Relationship between Urban Form and the CO_2 Emission of Energy Consumption Based on the Hi_PLS Model – a Case Study in Shanghai

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***Abstract*—We, firstly, collect the energy consumption (EC) of Shanghai and compute its CO_2 emission (CE). Then, we use three kinds' indexes (urban size, traffic infrastructure, and compactness) to analyze the relationship between city's form and its CE based on the Partial Least Squares (PLS) and the Hierarchical PLS (Hi_PLS). The indexes of urban size contain Gfs (area of housing construction) and Gds (area of road). Traffic infrastructure's indexes contain Tcar (possession of civilian vehicles), Tchl (length of city's road) and Tqln (number of city's bridge). Compactness indexes contain Pchl (pre-capita Tchl) and Pqln (pre-capita Tqln). The results show: the explanatory ability (result) of the Hi_PLS is stronger (better) than the PLS. Urban size is the biggest driving forces; traffic infrastructure follows it. Urban compactness can inhibit partly the growth of city's CE. Specifically, a 1% increase of the seven indexes above can make the Shanghai's CE grow 0.326%, 0.300%, 0.147%, 0.151%, 0.151%, -0.059% and -0.058%, respectively. The - means an inhibition.**

Keywords-urban form; CO_2 emission; Hi_PLS; energy consumption; PLS

I. INTRODUCTION

As known to all of us, human activities and fuel burning, especially in cities, are the major sources of global CO_2 emissions. So, it is necessary to analyze thoroughly the relationship between urban morphology (form) and the CO_2 emission (CE) arising from energy consumption (EC) nowadays. Some previous scholars have learned many about this interaction. For instance, the article [1] used the software package EnviMet to analyze the relationship between urban form and building CO_2 emissions. This article [2] took the New Zealand as an example to examine the policy opportunities of urban morphology and transport, and argued these issues have much potential to reduce the cities' CE. The article [3] took Manila, Jakarta, Ho Chi Minh City, New Delhi, and Chiang Mai as examples to study the carbon management's strategies, and found urban form affect the functions of the city (such as mobility, shelter, and food), and these functions have major influences upon the CO_2 emissions. The article [4] adopted an appropriate method to evaluate and analyze the urban form's influence on reducing the CO_2 emissions, and concluded the type of urban form was a significant determinant by facilitating the cycling, walking, and public transport provision.

However, the studies above are not deep enough. For instance, the next question cannot still be answered clearly up to now. What about the interaction between urban form and the CE of cities' EC? So, taking the Shanghai city as a case, we collect the EC-related data in 1997-2013 and compute corresponding CE, and identify their respective change. Then, we adopt the Partial Least Squares (PLS) and the Hierarchical PLS (Hi_PLS) to find the answer of this problem.

II. DATA AND METHODS

A. Data

The data sources of this study contain the article [5], the City Statistics Yearbook of China, the Yearbook of Shanghai Statistics, the Yearbook of Shanghai Energy Statistics, and so on.

B. Methods

The way of computing the CE is contained in the literature [5], which is the IPCC sectoral approach. The inventories include emissions from fuel combustion and cement production. The models of the PLS and Hi_PLS are interpreted in the literature [6], but omitted for saving space.

III. DYNAMICS OF EC AND CE

Fig. 1 indicates the change trend of Shanghai's EC and CE from 1997 to 2013. Fig. 2 indicates the related Cp and Cg. The Cp is the per-capita CE, and the Cg is the CE divided by the gross domestic product (GDP) with the 2000 constant price, in which the impact of the consumer price index (CPI) is excluded.

It can be easily found the Shanghai's EC is 1395.5 PJ in 1997, but it rises fast to 3419.8 PJ in 2013. The increase amount is 2024.3 PJ, with an average annual growth rate of 5.76% (Fig. 1). The regional CE is 108.86 Mt in 1997. It, similarly, grows rapidly to 253.25 Mt in 2013, with a growth's quantity of 144.39 Mt and an average annual growth rate of 5.42% (Fig. 1). So, it can be easily found that the change trend of the EC is almost the same as the CE. However, the following change's situations of the EC are omitted for saving space in this article. The growth trend above means people spend increasingly energy and time to engage in urban exploration and development activities with the deepening of reform and opening up in China.

It can also be easily seen the CE of Shanghai is 217.10 Mt in 2007. It increases quite slowly to 218.65 Mt in 2008, and decreases sharply to 200.98 Mt in 2009. The corresponding EC of Shanghai has a very obviously slow in 2009. This situation may be arising from the influence of the global financial crisis in 2008. In the crisis, people suffer from a shortage of energy supply. This influence becomes more prominent in 2009. However, the economy gradually enters the recovery track in 2010, so the CE has a growth again.

Similar to the total CE, the CE per-capita (Cp) has a globe growth trend and an obvious decrease in 2009 (Fig. 2). The Cg has an obviously decrease trend (Fig. 2), especially prominent in 2009. This indicates the energy intensity (energy consumption per unit of GDP) of Shanghai is decreasing. Namely, the efficiency of regional energy use may have an advance along with the development of economy and the enhancement of the science and technology.

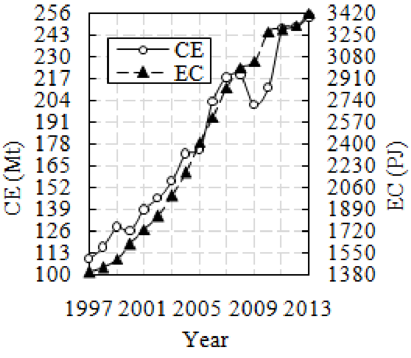

Fig. 1 Trend of the CE and the EC

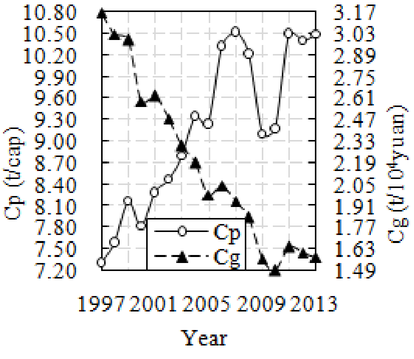

Fig. 2 Change of the Cp and the Cg

IV. RELATIONSHIP BETWEEN URBAN FORM AND THE CE BASED ON THE PLS AND THE HI_PLS MODELS

Table 1 indicates the coefficients' results of urban form's indicators by using the PLS and the Hi_PLS models.

TABLE 1 THE COEFFICIENTS OF URBAN FORM'S INDEXES BASED ON THE PLS AND THE HI_PLS

model	PLS	Hi_PLS	model	PLS	Hi_PLS
Constant	3.713	3.713	Pchl	-0.085	-0.059
Gfs	0.388	0.326	Pqln	-0.091	-0.058
Gds	0.045	0.300	R^2	0.962	0.941
Tcar	0.164	0.147	R^2X	0.978	0.996
Tchl	0.219	0.151	R^2Y	0.961	0.940
Tqln	0.212	0.151	Q^2(cum)	0.954	0.931

These indicators contain three perspectives: urban size, traffic infrastructure and compactness. The first contains Gfs (total area of various types' housing construction) and Gds (area of all kinds' road construction). The second contains Tcar (the possession of civilian vehicles at the end of the year), Tchl (length of city's road) and Tqln (number of city's bridge). The third contains Pchl (pre-capita Tchl) and Pqln (pre-capita Tqln).

R^2X is the variance matrix of the X by extracting all the PLS principal components. R^2Y is the Y's. R^2 reflects the fitting effect. The R^2 is closer to 1; the quality of the model is better. Q2(cum) is the cross validation. When the Q2(cum) is bigger than 0.5, the model is good. The total seven indicators can directly enter the PLS, but must be classified into three kinds for using the Hi_PLS as mentioned above.

Fig. 3 is the t_1/t_2 graph of the PLS, which is used to test the applicability of the PLS model. Only when the sample data are evenly distributed in the four quadrants and in the oval shape, the application of the PLS is appropriate. The t_1 is the first PLS principal component; t_2 is the second. Fig. 4 is the Yfit/Ycom graph of the PLS, which is used to identify the fitting effect as the R^2. Yfit is fitting value, and Ycom is the computing value. From the Fig. 3 and 4, we can find the PLS model in the Table 1 is good.

It can be easily found the coefficients of the Gfs, Gds, Tcar, Tchl, Tqln, Pchl and Pqln are 0.388, 0.045, 0.164, 0.219, 0.212, -0.085 and -0.091, respectively in the PLS model in Table 1. This means a 1% increase of the seven indicators can make the Shanghai's CE grow 0.388%, 0.045%, 0.164%, 0.219%, 0.212%, -0.085% and -0.091%, respectively.

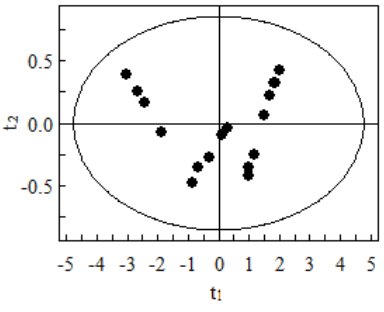

Fig. 3 t_1/t_2 graph of the PLS

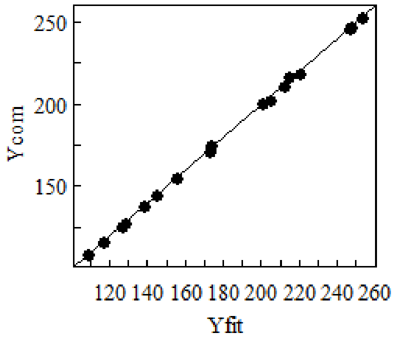

Fig. 4 Yfit/Ycom Graph of the PLS

However, when we classify these indicators' importance into three categories, a problem emerges. The Gfs is the most important drivers of the city's CE because its coefficient is the largest (0.388>0.164, 0.219, 0.212 and 0.045). This result can also be easily seen in the VIP's plot (Fig. 5). The order of these indicators' importance from big to small is arranged in the VIP's plot. Similarly, we can find the importance of the Gds is less than the Tcar, Tchl and Tqln only from the coefficients (0.045<0.164, 0.219 and 0.212). At the same time, the importance of the Gds is the least than the others from the VIP's plot (Fig. 5). So, whether the impact of urban size (Gfs and Gds) is bigger or smaller than the construction situation of the traffic infrastructure? We cannot answer this question only from the result of the PLS.

Fortunately, the Hi_PLS can just make up for the deficiency of this PLS model. In the Hi_PLS, we can first combine the Gfs and Gds into the G's indicator. Similarly, the Tcar, Tchl and Tqln are combined into the T, and the Pchl and Pqln into the P. Then, the first principal components (t_1) of the three groups' indicators (G, T and P) are extracted in the base PLS. In the end, the three groups' t_1 are being brought into the top PLS of the Hi_PLS to get the final result. The coefficients of Hi_PLS are shown in Table 1 and their corresponding VIP's plot shown in Fig. 6.

In Fig. 6, the $ sign means the Hi_PLS model is used. We can easily find the importance of the G (urban size) is the largest driving force of the city's CE, which is followed by the T (construction situation of traffic infrastructure). The P's importance is the least, which can reflect the compactness of the city.

Therefore, we can conclude the explanatory ability of the Hi_PLS is stronger than the PLS. The corresponding results of the Hi_PLS are more meaningful for helping us carry out the related policies of low-carbon urban development. Furthermore, the coefficients of the Gfs, Gds, Tcar, Tchl, Tqln, Pchl and Pqln are 0.326, 0.300, 0.147, 0.151, 0.151, -0.059 and -0.058 (Table 1). Namely, a 1% increase of the seven indicators can make the Shanghai's CE grow 0.326%, 0.300%, 0.147%, 0.151%, 0.151%, -0.059% and -0.058%, respectively. The - sign means an inhibition effect.

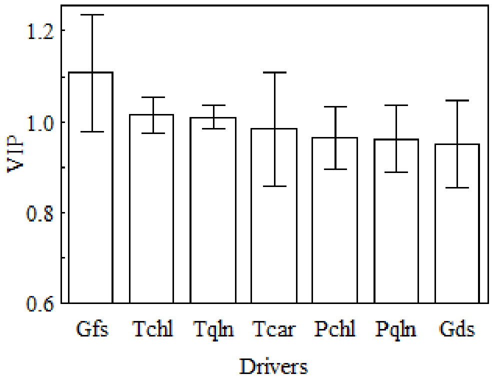

Fig. 5 VIP's plot of the PLS

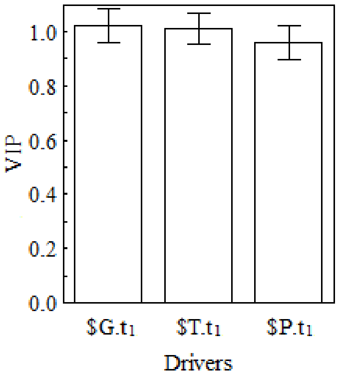

Fig. 6 VIP's plot of the Hi_PLS

V. CONCLUSIONS AND DISCUSSION

So far, there is an increasingly attractive issue in the domain of climate change: how about the relationship between urban form and the city's CE arising from its EC? For answering this question, we, firstly, collect the related EC's data of Shanghai in 1991-2003 and compute its corresponding CE, and identify their change trend. Then, we analyze this change trend with some indicators of urban form by using the Partial Least Squares (PLS) and the Hierarchical PLS (Hi_PLS). These indicators are Gfs (area of housing construction), Gds (area of road), Tcar (possession of civilian vehicles), Tchl (length of city's road), Tqln (number of city's bridge), Pchl (pre-capita Tchl) and Pqln (pre-capita Tqln).

The results show: the explanatory ability of the Hi_PLS is obviously stronger than the PLS. Based on the Hi_PLS, a 1% increase of the seven indicators can make the Shanghai's CE grow 0.326%, 0.300%, 0.147%, 0.151%, 0.151%, -0.059% and -0.058%, respectively. The - means a an inhibition. The impacts of urban size's indicators (Gfs and Gds, combined as G) are the biggest. The construction situations of traffic infrastructure (Tcar, Tchl and Tqln, as T) are the second impacts' source. However, the urban compactness (Pchl and Pqln, as P) can inhibit the increase of city's CE to some extent.

Therefore, it is necessary for us to construct a more compact city so that advancing the efficiency of land use and promoting its low-carbon development, especially in Shanghai.

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