“Decoupling” Indicators for Evaluation of Urban Low-Carbon Economy Development: a Case Study of Shanghai

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Abstract. Environment are closely related to energy and they are two of the most important issues this century. So the development of a low-carbon economy and the construction of environmental friendly society are the only way for the further development of China itself. In this study, “decoupling” indicators for evaluation of a low-carbon economy development are proposed. “Decoupling” indicators of energy consumption and economic growth were selected to reflect the response relationship between economic growth and the changes of resources, including weak, strong and expansive/recessive degree of decoupling. Similarly, “decoupling” indicators of carbon dioxide emissions and economic growth were chosen to reflect the response relationship between economic growth and the changes of environment. Shanghai, in the Eastern China, was selected as a special case. The results showed a change from expansive negative coupling to week decoupling regarding both of energy consumption and carbon emissions in Shanghai during the period 1991-2013, indicating that we have achieved some significant outcome in the process of the low-carbon economy development in Shanghai. However, in view of the possibility of expansive negative coupling, we should continue to make efforts for the development of the low-carbon economy.

1. Introduction
Environment are closely related to energy and they are two of the most important issues this century. It is reported that China was responsible for nearly three-quarters of growth in global carbon emissions from the burning of fossil fuels and cement production between 2010 and 2012 [1, 2]. However, researchers re-evaluated China’s carbon emissions and the results showed that China’s CO2 emissions from fossil fuel combustion and cement production is 14 per cent lower than the emissions reported by other prominent inventories in 2013, which is 2.49 gigatonnes of carbon [1, 3-5]. Anyway, as a responsible country China have an obligation to make strategies for carbon emission reduction as a response to climate change. If China cannot make efforts to reduce carbon emissions, the future economic and social development will be hampered. Given this, the development of a low-carbon economy and the construction of environment friendly society are the only way for the further development of China itself.

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2. A theoretical framework on decoupling to evaluate the development of the low-carbon economy

Although China has developed low-carbon economy in recent years, there were no criteria and indicators to measure it. The “decoupling” indicators of the development of a low-carbon economy was a good try. Referred to the conceptual model of decoupling and coupling [6, 7], “decoupling” indicators of energy consumption and economic growth was selected to reflect the response relationship between economic growth and the changes of resources in this paper, including three indicators: Gross Domestic Product (GDP), the total amount of energy consumption (TEC) and the energy consumption per unit of GDP (TEC/GDP). Similarly, “decoupling” indicators of carbon dioxide emissions and economic growth were chosen to reflect the response relationship between economic growth and the changes of environment, including three indicators: Gross Domestic Product (GDP), the total amount of carbon dioxide emission (CO$_2$) and the carbon dioxide emission per unit of GDP (CO$_2$/GDP).

The category of “decoupling” indicators of carbon dioxide emissions and economic growth is the same as “decoupling” indicators of energy consumption and economic growth (Table 1). In here, take “decoupling” indicators of energy consumption and economic growth as example. Decoupling (TEC/GDP<0)) can be divided to three subcategories: in weak decoupling, GDP and TEC both increase, strong decoupling occurs when GDP grows and TEC decreases and recessive decoupling when GDP and TEC both decrease. Similarly, negative decoupling (TEC/GDP>0) includes three subcategories: in expansive negative decoupling GDP and TEC both increase, in strong negative decoupling GDP decreases and TEC increases and weak negative decoupling occurs when both variables are decreasing.

| Degree                      | △TEC | △CO$_2$ | △GDP | △(TEC/GDP) | △(CO$_2$/GDP) |
|-----------------------------|------|---------|------|------------|---------------|
| Strong decoupling           | <0   | <0      | >0   | <0         | <0            |
| Weak decoupling             | >0   | >0      | >0   | <0         | <0            |
| Recessive decoupling        | <0   | <0      | <0   | <0         | <0            |
| Strong negative decoupling  | >0   | >0      | <0   | >0         | >0            |
| weak negative decoupling    | <0   | <0      | <0   | >0         | >0            |
| Expansive negative decoupling| >0 | >0      | >0   | >0         | >0            |

3. Statistical data on decoupling in Shanghai

Both of GDP and TEC data were from Shanghai statistical yearbook (2014) [8]. In order to eliminate the effect of currency fluctuations GDP in Shanghai was recalculated based on the base price in 1978. Then the comparable price was obtained and used to calculate the growth rate of GDP. The unit of the total energy consumption was ten thousand tons of standard coal, which did not involve the price factor. So these data can be used directly to calculate the growth rate of the total energy consumption.

3.1. The response relationship between economic growth and energy consumption in Shanghai

The results showed a change from expansive negative decoupling to weak decoupling regarding energy consumption during the period 1991-2013 in Shanghai (Table 2, Figure 1). In view of the growth rate of GDP and energy consumption, energy consumption elasticity coefficient was changed between 1991-2013. The energy consumption elasticity coefficient was 1.22 in 1991, indicating that the growth rate of energy consumption growth was faster than that of economic growth. Then in the
following years, the value of energy consumption elasticity coefficient was lower than 1 (for example, the lowest value was 0.11 in 2012, and 0.39 in 2013).

Table 2 The indicators of energy consumption, carbon dioxide emissions and economic growth in Shanghai 1991-2013

| Year | ΔTEC  | ΔCO₂   | ΔGDP   | Δ(TEC/GDP) | Δ(CO₂/GDP) |
|------|-------|--------|--------|------------|------------|
| 1991 | 275.46| 215.51 | 46.10  | 0.07       | 0.05       |
| 1992 | 190.40| 148.96 | 102.30 | -0.41      | -0.32      |
| 1993 | 289.81| 226.73 | 120.04 | -0.29      | -0.22      |
| 1994 | 229.91| 179.87 | 132.59 | -0.33      | -0.26      |
| 1995 | 289.23| 226.28 | 149.77 | -0.26      | -0.20      |
| 1996 | 160.34| 125.44 | 156.87 | -0.31      | -0.25      |
| 1997 | 132.61| 103.75 | 173.23 | -0.30      | -0.24      |
| 1998 | 115.29| 90.20  | 157.14 | -0.22      | -0.17      |
| 1999 | 245.08| 191.74 | 175.14 | -0.14      | -0.11      |
| 2000 | 380.29| 297.52 | 204.61 | -0.09      | -0.07      |
| 2001 | 395.30| 309.26 | 216.61 | -0.08      | -0.06      |
| 2002 | 354.56| 277.39 | 257.81 | -0.12      | -0.10      |
| 2003 | 547.00| 427.94 | 312.09 | -0.08      | -0.06      |
| 2004 | 609.30| 476.68 | 404.85 | -0.11      | -0.09      |
| 2005 | 819.41| 641.06 | 371.02 | -0.01      | -0.01      |
| 2006 | 650.65| 509.03 | 460.50 | -0.10      | -0.08      |
| 2007 | 794.75| 621.77 | 621.19 | -0.12      | -0.09      |
| 2008 | 536.91| 420.05 | 456.68 | -0.08      | -0.06      |
| 2009 | 160.02| 125.19 | 423.40 | -0.12      | -0.09      |
| 2010 | 833.75| 652.28 | 575.63 | -0.04      | -0.03      |
| 2011 | 69.35 | 54.26  | 505.52 | -0.13      | -0.10      |
| 2012 | 91.67 | 71.72  | 500.06 | -0.11      | -0.08      |
| 2013 | 341.52| 267.19 | 551.89 | -0.07      | -0.05      |

Data resource: 《Shanghai statistical yearbook 2014》[8]

Figure 1 Decoupling of energy consumption from economic growth in Shanghai 1991-2013
Overall, that the low energy consumption growth rate can support rapid economic growth may be due to the following two reasons: one is increased energy efficiency benefited from the technological progress and regime innovation; the other is optimized and upgrading industrial structure. Excluding the impact of price factor, according to the comparable price in 1990, the total energy consumption per ten thousand yuan GDP continued to reduce, and the energy efficiency in Shanghai was significantly higher than the national average value.

3.2. The response relationship between economic growth and environment stress in Shanghai

3.2.1 Calculation of carbon emissions. Because there were no direct monitoring data of carbon emissions in China, most of the researches were based on the energy consumption to obtain the carbon emissions data. Based on the existing research results of carbon emission estimation at home and abroad [9-11], the carbon emissions in China are estimated by the following formula:

\[ \text{Ems} = \alpha \times \varepsilon \]  

Where Ems is the amount of carbon dioxide emissions (unit: tons of carbon equivalent), \( \alpha \) for carbon dioxide emissions factors and \( \varepsilon \) for the amount of energy consumption (unit: tons of standard coal). According to the calculation method of CO\(_2\) emissions from fossil fuels combustion by Oak Ridge National Laboratory (ORNL), \( \alpha \) is 0.7194.

Based on the hypothesis that there was a positive correlation between carbon emissions and energy consumption, and considering the difference in the energy structure in different areas and the carbon emission factors in different energy types, the carbon emissions in different provinces was estimated by the following equation:

\[ \text{Ems}_i = \frac{E_i}{\varepsilon} \times \frac{\gamma_i}{\gamma} \times \text{Ems} \]  

Where Ems\(_i\) and E\(_i\) are the amount of carbon dioxide emissions and the amount of energy consumption in \( i \) province respectively; Ems and \( \varepsilon \) are the total carbon dioxide emissions and the total energy consumption in China respectively; \( \gamma_i \) for the average of carbon dioxide emissions factors in \( i \) province and \( \gamma \) for the average of carbon dioxide emissions factors in China. In this paper, \( \gamma \) is 0.8, \( \gamma_{sh} \) is 0.87[12].

![Figure 2](image)

**Figure 2** Decoupling of carbon emissions from economic growth in Shanghai 1991-2013

3.2.2 The response relationship between economic growth and energy consumption in Shanghai. The data showed a change from expansive negative decoupling to weak decoupling regarding CO\(_2\) emissions between 1991 and 2013 in Shanghai (Table 2, Figure 2), which was consistent with the results of decoupling of energy consumption from economic growth. With the rapid development of the economy in China, \( \Delta \) (CO\(_2\)/GDP) was greater than 0, indicating that the annual growth rate of CO\(_2\)
was greater than that of GDP in 1991. Fortunately, Shanghai experienced weak decoupling of CO$_2$ emissions from GDP between 1992 and 2013. However, as the growth rate of CO$_2$ emissions in Shanghai increased much more quickly than that of GDP in recent years, there will probably be change from weak decoupling to expansive negative coupling.

4. Conclusions
In summary, the statistics showed a change from expansive negative coupling to weak decoupling regarding both energy consumption and carbon emissions in Shanghai between 1991 and 2013, indicating that we have achieved some significant outcome in the process of the development of the low-carbon economy in Shanghai. The growth rate of energy consumption and carbon emissions were both lower than that of economic growth, and economic growth did not exhibit a positive correlation with energy consumption or environment stress during the period 1992-2013, suggested that weak decoupling from GDP to energy consumption and carbon emissions. However, in view of the possibility of expansive negative coupling, we should continue to make efforts for the development of the low-carbon economy.

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