Advanced Materials Research Vols. 807-809 (2013) pp 1052-1058
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.807-809.1052

An analysis of Carbon Footprint of Beijing Based on Input-output Model

Zhe Wang[1, 2, a], Yu Li[1, b], Zehong Li[1, c], Liang Yuan[1, 2, d], Ji Zheng[1, 2, e]

[1]Institute of Geographic Sciences and Natural Resources Research, CAS, China

[2]University of Chinese Academy of Sciences, China

[a]wangzhe_0121@126.com, [b]liy@igsnrr.ac.cn, [c]lizehong@igsnrr.ac.cn, [d]liangcrystal@126.com, [e]200911191012@mail.bnu.edu.cn

Keywords: Beijing; Carbon Footprint; Input-output Model; Carbon Emission

Abstract: Climate change caused by increasing carbon emission is harmful to global environment and human society. Developing low-carbon economy through reasonable industries planningand effective utilization of resources is a significant path to achieve the aim of energy saving and carbon emission reduction. The word carbon footprint means carbon emission caused by a certain industry, activity, product or individual, and the issue of carbon emission should be linked with economic activity to analyze, while input-output model is a reliable method to contact two factors. Based on input-output model, this paper calculated direct or indirect carbon emission which is demanded for the products of final consumption in Beijing, and analyzed carbon footprint of each industrial sector in 2005, 2007 and 2010 by operating Leontief matrix. The result demonstratesannual carbon emission of Beijing increased from10482.68×10^4 ton to 17407.28×10^4ton during 2000-2011. Manufacturing industry, excavating industry, transportation and postal industry exert supreme impact on carbon emission in Beijing. Carbon footprint oftransportation and postal industry and other tertiary industries such as information, business, service, education, science researching industries in 2010 had anobvious rise comparewith the data of 2005 and 2007.

Introduction

The idea of controlling emission of greenhouse gases and developing low-carbon economy have been deeply rooted in people's mind because of the crisis which may bring disaster to human society caused by the increase of density of greenhouse gases in atmosphere. The situation of carbon emission reduction that China against is very severe. On the one hand, China is experiencing a rapid urbanization development so that the countryside has a huge demand of energy consumption. Exceeding America and Europe, quantity of carbon emission in China hadtopped the world in 2006[1]. According to the data provided by IEA (InternationalEnergyAgency), in 2010, CO_2 emission of China had reached 24.1% of summation the world [2].*World Development Report 2010* from World Bank suggested that greenhouse gases per unit GDP in China have already occupied the first in the world[3]. On the other hand, in the 2009 United Nations Climate Change Conference, Chinese government promised to the world that in 2020, CO_2 emission of per unit GDP would decrease 40-50% by 2005. These two matters give birth to a serious conflict between continuing impelling countries' economy development and carbon emission reduction. As a result, taking metropolitan area as the focal point to advance construction of low-carbon city to help the country accomplish the objective of amount of carbon emission reduction is our urgent task.

Based on the concept of ecological footprint, some researchers put forward the word carbon footprint. Unlike other analysis methods, carbon footprint method can analyzecarbon emission process which is directly or indirectly related with humane activity through the perspective of life circle [4]. In addition, tracing carbon footprint could also help us to measure difference of carbon emission structure in many regions. For instance, B. K.Sovacooland M. A. Brown(2009) compared carbon footprints of 12 world-class metropolitans and concluded that there are different influence degrees of carbon emission factors on cities in different environmental conditions and characters [5]. *Bottom-up*process analysis and *top-down* input-output analysis are two frequently-used approaches to calculate carbon footprint. Input-output method is firstly put forward by American economist W. Leontief. Its prime function is to explicate relationship between departments in an economic system by input-output tables and relevant modeling [6]. After that, researchers in many fields expand function of input-output model. At present, ways based on input-output model to calculation ecological footprint and carbon footprint have become mature and been utilized in carbon emission researches of many areas. A.Druckmantook United Kingdom as an example to analyzed carbon footprint caused by residents' daily life in 1990-2004 through input-output model to look for residents'behaviors that affect carbon emission most seriously, then offer proposals to policy making in terms of energy saving and carbon emission reduction in communities[7]. Based on input-output model, J. Sun's research of China's carbon footprint indicated that in China, manufacturing, electric power, heating power industries and agriculture more deeply rely on carbon emission than other industries [8].

Beijing, the capital and the most populated and energy consumed city in China, whose economic development and carbon emission receive a wide attention from home and aboard. This paper calculated CO_2 emission through Inventory method advanced by IPCC (Intergovernmental Panel on Climate Change),took improved input-output model into research of carbon footprint in Beijing, and analyzedcorrelation degrees of different industrial sectors in carbon emission. The data we needed, total quantity of energy consumption of each sector andenergy balance tables, is separately collected from *Beijing Statistical Yearbook* and*China Energy Statistical Yearbook*. Finally, based on the analysis results of relationship between carbon emission and each industry, we put forward scientific suggestions to construction of low-carbon city in Beijing.

Estimation of Amount of CO2Emission in Different Industries of Beijing

Before input-output analysis, we calculated the amount of annual CO_2 emission of each industrial sector of Beijing. There are several models for calculation of carbon emission have been proposed since 1990, such as Kaya identity, LMDI method, CGE model, Mixture analysis method, UE model, FFDAS model, STIRPAT model, GRID model, Four-part Methodology and so on. Every method has advantages and disadvantages[9, 10]. Estimation total carbon emission of study area through macro consumption statistics is the common ground of the methods. Among them, Inventory method can be divided into three branches: producer responsibility, consumer responsibility and producer-consumer common responsibility [11]. The method used in this paper is cited from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and can be classified into producer responsibility branch. It calculated CO_2 Emission from 4 sectors: energy consumption, industrial process and production utilization, agriculture and forestry and other land use, waste [12]. Among the 4 sectors, estimation of CO_2 emission caused by energy consumption is actualized by transforming quantity of consumption of different kind of energy to quantity of standard coal and multiplying by carbon emission coefficient latterly:

$$Q_e = \sum_i k q_i \tag{1}$$

$Q_e$stands for the quantity of CO_2 emission caused by energy consumption, q_i denotes quantity of standard coal of kind i of energy consumed after conversion, k is conversion coefficient. Most used coefficient of CO_2 emission after transformation ranges from 2.42-2.72 in present China, this paper adopted 2.6 as the conversion coefficient. According to characters of industrial production in

Beijing, calculation of carbon emission from industrial production process mainly considers quantity of carbon emission in the production of intermediate input products such as steel, cement, lime and so on. In agriculture and forestry sector, carbon storage is the most dominating process, thus the quantity of carbon emission from this sector is minus. Annual carbon absorption of per hectare forest and grassy area is about 9.18 ton in line with the data provided by Beijing Garden and Greening Bureau[13]. We estimated quantity of carbon absorption through multiplying area of green space and 9.18 ton/per hectare. CO_2 emission from wastes sector mainly is CO_2 emission during the process of waste landfill and incineration.

It should be noticed that there is no authoritativecriterion of inventorying andestimation result based on different Inventory method differ widely. Consequently, despite method provided by *2006 IPCC Guidelines for National Greenhouse*achieve extensive application, without multilateral test, the estimation result should not be considered as standard data of the quantity of CO_2 emission in Beijing but a reference[11].

Fig.1 illustrates that the quantity of CO_2 emission in Beijing climbed from 10482.68×10^4 ton to 17407.28×10^4ton during 2000-2011. It is obvious that carbon emission start to quickly increase after 2003. The average annual rate of growth is 8.22% during the period of 2003-2007. Benefit from environment improvement and energy serving for holding 2008 Beijing Olympic Game, increasing speed of CO_2 emission fell after 2008. The average annual rate of growth is 2.51% during 2007-2011.

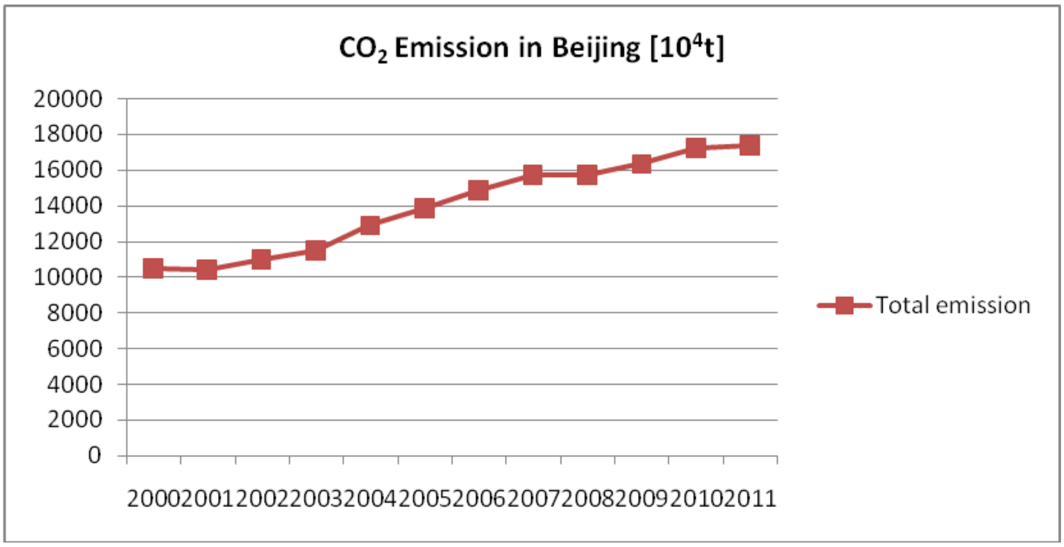

Fig. 1CO_2 emission in Beijing during the period of 2000-2011

Analysis of Carbon Footprint Based on Input-output Model

Primary function of input-output model is quantitativelyanalyzing relationship of input and output aspects between each production apartment or each area. Modified input-output model can calculate carbon footprint of every industries, and analyze association in carbon emission of every industries. Chinese researchers use this method posterior to America and Europe. From now on, Beijing Statistical Bureau has published input-output table of Beijing of 1997, 2000, 2002, 2005, 2007 and 2010. Among them, tables of 1997 and 2000 involved 40 industrial apartments and tables after 2002 involved 42 industrial apartments. Combining estimation result of CO_2 emission, this article chooseinput-output tables of 2005, 2007 and 2010 which refer to 42 industrial apartments in common. Indeed, 42 industrial apartments are too dispersive to interpret relationship and discrepancy of different industrial sectors, as a result we clustered 42 industrial departments into 7 large sectors (Table 1)and calculated input-output tables refer to 7 large sectors at first.

Table 1 Clustering of the industrial apartments

Part 1	agriculture, forestry, animal husbandry and fishery
Part 2	mining and quarrying industry
Part 3	manufacturing industry
Part 4	industry of generation and supplying of electric power, coal gas, water, and so on
Part 5	construction industry
Part 6	transportation, storage and post industry
Part 7	industry of information technology, commerce, service, education, scientific research and so on

To explain the process of building and analysis of the input-output model consulting method summarized by W. Wang et al. (2010), we take input-output table of 2010 as an example [4].

Step 1: building Leontiefinverse matrix$(I-A)^{-1}$, namely complete requirement matrix:

$$(I-A)^{-1} = \begin{pmatrix} 1.2208 & 0.0165 & 0.0388 & 0.0129 & 0.0275 & 0.0165 & 0.0199 \\ 0.1747 & 1.8555 & 0.2634 & 0.3067 & 0.2478 & 0.1283 & 0.0999 \\ 0.6774 & 0.8990 & 2.4651 & 0.6585 & 1.4507 & 0.9194 & 0.7652 \\ 0.2375 & 0.4063 & 0.2344 & 2.4190 & 0.2272 & 0.2230 & 0.1780 \\ 0.0178 & 0.0213 & 0.0232 & 0.0225 & 1.0450 & 0.0251 & 0.0446 \\ 0.2382 & 0.4477 & 0.3392 & 0.2821 & 0.3259 & 1.8066 & 0.2631 \\ 0.6608 & 0.6553 & 0.8092 & 0.6967 & 0.8259 & 0.6577 & 1.8076 \end{pmatrix} \quad (2)$$

In this expressions, I is unit matrix, A is direct consumption coefficient matrix calculated through input-output table.

Step 2: calculation of carbon emission of unit production value of industrial apartments called carbon emission intensity. We calculated carbon emission intensity column vector $r = (0.7946\ \ 1.3179\ \ 0.3870\ \ 0.4159\ \ 0.1370\ \ 1.0842\ \ 0.1858)^T$ as quantity of CO_2 emission of 7 industrial parts divided by gross output.

Step 3: After transforming the vector r to diagonal matrix, we got carbon emission intensity matrix R in which the values on diagonal line is carbon emission intensity of 7 sectors. Calculation of carbon emission multiplier matrix C is based on the following formula:

$$C = R(I-A)^{-1} = \begin{pmatrix} 0.9701 & 0.0131 & 0.0308 & 0.0102 & 0.0219 & 0.0131 & 0.0158 \\ 0.2303 & 2.4452 & 0.3471 & 0.4042 & 0.3266 & 0.1690 & 0.1317 \\ 0.2621 & 0.3479 & 0.9539 & 0.2548 & 0.5614 & 0.3558 & 0.2961 \\ 0.0988 & 0.1690 & 0.0975 & 1.0061 & 0.0945 & 0.0928 & 0.0740 \\ 0.0024 & 0.0029 & 0.0032 & 0.0031 & 0.1432 & 0.0034 & 0.0061 \\ 0.2582 & 0.4854 & 0.3678 & 0.3059 & 0.3533 & 1.9587 & 0.2853 \\ 0.1228 & 0.1218 & 0.1504 & 0.1295 & 0.1534 & 0.1222 & 0.3358 \end{pmatrix} \quad (3)$$

Step 4: based on the formula $f = Cq$, we got carbon footprint of 7 industrial sectors of 2010 (Fig. 2). In this expression, q stands for final demand volume sector. We can get carbon footprint of 2005 and 2007 by the same way.

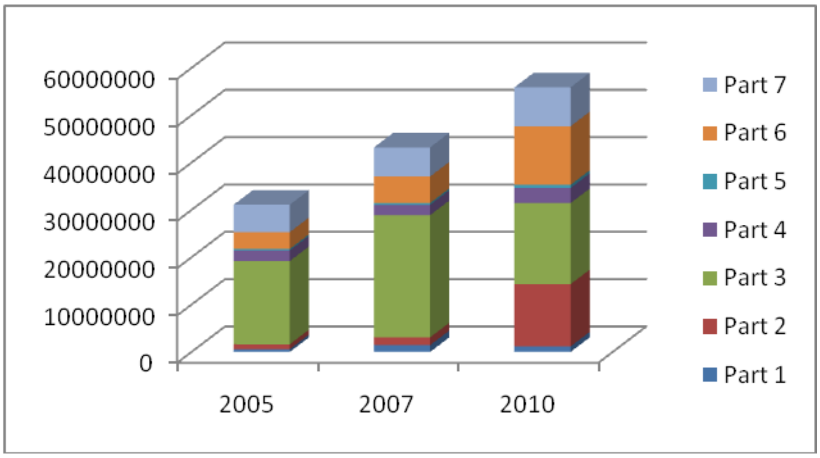

Fig. 2 Changes in total amount and structure of carbon footprints during the period of 2005-2010 [10^4t]

The Fig. 2 illustrates that in 2010, carbon footprints of manufacturing industry occupied biggest proportion (30.65%). Then, mining and quarrying industry and transportation, storage and post industry account for 23.52% and 22.14% respectively. Production value of industries of information technology, commerce, service, education, scientific research and so on occupied over 50%, obviously these industries are pillar industries of Beijing, however their carbon footprint merely account for 14.71%. Carbon footprints of the industries of generation and supplying of electric power, coal gas, and waterand so on account for just 5.71%. Take the fact that Beijing considerablyrely on supplying of electric power and water from other provinces into consideration, the number cannotstrictlyreflect carbon footprint of generation and supplying electric power, heating power and so on in Beijing. The lowest footprint is from apartment of agriculture, forestry, animal husbandry, fishery and apartment of building construction, occupied 2.08% and 1.20% respectively. Comparedwith the years of 2005 and 2007, carbon footprint of industries of transportation, storage and post and industries of information technology, commerce, service, education, scientific research and so on have increased more rapidly than other apartments obviously. Carbon footprint of mining and quarrying industry had a great increase because energy consumption of ferrous metals mining industry grew quickly since 2010.

Compared with calculation result of carbon footprint of China published by J. Sun, we can find that carbon footprintsproportion of the sector of agriculture, forestry, animal husbandry and fishery and the sector of generation and supplying of electric power, coal gas, and waterand so on in Beijing are much lower than national levels. While carbon footprints of the industry of information technology, commerce, service, education, scientific research and so on is higher than national level, which reflects a tertiary industry prominent structure of Beijing. Whereas opposite to the research result of B. K. Sovacool and M. A. Brown (2009) that energy consumption of building is primary part of Beijing's carbon footprint [5], in this paper we estimated a low carbon footprint of the industries of generation and supplying of electric power, coal gas, waterand so on. The reason is Beijing sorely rely on supplying of electric power and water from other areas. Take electric power for example, in 2010, generation of electric power merely occupied 32.51% of consumption in Beijing, while the statistical yearbook just count consumption of energy of the industry of electric power, coal gas, waterand so on in Beijing, which result in a deviation between estimation result and actual situation. However,as a whole, the estimation result reflects demand degree of energy consumption of each industrial apartments of Beijing factually.

Conclusion and Prospect

Based on the estimation of annual CO_2 emission in Beijing, this paper calculated carbon footprints of 2005, 2007 and 2010 through input-output model and analyzed carbon emission of 7 industrial sectors representing original 42 industrial apartments. Calculation result demonstrates that annual carbon emission of Beijing was increasing. Benefit from Beijing's efforts in industrial transformation and environmental treatment for holding 2008 Olympic Game, severalenterprises with high energy consumption and high carbon emission had been modified or moved, area of vegetation area raised, function of carbon fixation and carbon absorption of vegetation enhanced, therefore growth rate of carbon emission in Beijing decreased gradually. Industries of manufacturing, mining andquarrying, transportation, storage and post occupied largest proportion in Beijing's carbon footprint. In further development, Beijing should improve technological innovation vigorously to mitigate dependence on carbon emission of the 3 apartments. As a whole, carbon footprint structure of Beijing coincided with energy consumption character of each industrial apartments and industrial structure of Beijing. However, because of consumption of electric power, heating power and water in Beijing deeply relying on supplying from other provinces, the proportion of carbon footprint of this sector deviate from actual situation. The statistics just count quantity of generation without considering supply from other areas is the main reason to explain this problem.

Besides deviation caused by statistical definition, the method this paper used also has its limitation. At present, there are mature methods for calculating carbon emission and carbon footprint, but every method has its advantages and disadvantages, and results based on different methods may differ widely. Inventory method of producer responsibilityrepresented by *2006 IPCC Guidelines for National Greenhouse Gas Inventories*with the virtueof easy operating and low uncertainty has been adopted by various countries. But it may cause carbon leakage because developed area can achieve the goal of saving energy and decreasing carbon emission on the premise of consumer demand not be affected through dealing with other areas to obtain production with high energy consumption and high carbon emission such as electric power [11]. Moreover,the specialty of input-output model consist in estimating carbon footprint of a certain industrial apartments, but carbon emission implied inproducing process of products with same value may have a great difference, which may lead to deviation of calculation result. Above all, present estimation methods of carbon emission and carbon footprint become more and more mutual but far behind authoritative standard.Without multilateral test form other methods or observed data, calculation result based on a certain method merely could be a limited reference to weigh up connection between developing scale, industrial structure and carbon emission.

In view of advantages and disadvantages of the model this paper used, further correlative researches will mainly relate with comprehensive analysis of results of macroscopic estimation and microscopic simulation for deeply studying temporal and spatial mechanism of urban carbon emission.

Acknowledgements

This work was financially supported by National Natural Science Foundation of China (NO.41271186), The Major research project of Minzu University of China(Developmental patterns of Eco-city at minority areas in western China) and National Natural Science Foundation of China (NO.41101117).

Corresponding author: LI Yu, liy@igsnrr.ac.cn

References

[1] M. A. Brown, F.Southworth and A.Sarzynski: Policy and Society. Vol. 27 (2009), p. 285–304
[2] IEA: 2012 Key World Energy Statistics. (Prepared by the IEA, 2012)
[3] R. Mendelsohn: Journal of Economic Literature. Vol. 48(2010), p. 786-788
[4] W. Wang, J. Lin, S. Cui and T. Lin: Environmental Science & Technology. Vol. 33(2010), p. 71-78 (in Chinese)
[5] B. K.Sovacool and M. A. Brown: Energy Policy. Vol. 38 (2010), p. 4856–4869
[6] W. Leontief: The Structure of American Economy (IASP Publishing, America 1941)
[7] A. Druckman and T. Jackson: Ecological Economics. Vol. 68 (2009), p. 2066–2077
[8] J. Sun, Z. Chen, R. Zhao, X. Huang and L. Lai: China Population, Resources and Environment. Vol. 20 (2010), p. 28-34(in Chinese)
[9] IPCC: Climate change: the physical science basis (Cambridge University Press, 2007)
[10] B. W.Ang, F. L.Liu andE. P. Chew: Energy Policy. Vol. 31 (2003), p. 1561-1566
[11] C. Ma, H. Xu and M. Su: Progress in Geography. Vol. 32 (2013), p. 400-407(in Chinese)
[12] H. S. Eggleston, L. Buendia, K. Miwa, T.Ngara and K. Tanabe: *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. (Prepared by the National Greenhouse Gas Inventories Program, 2006)
[13] Information on http://www.bj.xinhuanet.com/bjpd_bjzq/2008-05/13/content_13238811.htm