# Chapter 7
# Resource Bottlenecks and Environment Constraints in Green Development

**Jinshe Liang, Hongrui Wang and Tao Song**

Resource and environmental problems have been existed for a long time. Since the industrial revolution, social productive forces have been rapidly developed, as well as the ability of the human being to transform nature. Meanwhile, the population has been rapidly expanding and resource consumption per capita continues to increase. Human being deprives more and more resources from nature, but returns to it with increasing waste and pollution. In China, although the total amount of resources is relatively abundant, natural resources per capita are far below the world's average level due to its large population. China is still at the stage of rapid development of heavy industry and is facing the challenge of high resource consumption and low output efficiency in its economic growth. The high demand for resources and heavy environmental pollution become a serious concern, which greatly restricts China's economic and social development.

The concept of green development in this chapter emphasizes natural resource scarcity and pollutant emission limit. In order to ensure the sustainable development of our society, the two natures require reducing resource consumption and pollutant emissions. In the first part of this chapter, we have calculated the relative scarcity index of natural resources and measured the permeability of natural resources in each industrial sector. The results of these two indicators reflect the resource bottlenecks and their impacts on the development of the national economy. Following that, we have measured the resource consumption in three dimensions—scale expansion, structural change and technological progress, to conduct path analysis for reducing the effects of resource shortage. In the second part, we have analysed the current situation of environmental pollution, pollutant emission and pollution control to evaluate the quality of the environment in China. At the end of the chapter, we have analysed the impact of China's economic expansion, structural change and technological progress on pollutant emissions for a better understanding of the potential constraints of environmental pressure on economic development.

X. Li and J. Pan (eds.), *China Green Development Index Report 2011*,
Current Chinese Economic Report Series, DOI: 10.1007/978-3-642-31597-8_7,

## 7.1 Resource Bottlenecks in China's Green Economic Development

Before discussing the impact of resource bottlenecks on China's economic growth, we will explain the meaning of "bottleneck" in the context. In general, all resources are scarce under the definition of economics. Scarcity is defined relative to the use of resources, namely, the limited resource supply is always less than the unlimited demand at a specific spatial and temporal scale. In reality, many production activities involve two or more kinds of resources in the same place at the same time. A resource is scarce in relation to other scarce resources. For example, both arable land and water resources in China are scarce resources. From an agricultural perspective, arable land resources in many areas of China have low production as a result of the shortage in water resources. In this case, water resources tend to be relatively scarcer than arable land resources and water resources have greater bottleneck effects than arable land resources for agricultural productivity. In this part, we first measure the scarcity of China's natural resources by comparing the resource use (consumption) and resource stock (reserves). Comparing the scarcity of each resource, we can identify which ones are relatively scarcer and have stronger bottleneck effects.

One aspect of resource bottleneck effect on economy is their different levels of participation in each economic sector. For example, water resources are involved in almost all kinds of production processes, while the iron ore is not. As a supplement analysis to relative scarcity for bottleneck effect, we use the concept of "induction" in input–output analysis to measure the participation level of natural resources in each economic sector, which is known as the permeability of resources on economy. Permeability analysis can be used to evaluate the importance of each resource to the economy.

Two factors cannot be ignored when evaluating the scarcity of natural resources. First, all resources have their "locations", that is, each resource is located at a particular location on the earth with its property rights. A relative abundant resource in the world does not mean it is also rich in a certain country or region. For example, water resources are relatively affluent in most parts of south China as the precipitation is abundant throughout the year and there are a large number of rivers and lakes in the region. By contrast, water resource is relatively scarce in northwest China as the region has a small amount of annual precipitation and few rivers and lakes. Second, resource consumption is highly related to technology and economic conditions. For example, oil consumption is related to oil extraction and processing technologies and oil price. As oil extraction technology improves, international oil supply will increase and oil prices will drop, which induces oil consumption growth. Considering all the factors above, this chapter mainly focuses on evaluating the bottleneck effects of China's natural resources by using relative scarcity and permeability analysis instead of the total amount.

### *7.1.1 Relative Scarcity Analysis of China's Natural Resources*

Based on the study conducted by Zhuang et al. (2011),[1] we first explain how to calculate the relative scarcity index by taking land and energy resources as examples. The relative scarcity index of China's energy resources is the ratio of China's share of the world's energy reserves to China's share of the world's energy consumption, calculated as formula (7.1) below:

$$\text{Relative scarcity index of China's energy resource} = \frac{\text{China's energy reserves} \div \text{World's energy reserves}}{\text{China's energy consumption} \div \text{World'senergy consumption}} \tag{7.1}$$

The denominator of formula (7.1) refers to China's relative energy consumption and the numerator refers to China's relative energy reserves. The ratio of the two values takes into account consumption and possession, as well as geographical location. Meanwhile, world's energy consumption indirectly considers the economic and technological factors.

When calculating the relative scarcity index of China's arable land, we need to take into account the special nature of land resources, which refers to the differences in their inputs and outputs in each country or region as a result of the differences in demands for agricultural products. In addition, arable land is a renewable resource, and the reserves will not be decreased under rational use. If we simply apply formula (7.1), it is not able to provide a reasonable comparison under a unified standard, and the results cannot accurately indicate the scarcity of arable land resources. Instead, we change the denominator of formula (7.1) from consumption to population, and then formula (7.1) changes to:

$$\text{Relative scarcity index of China's arable land resources} = \frac{\text{China's arable land reserves} \div \text{World'sarable land reserves}}{\text{China's population} \div \text{World's energy population}} \tag{7.2}$$

Formula (7.2) takes into account the total amount and locations of land resources, as well as demands and the renewable nature of arable land resources. For example, China currently feed approximately 1/5 of the world's population by 1/12 of the world's arable land. Based on formula (7.2), the relative scarcity index of arable land is approximately 2/5, which implies that arable land is a scarce resource in China. Formula (7.2) can be further adjusted as:

[1] Zhuang et al. (2011).

$$\text{Relative scarcity index of China's arable land resources} \\ = \frac{\text{China's arable land reserves} \div \text{China's population}}{\text{World's arable land reserves} \div \text{World's energy population}} \quad (7.3)$$

Formula (7.3) refers to the proportion of China's per capita share of arable land to the world's per capita share, which explains the relative scarcity of China's arable land resources from the perspective of per capita share. If China's per capita share of arable land is lower than the world's average level, the relative scarcity index is then less than one; and if China's per capita share of arable land meets or exceeds the world's average level, the relative scarcity index is then equal to or greater than one.

By using formula (7.1 and 7.2), we can calculate the relative scarcity index of each resource to evaluate its bottleneck effect. The smaller the relative scarcity index is, the scarcer the resource is. If the relative scarcity index of a resource is less than one, the resource is relatively scarce in China as relative to the world's average; and if the index is greater than one, the resource is relatively abundant in China.

As Fig. 7.1 shows, the relative scarcity of China's natural resources is not positive. Most natural resources are relatively scarce in China except for a few are relatively well-off. From the year 2003–2007, the relative scarcity index of vast majority of natural resources showed significant downward trends, and the index of some resources fell even more than 50 %. Many originally abundant resources were increasingly consumed, resulting some resources ran short. Particularly in 2007, in addition to silver, uranium, phosphorus, vanadium, tungsten and molybdenum, other natural resources of China were in shortage relative to the world's average level, and certain resources were extremely scarce. Taking oil as an example, it should be classified as a seriously scarce resource as its relative scarcity index was less than 0.2.

Table 7.1 shows the net imports of oil, natural gas and their relative products in China from the year 2000–2009. The data further confirmed the above results. From the year 2000–2009, some processed products of crude oil, such as gasoline and diesel, had net exports in certain years, which were shown as negative in the table. China's net imports of crude oil, the raw material of petroleum products, showed an uptrend except a marginal decline in 2001. The net import of crude oil in 2005 kept at the same level as in 2004 because of the impact of the serious downturn in the stock market on China's economy. In other years, the net imports, however, showed a rapid growth. Especially in the 4 years after 2005, the average increase of net imports nearly reached 20 million tons per year. The net imports of crude oil increased from 59.96 million tons in 2000 to 198.58 million tons in 2009, rising more than 200 %. China has excessive dependence on imported oil that is restricted by the international oil price. The high dependence on imports will be a serious threat to China's economic security.

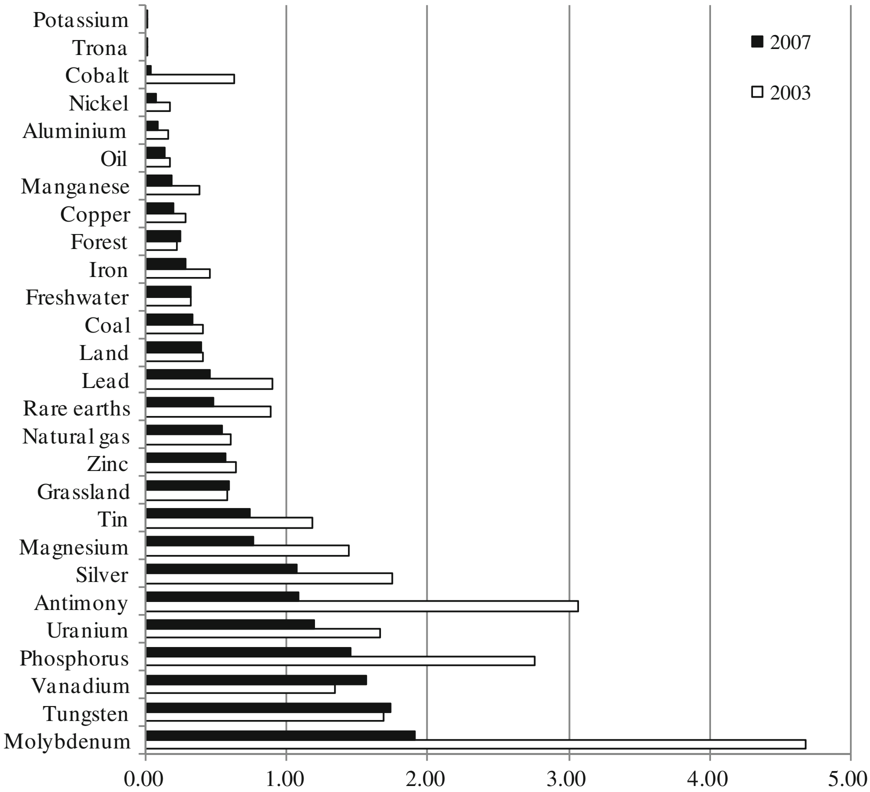


**Fig. 7.1** The relative scarcity of China's natural resources in 2003 and 2007. *Source* Zhuang et al. (2011)

Furthermore, water resources and arable land resources have strong regional disparities and low mobility. In order to comprehensively measure the shortage of water and arable land resources in China, we should pay more attention to their regional disparities in addition to their total amount when studying the impacts of their shortage and bottleneck effects on economic development. In a word, the mobility of resources should be considered other than the relative scarcity.

## *7.1.2 Permeability Analysis of China's Natural Resources*

The permeability of natural resources refers to their levels of participation in national economy. As mentioned earlier, each natural resource has different participation level in the economy. Resources with the same scarcity may have different bottleneck effects on China's economic development as a result of their

**Table 7.1** The net imports of oil, natural gas and relative products in China from the Year 2000–2009 (Unit: 10,000 ton)

| | Crude oil | Gasoline | Diesel | Kerosene | Fuel oil | Liquefied petroleum gas | Other petroleum products | Natural gas (100 million $m^3$) |
|---|---|---|---|---|---|---|---|---|
| 2000 | 5,996 | −455.2 | −29.5 | 56.6 | 1446.6 | 480.1 | −119 | 0 |
| 2001 | 5,271 | −572.5 | 1.9 | 19.7 | 1779.5 | 486.8 | −124.2 | 0 |
| 2002 | 6,175 | −612 | −76.3 | 44.5 | 1595.7 | 620.6 | 138.3 | 0 |
| 2003 | 8,288.7 | −754.2 | −139.2 | 8.6 | 2319.3 | 634.3 | 170.3 | 0 |
| 2004 | 11,722.8 | −540.7 | 211.3 | 77 | 2877.5 | 637.8 | 23.5 | −24.4 |
| 2005 | 11,875 | −560 | −94.4 | 59.6 | 2378.6 | 614.3 | −29.6 | −29.7 |
| 2006 | 13,883.3 | −344.9 | −7.1 | 189.8 | 2541.3 | 520.5 | −29.6 | −19.5 |
| 2007 | 15,928 | −441.6 | 96.1 | 76.3 | 2037.4 | 371.6 | 272.8 | 14.2 |
| 2008 | 17,464.8 | −4.7 | 561.4 | 111.4 | 1454.4 | 191.4 | 247.3 | 13.6 |
| 2009 | 19,858 | −487.5 | −267.1 | 17.7 | 1544.8 | 323.1 | 847.8 | 44.3 |

*Sources* China Statistical Yearbook 2010, China Energy Statistical Yearbook 2010

different participation levels. The permeability analysis of natural resources will be used as a supplement measure for relative scarcity analysis to evaluate the constraints of natural resources on the economy.

This study uses the induction coefficient in input–output analysis to evaluate the participation levels of natural resources in China's national economy. Induction coefficient is a measurement of forward correlations in the input–output method, which is similar to the definition of elasticity in economics. The induction coefficient of natural resources reflects the induction to demands for resources in each economic sector when increasing one unit of final product in all economic sectors. The value of induction coefficient reflects the level of demand for certain resources in each sector of the national economy.The greater value implies a higher demand and stronger permeability of the resource in national economy. As each economic sector consumes products produced by the natural resource extraction sector, the induction coefficient of the natural resource extraction sector can be used to measure the permeability of natural resources in economic sectors. For example, the induction coefficient of agriculture can be used to measure the permeability of arable land resources and the induction coefficient of coal mining industry can be used to measure the permeability of coal resources.

It should be noted that water production and supply can only reflect a small part of water consumption in the input–output table, which cannot accurately show the induction coefficient of water resources. The study conducted by Zhuang et al. (2011) does not calculate the induction coefficient of water resources. There is no doubt that water consumption exists in the production activities of all economic sectors. The manufacturing process and operations of any sector need to consume water resources. Although we did not calculate the specific values, it is certain that water resources have a relatively high induction coefficient and quite strong permeability in the national economy.

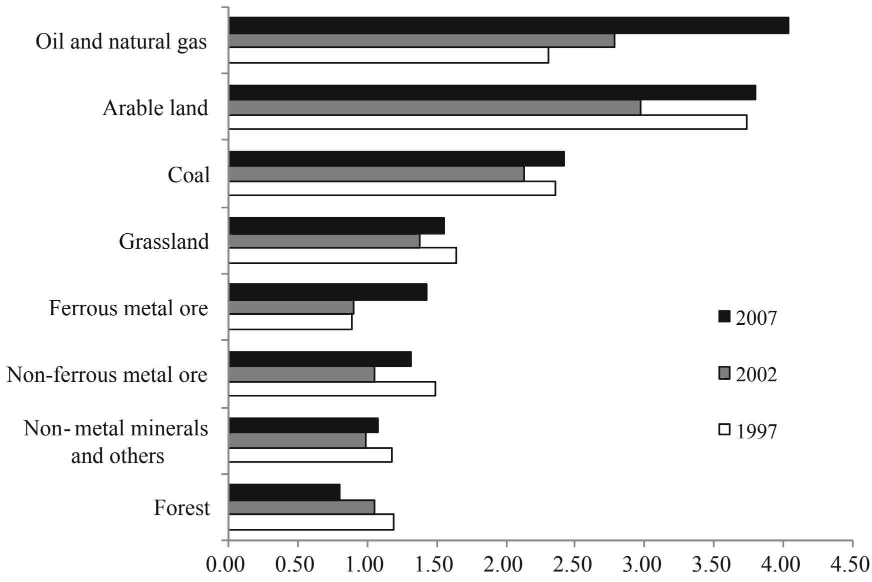


**Fig. 7.2** The induction coefficient of China's natural resources in the Year 1997, 2002, and 2007. *Source* Zhuang et al. (2011)

Figure 7.2 shows that the permeability of energy resources and arable land resources are very strong in the national economy. Regarding the changing trend, their induction coefficient had different increasing extent from the year 1997–2007, which indicates that the permeability of these resources has been increasing in the economy and affected the economic development. With regard to the value of the induction coefficient, the increase in oil, gas and ferrous metal ores was obvious in recent years, and especially the induction coefficient of oil and gas had a substantial increase from the original high level. The permeability of oil and gas is the strongest in natural resource sector as the value of induction coefficient increased from 2.3 in 1997 to 4.04 in 2007. Among the fundamental resources in economic development, arable land resources have the highest value of induction coefficient. Arable land resources have played an important role in China's economic and social development, and its permeability ranking has been in the forefront of all resources. Overall, China's coal, oil, gas, and arable land resources have significant impacts on the national economy and their impacts are going to be more and more important as the basis for the development of national economy.

### *7.1.3 The Combination of Relative Scarcity and Permeability Analysis*

Based on the results in the first two parts, we then combine the relative scarcity and permeability analysis of China's natural resources (Fig. 7.3). In Fig. 7.3, the

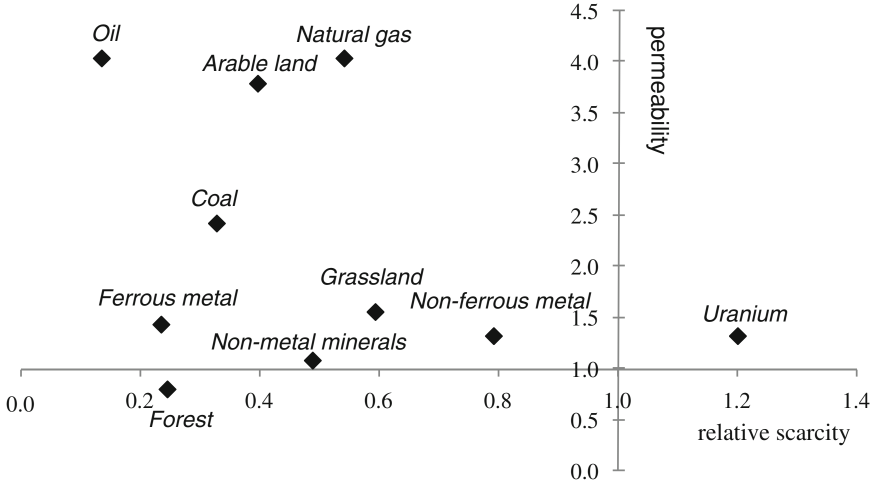


**Fig. 7.3** The scatter plot of relative scarcity versus permeability of China's natural resources in 2007. *Source* Zhuang et al. (2011)

horizontal axis refers to the relative scarcity index and the vertical axis refers to the induction coefficient of natural resources. Water resources are not included in the scatter plot as we are not able to accurately calculate the induction coefficient of water resources in the national economy. In accordance with the above analysis, water resources have a strong permeability and low relative scarcity index. We then infer about water resources should be located near the upper left corner of the second quadrant at where is close to oil and arable land resources.

Only a few mineral resources are located in the first quadrant at where are close to the horizontal axis, indicating that the participation level of these relatively abundant mineral resources is not high in China's national economy. Most of China's natural resources are located in the second quadrant at where are close to the horizontal axis. The distribution pattern indicates that these resources are relatively scarce, but their permeability in all sectors is not high. They are not the resources with most serious bottleneck effect to restrict the economic development. Energy, arable land, and water resources are located in the second quadrant at where are away from the origin. Their locations in the scatter plot show two features at least: first, the relative scarcity index of these resources is far less than one which means they are relatively scarce. The relative scarcity index of coal, arable land, water and oil resources in particular are less than 0.5. Second, the permeability of these resources is very strong in the national economy and they affect all aspects of economic development. Therefore, energy, arable land, and water resources are the bottleneck resources that constrain China's economic development. To break through the bottleneck effect of the current resource constraints, we need to release the pressure from meeting the challenge of the acute shortage in these resources.

### 7.1.4 The Impact of Economic Development on the Bottleneck Effect of Resources

In the three parts above, we have used relative scarcity index, induction coefficient, and the combination of the two to evaluate the bottleneck effect of natural resources in China. The results show that energy, water and arable land resources are the three resources with the strongest bottleneck effect that constrains the China's economic development. In fact, the national economy can adjust its scale, structure and use of technology to reduce the resource consumption. The bottleneck effect of resources is related to the resource reserves and consumption. The path choice of economic development has impacts on the resource consumption, and it thereby will affect the bottleneck effect of resources. Given the limited space available, this section only takes energy consumption as an example. We first evaluate the economic effects on energy consumption from three aspects, and then summarize the solutions to alleviate and improve the tense relation between China's economic development and resource consumption.

In this part, we use the decomposition method of energy consumption growth developed by Liang et al. (2009) to analyse the effects of scale expansion, structural change and technological progress on energy consumption in economic development.[2] The formula is[3]:

---

[2] Liang et al. (2009).

[3] Let Y express the GDP. A denotes the column vector, in which each component represents one industrial sector's output share in GDP. The sum of these components is one. B denotes the column vector with components representing each industrial sector's energy consumption for output per unit. We use subscript to represent the time point t and 0.

There are two ways for the decomposition.

The first decomposition is: energy consumption increase ($\Delta E_{tot}$) is

$$\Delta E_{tot} = A_t^T B_t Y_t - A_0^T B_0 Y_0 = (A_t^T - A_0^T) B_t Y_t + A_0^T (B_t - B_0) Y_t + A_0^T B_0 (Y_t - Y_0) \qquad \text{(A1)}$$

In the equation, the first part on the right side of the second equal sigh refers to the changes in energy consumption caused by the share change in each sector, which is known as structural effect on energy consumption and calculated by energy consumption per unit at the time t. The second part refers to the changes in energy consumption caused by the change in energy consumption per unit in each sector, which is known as the technological effect on energy consumption and calculated based on the industrial structure at the time 0. The third part simply refers to the change in energy consumption caused by the changes in GDP, which is known as the scale effect on energy consumption. The second decomposition is:

$$\Delta E_{tot} = A_t^T B_t Y_t - A_0^T B_0 Y_0 = (A_t^T - A_0^T) B_0 Y_t + A_t^T (B_t - B_0) Y_t + A_0^T B_0 (Y_t - Y_0) \qquad \text{(A2)}$$

The meaning of formula (A2) is similar to formula (A1). They are different because of the difference in the referenced energy consumption per unit and industrial structures when calculating structural and technological effects. The two formulas can be combined:

$$\begin{aligned} \Delta E_{tot} &= A_t^T B_t Y_t - A_0^T B_0 Y_0 \\ &= 0.5(A_t^T - A_0^T)(B_0 + B_t) Y_t + 0.5(A_t^T + A_0^T)(B_t - B_0) Y_t + A_0^T B_0 (Y_t - Y_0) \end{aligned} \qquad \text{(A3)}$$

$$\Delta E_{tot} = \Delta E_{str} + \Delta E_{tec} + \Delta E_{sca} \quad (7.4)$$

In formula (7.4), $\Delta E_{tot} = A_t^T B_t Y_t - A_0^T B_0 Y_0$ refers to the energy consumption growth between the two time points (0 and t); $\Delta E_{str} = 0.5\left(A_t^T - A_0^T\right)(B_0 + B_t)Y_t$ refers to the energy consumption growth due to changes in industrial structure during this time period, known as structural effect; $\Delta E_{tec} = 0.5\left(A_t^T + A_0^T\right)(B_t - B_0)Y_t$, refers to the changes resulted from energy consumption per unit output in each industry during the time period, or the energy consumption growth due to the change in production technology, known as the technological effect; $\Delta E_{sca} = A_0 B_0\left(A_t^T - A_0^T\right)$ refers to the energy consumption growth due to economic scale expansion without considering the structural effect and technological effect, known as scale effect. It should be noted that structural and technological effects on energy consumption trends are uncertain, which may cause the energy consumption growth either positive or negative. The scale expansion, however, will only increase the demand for energy consumption, so the increment is always positive.

Based on the above decomposition method, structural effect, technological effect, and scale effect in the 20 years from 1985 to 2007 are presented in Table 7.2 except the missing data in 1993 and 1995. The table shows the overall trend of China's energy consumption growth was positive except the negative growth in 1998 and 1999, and the growth was rapid especially after the year 2002. The major factor of the energy consumption growth was the effect of economic scale expansion. Technological progress was a key factor in reducing energy consumption, and the structural effect did not play a significant role. Except for a few years, the industrial restructuring had positive effects on energy consumption growth. From 1986–1991, China's energy consumption growth was small and relatively stabilized. The energy consumption growth caused by the economic scale expansion was not very significant. One reason is that the total economic output was small, as well as the economic growth and energy consumption, although the average economic growth rate reached 8.52 % during this period. Another feature of the energy consumption growth during this period is the big changes in structural effect. China was in the stage of industrial restructuring during this period, and the overall trend in energy consumption is increasing.

From 1992 to 2002, the annual energy consumption growth was in large differences because of the instability of technological effect and structural effect. Overall, the technological effect made some progresses during this period compared to the 1980s and it played a crucial role in restraining energy consumption growth. Structural effect continued on a large variation during this period, but the overall

(Footnote 3 continued)

Let: $\Delta E_{tot} = A_t^T B_t Y_t - A_0^T B_0 Y_0$, $\Delta E_{str} = 0.5(A_t^T - A_0^T)(B_0 + B_t)Y_t$, $\Delta E_{tec} = 0.5(A_t^T + A_0^T)(B_t - B_0)Y_t$, $\Delta E_{sca} = A_0^T B_0(Y_t - Y_0)$.

The change in energy consumption between any two time points can be decomposed into structural effect, technological effect and scale effect, that is, formula (7.4).

**Table 7.2** The decomposition of China's energy consumption growth (1985−2007) (Unit: $10^4$ t standard coal)

| | Energy consumption growth | Structural effect | Technological effect | Scale effect |
|---|---|---|---|---|
| 1985 ~ 1986 | 4,058 | 938 | −1,573 | 4,691 |
| 1986 ~ 1987 | 4,567 | 670 | −6,224 | 10,121 |
| 1987 ~ 1988 | 4,662 | 5,257 | −6,538 | 5,942 |
| 1988 ~ 1989 | 3,606 | −2,333 | 4,866 | 1,073 |
| 1989 ~ 1990 | 1,145 | 4,594 | −6,901 | 3,452 |
| 1990 ~ 1991 | 4,381 | 513 | −1,514 | 5,382 |
| 1991 ~ 1992 | 5,688 | 6,427 | −11,305 | 10,566 |
| 1992 ~ 1994 | 20,690 | 11,520 | −21,481 | 30,651 |
| 1994 ~ 1996 | 13,635 | 3,416 | −9,888 | 20,107 |
| 1996 ~ 1997 | 472 | −661 | −10,341 | 11,474 |
| 1997 ~ 1998 | −3,600 | −3,016 | −6,559 | 5,976 |
| 1998 ~ 1999 | −2,264 | 2,207 | −15,043 | 10,571 |
| 1999 ~ 2000 | 7,021 | 1,519 | −7,521 | 13,023 |
| 2000 ~ 2001 | 4,016 | 2,533 | −11,673 | 13,157 |
| 2001 ~ 2002 | 7,665 | 781 | −9,446 | 16,330 |
| 2002 ~ 2003 | 20,893 | 3,788 | −5,046 | 22,152 |
| 2003 ~ 2004 | 26,783 | 4,911 | 9,305 | 12,566 |
| 2004 ~ 2005 | 17,980 | 1,168 | −37,775 | 54,586 |
| 2005 ~ 2006 | 20,956 | 1,458 | −17,983 | 37,481 |
| 2006 ~ 2007 | 17,911 | 2,199 | −33,934 | 49,646 |

*Sources* Statistics from "China Statistical Yearbook" and "Industrial Economic Statistical Yearbook". Energy unit is $10^4$ t stardard coal, energy consumption for output per unit is expressed in $10^4$ t Standard coal/$10^8$ yuan output value. In order to eliminate the impact of inflation on the results, constant prices are used for the added value of each sector. To unify the data and make results comparable, the energy consumption in each sector is conversed to $10^4$ t standard coal by using conversion coefficient based on energy statistics

trend was increasing with negative growth only in certain years. Industrial restructuring is still in progress and has a long way to go. Scale effect was relatively stable and fluctuated between $10{,}000 \times 10^4$t ~ $15{,}000 \times 10^4$t standard coal.

The energy consumption growth from 1992 to1996 was significantly higher than the 1980s. Despite technological effect was greatly improved over the previous period, it still cannot keep up with the pace of scale effect and structural effect. During the three-year period of 1997–1999, energy consumption was improved, and it even showed negative growth in the year 1998 and 1999. There are mainly two reasons for the negative growth in energy consumption during the 2 years: first, the buyer's market appeared in China's economy in 1997 for the first time. Overproduction led to the market supply exceeded demand, and enterprises could only reduce their production in order to keep down the inventory. Meanwhile, the Asian financial crisis caused weak domestic demand and reduction in energy consumption. Second, during the industrial restructuring in recent years, there were quite a number of the "five small" enterprises[4] with high energy consumption, low efficiency and heavy pollution being shut down, which effectively reduced the energy production and consumption.

Compared to the 1980s, the scale effect of China's energy consumption in the 1990s significantly increased as a result of the average GDP growth at an alarming rate up to 10.25 %. During this period, China's foreign trade exports also increased significantly. However, in the 1990s, most of the China's export business was "Processing & Assembly", which refers to the processing materials supplied by customer, processing according to customer's samples, assembling parts supplied by customer, and compensation trade. These trades have high energy consumption and relatively low economic efficiency. On the other hand, the technological effect of this period performed well. To a certain extent, it offset the growth in energy consumption caused by the scale effect. The progresses in production and energy-saving technologies enabled China to support a rapid economic growth with relatively low energy cost.

From the year 2003–2007, China's energy consumption increased rapidly, of which scale effect contributed most, technological effect was fluctuating, and structural effect remained unchanged. Although China's economic growth had an average rate around 10.5 % in these years, the average growth rate of energy consumption was 10.9 % and the elasticity coefficient of energy consumption to economic growth was higher than one. There are three main reasons for the more rapid growth in energy consumption than economic growth during this period: first, the scale effect increased too fast with an average increment over $30{,}000 \times 10^4$ t standard coal and the peak of $54{,}586 \times 10^4$ t standard coal in 2005. Second, the effect of technological progress was poor. During these years, a large amount of energy and raw materials were consumed in order to achieve rapid economic growth. More attention was paid to high investment than technological progress, particularly in high energy-consuming sectors such as oil and chemical industries. In these high energy-consuming sectors, the energy consumption of output per unit was increasing instead of dropping down, despite the technological effect made significant progress in 2005. The overall energy consumption was not dropping down as a result of the offset of the growth in scale effect. Third, the structural effect was prominent. In 2004, the proportion of secondary industry and tertiary industry accounted for 52.9 and 31.9 % respectively, which were increased by 2.5 % and decreased by 2.4 % compared to the year 2002. The proportion of industry accounted for 45.9 %, which was increased by 2.2 % compared to the year 2002. As the energy consumption of output per unit in secondary industry is much larger than the tertiary industry, the increase in the proportion of the secondary industry and decline in the proportion of the tertiary industry accelerated the increase in energy consumption. In addition, high energy-consuming industries such as steel, cement, electrolytic aluminum in the secondary industry were rapidly expanding, which also accelerated the energy consumption growth.

[4] The "five small" enterprises refer to small iron smelting company, small coke-making company, small chemical fertilizer company, small paper-making company, and small coal mine.

So far, we took the energy consumption as an example to show how to analyse the impact of economic development on resource bottleneck effect from three dimensions: technological effect, structural effect and scale effect. It should be noted that, standard coal used in the analysis of energy consumption cannot apply to other natural resources. When analysing the consumption of certain resources, units need to be unified by using the statistical standard conversion coefficient in order to make the data comparable among the three dimensions.

Based on the analysis above, the increasingly tension between economic development and resource consumption can be eased from three aspects: first, strictly control on the expansion of the economic scale. The goal for economic development should be made according to the carrying capacity of natural resources instead of excessive emphasis upon the economic scale and GDP growth. Second, making technological progress and developing innovation to reduce resource consumption, and increasing product value with less resource consumption. Third, speeding up the industrial restructuring and shifting the economic growth from the secondary industry with high resource consumption to the tertiary industry with relatively low resource consumption. Moreover, adjustment in the foreign trade mode and improvement in independent innovation capacity will also help change China's role as a world's factory in the global industrial chain.

## 7.2 The Environmental Constraints on China's Economic Development

Population growth and the increased consumption levels jointly promote production expansion. While consuming a large amount of resources, a variety of waste is emitted to the environment. If the emission of hazardous substances exceeds the limited self-purification ability or environment capacity, the environmental quality will deteriorate, which will endanger human health and cause environmental destruction and significant obstruction to human survival and development. All the effects are the environmental constraints on economic development.

This part examines China's environmental problems from three aspects: the current situation of environmental pollution, the growth trends of pollutant emissions, and the progress in pollution control. Obviously, if the pollution situation is serious and pollutant emissions exceed the pollution control, the environmental quality will be inevitably led to further deterioration and the green development of China's economy would be impossible. Based on the current environmental situation, we will use the same decomposition method of energy consumption growth to divide the pollutant emission growth in China's economic development into three parts: scale effect, structural effect and technological effect. We will also analyse the potential constraints of environmental pressure on China's economic development taking into account the inputs of pollution control.

## 7.2.1 China's Environmental Problems

### 7.2.1.1 Heavy Environmental Pollution and Grim Environmental Situation

After nearly 30 years' rapid development, China has been one of the world's largest economies, but also a country with heavy environmental pollution. The surface water has been heavily polluted. The water quality of the seven major river systems has been labelled as light pollution, the eutrophication problem of the "three lakes and one reservoir"[5] is serious, and "bloom" phenomenon frequently occurs. The underground water quality of 202 cities in China is ranked as good to poor (among the 5 classes), and shows an overall trend of deterioration. The improving trend only shows in a dispersed distribution pattern. Overall quality of coastal waters is in light pollution. The degree of air pollution is as bad as water pollution. Photochemical smog, atmospheric haze and acid deposition pollution frequently occur. In 2010, with regard to the ambient air quality in 113 key environmental protection cities, 26.5 % of the cities cannot meet the second class of the national ambient air quality standards.[6] The area suffered acid rain (annual average pH value is less than 5.6) was approximately 12.6 % of the China's land area. In addition, the total amount of domestic garbage, industrial solid waste, and hazardous waste continues to grow. Gas, liquid penetration, and leaching water generated by stockpiling of hazardous waste have become a major source of pollution. Solid waste pollution becomes more and more serious and the influenced area is expanding.

### 7.2.1.2 The "Three Wastes" Emissions and Environmental Pressures Continue to Increase

At the same time as the rapid social and economic development in China, a variety of waste emitted to the environment has continued to increase. Wastewater, waste gas and solid waste emissions have been increased year by year. China's wastewater emissions increased from 43.29 billion tons in 2000 up to 58.92 billion tons in 2009, of which the proportion of domestic sewage discharge was higher than industrial wastewater. China's industrial waste gas emissions also increased rapidly from 13.81 trillion standard cubic meters in 2000 up to 43.61 trillion standard cubic meters in 2009. In addition, China's industrial solid waste discharge increased from 816.08 million tons in 2000 to 2.04 billion tons in 2009. The transferred domestic garbage showed a slowly rising trend after the declined in 2006, and then reached 157.34 million tons in 2009. Within the rapid

---

[5] The "three lakes and one reservoir" refers to Tai Lake, Chao Lake, Dian Lake, and Three Gorges Reservoir.

[6] Ministry of Environmental Protection of China. (2011). *The Notice of Water Quality in Key Drainage Valleys and Ambient Air Quality Status in Key Environmental Protection Cities in 2010*, 2011, No. 8. (In Chinese).

industrialization and urbanization process, the amount of pollutants continues to increase, which will increase the environmental pressures that China faces.

#### 7.2.1.3 Initial Success of Environmental Governance and Continuing Effort for Environmental Protection

As the environmental pollution is getting worse, environmental protection receives more and more attention, and environmental governance has gained initial success. China's total investment in environmental pollution control increased year by year, as well as the proportion of investment in environmental pollution control to GDP. China's pollutant emission compliance rate and processing rate also show uptrends. Both the industrial wastewater processing rate and urban sewage processing capacity have increased rapidly, which reached 94.2 and 75.3 % in 2009 respectively. The emission compliance rates of industrial $SO_2$, smoke and dust have been increasing steadily and reached 91, 90.3 and 89.9 % in 2009 respectively. Environment-friendly disposal rate of domestic garbage increased rapidly after 2006 and the comprehensive utilization rate of industrial solid waste has steadily increased, which reached 71.4 and 67 % in 2009 respectively.

In general, China's environmental situation can be summarized as: certain aspects have been improved, overall situation is still grim, and the pressure continues to increase.[7] China's natural environment is fragile, population is large, economic growth pattern is extensive, and the environmental regulations are lagging behind. All these features, coupled with the rapid economic and social development, make problems that happened at various stages of a century's industrialization process in developed countries collectively happened in China within several decades. The conflicts between environment and development are increasingly prominent. Environmental degradation caused by pollution, destruction of ecological balance, and public health hazards, become constraints on sustainable economic growth and social harmony. Environmental problems have become one of the most serious challenges that China currently faces, as well as in the future.

### *7.2.2 The Environmental Constraints on Economic Development*

The constraint of environment on economic development is that the limited environmental capacity cannot eliminate the growing pollutant emissions. The environmental pressure of economic growth depends on pollutant emissions and

[7] Chinese Academy of Engineering, and Ministry of Environmental Protection of China (Chinese 2011).

pollution control to some extent. Increased emissions have a negative impact on the environment, while environmental governance has a positive impact. However, to strengthen environmental governance requires more inputs including human, material and financial resources and technologies. Existing research shows that economic growth affects pollutant emissions through three ways: scale effect, structural effect and technological effect.[8] Scale effect refers to the emission expansion resulting from the growth of economic scale when other conditions are the same. If economic scale and the emission intensity of each sector are the same, the changes in pollutant emissions resulting from changes in economic structure are known as structural effect. In the process of economic growth, if the economic structure changes to the direction of reducing pollution, the pollutant emissions are likely to remain stable or even decline; and if the economic structure changes to the direction of increasing pollution, the pollutant emissions may rapidly increase and accelerate environmental degradation. Technological effect refers to the change in pollution emission resulting from the differences in technologies under the same economic scale and structure. Technological effect is effective in two aspects: one aspect is that technological progress is able to increase productivity, improve the efficiency of resource utilization, cut down inputs for output per unit, and reduce the negative effects of production on environment when other aspects are stable; and the other aspect is that the development of clean technology, replacement of the old technologies, and effective recycling of resources will help reduce the emissions of output per unit.[9] Obviously, pollutant emissions should be limited and environmental governance should be strengthened in order to reduce the high pressure of the serious environmental problems in China. Economic development, however, has scale, structural and technological effects on pollutant emission. Therefore, pollutant emission limits have constraints on the economic growth rate and scale, industrial structure and technology. To support this argument, this part uses the same decomposition method of energy consumption growth to analyse China's the pollutant emission effects resulting from the economic expansion in three aspects—scale expansion, structural change and technological progress in the past decade. The results will help us understand the constrains of environmental emission limits on economic scale and growth rate, industrial structure and technologies, and also shed light on potential solutions for reducing environmental pollution and improving environmental quality.

Taking into account the availability of data, this study only decomposes the emission growth in the industrial sector. The data on added value and pollutant emissions of each industrial sector are used to calculate the contribution of structural, technological and scale changes to China's industrial wastewater, waste gas and solid waste emission growth from the year 1991–2007. The results further explain the environmental constraints on economic development.

---

[8] Grossman and Krueger (1991).

[9] Zhong and Zhang (2010).

**Table 7.3** The decomposition of the emission growth of China's industrial "three wastes" in 1991–2007

| | Industrial wastewater discharge (Unit: 10,000 tons) | | | | Industrial waste gas emission (Unit: 10,000 tons) | | | | Industrial solid waste discharge (Unit: 10,000 tons) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Increment | Structural effect | Technological effect | Scale effect | Increment | Structural effect | Technological effect | Scale effect | Increment | Structural effect | Technological effect | Scale effect |
| 1991 ~ 1992 | −20,154 | 26,095 | −545,557 | 499,308 | 4,979 | 10,608 | −23,550 | 17,920 | −789 | 414 | −1,918 | 714 |
| 1992 ~ 1993 | −143,613 | −198,924 | −414,502 | 469,812 | 3,790 | −7,566 | −6,651 | 18,007 | −434 | −217 | −736 | 520 |
| 1993 ~ 1994 | −39,810 | 30,279 | −485,176 | 415,088 | 4,042 | 1,201 | −14,827 | 17,667 | −221 | 54 | −682 | 407 |
| 1994 ~ 1995 | 63,830 | 97,839 | −336,631 | 302,622 | 10,012 | 10,542 | −14,216 | 13,686 | 312 | 255 | −215 | 271 |
| 1995 ~ 1996 | −279,758 | 30,315 | −587,564 | 277,491 | −1,138 | −5,578 | −9,000 | 13,441 | −661 | −82 | −859 | 280 |
| 1996 ~ 1997 | 133,890 | −56,387 | −29,248 | 219,525 | 17,366 | 721 | 4,607 | 12,038 | 1,236 | −25 | 1,082 | 179 |
| 1997 ~ 1998 | −67,082 | −38,003 | −213,581 | 184,502 | −2,513 | 1,570 | −15,093 | 11,010 | 4,309 | −303 | 4,361 | 251 |
| 1998 ~ 1999 | −85,047 | 7,321 | −263,206 | 170,839 | 5,576 | 2,822 | −7,567 | 10,321 | −3,256 | −4 | −3,859 | 607 |
| 1999 ~ 2000 | −27,390 | −17,582 | −197,790 | 187,983 | 11,356 | −4,338 | 3,289 | 12,405 | −599 | 403 | −1,381 | 379 |
| 2000 ~ 2001 | −36,355 | 704 | −201,235 | 164,176 | 25,124 | 1,191 | 11,958 | 11,976 | −1261 | −232 | −1,313 | 284 |
| 2001 ~ 2002 | −17,266 | −7,010 | −195,428 | 185,171 | 11,988 | −2,188 | −2,100 | 16,277 | −177 | −115 | −262 | 201 |
| 2002 ~ 2003 | 59,351 | −20,343 | −154,912 | 234,606 | 23,839 | −585 | 2,080 | 22,344 | −115 | 19 | −368 | 234 |
| 2003 ~ 2004 | 79,095 | −4,061 | −135,451 | 218,607 | 38,105 | 11,278 | 3,913 | 22,914 | −149 | 197 | −544 | 198 |
| 2004 ~ 2005 | 181,401 | −8,651 | −38,976 | 229,029 | 30,872 | −12,398 | 15,813 | 27,457 | −77 | 39 | −297 | 182 |
| 2005 ~ 2006 | −79,340 | −45,602 | −311,833 | 278,095 | 62,936 | −1,995 | 30,417 | 34,515 | −293 | 6 | −491 | 192 |
| 2006 ~ 2007 | 127,128 | 4,958 | −187,958 | 310,128 | 57,151 | 5,248 | 2,563 | 49,340 | −124 | −38 | −265 | 179 |

*Notes*

1. Data presented in the table are calculated by the industrial added value, industrial wastewater discharge, industrial waste gas emission, and industrial solid waste discharge of each sector in the calendar year

2. To eliminate the impact of inflation on the results, the data on industrial added value of each sector are calculated in constant price

3. In order to unify the calculation and make data comparable, the industries are merged into19 industrial sectors (mining; food, tobacco and beverage manufacturing; textiles; leather, fur, feather products industry; paper and paper products industry; printing, reproduction of recorded media; petroleum processing and coking industry; chemicals and chemical products manufacturing; pharmaceutical manufacturing; chemical fiber manufacturing; rubber products; plastic products; nonmetallic mineral manufacturing industry; ferrous metal smelting and rolling industry; non-ferrous metal smelting and rolling industry; fabricated metal products; machinery, electrical appliances and electronic equipment manufacturing; electricity, gas and water production and supply industry; and other industries)

*Sources* China Environment Statistical Yearbook; China Industrial Economy Statistical Yearbook. (1992–2008)

The results of the three types of decomposed emission growth are presented in Table 7.3. From the year 1991–2007, China's industrial wastewater discharge was in a negative growth in most of the years, but it showed a deteriorated trend in recent years. During the five years from 2003 to 2007, the wastewater discharge in 4 years had positive growth. The industrial waste gas emissions were in an increasing trend except the year 1996 and 1998, and the emissions increased significantly especially after 2000. The situation of industrial solid waste discharge was better. In addition to a positive growth in individual years, the solid waste discharge was generally in a negative growth trend.

Similar to the results in the decomposition analysis of energy consumption growth, the results of the decomposition analysis on emission growth show that the scale effect of "three wastes" was positive in all years and scale effect is the main factor of emission growth. The technological effects of industrial wastewater and solid waste emissions were generally negative, which is a key factor of emission reduction. The technological effect of industrial waste gas emission growth, however, was positive after the year 2000. The structural effect of "three wastes" emissions were either positive or negative, namely, the industrial restructuring tended to reduce pollution emissions in certain years or increase emissions in the other years.

One important implication from the results in Table 7.3 is that China's industrial restructuring and technological innovation did not play an active role in comprehensively and sustainably reducing the pollutant emissions. If the situation does not improve in the future economic development, the environmental factors will inevitably slow down the speed of economic growth.

Although the contribution of structural effect is not in a large proportion to the environmental pollutant emission growth, the decomposition analysis of structural effect clearly shows its fluctuating pattern in recent years. The results indicate that China is in the process of industrial restructuring which does not keep insisting on reducing pollution emissions in industrial sectors. In the future development, if China plans to maintain a high economic growth rate and the structural effect cannot play a more significant role in pollutant emission reduction, technological effect will definitely face much more pressure in reducing pollutant emissions.

Technological effect is the main driving force to reduce pollutant emission. It, however, has poor performance in recent years and the emissions even increased in certain years. On one hand, the technologies adopted in China's industrial production are lagging behind and China's economic growth is in an extensive pattern; On the other hand, there is still space for reducing China's pollutant emissions through technological progress. Governments should restrict the use of traditional production techniques with high pollutant emission intensity in order to stop enterprises making profits from the cost of environmental pollution. In addition, promoting an eco-friendly and civilized consumption behaviour and reducing the pollutant emissions in final consumptions will also help in pollutant emission reduction.

## References

Chinese Academy of Engineering, and Ministry of Environmental Protection of China (2011) Macro strategy for China's environment, China Environmental Science Press, Beijing, (In Chinese)

Grossman G, Krueger A (1991) Environmental impact of a North American free trade agreement. NBER Working Paper, 3914

Liang J-S, Hong L-X, Cai J-M (2009) The decomposition of energy consumption growth—during the process of China's urbanization:1985–2006. J Nat Resour 24(1):20–29 (In Chinese)

Zhong M-C, Zhang X-G (2010) Summary about the critique of environmental kuznets curve. China Popul, Resour Environ 20(2):62–67 (In Chinese)

Zhuang L, Liu Y, Liang J-S (2011) Research on natural resources scarcity and penetration in China. Geogr Res 30(8):1351–1360 (In Chinese)