A Spatial-EF and Econometrics Model Integrated Approach to Explore Land Use Sustainable Forecast Model-in Case of Shandong Province

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Abstract

This paper constructed land use sustainable forecast model, which was based on spatial ecological footprint and econometrics model, to find an effective approach and technique for land use sustainable forecast. What’s the spatial ecological footprint(S-EF)? The paper firstly answered the question, namely the improved and expanded EF based on GIS. Then S-EF and econometrics model, such as GM(1,1), regression model were integrated to build the forecast model. As follows, the Shandong’s land use sustainable was forecasted by the above model, and the future will not be optimistic. The conflict between supply and demand of fossil energy land becomes more evident based on the time and spatial information diagram. In general, this model can be used to forecast the land use sustainable from time to space and was tested effectively; the forecast result may offer datum which are beneficial for land administrators to make land use planning and land administration.

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1. Introduction

With the sharp increase of population and the rapid development of urbanization, the contradiction between man and land becomes more and more serious. According to present mode of land use, is our
future land use sustainable? In recent years, many scholars have been studying the methods for land sustainable use forecast and setting up various forecast index systems [1-9]. They have made some achievements, but the achievements have some limitations. In view of these, this paper constructed a model which is a spatial-EF [10] based and econometrics model integrated approach and can afford effective datum, including technique for land use planning, land administration, and so on. Firstly, the spatial ecological footprint (S-EF) was put up with; secondly, the land use sustainable forecast model was constructed based on S-EF and econometrics model, such as GM(1,1), regression model, main component analysis;thirdly, the land use sustainable forecast in Shandong was evaluated and forecasted; finally, some conclusions were discussed.

2. Land use sustainable forecast model

The ecological footprint analysis method (EFA), which was put forward by Canada’ ecological economist William Rees in 1992, and perfected by his doctor Wackenagel[10], is a measure of the evaluation for utilization degree of natural resource by human being and life support services function provided by the nature, and is an effective method to measure the sustainable development from biophysical angle. At present, it has been applied in all kinds of research realm [10-12], however, it can’t be evaluate dynamically. In order to improve the function of EF, S-EF was put forward which was integrated by GIS [13], which can evaluate the spatial change of land use sustainable. Furthermore, the land use sustainable forecast model was constructed through S-EF integrated econometrics model, which is a quantitative method on the land’ sustainable development degree through the comparison between ecological footprint (demand) which is demanded on natural resource and waste ,consumed by human and the ecological capacity(supply).The main model frame is made of three parts. Ecological deficit (ED) occurred when ecological footprint (EF) was lower than ecological capacity (EC), adversely, ecological plus (EP) occurred.

2.1 Ecological footprint model

The ecological footprint is the total productive land area which is needed to produce all resources consumed and digest all the waste produced by people. Land demand of any city or country may be calculated through the ecological footprint demand [10][14].

The EF computation formula is:

\[ EF = \sum_{i} x_i x_j x_i x_j \sum_{a} x_a \cdot x_j \sum_{c_i} x_{c_i} / p_i \]  

(Formula 2.1)

In 2.1, EF for the total ecological footprint, N for population, ef for per capita ecological footprint, I for consumer goods and investment, j for consumer goods and types of input for biological productive land, ci as i kind of types of consumer goods, for the per capita consumption of consumer, pi for I average per capita production capacity.

According to the demand, we divided the human resource consumption into two categories: biological resources and energy resources account. The datum can be obtained from certain region’s statistical yearbook, rural statistical yearbook and city statistical yearbook.

The multi-index synthesis method was used in the forecast of EF. In detail, this method makes full consideration of many factors and the origin which is consisted of EF, then forecasts the trend of every

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origin of EF and calculates EF based on formula 2.1. The forecast approach of every origin of EF is as follows.

2.2 Ecological capacity model

Ecological capacity means ecological space. Its computation formula is:

\[ EC = N \cdot ec = N \cdot \sum a_j \cdot n_j \cdot y_j \]  \hspace{1cm} \text{(Formula 2.2)}

In 2.2, EC for the overall regional ecological capacity, N for population, and ec, per capita ecological capacity.

The related datum can be obtained from the whole land use investigation and the changeable land use investigation.

The forecast of EC is executed by the means of GM(1,1) and the system dynamical model modified. Certainly, we also pay attention to the man-made factors such as the influence of land planning.

2.3 Land use sustainable degree (LUSD)

LUSD is used to denote the situation of certain region’s land use. High as ED is, ecological pressure index (EPI) is large and LUSD is weak accordingly; on the contrary, low as ED is, EPI is small and LUSD is strong accordingly. The formula is as follows.

\[ LUSD = \frac{EC}{(EC - EF)} \]  \hspace{1cm} \text{(Formula 2.3)}

3. Case study-Shandong province

3.1 Brief introduction of Shandong

Shandong province is situated at the east coastline and lower reaches of Yellow River. Its absolute location is N34°22.9’-38°24.0’ and E114°47.5’-122°42.3’, whose total area is 156.7 thousand km^2. Hills are the main terrain of east peninsula; the middle and lower mountains are situated in middle-south Shandong; the plain is lain out in the west-south and north of Shandong. In 2002, there is 17 cities and 90820 thousand people, among which 64350 thousand people is working for agriculture. Per cap EF is 2.33276 hm^2; per cap EC is 0.573459 hm^2; per cap ED is 1.7593 hm^2; per cap EP is 3.07; per cap LUSD is 0.33\[15\].

3.2 Time and spatial dynamical analysis of LUSD from 1990 to 2002

1) Time dimension

From Fig.1, we can see that LUSD is decreased from 1990 to 2002. It decreased from 0.7533 to 0.3260, and EPI increased from 1.3275 to 3.0679, which doubled the ecological pressure area and aggravated the conflict between human and land.
2) **Spatial dimension**

From Fig. 2, we can see that EPI is larger in the east and middle of Shandong; however, it is much little in the west, north and east-south of Shandong. According to cities, Heze, Liaocheng, Dezhou, Binzhou, Dongying is lower on EP; yet Qingdao, Zibo, Jining, Jinan is higher, and the EP is 5. From the whole layout of EP, east-north and west-south are high region on EP; in my opinion, it is relevant to the population, the level of economical development and the level of residents consumption.

3.3 **EF forecast**

3) **Arable land EF**

GM(1, 1) model is used in the forecast of cereal consumption. In order to improve the precise of forecast, we modified the model and adopted metabolism GM(1, 1), based on the data from 1952 to 2002. The differential equation and the forecast model are as follows. To speak of, the error is small by means of test, for example, later tested error ratio is 0.305009, little error probability is 0.962963, the average error value is 7% (Tab. 1).

\[
\text{Differential equation: } \frac{dx(t)}{dt} + (-0.03068723) \times x(t) = 917176.5 \\
\text{Equation solution: } x(t) = 30757890e^{0.03068723 \cdot t} - 2988790 \\
\text{Forecast model: } x_0(t) = 929537.3e^{0.03068723(t-1)}
\]

(x is the consumption of cereal, t is time) \hspace{1cm} (3.1)

The cereal consumption will be 6042720 ton, the total arable land EF will be 32487742hm², and per cap arable land EF will be 0.342589hm² by the year of 2010. In 2020, the cereal consumption will be 8213056 ton, the total arable land EF will be 35441173hm², and per cap arable land EF will be 0.354518hm². To be mentioned, the total population will reach 94830 thousand by 2010 based on Logistic model; the total population will reach 9997 thousand by 2020.
4) Forest EF
Regression model is used in the forecast of fruits consumption.

Index equation: \[ y = 16349.4 \times e^{0.0724x} \]
(y is the consumption of fruits, x is time) (3.2)

To speak of, the error is small by means of test; decisive coefficient is 0.991 and the average error value is 6%.
The fruits consumption will be 14572242 ton, the total forest EF will be 3683580 hm², and per cap forest EF will be 0.0388 hm² by the year of 2010. In 2020, the fruits consumption will be 3006398 ton, the total forest EF will be 3274611 hm², and per cap forest EF will be 0.0328 hm².

5) Pasture EF
Regression model is used in the forecast of meat, eggs, milk consumption.

Exponential equation for meat consumption: \[ y = 7494.59 \times e^{0.0792x} \]
(y is the consumption of meat, x is time) (3.3.1)

The error is small by means of test, for example, decisive coefficient is 0.906 and the average error value is 6%. The meat consumption will be 1017121 ton by the year of 2010 and 2245662 ton in 2020.

Quadratic equation for eggs consumption: \[ y = 87760.3x^2 + 28831.2x - 351.09 \]
(y is the consumption of eggs, x is time) (3.3.2)

The error is small by means of test, for example, decisive coefficient is 0.990 and the average error value is 0.11%. The eggs consumption will be 538384.9 ton by the year of 2010 and 636715.7 ton in 2020.

Exponential equation for milk consumption: \[ y = 168.303 \times e^{0.0724x} \]
(y is the consumption of milk, x is time) (3.3.3)

The error is small by means of test, for example, decisive coefficient is 0.974 and the average error value is 0.87%. The milk consumption will be 230177.9 ton by the year of 2010 and 737675 ton in 2020.

Based on formula 2.1, we can evaluate the pasture EF, which add up to 12266824 hm² by 2010 and reach 10862610 hm² in 2020. In view of per cap, it is going to be 0.1294 hm² in 2010 and 0.1087 hm² by 2020.

6) Sea EF
Regression model is used in the forecast of marine products consumption.

Exponential equation for marine products consumption: \[ y = 98031.8 \times e^{0.0736x} \]
(y is the consumption of marine products, x is time) (3.4)

The error is small by means of test; decisive coefficient is 0.899 and the average error value is 7.6%.
The marine products consumption will be 9425591 ton, the total forest EF will be 224418833.3 hm², and per cap marine products EF will be 2.3665 hm² by the year of 2010. In 2020, the marine products consumption will be 19685113 ton, the total marine product EF will be 181261365.4 hm², and per cap marine product EF will be 1.8132 hm².

7) Built-up EF
Although there are many factors that influence built-up EF, yet we replace the origin source of built-up EF with electricity because it stands for the most of built-up EF and others can’t be quantitative.
Metabolism GM(1,1) was used to forecast electricity. The error is small by means of test; later tested error ratio is 0.2199307, little error probability is 1, the average error value is 0.21%.

- Differential equation: \[
\frac{dx(t)}{dt} + (-0.07121785) \times x(t) = 591.6314
\]

- Equation solution: \[
x(t) = 8307.348e^{0.07121785t} - 8307.348
\]

- Forecast model: \[
x_u(t) = 571.0551e^{0.07121785(t-1)}
\]

(x is the consumption of electricity, t is time) (3.5)

The electricity consumption will be 205.8 billion kilo-watt hours; the total built-up EF will be 6174000 hm²; and per cap built-up land EF will be 0.0651 hm² by the year of 2010. In 2020, the electricity consumption will be 5064 billion kilo-watt hours; the total built-up EF will be 7483636 hm²; and per cap built-up EF will be 0.0749 hm².

8) Fossil energy EF

The main influential factors were chosen based on main component regression model. After forecasting by means of metabolism GM(1,1), we can obtain the independent variable (z) at yearly which was built regression model so as to forecast the energy consumption (y). The related coefficient between y and z was 0.958 and the decisive coefficient was 0.918; so, we can manage to construct the line regression model.

Regression model: \[
y = 9537.74 + 3240.89z \quad (3.6)
\]

The standard coal equivalent consumption will be 19514.6 ton; the total fossil energy EF will be 105645361.5 hm²; and per cap fossil energy EF will be 1.1141 hm² by the year of 2010. In 2020, the standard coal equivalent consumption will be 36409.6 ton; the total fossil energy EF will be 111371578.5 hm²; and per cap fossil energy EF will be 1.5625 hm².

Above all, the total EF will be 2.94 hm² by 2010; and when it comes to 2020, it will be 3.37 hm².

3.4 EC forecast

The forecast of five kinds of land use is executed by GM(1,1) and the system dynamical model modified. The land change velocity yearly was set. For example, the arable land was 14%; the forest land was 9%; the pasture was 20%; the sea was 14%; the built-up was 27%. To make sure the accessibility, we referred to the land use planning of Shandong (2006-2020), and drew a conclusion about five kinds of land use.

Based on the total EC and per cap EC, by 2010, per cap arable land EC will be 0.079 hm²; the forest EC will be 0.026 hm²; the pasture EC will be 0.000554 hm²; the built-up EC will be 0.027 hm²; the sea EC will be 0.012 hm². Summing all these, we can conclude that the total EC will reach 52213398 hm² in 2010; it will increase 52724178 hm² by 2020. However, per cap EC will be 0.5506 hm² in 2010; and it may decrease 0.5274 hm² by 2020.

3.5 LUSD forecast

According to the forecast result, EF in 2020 is 0.4298 hm² more than that of 2010, and the increasing velocity yearly is 1.37% which is more slow than that of 1990-2002. Unfortunately, EC is decreasing which in 2020 is 0.4521 hm² less than that of 2010. Thus, ED may reach 2.8466 hm² and EPI increases 5.397; inversely, LUSD may decrease 0.1853 in 2020.
3.6 Result analysis and discussion

(1) Land use sustainable forecast model which can build time and spatial information diagram and is easy for us to forecast the land use change trend was explored based spatial-EF and econometrics model. It is precise and accessible for us to forecast LUSD based on this model.

(2) Based on EF and EC accounts, we found that per cap EF is still increasing, but the increasing velocity yearly grows slowly and the velocity from 2010 to 2020 is lower (1.37%) than that from 1990 to 2002 (7.23%). At the same time, the total EC is increasing though per cap EC is decreasing, that’s to all, per cap EC in 2020 may be 0.046 hm² lower than that of 2002; however, the total EC in 2020 is 717181.3 hm² more than that of 2002. Although we may adjust the structure of land use and enhance the economical supply, yet the ED is increasing gradually, because the population grows rapidly. By 2020, per cap ED may be 5.3973 hm² and the total ED may be 2485.7 billion hm², furthermore, we are still faced up with large threat.

Figure 3 The structure diagram of EF in 2010 , 2020

(3) From the structure of EF (Fig.3), we can see that the fossil energy EF may increase rapidly. The ratio of total EF may increase from 27% to 40%, respectively from 2010 to 2020. We can make conclusion that the demand for fossil energy becomes much higher, correspondingly carbon emission increases, which make us confront serious environment problem. To protect our living environment, we should take measures to control the rapid demand for all kinds of natural resources and waste disposed. Certainly, to make it true, we should change our consumption mode, especially for energy consumption.

(4) From the time and spatial dynamical development, we can draw conclusions that the more rapid certain region development of urbanization and industrialization, the higher the ED is. How to degrade ED is a challenge for us to ensure economical development. Based on the forecast result of ED and EF, it is urgent to make out rational layout and intensive use of land; controlling population growth and guiding low carbon consumption mode are an effective way to decrease EF. EPI will not be relieved until we take countermeasures; not to mentioned, land use sustainable becomes true if we didn’t care about the present situation.

4. Conclusions

This paper put up with S-EF based on EF improved and applied it integrated econometrics model to explore land use sustainable forecast model, which overcome the deficiency of land use sustainable forecast and evaluation. By means of this model, the time and spatial information can be built and a new approach to forecast land use sustainable was put forward. Furthermore, this model can adapt to differential extent, such as countries, cities, and so on, to monitor dynamical change of land use. Certainly, it is supportive for land planning, land administration, policy designed on the basis of forecast result. With the mathematical method improving, this model may be needed to modify to be more perfect.
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