Appendix

Appendix A Calculation method of the index to measure TRSEP

The calculation process of the index that measures TRSEP are as follows:

(1) The first step is to calculate the ratio of various control targets for major pollutants to GDP growth targets. The pollutants include sulfur dioxide (SO_2) and chemical oxygen demand (COD). The calculation formula is as follows:

$$Po_{ij} = \frac{P_{ij}}{GDP_i} \quad \text{(A1)}$$

Where, P_{ij} represents the control targets for major pollutant j (j=1,2) in province i (i=1,2…30)[1], GDP_i represents the expected GDP targets of province i, Po_{ij} represents the control target for major pollutant j of per GDP value in province i. Meanwhile, the GDP targets are deflated based on 2000 to eliminate the impact of price factors and inflation.

(2) To make the Po_{ij} comparable, we construct a relative index expressed as:

$$Po_{ij}^* = \frac{Po_{ij}}{\frac{1}{n}\sum_{i=1}^{n} Po_{ij}} \quad \text{(A2)}$$

Po_{ij}^* represents the value of Po_{ij} that is standardized, n represent the total number of provinces (n=30). If Po_{ij}^* is greater, the higher emission intensity target of pollutant j in province i is compared with the average of other provinces.

(3) Sum up the Po_{ij}^*, then average it:

$$Potarget_i = (Po_{i1}^* + Po_{i2}^*)/2 \quad \text{(A3)}$$

$Potarget_i$ reflects the expected emission target of major pollutants per unit of GDP of region i. The smaller it is, the stronger the constraint of the TRSEP.

(4) To express conveniently, this study takes the reciprocal of $Potarget_i$:

$$TRSEP_{it} = \frac{1}{Potarget_i} \quad \text{(A4)}$$

$TRSEP_{it}$ eliminates the dimension differences between pollutants through standardization, and it is possible to comprehensively measure the constraint strength of the TRSEP. The larger the value, the stronger the constraint of the TRSEP is.

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1. This study encompasses 30 provinces (municipalities, autonomous regions) in China. Due to the spatial range of China's TRSEP implementation and data availability constraints, the Hong Kong Special Administrative Region, the Macao Special Administrative Region, Taiwan province and Xizang Autonomous Region are excluded from the analysis.

Appendix B Calculation model and indicator system of green economic efficiency

The Measurement Model of Green Economic Efficiency

The definition and calculation of green economic growth should include resource and environmental indicators. Traditional DEA models are mostly radial and do not consider the slack of input or output variables. Also, they cannot accurately calculate the efficiency value when undesirable outputs are involved. The non-radial and non-directional SBM model introduces slack variables into the objective function and incorporates undesirable output indicators into the model, which overcomes the problem of input-output slack and considers both desirable and undesirable outputs [40]. However, the efficiency value calculated by this model ranges from 0 to 1, and it is impossible to compare the efficiency between the efficient decision-making units. Subsequently, the super-efficient DEA model that realized the comparison and differentiation between efficient decision-making units. This study uses the super-efficiency SBM-DEA model that includes desirable and undesirable outputs to measure the green economic efficiency of each province.

Specifically, each region is regarded as an independent decision-making unit (DMU) consisting of inputs, desirable outputs and undesirable outputs. The input is $x = (x_1, \dots, x_m) \epsilon R_+^m$, desirable output $y = (y_1, \dots, y_n) \epsilon R_+^n$, undesirable output $b = (b_1, \dots, b_n) \epsilon R_+^k$. The input-output combination of region i in the year t is expressed as $\left(x^{i,t}, y^{i,t}, b^{i,t}\right)$, the production possibility set of green economic efficiency is:

$$p^t(x^t) = \left\{(y^t, b^t) \mid x_{im}^t \geq \sum_{i=1}^{I} w_i^t x_{im}^t; y_{in}^t \leq \sum_{i=1}^{I} w_i^t y_{in}^t; b_{ik}^t \geq \sum_{i=1}^{I} w_i^t b_{ik}^t; w_i^t \geq 0, \forall m, n, k\right\} \quad \text{(B1)}$$

w_i^t represents the weight vector. Equation (1) measures the situation when the returns to scale are variable, so the super-efficiency SBM-DEA model that includes desirable and undesirable outputs is set as follows:

$$\rho^* = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^x}{x_{i0}}}{1 - \frac{1}{n+k}\left(\sum_{r=1}^{n}\frac{s_r^y}{y_{r0}} + \sum_{l=1}^{k}\frac{s_l^b}{y_{l0}}\right)} \quad \text{(B2)}$$

$$\text{s.t. } x_{i0} \geq \sum_{j=1}^{J} w_j x_j - s_i^x$$

$$y_{r0} \leq \sum_{j=1}^{J} w_j y_j - s_r^y$$

$$b_{l0} \geq \sum_{j=1}^{J} w_j b_j - s_l^b$$

$$s_i^x \geq 0,\ s_r^y \leq 0,\ s_l^b \geq 0,\ \sum_{i=1}^{n} w_j = 1, w_j \geq 0,\ \forall i, j, r, l$$

ρ^* is the efficiency value of DMU, which represents green economic efficiency. The larger the value, the higher the green economic efficiency. s_m^x、s_n^y、s_k^b represent redundancy of inputs, insufficient desirable outputs, and redundancy of undesirable outputs, respectively.

Variables and Indicators of Green Economic Efficiency

Since green economic efficiency measures the economic efficiency, which includes unexpected outputs such as pollutant emissions and other environmental indicators, the measurement of green economic efficiency usually needs to consider indicators in both input and output dimensions.

①Input indicators

Based on the study of He et al.[41], the green economic efficiency model usually contains three input indicators (capital, labor force and energy). The labor force (L) is represented by the total employees. The capital (K) is calculated using the perpetual inventory method. Energy (E) is measured by the total energy consumption of each province.

②Output indicators

The output indicators of measuring green economic efficiency include desirable and undesirable outputs. Referring to the research of Zhang et al.[42], the desirable output is represented by real GDP (Y) that is deflated based on 2000. This study uses SO_2 emissions (ESO) and COD emissions (ECOD) as the undesirable outputs. These two undesirable outputs are representative since they were widely used in prior studies analyzing regional green economic efficiency [43]. The data description of these inputs and outputs indicators is presented in Table B1.

Table B1. Description of input-output indicators about green economic efficiency.

Indicators		Variables	Measures
Input		Capital (*K*)	Capital stock: calculated by the perpetual inventory method
		Labor force(*L*)	Total employees
		Energy (*E*)	Energy consumption
Output	Desirable output	Economic output (*GDP*)	Real GDP that is deflated based on 2000
	Undesirable output	Pollutant Emission (*ESO*, *ECOD*)	Emissions of SO_2, Emissions of COD
Note: the data mentioned in this table mainly stems from the China Statistical Yearbook, China Environmental Yearbook, EPS database, and the National Bureau of Statistics in China.			