The relationship between consumption and production system and its implications for sustainable development of China

Jingru Liu^{*}, Rusong Wang, Jianxin Yang, Yao Shi

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O. Box 2871, Beijing 100085, China

ARTICLE INFO

Article history:

Received 10 June 2009

Received in revised form 1 January 2010

Accepted 4 February 2010

Available online 2 March 2010

Keywords:

Sustainable consumption and production

Household consumption

Carbon dioxide emission

Life cycle analysis

ABSTRACT

Rapidly developing economy in China makes great improvement in human life quality. At the mean while, it brings great pressures on environment which has drawn broadly attentions all over the world. The 'problems of consumption' comes both from consumers and producers. Hybrid life cycle analysis method and structural decomposition analysis model were used in this paper to explore the interaction of consumption and production and how technology development and household consumption contributed to CO₂ emissions in the period of 1992–2002. The achievements of technology development in the last two decades reduced the emission intensity and technical coefficients which lowered the CO₂ emissions. But the household consumption has offset this technological contribution and resulted in the growth of CO₂ emission. Interaction analysis results showed that consumer's demand for energy-intensive product was an important driving force of pollution production. Household consumption in China contributed a lot to the expansion of manufacturing activities in the last two decades. We concluded that sustainable development could not be achieved if policy makers continuously emphasize the control of polluting industries. The government should simultaneously emphasize technological development and consumer policies to curb these emissions and induce more environmental conscious production and consumption patterns.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

People kept exploring the applicable path for sustainable development for decades and social responses to environmental problems have focused largely on the production side of economic activities. But evidences have shown that over the last decade, changes in consumption patterns have offset the environmental achievements from industrial technological improvement (UNEP, 2002; Spangenberg and Lorek, 2002; Princen, 2003; Clark, 2007). During the UNCED conference in Rio de Janeiro 1992, unsustainable consumption patterns, together with unsustainable production patterns were identified as the key driving forces behind the unsustainable development of the world. This became the starting point for international work directed to improving understanding of global consumption patterns and their environmental impacts (Lintott, 1998; Farah and Allely, 2003; Nansai et al., 2007).

Households are the mainly final consumption sectors which consist of the most part of gross domestic product. The households' consumption behavior can impact the environment directly and indirectly. The indirect impacts are associated with the production processes of commodities and services for households (Noorman,

1998). From a life cycle point of view, consumption behavior is not an isolated phase. The resources consumed as well as the pollution released from production process can be allocated to end-uses. Thus, the UNEP proposed a life cycle thinking when it brought forward the definition of sustainable consumption in 1994 (UNEP, 1994).

China is a rapid developing country with huge population. The human life quality in China has been great improved after taking the open-the-door policy. Along with income increase and living standard improvement, private consumption brings great pressures on the deteriorating environment which has drawn broadly attention all over the world (Liu and Diamond, 2005). The government is now facing a serious situation to balance the economy development and environmental protection. It is now widely accepted by managers that shifting from cleaner production practices to sustainable production and consumption economy activities is an indispensable path for achieving sustainable development in China (China's Agenda 21, 1994). It is essential to analyze the synergetic relations of production and consumption systemically to set out a course of action for sustainable development practices.

China is the second largest CO₂ emitter in the world and households is an important contributor of GHG emissions (Lenzen, 1998; Munksgaard et al., 2002; Lenzen and Dey, 2002). In this research, we chosen CO₂ emissions connected with energy consumption as an indicator to reflect the environmental impact

^{*} Corresponding author. Tel.: +86 10 62849110; fax: +86 10 62943807.
E-mail address: liujingru@cees.ac.cn (J. Liu).

Table 1CO₂ emission factors of energy fuels.

Fuel	Emission factor (Tc/TJ)	Carbon oxidation rate (%)	NCV (MJ/t m ³ , tce)	Emission factor (CO ₂ /TJ)
Raw coal	24.74	94.4	20908	90.65
Clean coal	24.74	94.4	26344	90.65
Other washed coal	24.74	94.4	8363	90.65
Coke		97	28435	74.02
Coke oven gas	20.2	99	16726	
Other gas	20.2	99	5227	74.02
Crude oil	20	98	41816	73.28
Diesel	20.2	98	42652	74.02
Fuel oil	21.1	98	41816	77.31
LPG	17.2	99	50179	63.02
Refinery gas	20	99	46055	73.28
Natural Gas	15.3	99	38931	56.06
Other petroleum products	20.2	98	41816	74.02
Other coking products	25.8	97	28435	94.54

Datasources: (1) Climate Change Country Study, 57–58; (2) Wu Zongxin, Chen Wenying. Coal based diversified clean energy strategy, 145–146; (3) 94.4 is lower than the IPCC default value, which is the estimation of industrial average value in China.

of household consumption. Using the hybrid life cycle analysis method and related mathematic models, we established an environmental extended input–output table of China by combing with energy statistic data and calculated the carbon dioxide (CO₂) emission intensities of production sectors in 1992, 1997 and 2002. Structural decomposition analysis was then used to calculate the contribution of technology development and lifestyle changes to the total consumption-related CO₂ emission changes from 1992 to 1997 and 1997 to 2002. The relationship of CO₂ emissions between consumption and production system was analyzed. The key points for Chinese sustainable consumption and production development were identified and discussed.

2. Methods, data sources and models

2.1. Hybrid life cycle analysis

There are two basic methods in compiling life cycle inventory: process analysis and input–output analysis (Suh et al., 2004). Process analysis is a bottom-up technique and input–output analysis is a top-down macroeconomic technique that uses sectoral monetary transactions matrix to describe the structure of an economy in terms of interactions among industries and between them and households (Lenzen, 2002). One of the most important applications of input–output analysis is to calculate the total input requirements for a unit of final demand. By doing this, one can assess not only the direct requirement in the production process of the analyzed sector itself, but also all indirect requirements resulting from intermediated product deliveries from other sectors (Hubacek and Giljum, 2003). Consumption is related with products, by using hybrid LCA, it is easy to analyze the interactions between consumption and production. Since the input–output analysis is based on publicly available data, the method is less time consuming than process analysis (Munksgaard et al., 2005).

2.2. Data sources and treatment of data

By combing the Chinese input–output table, energy statistical book and CO₂ emission factors, we calculated the CO₂ emission intensity of industrial sectors. The Chinese input–output table was published each five years in 1992, 1997 and 2002. There are 118 industrial sectors in 1992s input–output table, 124 sectors in 1997s table and 122 sectors in 2002s table. To make a consistent analysis, we aggregated the number of industrial sectors to 97 according to the Chinese National Standard.

Eighteen kinds of energy fuels used by 40 industrial sectors are compiled in the Chinese energy statistic books. These 40 sectors'

energy consumption and related CO₂ emissions were disaggregated to 97 industrial sectors in input–output tables. The economic input–output table was linked with energy matrices based on some basic assumptions. The method of desegregation in this process is very important. More detailed methods are described in other references (Vringer and Blok, 1995; Lenzen et al., 2003; Sangwon, 2006; Hoekstra and Bergh, 2006). Allocations among sectors were based on the percentage of sector's price output to the total outputs of same group sectors.

The amount of CO₂ emission is determined by types of fuel, discharge coefficient of carbon and oxidation rate (Table 1). To avoid double counting, we only considered the primary fuels for constructing emissions data. For example, the emission of coal was calculated, but the secondary energy of coal, like electricity, was out of our consideration. During the calculation, energy loss should be considered. The amount of total energy losses was achieved in China energy statistics yearbooks. We divided the total energy losses into each sector according to the amount of total energy used by that sector. The indirect CO₂ emissions of household consumption are calculated by multiplying the sectoral cumulative CO₂ intensities with household expenditures.

2.3. Models

2.3.1. The basic input–output model

The basic concepts of input–output analysis were developed by Leontief in the last 60th. Expanded models with environmental multipliers have been widely used and discussed since then (Chapman, 1974; Gay and Proops, 1993; Duchin, 1992; Lenzen, 1998; Hertwich, 2005). The basic equation of input–output analysis is:

$$x = A_x + y \quad \text{or} \quad x = (I - A)^{-1}y \quad (1)$$

where x is the elements of a matrix ($n \times n$) of intermediated demand of industries $j = 1, \dots, n$ from industries $i = 1, \dots, n$. y is the vector ($n \times 1$) of final demand from industrial sectors. Each column A_j is the requirements for one unit of output of sector. $(I - A)^{-1}$ is the key of input–output analysis, which is called Leontief inverse matrix.

2.3.2. Expand input–output model with CO₂ emission multiplier

Assuming the total CO₂ emission of industrial sector is T_i , the ratio of T_i to X_i can be defined as the direct CO₂ emission coefficient of sector i :

$$w_i = \frac{T_i}{X_i} \quad (2)$$

Table 2Household expenditure and its CO₂ emission pattern in 1992.

	Expenditure of households (ten thousand RMB Yuan)	CO ₂ emission (Ton)
Electricity, steam and hot water production and supply	573911	39840402
Other food products	3896480	12082807
Gas production and supply	348342	11050899
Health services	3090651	6701261
Grain mill products	3574215	6193993
Chemical products for daily use	742268	5384558
Livestock and livestock products	5963073	4774211
Wines, spirits and liquors	1352941	3919784
Other agricultural products	4769515	3818613
Pottery, china and earthenware	168237	3505479
Highway passenger transport	875985	3061655
Non-alcoholic beverage	835363	2420240
Slaughtering, meat processing, eggs and dairy products	1169935	2027458
Wholesale and retail trade	4558410	1994890
Culture and arts, radio, film and television	783969	1699830
Cotton textile	865103	1561620
Fishery	1895157	1517318
Education services	688379	1492568
Residential services	1826097	1451454
Storage and warehousing	408871	1429045
Total of top 20 sectors	38386902	115928086
Total in 1992	58885729	140199284
Percentage of top 20 sectors to total in 1992	65.19%	82.69%

Then the complete emission coefficient of sector i can be calculate by Eq. (3):

$$C = w + wA + wA^2 + wA^3 + \dots = w(I - A)^{-1} \quad (3)$$

where C is the complete emission coefficient.

By combing the household consumption multiplier y , we can get:

$$TW = w(I - A)^{-1}y = Cy = \sum_{i=1}^n C_i \times y_i \quad (4)$$

where TW is total CO₂ emission of household consumption. Eq. (4) can be used to track inputs and outputs along the full supply chain by identifying and quantifying both direct and indirect inputs to the final products under analysis. This makes the hybrid LCA a useful tool to investigate the linkage between consumption, production and environmental effects.

2.3.3. Structural decomposition model

Structural decomposition analysis (SDA) used in hybrid LCA has illustrated the power of this framework to address the relations between technology, lifestyle and the environment (Duchin, 1998). The CO₂ emission different between time t and time $t + 1$ is caused by three factors:

$$TW(t) - TW(t - 1) = \Delta w(I - A)^{-1}(t)y(t) + w(t - 1)\Delta(I - A)^{-1}y(t) + w(t - 1)(I - A)^{-1}(t - 1)\Delta y \quad (5)$$

where Δw , $\Delta(I - A)^{-1}$ and Δy reflect the contribution of emission intensity, technology development and consumption behaviors to the total changes of CO₂ emissions between time t and time $t + 1$. This mathematical model can be used to explore the key contributor of environmental impacts and identify opportunities for reducing environmental impacts.

Table 3Household expenditure and its CO₂ emission pattern in 1997.

	Expenditure of households (ten thousand RMB Yuan)	CO ₂ emission (Ton)
Electricity production and supply	2486506.1	61924810
Bricks, tiles, lime and light-weight building materials	2254239.5	13503005
Gas production and supply	782239.6	11894629
Grain mill products, vegetable oil and forage	9352178.3	5838455
Other food products	10855131.5	5744349
Livestock and livestock products	17685110.5	5660173
Telecommunication	2162589.4	5357378
Chemical products for daily use	1855719.2	4152877
Crop cultivation	10486508.5	3361048
Steam and hot water production and supply	122433.4	3054144
Pottery, china and earthenware	457287.8	2737684
Wines, spirits and liquors	4414956.7	2705351
Wholesale and retail trade	11153463.6	2425659
Slaughtering, meat processing, eggs and dairy products	3760775.0	2346038
Cement and asbestos products	388366.4	2323116
Glass and glass products	362640.4	2169911
Health services	7389074.0	2109602
Cement	346438.4	2072574
Fishery	5601723.2	1794287
Non-alcoholic beverage	2561443.0	1569673
Total of top 20 sectors	94478824.6	142744763
Total in 1997	179806593.9	168968965
Percentage of top 20 sectors to total in 1997	52.54%	84.48%

3. Results

3.1. Relationship of consumption and production

Using Eq. (4), we calculated the CO₂ emissions patterns of Chinese household consumption in 1992, 1997 and 2002, respectively. The top 20 sectors which affect most in household

Table 4Household expenditure and its CO₂ emission pattern in 2002.

	Expenditure of households (ten thousand RMB Yuan)	CO ₂ emission (Ton)
Electricity, steam and hot water production and supply	9203126	153723643
Cement, lime and plaster	2783595	24234796
Gas production and supply	1566024	10753325
Telecommunication service	7988056	8557116
Animal husbandry	26468219	8426237
Agriculture	19828897	6312589
Glass and glass products	695818	6057996
All other food manufacturing	17895326	5456194
Educational services	21994855	5201730
Residential and other personal service	17580403	4157723
Chemical products for daily use	2543219	4022053
Pottery, china and earthenware	442751	3854720
Health	16025274	3789939
Urban public transport service of passengers	3391052	3632626
Other non-metallic mineral products	375481	3269048
Food serving services	25546781	3197336
Real estate	23338895	2921006
Fishery	8807141	2803780
Water transport	2615136	2801435
Wholesale and retail trade services	21811525	2729846
Total of top 20 sectors	230901574	265903139
Total in 2002	362695996	305518631
Percentage of top 20 sectors to total in 2002	63.66%	87.03%

Table 5Expenditure and CO₂ emission patterns of households in 1992, 1997 and 2002.

Year	The first industry		The second industry		The third industry	
	Percentage of expenditure	Percentage of CO ₂ emission	Percentage of expenditure	Percentage of CO ₂ emission	Percentage of expenditure	Percentage of CO ₂ emission
1992	43.04	19.14	27.37	68.11	29.58	12.74
1997	35.75	7.58	42.34	85.49	21.92	6.93
2002	23.86	6.59	20.33	83.62	54.69	8.27

Table 6Structural decomposition analysis of changes in household CO₂ emissions (unit: tCO₂).

Time period	Emission intensity	Technical coefficients	Household consumption	Sum
1992–1997	−3.64E+08	−7.56E+07	1.08E+09	6.38E+08
1997–2002	−5.52E+08	−2.38E+07	6.21E+08	4.53E+07
1992–2002	−9.16E+08	−9.94E+07	1.70E+09	6.84E+08

CO₂ emissions are listed in Tables 2–4. It was shown that in 1992, 82.69% of household CO₂ emission came from the top 20 sectors and about 65.19% of total household expenditure was used in these sectors. In 1997, 84.48% of total CO₂ emission was caused by the top 20 sectors, and 52.54% of total expenditure was used in these sectors (Table 3). In 2002, the CO₂ emission amount of those 20 sectors accounted for 87.03% of total emission, and their expenditure was 63.66% of total expenditure (Table 4).

According to the industry classification standard of China, all sectors are classified into three industries categories, which are defined as the first, the second and the third industry, respectively. The first industry includes agriculture, forest, farming, and fishing. The second industry includes mining, manufacturing, electric power production, gas and water production, architecture and so on. The third industry includes all sectors which mainly include service sectors. The second industry is the most environmentally polluted industry and the third industry is considered as the most environmental friendly industry.

Based on this classification standard, we rearranged the sectors as shown in appendix 1 to appendix 3 and the results were summarized in Table 5. It was shown that for Chinese household consumption, the percentage of CO₂ emission caused by the first industry was reducing gradually, and so did the expenditure on this industry. The expenditure on the third industry was increasing rapidly from 29.58% in 1992 to 54.69% in 2002, but the accordingly CO₂ emission decreased. The contribution of the second industry to household CO₂ emission reaches a peak to 85.49% in 1997. This was consistent with the rapidly saturation of electric equipments in the middle of 1990s. In 2002, the contribution of the second industry still accounted for more than 80% of the total household CO₂ emission, yet the expenditure on it was only half of 1997, indicating that household had shifted their consumption to more pollution intensively products, such as private car and house.

3.2. Technology, environment and lifestyle changes from 1992 to 2002

The environmental impacts of households were decomposed into three determinants: the level of consumption, the composition of consumption and the environmental intensity of the goods and services produced for consumption (Ropke, 2001). The first two factors are related with consumption behavior and the third factor is decided by technology development. Eq. (5) was used to analyze the changes of households CO₂ emission and the contribution of technology development and consumption behavior from 1992 to 2002. The structural decomposition analysis results are shown in Table 6. Changes in emission intensity and technical coefficients reduced the CO₂ emissions, this shows the

achievement of technology development and we can conclude that the Chinese industry is now moving towards a less-polluting structure. But the household consumption has offset this technological contribution, resulting in the growth of CO₂ emission. This reflects the limitation of technology development to the society sustainable development.

4. Conclusions and implications for Chinese sustainable development

In the last two decades, the resulting gains in Chinese people's living standards have been impressive, but the environmental cost is also very huge. There is growing recognition that multiple actors are interacting with diverse rules across complex decision-making arenas (Saravanan, 2008). Structural component analysis method was used in this paper, the results showed that in the last two decades, the increasing consumption CO₂ emission had offset the achievements taken by technology development. Households are becoming a more and more important contributor for the generation of CO₂ due to the indirect impact of their demand for products and services. Interaction analysis results showed that consumer's demand for energy-intensive product was an important driving force of pollution production. In the last two decades, household consumption has significant contribution to the expansion of manufacturing activities in China.

The government should simultaneously emphasize technological development and consumer policies to reduce these emissions and induce more environmental conscious production and consumption patterns (Kim, 2002). Pollution control measures and actions of Chinese government have focused largely on the production side of economic activities: innovative technologies for material mining, energy supply and manufacturing. But the China's rapid increase in household number and reduction in household size also have had significant environmental consequences (Liu and Diamond, 2005). It is important for China to put forward sustainable consumption and ensure sustainable development.

The Chinese government is now actively seeking policies to promote sustainable consumption. However, fundamental research on sustainable consumption obviously lags behind the demand of enacting policies. In 1994, the Chinese government published its Agenda 21, in which the Chapter 7 was devoted to issues concerning sustainable consumption (China's Agenda 21, 1994). This was followed up by a lot of practical activities organized by the government and the NGOs (CI and UNEP, 2004). The government plays an important role in promotion organic food, ISO 14000 certification and eco-labeling. Compared with developed countries, China still needs to do a lot of work to promote sustainable

consumption and production patterns. It is imperative for China to clearly understand its consumption patterns and its mechanisms and to take activities to promote sustainable patterns of production and consumption. If policy makers continuously emphasize the control of polluting industries and products, it may be difficult to achieve a satisfactory environmental performance. If proper measures were taken, the consumer will become an influential force through their demand side pushing production to be more environmental friendly pattern.

Acknowledgements

This research was supported by the Chinese National Scientific Foundation (No. 70873122) and National Basic Research Program of China (No. 2005CB724206). We gratefully acknowledge the discussions with and the support of Edgar Hertwich and Peters Glen from Norwegian University of Science and Technology.

References

- Chapman, P.F., 1974. Energy costs: a review of methods. *Energy Policy* 2 (2), 91–103. Chinese Environmental Sciences Press, Beijing.
- Consumers International, UNEP, 2004. Tracking Progress: Implementing Sustainable Consumption Policies. CI & UNEP, Kenya.
- Clark, G., 2007. Evolution of the global sustainable consumption and production policy and the United Nations Environment Programme's supporting activities. *Journal of Cleaner Production* 15, 429–498.
- Duchin, F., 1992. Industrial input–output analysis: implications for industrial ecology. *Proceedings of the National Academy of Sciences* 89, 851–855.
- Duchin, F., 1998. Structural Economics—Measuring Changes in Technology, Life-styles, and the Environment. Island Press, Washington, DC.
- Farah, A.Z., Allely, E.G., 2003. Household consumption patterns in OECD countries: trends and figures. *Journal of Cleaner Production* 11, 819–827.
- Gay, P.W., Proops, J.L.R., 1993. Carbon-dioxide production by the UK economy: an input–output assessment. *Applied Energy* 44, 113–130.
- Hertwich, E.G., 2005. Life cycle approaches to sustainable consumption: a critical review. *Environmental Science and Technology* 39, 4672–4684.
- Hoekstra, R., Bergh, J.G.J.M., 2006. Constructing physical input–output tables for environmental modelling and accounting: framework and illustrations. *Ecological Economics* 59, 375–393.
- Hubacek, K., Giljum, S., 2003. Applying physical input–output analysis to estimate land appropriation of international trade activities. *Ecological Economics* 44, 137–151.
- Kim, J.H., 2002. Changes in consumption patterns and environmental degradation in Korea. *Structural Changes and Economic Dynamics* 13, 1–48.
- Lenzen, M., 1998. Energy and greenhouse gas cost of living for Australia during 1993/94. *Energy* 23, 497–516.
- Lenzen, M., 2002. A guide for compiling inventories in hybrid life-cycle assessments: some Australian results. *Journal of Cleaner Production* 10, 545–572.
- Lenzen, M., Dey, C.J., 2002. Economic, energy and greenhouse emissions impacts of some consumer choice, technology and government outlay options. *Energy Economics* 24, 377–403.
- Lenzen, M., Murray, S.A., Korte, B., Dey, C.J., 2003. Environmental impact assessment including indirect effects—a case study using input–output analysis. *Environmental Impact Assessment Review* 23, 263–282.
- Lintott, J., 1998. Beyond the economics of more: the place of consumption in ecological economics. *Ecological Economics* 25, 239–248.
- Liu, J.G., Diamond, J., 2005. China's environment in a globalizing world: how china and the rest of the world affect each other. *Nature* 435 (30), 1179–1186.
- Munksgaard, J., Pedersen, K.A., Wien, M., 2002. Impact of household consumption on CO₂ emissions. *Energy Economics* 22, 423–440.
- Munksgaard, J., Wier, M., Lenzen, M., Dey, C., 2005. Using input–output analysis to measure the environmental pressure of consumption at different spatial levels. *Journal of Industrial Ecology* 9, 169–185.
- Nansai, K., Kagawa, S., Moriguchi, Y., 2007. Proposal of a simple indicator for sustainable consumption: classifying goods and services into three types focusing on their optimal consumption levels. *Journal of Cleaner Production* 15, 879–885.
- Noorman, K.J., 1998. Green households? Domestic, consumers, environment and Sustainability. Earthscan Publications Ltd., London.
- Princen, T., 2003. Principles for sustainability: from cooperation and efficiency to sufficiency. *Global Environmental Politics* 3, 33–50.
- Ropke, I., 2001. The environmental impact of changing consumption patterns: a survey. *International Journal of Environment and Pollution* 15, 127–145.
- Sangwon, S., 2006. Handbook on Input–Output Economics in Industrial Ecology. Springer, Netherlands.
- Saravanan, V.S., 2008. A systems approach to unravel complex water management institutions. *Ecological Complexity* 5, 202–215.
- Spangenberg, J.H., Lorek, S., 2002. Environmentally sustainable household consumption: from aggregate environmental pressures to priority fields of action. *Ecological Economics* 43, 127–140.
- Suh, S., Lenzen, M., Treloar, G.J., Hondo, H., Horvath, A., Huppes, G., Joliet, O., Klann, U., Krewitt, W., Moriguchi, Y., Munksgaard, J., Norris, G., 2004. System boundary selection in life-cycle inventories using hybrid approaches. *Environmental Science and Technology* 38, 657–664.
- United Nations Environment Programme, 1994. Elements for policies for sustainable consumption. In: Symposium: Sustainable Production and Consumption Pattern, Oslo.
- United Nations Environment Programme, 2002. Sustainable Consumption—A Global Status Report. UNEP, Paris.
- Vringer, K., Blok, K., 1995. The direct and indirect energy requirements of households in the Netherlands. *Energy Policy* 23, 893–910.