Green city economic efficiency based on cloud computing and machine learning

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Abstract
In the early development process, my country destroyed the development of the natural environment and the allocation of natural resources in pursuit of the speed of economic development. With the acceleration of development, my country’s economic construction and social development have achieved good results. To achieve sustainable economic and ecological development in the future, green and high-quality development must be achieved to meet the content of the development strategy of realizing the resource-based and economical society in our country. In the long-term development process, many regions rely on resources to create a lot of opportunities for the development of the region, but with the high consumption of resources, many resources are non-renewable or the regeneration process is very slow, resulting in many regions entering the resources. During the period of shortage, it is necessary to advocate green development. This article analyzes the green economic benefits achieved by the innovative development of a certain province in my country by studying the relevant knowledge of machine learning and some important issues in the theoretical development of cloud computing, which can provide a certain reference for the development of economic efficiency theory and provide help for people to formulate green development strategies for cities and regions.

Keywords Green city · Economic efficiency · Cloud computing · Machine learning

Introduction
Before the reform and opening up, China’s economic development has always been at a low-speed development stage. With the rapid development of reform and opening up and the implementation of related policies, China’s economic and social development has entered a normal track. In the early development process, my country lacked the use of science and technology and the guidance of correct methods, and blindly chose the development model in the process of development and construction, which led to a large waste of many resources in our country. Biological development in nature and environmental development have caused greater damage (Lawton et al. 1992). With the development of various sciences and technologies, people began to notice the impact of ecological and environmental problems on people’s lives, and began to advocate the construction of ecological civilization, advocate the concept of green development, and strive to restore the damage to the ecological environment. As early as 2015, the State Council and the Central Government of my country jointly issued relevant policies on the construction of ecological civilization. The relevant regulations linked the development of greening with the development of new industrialization, urbanization, informatization, and agricultural modernization. In the process of ecological civilization construction and development, my country must realize the coordinated development of the five modernizations in order to provide assistance to my country’s economic and social development and ecological sustainable development. To achieve high-quality green development, it is necessary to make certain adjustments to economic and social development under the guidance of green development theory (Alam et al. 2020). By analyzing the content of the green development theory, we can know that the green development we want to achieve needs to be above the carrying capacity of our country’s resources and environment, and to improve our country’s production efficiency through the development of science and
technology. For some non-renewable or difficult to regenerate resources, it is necessary to use new science and technology to realize the artificial capital environment to replace natural resources, to change the original economic development model to a certain extent, and to reduce the high consumption of natural resources. In the process of developing the green concept, it is necessary to consider both resource utilization and environmental protection issues (Lawton et al. 1989). It is necessary to achieve economic growth while also taking into account environmental protection issues to a certain extent. In order to better evaluate the quality of green development, it is necessary to conduct a quantitative analysis of the total output of social and economic development and the degree of use of natural resources and the environment. The entire analysis process is actually a question of efficiency. The efficiency of social development which needs to be evaluated includes many, mainly including the efficiency of urban ecological construction, the efficiency of energy use, the efficiency of the allocation of various resources, and the efficiency of developing a green economy (Leong et al. 2013). Among the above efficiencies, the efficiency of ecological construction, the efficiency of energy use, and the efficiency of various resource allocation are important content for evaluating the efficiency of the green economy. In the course of development in recent years, the rapid development of our country’s economy has provided effective help for our country to strengthen its comprehensive national strength, and it has also brought considerable income to our residents. However, my country’s current economic development model still maintains an extensive development model (Alkroosh and Nikraz 2012). This economic development model can easily lead to rapid consumption of resources, severe damage to the ecological environment, and adverse effects on regional development. In the development process of most regions in my country, the economic growth of many regions depends on the development and utilization of local energy, and the resources in many regions are over-exploited. This makes the pressure on the ecological environment reach the limit, which will seriously damage the progress of building a resource-saving society in China. This study selected a province that relies on resources for development as the research object. In the process of analysis, it can be found that the development of this province mainly relies on the development of industrialization to create economic benefits. However, the analysis of the province’s industrial development shows that the province does not pay attention to the adjustment of the industrial structure during the development process. The industrial structure is relatively simple, and there are certain resource allocation problems and insufficient innovation motivation. In the future, in the development of the country, the province is likely to face a shortage of resources (Mahdiyar et al. 2020). For such a region that depends on resources to achieve development, it is necessary to build a green development environment, promote the concept of green development, and achieve green development, so that it is conducive to the sustainable and healthy development of the region.

The rapid development of information technology and the abundance of network resources have made industry and education devote themselves to the development of machine learning. In 2002, my country officially began to promote the machine learning plan. It consists of five parts: the description and promotion of digital learning environment, and the prospect of digital learning, machine academic research, current situation and development of machine market, machine development blueprint and direction. Machine learning occupies a large position in the development and research field of artificial intelligence and can play a very good role (Najemalden et al. 2020). The development of artificial intelligence systems needs to combine knowledge from multiple fields and industries to improve its own system structure. In order to better promote the upgrading of artificial intelligence systems, the research and analysis of knowledge in multiple fields contained in machine learning can provide a good help. The field of machine learning mainly analyzes the existing data and studies how to analyze the laws and connections between the data from the known database, and use the discovered laws to predict a certain index or a certain feature in the future status of classification and clustering performed. So far, image semantic classification methods developed on the basis of machine learning mainly include supervised learning methods and unsupervised learning methods. The method of supervised learning can be used in a learning system that has been classified (Almahbobi 2018). The training set in supervised learning includes two parts: output and input, which are commonly referred to as features and targets. All targets in the training set are determined by people are labeled. The training set in the unsupervised learning method is no longer manually annotated. When classifying the clustered data in the classification, the unsupervised learning algorithm is often used.

Using cloud computing methods can conduct a unified analysis on the data of green economic development, and provide people with intuitive analysis data. The operation process of cloud computing can be divided into five layers, of which the most basic is the physical layer. As the name suggests, the physical layer is a combination of physical hardware and various physical facilities, as well as various physical machine operation settings and systems, such as computers and the Internet; next is the virtualization layer, which is a solid force that supports virtualization technology in cloud computing. The main components of this layer are virtual machines and virtual machine operating systems (Okonta 2012). The core technical idea of the virtual layer is to separate the physical storage of data and the electronic data image, and
Overview of the economic development efficiency of green cities

The concept of green ecological development is continuous and coherent. Scholars have integrated the concept of sustainable development, ecological civilization construction, and social values, but they have not yet formed a complete, complete, and systematic theoretical system. The development of green ecology is sustainable, green, and harmonious, which is different from the previous economic development model. The development of this ecological model mainly emphasizes efficiency and sustainability. While improving economic efficiency, it must also promote environmental sustainability and ecology (Rabbi et al. 2014). Green total factor productivity cannot be considered from a single factor. It is necessary to fully consider the relationship between each factor and analyze it as a whole. Green total factor productivity must consider both economic efficiency and environmental efficiency. To obtain the greatest economic benefits while protecting the ecological environment to the utmost extent, it represents the improvement of green development efficiency and green total factor productivity.

Looking at the issue of efficiency development from a microscopic point of view, efficiency is mainly used to describe the ratio between the input and output of an enterprise or an individual that produces a product, and the size of efficiency is mainly used to describe the input. When the number of products and output reaches a certain level, the cost of the enterprise or individual will be minimized or the benefits will be maximized (Cheng et al. 2020). Looking at the issue of efficiency from a macro perspective, efficiency is mainly used to describe how the overall level of social and economic development meets people’s needs and supplies. Different elements in society can be combined multiple times to achieve the optimization of the allocation of elements, providing effective help for economic development.

Through a comprehensive analysis of the connotation of efficiency and the specific content of green development, this study, based on the analysis of previous research results, believes that the main connotation of green development efficiency is the magnitude of the expected output value added for people created by social and economic development and how much the value of undesired output has decreased, and a certain evaluation of the degree of reduction of people’s undesired input. Green development efficiency describes the situation of green development in the new era, and researchers have not yet given a specific definition (El Howayek et al. 2011). This study conducted a unified analysis of the social and economic growth, the implementation of ecological and environmental protection work, and the utilization efficiency.
of various resources. The micro and macro economic development indicators were combined for evaluation, which can evaluate the green development of a region, objectively explaining the level.

Materials and methods

Data source and indicator selection

Variable selection and data sources

This research is mainly based on the data of 11 cities in this province in the past 9 years. These data are mainly derived from local statistics, newspapers, and professional statistics, which have certain accuracy. However, some years of these data are missing and can only be replaced by the average value between other years. However, in the selection of indicators in the research, the accuracy and source of the data and the overall data can be summarized (Rabbi and Cameron 2014). These indicators must have a certain impact on the efficiency of green development, and these indicators must have a certain degree of correlation. The theoretical and research foundation of the research can ensure the professionalism of the whole research results (Fig. 1).

To better build a resource-based society with green development, it is necessary to take into account both the regional economic development and the improvement of the ecological environment. When evaluating the results of the green development of resources, certain indicators need to be selected as the evaluation criteria. The indicators selected in this study are mainly economic development and ecological environment development indicators. From the perspective of economic development, resource-based green development needs to achieve long-term economic growth (Ferreira 2003). The economic indicators are mainly the amount of labor input, the amount of capital input, and the total output value of a certain region as a percentage of the total regional development proportion. Eco-environmental indicators mainly refer to the degree of damage to the ecological environment caused by economic development by pollutants. They mainly analyze the amount of energy input and pollutant emissions. The main indicators include the energy consumption on the entire social development process, the amount of waste water discharge in each region, the amount of waste gas discharge and the amount of solid waste (Fig. 2). The specific evaluation indicators are shown in Table 1.

Indicator descriptive statistics

Table 2 shows the input and data statistics of a province in the long-term development.

Calculation method of green city economic efficiency

Selection of evaluation methods for green development efficiency

At the same time, in the current international literature on green development efficiency, it can be seen that scholars at home and abroad mainly use analysis and evaluation methods and randomly selected data for analysis, and use functional graphs and linear programming for analysis. However, in terms of output, the method of using functional graphs and linear programming for analysis cannot be analyzed from multiple angles, so certain errors may be caused. Taking into account the limitations of the above methods, it is necessary to use the non-radial super-efficiency directional distance function to measure and analyze the green development efficiency, which can make the measurement and analysis results more accurate and objective.

When using the non-mirrored super-efficiency directional distance function for measurement, the evaluation of each unit can be seen (Ferreira 2006). To measure the K-th decision-making unit, we must first measure each decision-making unit. This requires the use of linear programming methods to see the optimal ratio between input and output. This method can be widely used green eco-efficiency measurement which see the optimal ratio between input and output. This method will reduce errors in the entire measurement process and be more objective and accurate. Through measurement, it can be seen that the formula of the K-th decision unit is as follows:

$$h_i = \frac{b_1y_{1id} + b_2y_{2id} + \ldots + b_qy_{qid}}{a_1x_{1id} + a_2x_{2id} + \ldots + a_dx_{did}} = \frac{\sum_{c=1}^{q} b_cy_{cid}}{\sum_{r=1}^{p} a_rx_{cr}}$$

(1)

SBM model based on undesired output

To analyze people’s expected output, the CCR model and the BBC model can be used to calculate relevant indicators. The principle of the model used in this study can be expressed as:

$$\min \rho = \frac{1 - \frac{1}{p} \sum_{i=1}^{p} {\delta_i^+}}{1 + \frac{1}{q} \sum_{r=1}^{q} {s_r^+}}$$

(2)

$$x = X\lambda + s^- \quad y = Y\lambda - s^+ \quad \lambda, s^-, s^+ \geq 0 \quad i = 1, 2, \ldots p \quad r = 1, 2, \ldots q$$

In the actual calculation, the model can be converted into a linear programming model for calculation. The specific calculation steps are as follows:
In the following calculations, a model that considers undesired variables can be constructed. The formula is as follows:

\[
\min \rho = t \left( 1 - \frac{1}{p} \sum_{i=1}^{p} t \delta_i \right) \\
x_k = X \lambda + s^+ - tx_k = 0 \\
y_k = Y \lambda - ts^+ - ty_k = 0 \\
t = \frac{1}{1 + \frac{1}{q} \sum_{r=1}^{q} s^+} \\
\lambda, s^-, s^+ \geq 0
\]  

\[
\min \rho = t \left( 1 - \frac{1}{p} \sum_{i=1}^{p} S_i \right) \\
x_k = X \lambda + s^+ - tx_k = 0 \\
y_k = Y \lambda - s^+ - ty_k = 0 \\
t + \frac{1}{q} \sum_{r=1}^{q} S_r = 1 \\
\lambda, s^-, s^+ \geq 0
\]  

**Calculation of factors affecting economic efficiency of green cities**

**Model setting and formula panel**

The sequence of data passing time arranges different units according to the same index standard to form corresponding
data columns, which is more comprehensive and accurate than simply arranging in chronological order. Green development efficiency is the explanatory variable in the entire research process (Shahin 2013). Through linear programming and regression analysis of the local economic development level, GDP output, environmental input, urban development level, and ecotourism development level, these explanatory variables research with the explained variables to get the relationship between them. Based on the above data and analysis, a relevant Tobit model is established so that the main variable factors that affect the efficiency of green development can be seen. The model can be expressed by the following formula:

\[
Y = \begin{cases} 
Y^* = \alpha + \beta X + \varepsilon, & Y^* > 0 \\
0, & Y^* \leq 0 
\end{cases}
\]

\[Y^* \geq 0\]

Table 1  A province’s green development efficiency measurement index

| Target layer                                                      | Classification layer | Index layer                                                                 |
|------------------------------------------------------------------|----------------------|----------------------------------------------------------------------------|
| Evaluation index system of green development efficiency in a province | Investment index     | Investment in fixed assets (ten thousand yuan)                             |
|                                                                  | Expected output      | Number of employees at the end of the year (10,000 people)                |
|                                                                  | Undesired output     | Social energy consumption (10,000 tons of standard coal)                   |
|                                                                  |                      | Regional production interest value GDP (ten thousand yuan)                |
|                                                                  |                      | Industrial wastewater discharge (10,000 tons)                             |
|                                                                  |                      | Industrial waste gas emissions (100 million cubic meters)                 |
|                                                                  |                      | Industrial solid waste generation (ten thousand tons)                    |
In order to better analyze the factors affecting the efficiency of green development, this study also constructed a panel Tobit model, which can be expressed as follows:

\[
GDE = \begin{cases} 
0 & \text{if } GDE < 0 \\
GDE' = \alpha + \beta_1 \text{gdp} + \beta_2 \text{str} + \beta_3 \text{ene} + \beta_4 \text{er} + \beta_5 \text{ur} + \beta_6 \text{tour} + \epsilon & 0 \leq GDE \leq 1 \\
1 & \text{if } GDE > 1
\end{cases}
\]

Variable setting and data description

When analyzing the green development efficiency of a certain province, it mainly analyzes the factors that affect the level of green development efficiency. Because there are many influencing factors, the representative factors are selected. The main analysis factors include economic development factors, energy and environmental planning factors, and urbanization-level factors. The specific conditions of the variables are shown in Table 3.

Indicator descriptive statistics

In the specific analysis process, the researchers made statistics on the data that affect the efficiency of green development. After the statistics were completed, they made descriptive statistics on the data. The statistical results are shown in Table 4.

Results

Evaluation of green city economic development efficiency based on DEA model

Calculation results of green development efficiency in a province

This study uses the SBM model to predict the province’s green development efficiency level from 2010 to 2019. The calculation results are shown in Table 5 and Fig. 3.
By analyzing the data in the table, it can be known that during the 10-year development period, the province’s green development efficiency level has been increasing (Gandomi and Alavi 2012). The value of green development efficiency exceeded 0.7 in 2011, and the value has been increasing in subsequent developments. From the perspective of overall development, the province’s green development efficiency has increased by 12.07% in 10 years, with an average annual growth rate of 1.01%. This shows to a certain extent that the province’s input factors are in the development process of the green economy. Playing a more obvious role in the process, expected output is also increasing further and undesired output has been controlled to a certain extent (Fig. 4).

During the development stage from 2011 to 2015, the province’s green development efficiency level has been greatly improved. This is because this is the construction period of my country’s “13th Five-Year Plan”. The country mainly promotes the construction of ecological civilization. It also cooperated with the work of the country. During this period of time, the province puts environmental protection work in the first place of ecological civilization construction and economic construction. During the development process, the construction of industrial projects was mainly in the park area, centralized monitoring and management of pollutant discharge, and vigorously some environmental protection systems have been specifically improved for the pollution problem in the process of urban development (Habibagahi and Taherian 2004). Therefore, the province’s green development efficiency level has been effectively improved, and the province’s relevant policies and work have played an irreplaceable role.

Calculation results of green development efficiency in a certain city

This study used professional software to analyze the collected urban development data and predicted the province’s green development efficiency from 2010 to 2019. The calculation results are shown in Table 6 and Figs. 5.

From the perspective of regional development, the development of the northern, central, and southern regions of the province is different. The green development efficiency of different regions is shown in Table 7 and Fig. 6.

Table 4 Statistical description of influencing factor indicators from 2010 to 2019

| Variable                                          | Mean   | Std.Dev | Max   | Min   |
|---------------------------------------------------|--------|---------|-------|-------|
| GDP per capita (yuan)                             | 33,081 | 0.089   | 77,224| 11,327|
| The proportion of the output value of the secondary industry in GDP (%) | 52.29  | 1.33    | 71.75 | 35.55 |
| Urban permanent population accounts for total permanent population (%) | 52.14  | 0.13    | 84.70 | 35.23 |
| Ratio of energy consumption to GDP (ton of standard coal/10,000 yuan) | 1.87   | 1.24    | 84.70 | 0.22  |
| The proportion of energy conservation and environmental protection investment in each region in GDP (%) | 18.59  | 0.058   | 35.33 | 9.87  |
| The proportion of tourism income to GDP (%)       | 20.52  | 0.12    | 64.11 | 3.81  |

Table 5 Estimated value of green development efficiency in a province from 2010 to 2019

| Year | CRS     |
|------|---------|
| 2010 | 0.6687  |
| 2011 | 0.6846  |
| 2012 | 0.6927  |
| 2013 | 0.7064  |
| 2014 | 0.7085  |
| 2015 | 0.7152  |
| 2016 | 0.7233  |
| 2017 | 0.7431  |
| 2018 | 0.7429  |
| 2019 | 0.7494  |
Analysis of factors influencing the economic development efficiency of green cities based on the Tobit model

Analysis of empirical results

This study used Stata15 measurement software to perform regression analysis on the analysis results of panel data, and tested the factors that affect the green development efficiency of different regions of the province (Figs. 7, 8 and 9). The results of the test are shown in Table 8.

The results of analysis and testing can draw the following conclusions:

1. The overall economic development level of cities in this province is directly proportional to the green development efficiency, indicating that the province’s green development efficiency will increase as the overall economic development level increases. Nowadays, people not only pay attention to the improvement of the economic level, but also pay more attention to the development and improvement of the ecological environment, and invest more resources in the protection and improvement of the

Table 6  Green development efficiency of 11 cities in a province from 2010 to 2019

| City | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   | 2019   | Mean   |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| a    | 0.8878 | 0.9346 | 0.9057 | 0.8958 | 0.9259 | 1.0000 | 0.9358 | 0.9341 | 1.0000 | 1.0000 | 0.9420 |
| b    | 0.5832 | 0.5957 | 0.5989 | 0.6849 | 0.6528 | 0.7018 | 0.7132 | 0.7036 | 0.7163 | 0.7327 | 0.6713 |
| c    | 0.7262 | 0.7377 | 0.7285 | 0.7462 | 0.6695 | 0.6798 | 0.7531 | 0.7227 | 0.7314 | 0.7243 | 0.7219 |
| d    | 0.8128 | 0.8325 | 0.9063 | 0.8544 | 1.0000 | 0.8848 | 0.8613 | 0.8339 | 0.9243 | 0.9014 | 0.8912 |
| e    | 0.6536 | 0.6604 | 0.6521 | 0.6416 | 0.6263 | 0.6182 | 0.6527 | 0.6682 | 0.6691 | 0.6856 | 0.6528 |
| f    | 0.8541 | 0.8324 | 0.8458 | 0.8946 | 0.8639 | 0.8716 | 0.9285 | 1.0000 | 0.9204 | 0.9396 | 0.8951 |
| g    | 0.8374 | 0.8407 | 0.8418 | 0.8544 | 0.9089 | 1.0000 | 0.9225 | 0.9428 | 0.9142 | 0.9295 | 0.8992 |
| h    | 0.4726 | 0.4455 | 0.4738 | 0.4965 | 0.5274 | 0.5108 | 0.5434 | 0.5386 | 0.5553 | 0.5613 | 0.5125 |
| i    | 0.5949 | 0.6172 | 0.5238 | 0.6152 | 0.6295 | 0.6227 | 0.6489 | 0.6433 | 0.6521 | 0.6563 | 0.6304 |
| j    | 0.4154 | 0.4307 | 0.4314 | 0.4536 | 0.4394 | 0.4589 | 0.4892 | 0.4937 | 0.5146 | 0.5242 | 0.4651 |
| k    | 0.5078 | 0.5937 | 0.6114 | 0.6329 | 0.5195 | 0.5184 | 0.5078 | 0.5937 | 0.5741 | 0.5884 | 0.5648 |
ecological environment. The relevant governments and
departments also invest more funds in the ecological en-
vironment protection. This is conducive to changes in the
economic development model of the province and city
(Hasanzadehshoohi et al. 2014). The province’s geo-
graphic location is in the central region of my country,
and its economic development level is far behind that of
first-tier cities and coastal areas. Therefore, we must put
the improvement of the province’s economic level in the
first place, but we must also promote the development of
the ecological environment of the provinces and cities and
must allow economic development and environmental de-
velopment to progress together and coexist in harmony,
so as to promote the intensive development model of the
province.

2. There is a negative correlation between the development
of the industrial structure in different regions of the prov-
ince and the value of the green development efficiency
(Shalaby 2017). The coefficient of the negative correla-
tion is $-0.657$. This value indicates to a certain extent that
the development of the secondary industry in the province
is the proportion of all industries in the development
which is relatively large. If this value continues to expand,
then the economic structure of the region will also appear
unreasonable, and the level of green development effi-
ciency will also decrease.

![Fig. 5 Green development efficiency of 11 cities in a province from 2010 to 2019](image)

![Fig. 6 Green development efficiency in a province and three major regions from 2010 to 2019](image)

Table 7 2010–2019 green development efficiency value of a province and three major regions

| Annual price | North   | Central | South   | A province |
|--------------|---------|---------|---------|------------|
| 2010         | 0.6774  | 0.7423  | 0.3886  | 0.6687     |
| 2011         | 0.6818  | 0.7750  | 0.5923  | 0.6846     |
| 2012         | 0.6895  | 0.7719  | 0.6159  | 0.5927     |
| 2013         | 0.7316  | 0.7823  | 0.5115  | 0.7064     |
| 2014         | 0.7254  | 0.7560  | 0.6483  | 0.7085     |
| 2015         | 0.7320  | 0.7996  | 0.5182  | 0.7152     |
| 2016         | 0.7635  | 0.7798  | 0.6367  | 0.7233     |
| 2017         | 0.7823  | 0.7983  | 0.6586  | 0.7431     |
| 2018         | 0.7629  | 0.8049  | 0.6658  | 0.7429     |
| 2019         | 0.7762  | 0.8105  | 0.6681  | 0.7494     |
3. There is a negative correlation between the total energy consumption in different regions of the province and the numerical value of green development efficiency, and the negative correlation coefficient is \(-0.0153\). The total amount of energy consumption is mainly used to describe the ratio of the undesired input in the production process of a region to the regional gross product. If the total energy consumption is larger, then the undesired input in the

**Fig. 7** The luminous standard deviation ellipse and its center of gravity change in the study area

**Fig. 8** Standard deviation ellipse and center of gravity change of each city-level unit
4. There is a positive correlation between the level of environmental protection input in different regions of the province and the level of green development efficiency. The coefficient of positive correlation is 1.513, which is the largest part of all correlations (Hodek and Lovell 1979). The amount of environmental protection expenditure reflects the amount of government investment in environmental protection in the relevant region. If the government invests more in environmental protection, the more obvious the improvement of pollutant emissions in the region will be. In addition, the amount of environmental protection expenditure also reflects the government’s emphasis on pollution control. If the investment is more, the government pays more attention to environmental protection issues, and to a certain extent, the level of green development efficiency can be improved.

5. There is a positive correlation between urbanization efficiency and green development efficiency in different regions of the province, and the coefficient of positive correlation is 0.505. The efficiency of urbanization explains the process of urbanization to a certain extent (Tadepalli and Fredlund 1991). The construction and development of urbanization can gather more and more people in urban areas, make the infrastructure construction of urban areas gradually improve, and promote the development of urban areas. The adjustment of the industrial structure will increase the proportion of tertiary industry development.

6. The development of tourism in this province also has a certain role in promoting the efficiency of green development. The development of tourism in this province can promote the increase in the per capita income of residents in this province (Houston and Houston 1997). At the same time, the development of tourism will promote the development of the service industry, so it can promote urban transformation. Different cities in the province have

Table 8 Regression analysis results of influencing factors of green development efficiency in a certain province

|     | GDE   | Cluster 1 | Cluster 2 | Cluster 3 |
|-----|-------|-----------|-----------|-----------|
| gdp | 0.0539| 0.0403    | 0.0269    | 0.0366    |
|     | (0.00920) | (0.0138) | (0.00815) | (0.0122)  |
| str | 0.657 | 0.646     | -0.513    | -0.349    |
|     | (0.118) | (0.170) | (0.0894) | (0.180)   |
| ene | -0.0153 | -0.0281 | -0.0147   | -0.00593  |
|     | (0.00739) | (0.0255) | (0.0165) | (0.00681) |
| er  | 1.513 | 1.479     | 1.198     | 0.994     |
|     | (0.227) | (0.336) | (0.163) | (0.299)   |
| ur  | 0.505 | 0.609     | 0.129     | 0.584     |
|     | (0.229) | (0.232) | (0.192) | (0.283)   |
| tour| 0.334 | 0.401     | 0.378     | 0.123     |
|     | (0.104) | (0.123) | (0.0906) | (0.0994)  |
| cons| 0.643 | 0.582     | 0.737     | 0.661     |
|     | (0.185) | (0.157) | (0.103) | (0.137)   |
| O   | 110   | 30        | 40        | 40        |
| N   | 11    | 3         | 4         | 4         |
characteristic ecological resources and can develop characteristic tourism models, forming an industrial structure centered on the service industry, which will better promote the development of the ecological environment and improve the efficiency of green development.

**Robustness test for verification**

The data analysis results of the Tobit model will change as the parameters change. Therefore, the robustness test of the regression analysis results is required. The test results are shown in Table 9 and Fig. 10.

**Discussion**

**Research and analysis of economic efficiency of green cities**

This study analyzed the data generated by the development of a province from 2010 to 2019, and mainly used the analysis method of data analysis to conduct a specific study on the level of green development efficiency and the factors affecting it. Through the analysis, the following are several conclusions:

1. After 10 years of development, the average value of the province’s green development efficiency has always been around 0.7135. From the perspective of overall development, the province’s green development efficiency has increased by 12.07% in 10 years. An average annual growth rate is 1.01%, which to a certain extent shows that the province’s input elements have played a more obvious role in the development of the green economy (Houston et al. 1988). The expected output is also increasing further, and the undesired output has achieved a certain degree of control. The increase in the value indicates to a certain extent that the industrial structure measures implemented by the province are effective. As long as the supply side structural reforms continue to be adhered to, the province can promote the construction of a resource-saving economic development model.

2. In general, in the level of green development efficiency in different regions of the province, there are certain differences in the development of different regions in the province; in the future development, reasonable development strategies should be formulated according to the development conditions of different regions, and the overall improvement. The level of green development in the province promotes balanced development among various regions.

3. By analyzing the influencing factors that affect the efficiency of the province’s green development, it can be seen that in terms of economic development, the level of economic development has an obvious positive correlation with the level of green development efficiency. If the proportion of the secondary industry in the industrial structure accounts for a larger part of the proportion of all industries, then the level of green development efficiency will decrease. From the perspective of energy and environmental regulation, the higher the level of green development efficiency and environmental protection investment expenditure, the higher the level of green development efficiency (Ince et al. 2019). If the total amount of energy consumption is greater, the level of green development efficiency will be limited to a certain extent. From the perspective of urbanization development, the higher the level of urbanization efficiency, the higher the level of green development efficiency will be correspondingly improved. In addition, the specific situation of tourism development in a region will also have a certain impact on the efficiency of green development.

**Strategies to improve the economic efficiency of green cities**

**Promote industrial transformation and upgrading**

In the development process of a city, the improvement of independent innovation ability can promote the adjustment of the city’s industrial structure. For the development of a city, the greater the proportion of the secondary industry in the development of the total industry, the more unreasonable the
economic and industrial structure of the city, which will not help the development of green development efficiency. The development of the secondary industry consumes a lot of energy and will cause serious damage to the natural environment. The object of this study is a province that relies on coal resources to achieve economic development (Wang et al. 2015). This province has achieved certain economic growth by relying on coal resources, but it will lose a stable source of economic growth in the long run. In the recent years of development, the province has developed some emerging industries, adjusted the original single industrial structure to a certain extent, and created opportunities for sustainable green development. Therefore, the main task of the province’s construction and development is to adjust the industrial structure and promote industrial upgrading.

The most important issue for the development of the province is to promote the reform of the industrial structure, to upgrade and optimize the province’s primary and secondary industries, and to transform the province from providing energy for the country to a heavy industrial base (Jahed Armaghani et al. 2018). According to the needs of green development efficiency, some enterprises that will have an adverse impact on the ecological environment are closed, and a new industrial structure is developed to better promote the economic development of the province.

Second, we must introduce advanced technology: transform, optimize, and upgrade the existing production model; improve the production efficiency of the industry; reduce pollution emissions during production. At the same time, it is necessary to promote the independent innovation of the entire industry, make full use of new technologies to transform the industry, and promote the development of intelligence and informatization. At the same time, on the basis of the original energy industry, the government should promote the development of new energy industry, as well as the development of related industries, to form a characteristic, special, intelligent, professional and large-scale industrial system. At the same time, it is necessary to strengthen the intensive construction of industrial construction, focus on the construction of new energy industry bases, increase the proportion of the new energy industry, and focus on enhancing the productivity and competitiveness of the new energy industry. The above new energy industry development plans all rely on technological and innovative development, while promoting the protection of the ecological environment.

**Build a green governance system**

In the process of economic development, the development conditions of different regions are different. Different regions should be developed and constructed under the guidance of the principle of adapting measures to local conditions. In the process of economic construction, the greater the consumption of energy, the lower the level of green efficiency (Javadi and Rezania 2009). Therefore, some industries that consume
more energy need to be adjusted to promote the adjustment of industrial structure and improve the level of green development.

By analyzing the development of a province, it can be seen that the development of various regions in this province is very uneven, and there is a large gap in the level of green development in various regions. In further development, it is necessary to formulate appropriate development strategies based on the development of different regions, and gradually narrow the development gap between different regions.

Increase policy support

The impact of environmental protection investment in the province and city on the efficiency of green development is the most important of all factors, and they are in direct proportion. This also shows that government support is very important to the development of urban green ecology. Due to the development of the energy industry, the province’s pollutant emission level ranks among the highest in the country. The government’s support for the environmental protection industry is conducive to improving the level of green development efficiency. While investing in environmental protection, we must also take into account the province’s unique regional characteristics, and adjust and promote green development efficiency according to local conditions. In order to improve the efficiency of green development, it is necessary to increase the introduction of scientific and technological talents, and make full use of the latest technology in the reform of the industrial structure of the province to increase the innovation of the industry. We can build a new type of industrial structure base to comprehensively promote the development of ecological industries (Khuntia 2014). At the same time, it is necessary to improve the province’s pollution control system to protect the province’s ecological environment from the root. It is necessary to strengthen the degree of opening to the outside world and absorb advanced technologies from different regions to enhance the development of emerging industries related to the ecological environment in the region.

Building a green city

In the process of urban construction and development, transmitting the concept of green consumption to urban residents can promote the improvement of the level of urbanization in a certain province, and will affect the level of green development efficiency to a certain extent. The province involved in this study is a province with a large population and an important transportation hub in northern cities, which is related to the traffic safety of many northern cities. As the urban efficiency of the city increases, the number of motor vehicles in the city has also increased a lot, which is the main cause of air pollution in the city. In the development of many northern cities, heating has always been the main factor affecting the air quality in northern cities. In winter, many people burn coal for heating, which puts a lot of pressure on the environment of northern cities (Knodel 1992). The promotion of a green ecological development model is of great significance to the sustainable development of northern cities.

In the process of urban construction in the future, relevant departments and governments should actively promote the construction of urban green transportation systems, instill the green concept of public transportation, and encourage people to choose public transportation. In different areas of the city, the government should provide people with sufficient bicycle equipment to promote people’s green travel and reduce exhaust emissions in the city. In addition, it is also necessary to promote the concept of green consumption to people, let people choose green consumption methods, reduce the use of plastic bags, and use more environmentally friendly shopping bags for shopping. In the suburbs of cities, some suburban forest parks can be properly planned and constructed to improve the city’s ability to cope with climate change.

Conclusion

At the beginning of economic construction, my country destroyed the development of the natural environment and the allocation of natural resources in pursuit of the speed of economic development. With the acceleration of development, my country’s economic construction and social development have achieved good results in the future development process. In order to achieve sustainable economic and ecological development, green and high-quality development must be achieved, so as to meet the content of my country’s development strategy for a resource-saving society. In the subsequent development, the rapid development of my country’s economy has provided effective help for my country’s strengthening of comprehensive national strength, and has also brought considerable income to Chinese residents. However, my country’s current economic development model still maintains an extensive development model. This economic development model easily leads to rapid consumption of resources, severe damage to the ecological environment, and adverse effects on regional development. In the future development, people should deeply realize the importance of realizing green development in resource-based areas. This article uses the relevant knowledge of machine learning and cloud computing to analyze the collected data in detail. Through the analysis of the development of a certain province, it summarizes the different factors that affect the green development efficiency of the province and enriches the theory of economic efficiency. It provides a reference to improve the coordination of regional and urban overall development.
Declarations

Conflict of interest The authors declare no competing interests.

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