub>” to measure a country’s air quality. Finally, forest coverage is an indicator recognized by most studies (Carlucci and Pisani, 1995; Bravo, 2014; UNDP, 2020a).

## 2.2 Social Dimension

From HDI and HSDI, we select life expectancy at birth, expected years of schooling, and mean years of schooling as indicators of health and education, respectively. Using life expectancy would lead to a higher score in aging countries (regions) (Herrero et al., 2019). If the population of these countries (regions) continues to grow negatively, it does not meet the requirements of sustainable development, so population dynamics need to be considered. However, it is difficult for us to formulate a standard to record the population growth rate. We finally use the mortality of newborns to measure the sustainability of a country’s population (Goal 3, 2021) because a country with a high neonatal mortality rate is not sustainable in population even if its population growth rate is high. In other words, reducing the neonatal mortality rate is more important than human reproductivity (Streeten, 1994). The land ecosystem will be excessively destroyed due to population growth too fast.

Failure to consider the inequality is another problem of HDI and HSDI (Foster et al., 2005; Dervis and Klugman, 2011). Some

scholars have improved the income indicator of HDI by adding inequality factors (Anand and Sen, 1994; Anand and Sen, 1997; Hicks, 1997; Grimm et al., 2008; Harttgen and Klasen, 2012). UNDP has also adjusted income indicators using the Atkinson family of inequality measures. The purpose of introducing the income indicator is to measure the quality of life (Easterly, 1999), but the adjustment of the previous studies seems to have excessively narrowed the gap between high-income countries (regions) and low-income countries on the income indicator (Trabold-Nübler, 1991; Gormely, 1995; Noorbakhsh, 1998; Sagar and Najam, 1998). The adjusted income indicator does not truly reflect a country’s living standards, and UNDP canceled this approach accordingly. Therefore, this article introduces the property Gini coefficient in addition to GNI per capita to not only reflect the real living standard of the country but also take inequality into account. There are two main reasons for this choice. First, income allocation inequality has been studied by many scholars, and we are more concerned about the impact of property allocation, especially land allocation, on sustainable development. Second, the income Gini coefficient lacks data for many countries (regions), and the property Gini coefficient is more comprehensive. In addition, sustainable development requires the elimination of poverty, and the employment rate is introduced to measure its achievements in poverty reduction (Osberg and Sharpe, 2002; Mihci et al., 2012).

## 2.3 Economic Dimension

The limitations of per capita GNI in measuring living standards are mentioned earlier, and there are also limitations in measuring economic development. First, GNI per capita cannot measure the potential of economic development. As an example, China has maintained rapid economic development over the past 30 years, and the growth trend continues. However, due to the large population base, China’s GNI per capita is relatively low. In contrast, considering the low or negative economic growth of some high-income countries (regions), it is inappropriate to solely consider the income level for rapidly developing emerging countries because sustainable economic growth is in line with sustainable goals. Therefore, we introduce the GDP growth rate to measure the country’s potential for economic development. Second, some countries benefit from energy and mineral exports to maintain high-income levels (Neumayer, 2012). These industries have high energy consumption, lack diversity, and destroy the land ecosystem. Energy consumption and concentration indicators should be introduced to solve these problems that cannot be measured by GNI per capita (Yumashev et al., 2020). Third, GNI per capita cannot measure the quality of a country’s economic development (Ravallion, 1997). The ability of technological innovation and industrial upgrading is crucial to the sustainable development of the economy. An indicator that can represent the ability of technological innovation and industrial upgrading is the number of patent applications. However, due to the serious lack of data on the number of patent applications, it cannot be used as an index. After comparing some indicators, we finally chose the Internet penetration rate to represent a country’s technological innovation and transformation and upgrading capabilities.

**TABLE 1** | Description of first-level and second-level indicators of SDI.

First-level indicators	Second-level indicators	Unit	Connotation	Effect
Environment	Mean population exposure to PM2.5	Mcg/m2	Air quality	Negative
	Per capita carbon emissions	Ton/p	Sustainability of climate	Negative
	Forest coverage	%	Sustainability of forest resources	Positive
	Maximum water extent	%	Sustainability of water resources	Positive
	Proportion of land protected area	%	Species diversity	Positive
Economy	Internet penetration	%	Information level	Positive
	Concentration index	-	Industrial structure	Negative
	GDP per ton of carbon emissions	USD/ton	Production efficiency	Positive
	Per capita GDP growth rate	%	Economic development potential	Positive
	Per capita GNI-PPP	USD	Living standard	Positive
Society	Property Gini coefficient	-	Inequality	Negative
	Expected and mean years of schooling	Year	Education	Positive
	Unemployment rate	%	Employment	Negative
	Neonatal mortality rate	%	Sustainability of population	Negative
	Life expectancy at birth	Year	Health	Positive

① Concentration index, per capita GNI-PPP, expected and mean years of schooling, and life expectancy at birth data from the human development report. ② Forest coverage, proportion of land protected area, Internet penetration, per capita GDP growth rate, unemployment rate, and neonatal mortality rate data from the World Bank (<https://data.worldbank.org/>). ③ Mean population exposure to PM2.5 and maximum water extent data from OECD (<https://www.oecd.org/>). ④ GDP per ton of carbon emissions = GDP/total carbon emissions, GDP data from the World Bank, per capita carbon emissions, and total carbon emissions data from Global Carbon Project (<https://www.globalcarbonproject.org/>). ⑤ Property Gini coefficient data from the Global Wealth Databook. ⑥ Interpolation method is used for missing data, including regional regression, average, and substitution. The interpolation method refers to the HDR.

There are two reasons for choosing this indicator: first, in the information age, the Internet penetration rate represents the potential of a country to move from traditional handicraft agriculture and manufacturing to the technology industry; second, the data set is complete and suitable for use as a composition of the index.

## 2.4. Summary

We have selected three first-level indicators and fifteen second-level indicators. Each first-level indicator contains five second-level indicators (Table 1). “Per capita carbon emissions,” “per capita GNI-PPP,” “expected and mean years of schooling,” and “life expectancy at birth” are already included in HSDI; “forest coverage,” “maximum water extent,” “proportion of land protected area,” “GDP per ton of carbon emissions,” “concentration index,” and “property Gini coefficient” are selected to measuring land ecology and allocation, and these are key indicators of this article. The remaining indicators are used to measure other sustainable development factors to ensure that the weights of the three dimensions are the same. In addition, we believe that as a global index, and its indicators should be publicly available and include as many countries as possible, which is conducive to popularization.

## 3 MATERIALS AND METHODS

### 3.1 Calculation of SDI

Both the SDI and the first-level indicators are calculated by the geometric mean method as follows:

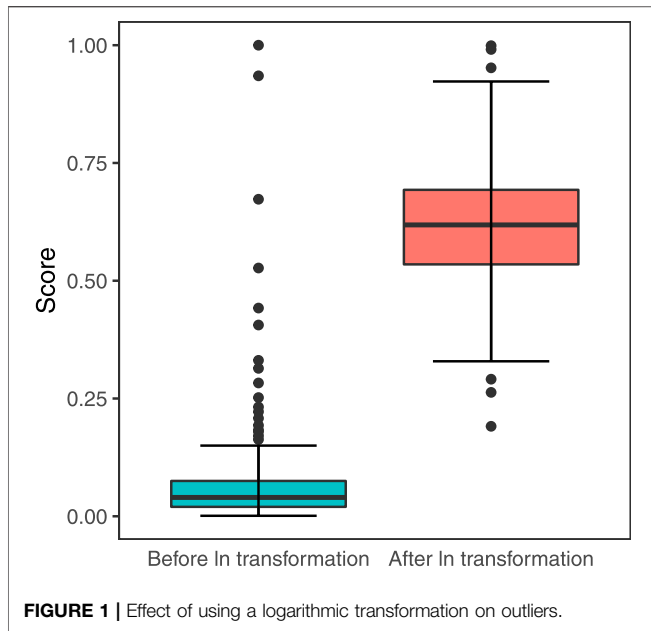
$$SDI = \sqrt[3]{I_{society} \cdot I_{economy} \cdot I_{environment}} \quad (1)$$

$$I_{society} = \sqrt[5]{I_{education} \cdot I_{health} \cdot I_{employment} \cdot I_{population} \cdot I_{inequality}} \quad (2)$$

Calculation methods of  $I_{economy}$  and  $I_{environment}$  are the same as  $I_{society}$ . There are conflicts between innovation, comparability, and generalizability in the selection of index calculation methods. Adopting the new calculation method would make the different indices not comparable, and complex calculation methods would reduce the generalizability of indices (Morse, 2003b). At present, HDI is still the most recognized composite index because of its simple calculation method and index system. Therefore, we believe that the innovation of establishing the index should be reflected in the establishment of the index system, and the calculation method should be comparable and generalizable (Neumayer, 2001; Morse, 2003a; Maccari, 2014).

As the SDGs raise the importance of balanced development, there should be a nonlinear substitution relationship between indicators. The geometric mean method can ensure that the weight of each level of indicator is the same and penalizes countries (regions) with unbalanced development (Herrero et al., 2010; UNDP, 2010; Herrero et al., 2012; Ravallion, 2012; Zambrano, 2014). These are the advantages of using the geometric mean method to calculate the SDI. Meanwhile, we have established a secondary index system, which is an innovation in the application of calculation methods. This system makes the assessment of SDI accurate and unbiased, and countries have more data for reference in sustainable development construction.

In general, the geometric mean method is suitable to calculate SDI. First, it solved the conflict caused by the new calculation method. Second, it was combined with the secondary index system to make the evaluation accurate and unbiased. Third, it met the requirements and connotation of sustainable development.



### 3.2 Normalization of Indicators

All second-level indicators need to be normalized to eliminate dimensional discrepancy, and the normalization equations are as follows:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}}, \tag{3}$$

$$x' = \frac{x_{max} - x}{x_{max} - x_{min}}, \tag{4}$$

Equations 3 and 4 apply to positive and negative indicators, respectively, and the standardized indicators are within the interval (0,1). However, the geometric mean method with a standardized indicator of zero would result in an SDI score of zero. We need to set a minimum value to ensure that all standardized indicators are within the interval (0,1), and the

upper limit also needs to be set (UNDP, 2020b). The specific maximum and minimum values and index calculation processes are shown in Section 3.3.

The max-min normalization method is not suitable for indicators with extreme values, and we need to process these indicators with logarithmic transformation before normalization. Figure 1 shows that after logarithmic transformation, the score distribution of maximum water extent becomes more reasonable (Aguña and Kovacevic, 2010).

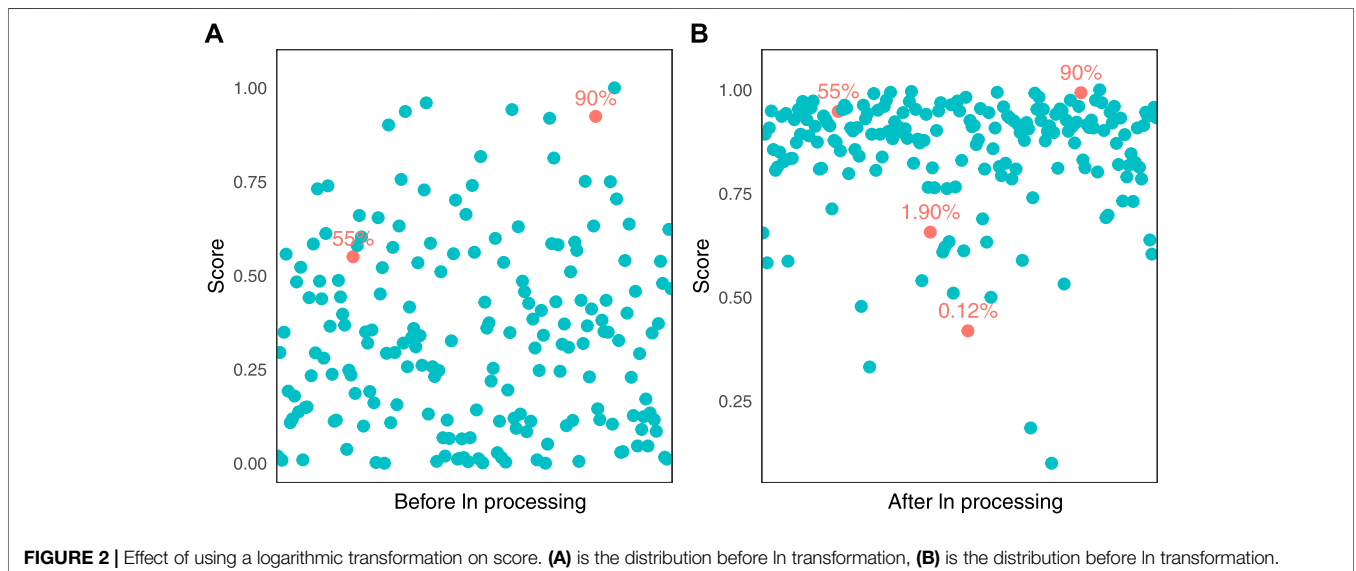
Logarithmic transformation can also reduce the margins of land ecological indicators such as forest coverage. The endowment of forest resources is related to the country’s geographic location, and some countries (regions) have a natural coverage rate of 90%, while others suffer from a coverage rate from 1 to 10%. Therefore, it is inappropriate to give a score of 10 and 90 to countries (regions) with a forest coverage rate of 10% and 90%. Figures 2A and B show that logarithmic transformation reduces the score gap between 55% and 90%, and the bonus points obtained from 0.12% to 1.9% are far greater than the bonus points from 55% to 90%. Logarithmic transformation effectively prevents excessive punishment of countries (regions) with insufficient resource endowments. In addition, it is necessary to ensure that all values are greater than one before the logarithmic transformation.

### 3.3 Goalposts Selection and Calculation Process

The specific maximum and minimum values are called goalposts, which are an important part of the standardization of index establishment. This section will present an example of index calculation and describe how we select goalposts. The calculation of SDI is divided into three parts: normalization of the indicators, calculation of first-level indicators, and calculation of SDI.

First, the normalization method uses Equations (3) and (4). The results are as follows:

$$\text{Mean population exposure to PM}_{2.5} = \frac{100 - 47.7}{100 - 0} = 0.523, \tag{5}$$



$$\text{Per capita carbon emissions} = \frac{50 - 7.09}{50 - 0} = 0.858, \quad (6)$$

$$\text{Forest coverage} = \frac{\ln(22.94 \cdot 1000) - \ln(1)}{\ln(98 \cdot 1000) - \ln(1)} = 0.874, \quad (7)$$

$$\text{Maximum water extent} = \frac{\ln(2.58 \cdot 100) - \ln(1)}{\ln(47 \cdot 100) - \ln(1)} = 0.657, \quad (8)$$

$$\begin{aligned} \text{Proportion of land protected area} &= \frac{\ln(15.45 \cdot 100) - \ln(1)}{\ln(55 \cdot 100) - \ln(1)} \\ &= 0.853, \end{aligned} \quad (9)$$

$$\text{Internet penetration} = \frac{\ln(62.8) - \ln(1)}{\ln(100) - \ln(1)} = 0.899, \quad (10)$$

$$\text{Concentration index} = \frac{1 - 0.094}{1 - 0} = 0.906, \quad (11)$$

$$\begin{aligned} \text{GDP per ton of carbon emissions} &= \frac{\ln(1405.4) - \ln(100)}{\ln(20000) - \ln(100)} \\ &= 0.499, \end{aligned} \quad (12)$$

$$\text{Per capita GDP growth rate} = \frac{5.57 - (-20)}{10 - (-20)} = 0.852, \quad (13)$$

$$\text{Per capita GNI - PPP} = \frac{\ln(16057) - \ln(100)}{\ln(75000) - \ln(100)} = 0.767, \quad (14)$$

$$\text{Property Gini coefficient} = \frac{100 - 75.14}{100 - 55} = 0.552, \quad (15)$$

$$\begin{aligned} \text{Expected and mean years of schooling} &= \frac{1}{2} \left( \frac{14 - 0}{18 - 0} + \frac{8.1 - 0}{15 - 0} \right) \\ &= 0.657, \end{aligned} \quad (16)$$

$$\text{Unemployment rate} = \frac{30 - 4.6}{30 - 0} = 0.847, \quad (17)$$

$$\text{Neonatal mortality rate} = \frac{100 - 3.9}{100 - 0} = 0.961, \quad (18)$$

$$\text{Life expectancy at birth} = \frac{76.9 - 20}{85 - 20} = 0.876, \quad (19)$$

The Human Development Report gives an approach to setting goalposts. Regarding the minimum (UNDP, 2020a), they could be set to “natural zeros”; Regarding the maximum, they could be set to observed maximum values. However, for the negative indicators, the minimum and maximum have opposite meanings.

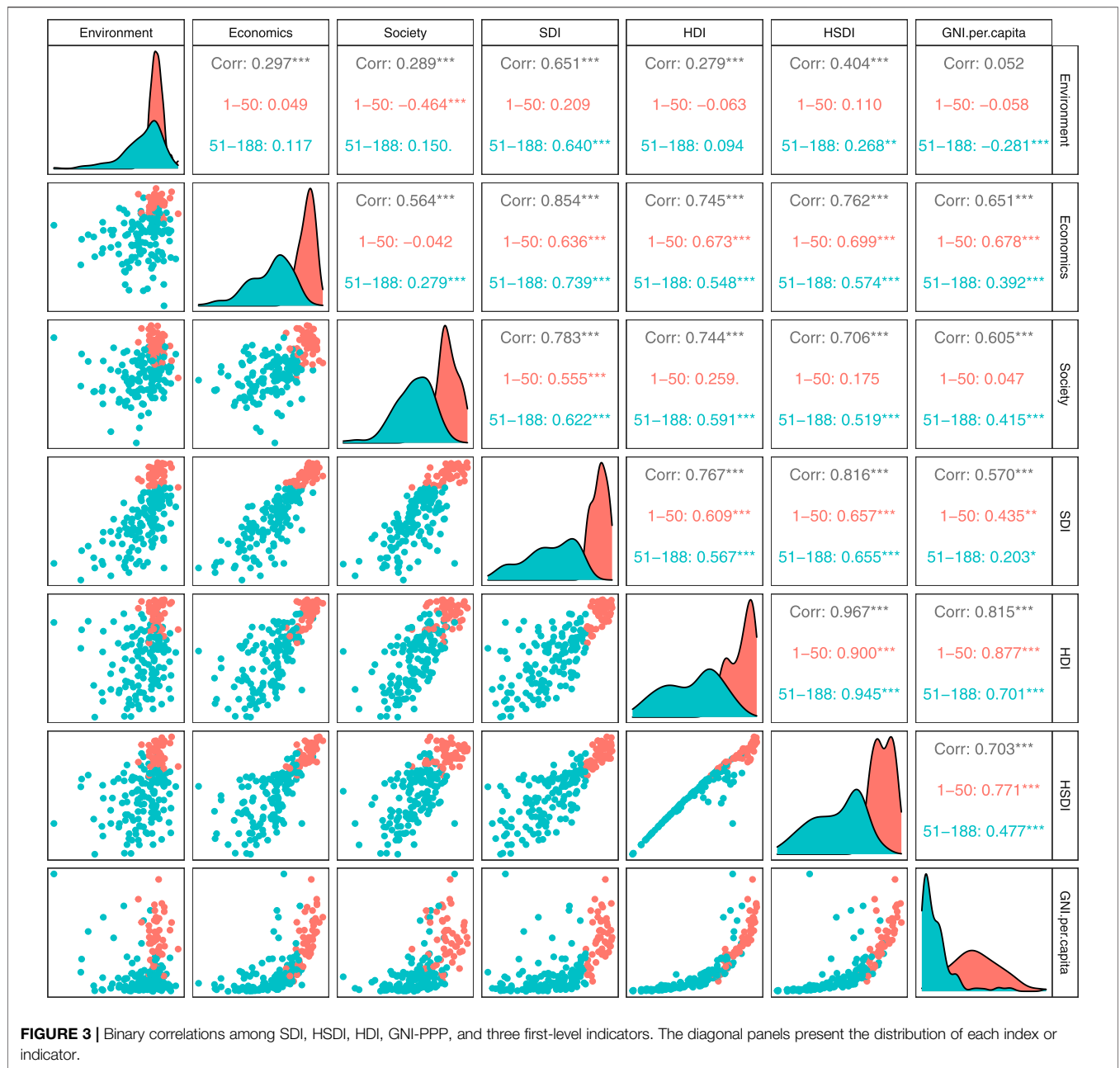
The goalposts of Eqs 6 and 14, 16, and 19 are the same as HDI and HSDI. In Eqs 7 and 8, 9, and 10, the maximum is set to the highest observed value in the 2015–2019 period and the minimum is set to 1. In Eqs 5, 17, the maximum is set to the highest observed value in the 2015–2019 period and the minimum is set to zero. Eq. 13 refers to the HDR method, and the maximum value is 20,000 (only one country exceeds the \$20,000 GDP per ton of carbon emission ceiling), and the minimum is set to a quarter of the 5-year minimum. In Eq. 15, the maximum is set to 100 (maximum Gini coefficient), and the minimum is set to the lowest observed value in the 2015–2019 period. In Eq. 13, the maximum is set to 10 and the minimum is set to -20, which excludes extreme values. The concentration index is within the interval (0,1); therefore, we select 1 as the maximum and the minimum is set to zero in Eq. 11. The unit of neonatal mortality rate is permillage; therefore, we select 100 as the maximum and the minimum is set to zero in Eq. 18.

The max-min normalization method will be controversial in the selection of goalposts. Although the HDR gives the basis for the selection of goalposts, the ranges of these indicators will change over time. Therefore, this article suggests that we can only select the goalposts as objectively as possible, and then do not replace the goalposts within 5 years so that SDI is comparable in time. In addition, SDI selects more indicators so that the sensitivity of the SDI scores to the goalposts is reduced, and the ranges of three first-level indicators are reasonable (Table 2).

Second, by taking the results of Eqs 5 and 6, 7, 8, and 9 into Eq. 2, we can get the score of environmental sustainability:

**TABLE 2 |** The statistical description of indicators after normalization.

Indicators	Maximum	Minimum	Average	Std. deviation
Mean population exposure to PM2.5	0.944	0.167	0.724	0.178
Per capita carbon emissions	0.999	0.228	0.909	0.113
Forest coverage	1.000	0.100	0.852	0.142
Maximum water extent	0.999	0.191	0.614	0.132
Proportion of land protected area	0.998	0.185	0.816	0.136
Internet penetration	0.999	0.058	0.815	0.181
Concentration index	0.947	0.052	0.671	0.207
GDP per ton of carbon emissions	1.000	0.143	0.629	0.143
Per capita GDP growth rate	1.000	0.050	0.713	0.112
Per capita GNI-PPP	1.000	0.305	0.713	0.173
Property Gini coefficient	1.000	0.206	0.602	0.161
Expected and mean years of schooling	1.000	0.249	0.660	0.175
Unemployment rate	0.996	0.051	0.771	0.172
Neonatal mortality rate	0.992	0.572	0.874	0.104
Life expectancy at birth	0.998	0.512	0.810	0.114
Environment (first level)	0.925	0.301	0.764	0.096
Economy (first level)	0.894	0.301	0.689	0.119
Society (first level)	0.917	0.384	0.723	0.098



**FIGURE 3 |** Binary correlations among SDI, HSDI, HDI, GNI-PPP, and three first-level indicators. The diagonal panels present the distribution of each index or indicator.

$$I_{environment} = \sqrt[3]{0.523 \cdot 0.858 \cdot 0.874 \cdot 0.657 \cdot 0.853} = 0.738. \quad (20)$$

By taking the results of Eqs 10 and 11, 12, 13, and 14 into Eq. 2, we can get the score of economic sustainability:

$$I_{economy} = \sqrt[3]{0.899 \cdot 0.906 \cdot 0.499 \cdot 0.852 \cdot 0.767} = 0.767. \quad (21)$$

By taking the results of Eqs 15 and 16, 17, 18, and 19 into Eq. 2, we can get the score of social sustainability:

$$I_{society} = \sqrt[3]{0.552 \cdot 0.657 \cdot 0.847 \cdot 0.961 \cdot 0.876} = 0.763. \quad (22)$$

Third, by taking the results of Eqs 20, 21, and 22 into Eq. 1, we can get the score of SDI:

$$SDI = \sqrt[3]{0.738 \cdot 0.767 \cdot 0.763} = 0.756. \quad (23)$$

## 4 RESULTS AND DISCUSSION

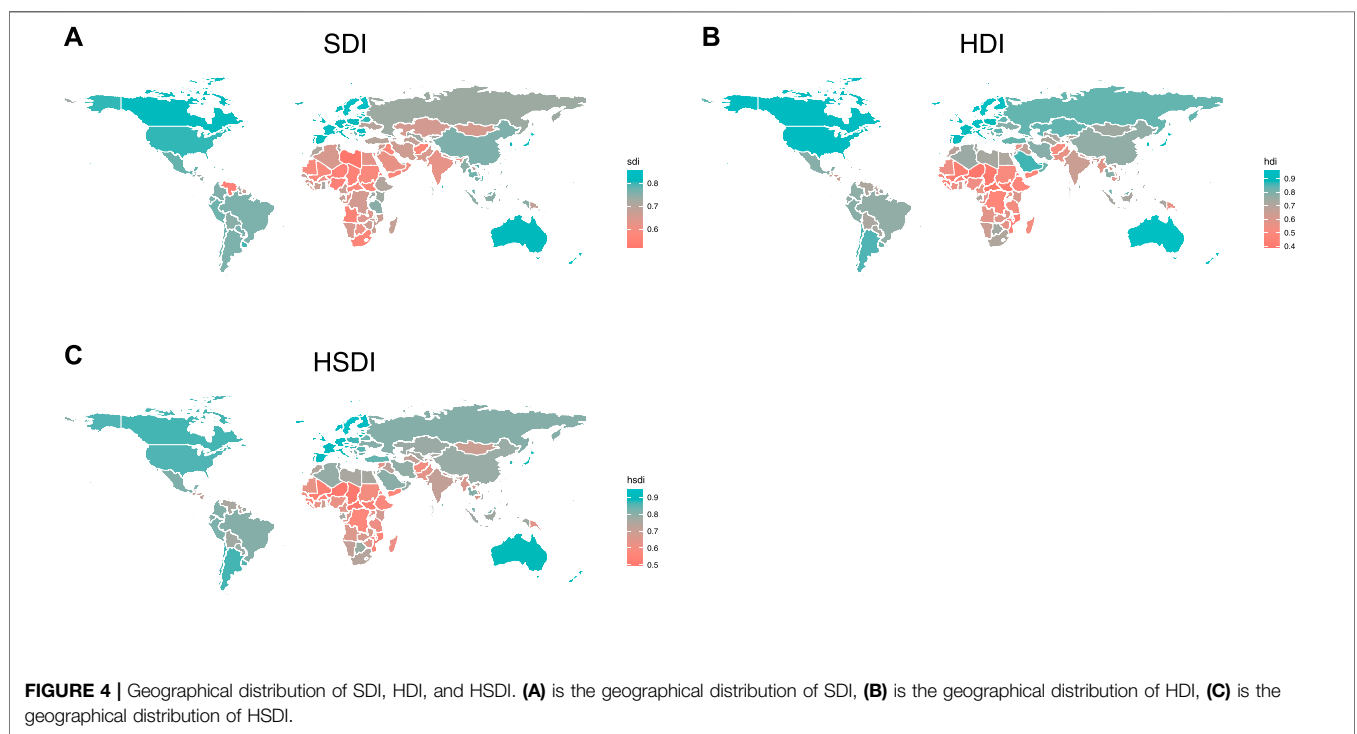
All calculation results are in appendix A. First-level indicator score, SDI rankings, and changes are shown in **Supplementary Appendix Table SA1**.

### 4.1 Correlation Analysis

Taking into account the completeness of the data, we calculated the SDI from 2015 to 2019. Finally, we selected 2019 data as a representative for analysis. Before the discussion, we need to

**TABLE 3 |** The top 10 countries (regions) with the most ranking progress and regression.

Country	Environment	Economy	Society	SDI	SDI rank	HDI rank	Change
Tanzania	0.879	0.669	0.706	0.746	84	162	78
Cambodia	0.889	0.680	0.727	0.760	67	143	76
Vietnam	0.853	0.715	0.774	0.779	53	116	63
Uganda	0.830	0.675	0.694	0.730	95	158	63
Timor-Leste	0.815	0.675	0.767	0.750	79	140	61
Myanmar	0.803	0.684	0.753	0.745	86	146	60
Ethiopia	0.763	0.674	0.682	0.705	113	172	59
El Salvador	0.805	0.731	0.746	0.760	67	123	56
Tonga	0.860	0.681	0.820	0.783	50	103	53
Guatemala	0.804	0.749	0.721	0.757	73	126	53
South Africa	0.715	0.665	0.384	0.567	179	113	-66
Iran	0.709	0.546	0.758	0.664	139	69	-70
Venezuela	0.854	0.301	0.669	0.556	183	112	-71
Bahrain	0.601	0.683	0.816	0.694	121	41	-80
Kuwait	0.549	0.682	0.756	0.657	145	63	-82
Libya	0.436	0.508	0.642	0.522	188	104	-84
Kazakhstan	0.694	0.604	0.677	0.657	145	50	-95
Oman	0.440	0.637	0.788	0.605	168	59	-109
Saudi Arabia	0.473	0.660	0.754	0.618	164	39	-125
Qatar	0.301	0.708	0.862	0.569	178	44	-134



examine the correlation between SDI and HDI (HSDI) and among first-level indicators to avoid SDI becoming another redundant indicator. The correlation among the three first-level indicators is weak, and these three indicators can independently measure the sustainable development level of each dimension (Figure 3). The correlation coefficient between HSDI and HDI is as high as 0.967, and the correlation coefficient between SDI and HDI is only 0.767. Comparing 1 to 50 and 51 to 188 countries, respectively, it can be found that the correlation

coefficients between SDI and HDI are only 0.609 and 0.567. We also examine the correlation between SDI and GNI per capita, and the correlation coefficient is only 0.570.

Although HDI and HSDI are simple to calculate and easy to generalize, their high correlation with GNI per capita makes them a redundant index (Bravo, 2014). The correlation results show that the index we created is not redundant. The highly nonlinear relationship between the index and indicators makes the existence of SDI meaningful. As can be seen



from the last column of **Figure 3**, the distribution of SDI and first-level indicators in the GNI is more dispersed than that in HSDI and HDI, which solves the problem of too high correlation between HSDI (HDI) and GNI per capita (**Figure 3**). In general, SDI has made great progress compared with HSDI, and it can be considered as a new index.

## 4.2 Discussion of SDI Ranking Results

Compared with HDI 2019, the ranking of SDI 2019 changes a lot (**Supplementary Appendix Table SA1**). Except for Switzerland and Sweden, the top 10 countries (regions) in HDI have all fallen out of the top 10 in SDI. Among them, Norway, Ireland, Hong Kong, Denmark, and Germany have lowered their social scores due to property inequality, which represents the inequality in land allocation. Germany also lowered its economic scores due to too low economic growth and high energy consumption. Australia lowered its environmental scores for high per capita carbon emissions and water shortages and lowered its economic scores for the single industrial structure, too high energy consumption, and too low economic growth. Iceland lowered its environmental scores due to water and forest shortages while lowering its economic score due to the single industrial structure. Japan became the No. 1 country in the SDI, followed by New Zealand, Switzerland, Finland, Estonia, Lithuania, Hungary, the United Kingdom, Belgium, Slovenia, and Sweden. The change in the rankings of these countries shows that our added dimension is effective in reassessing the level of sustainable development.

The top 40 countries (regions) have basically not changed, and the countries (regions) with great changes appear in the middle and lower rankings. We select the top 10 countries (regions) with the most ranking progress and regression (**Table 3**), which show that countries (regions) with more ranking progress have higher environmental scores. None of these countries scored above 0.8 for their economy and society, and none of them are developed countries. This shows that developing countries can rely on ecological protection to obtain higher scores instead of developing their economies through sacrificing the environment. The countries (regions) with more ranking regression are mainly oil-producing countries, which rank high in HDI by relying on high per capita income. The ranking regression of oil-producing countries is due to deterioration of land ecology, such as water and forest shortages, which lower the environmental score, and the economic score of HDI is revised after adding industrial structure and energy consumption to SDI.

Regarding the geographical distribution of SDI 2019, **Figure 4** shows that most countries (regions) in North America, Western Europe, Northern Europe, and Oceania still maintain high scores; they did not fall sharply in ranking due to the addition of land ecological indicators. We believe that these countries have maintained good land ecology in the process of economic development. The scores of South America and East Asian countries (regions) remained basically unchanged except for Hong Kong, Argentina, Suriname, and Venezuela. The scores

of the Middle East, North Africa, and Kazakhstan have dropped significantly, and the main reason is the deterioration of land ecology. The scores of Russia and the United States fell because of property inequality. The scores of South Africa and Argentina declined slightly because of lower social scores. The scores of East African and Southeast Asian countries (regions) have increased significantly, and the main contribution comes from a good land ecology.

## 5 CONCLUSION

In this article, we assess the level of sustainable development over the world in terms of multidimensional. We conclude the following:

First, we have established a secondary index system and increased the number of assessment sustainability indicators. These methods solved the deficiencies of existing indices, such as the high correlation between HDI, HSDI, and GNI, the imbalance of EFHDI and EHDI, and the lack of countries of other indices (Morse, 2003a; Togtokh, 2011; Bravo, 2014; Maccari, 2014; Liang et al., 2019). It also makes up for the shortcomings of SDGs without comprehensive indicators. SDI can be considered as a new index because of the weak correlation with SDI and HDI, and it is easy to generalize. Therefore, SDI provides a solution for accurately assessing global sustainable development.

Second, SDI makes countries (regions) pay more attention to land ecological protection, and developing the economy at the expense of the environment will not get a great score in SDI. The regression of oil-producing countries in the Middle East on SDI demonstrates that it is not appropriate to focus only on GNI or GDP, and land ecological protection is equally important to the measure. On the contrary, Southeast Asian and East African countries (regions) have made progress because of land ecological protection. However, it does not mean that economic development is not important; for example, Venezuela has a high environmental score, but its ranking has fallen sharply due to the long-term economic collapse (**Supplementary Appendix Table SA1**).

Third, balanced development plays a vital role in improving the ranking of SDI. Under the geometric mean method, the contribution of each index to the total score is marginally decreasing, and countries (regions) with unbalanced development will be penalized. For example, Palau has good scores in environment and society, but the single industrial structure has lowered its economic score, making the SDI ranking only 94; Australia's social score is as high as 0.903, but its environmental and economic scores are only 0.780 and 0.782, respectively, resulting in the SDI ranking only 27, while Latvia's three scores are 0.839, 0.836, and 0.832, making its SDI ranking 13 (**Supplementary Appendix Table SA1**).

Fourth, it is not enough to rely on a certain indicator to become a top country. Some countries (regions) have made great progress in the SDI ranking by relying on a high environmental score, but this can't make them enter the top 50, and too low economic and social scores have become the obstacles to their

SDI ranking. This is an important conclusion of this study. The protection of the ecological environment and economic development must be promoted at the same time. In other words, developing countries should not only advocate ecological protection while ignoring economic development. The per capita carbon emissions have little impact on the environmental scores of the top countries (regions). This study holds that the top countries (regions) pay more attention to the sustainable development of the environment (**Supplementary Appendix Table SA1**). It is reasonable for countries (regions) with the strong financial strength to fund public welfare projects, such as air purification, afforestation, and the establishment of nature reserves. Therefore, economic development is more important than environmental protection for developing countries.

Fifth, it is property inequality, not per capita carbon emissions, that affects the SDI ranking of the top countries, which is different from the conclusions of some existing studies (Togtokh, 2011; Bravo, 2014; Maccari, 2014). Surprisingly, the main reason for the differences between SDI and HDI in the top countries (regions) is property inequality, which is proved by the changes in rankings of Norway, the United States, Ireland, Denmark, Germany, Hong Kong, and Israel. What is more, in general, property inequality has become an important factor hindering sustainable development. Countries (regions) in the world, especially the developed countries (regions), need to take measures to solve property inequality, such as optimizing land allocation.

Our research results provide a reference for countries around the world to improve the level of sustainable development. For developed countries, the gap between the rich and the poor is an issue that cannot be ignored in sustainable construction. Rising inequality will intensify conflicts and cause various social problems. Inequality is also a worldwide problem, with billions of people facing disease, poverty, and hunger every day. Developed countries should take more responsibility for inequality. For developing countries, it is necessary to pay attention to the balance between economic development and ecological protection. We also note that many developing countries are also facing the problem of property inequality. Since the per capita income of developing countries is not high, their property inequality problem is caused by the economic bubble caused by rapid economic development. For example, China has been criticized for its high housing prices in

big cities, and most young people cannot afford mortgages, which is consistent with China's property inequality score of only 0.552. The government needs to strengthen the construction of institutions to prevent economic bubbles and overheating speculation. Another important implication of our research is to promote the collection and publication of sustainability data. The completeness of indicators plays a critical role in the accuracy of SDI. However, the official organizations have not done enough in the statistics of such indicators. For example, the Gini index published by the United Nations, the World Bank, the International Monetary Fund, and other international organizations lacks data from many countries. The relatively complete inequality data we found come from Credit Suisse (Credit Suisse Research Institute, 2019), a non-official organization. The author hopes to promote the statistics and release of sustainability indicators through the establishment of SDI.

This article has limitations in the selection of indicators and goalposts. In future research, we will commit to enhancing the accuracy of the SDI by finding more sustainability indicators and improving the selection of goalposts.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**; further inquiries can be directed to the corresponding author.

## AUTHOR CONTRIBUTIONS

YP: conceptualization; methodology; software; formal analysis; data curation; writing-original draft preparation; visualization. HZ: investigation; writing-review and editing; supervision.

## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2022.957095/full#supplementary-material>

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