The Comparision among Four Carbon Footprint Estimation Boundaries of the Sectors Using Chongqing as a Case

L.P., Ju, B. Chen

State Key Laboratory of Water Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, China, 100875

Abstrct: International negotiations of reducing CO_2 emissions address the question of how to meet commitments with more explicit engagment with subnational action and how to account annual CO_2 emissions of each sector of one city. This study is to establish the CO_2 inventories focused on four tiers of CO_2 emissions form each sector, e.g. agriculture, industry, transportation and tertiary industry. Carbon footprint is chosen to evaluate 28 sectors of Chongqing, from four tiers, including direct emissions, emissions from purchased energy, the total supply chain, supply chain plus industrial process. Results showed that the first two tiers, only cover a small fraction of the total supply chain, especially for industrial sectors. We suggested that desion makers must acquire that tier 3 is intended to aid effective management strategies and climate change policies.

Keywords: Input-output analysis, Carbon footprint, Chongqing

1.Introduction

In Kyoto, December 1997, an international agreement has been reached on reducing global CO_2 emissions to the atmosphere. From then on, the countries, policy makers enterprises, even consumers are interested in cutting back CO_2 emissions (Lash, J., Wellington, F., 2007). International negotiations of reducing CO_2 emissions address the question of how to meet commitments with more explicit engagment with subnational action. So a shift to subnational climate governances has emerged in the last few years, resulting in many camaigns such as the "Cities for Climate Protection(Wheeler, S., 2008)" and "Pilot projects for low carbon city"in China. Measuring the local climate action of each sector in one city is the basis of subnational action about climate mitigation.

Carbon footprint, which is rooted in the literature of ecological footprint (Matthews, et al., 2008), has many definitons that differ in which gases are accounted for, where boundaries of analysis are drawn and other criterias (Wiedmann and Minx, 2007). Many protocols, such as World Resources Institute (2004), Local Government Operation Protocol (2008) aim at direct emissions and emissions from the generation of purchased electricity. However, bigger scopes or tiers of carbon footprint is expected from the perspective of life cycle accounting (World Resources Institute, 2009). To track all activities across the supply chain for a special industry and assess the carbon embodied in a product, input-output life cycle assessment (IO-LCA) methods were introduced. (Machado, et al., 2001; Munksgaard and Pedersen, 2001; Peters, 2008; Alcántara and Padilla, 2009; Pan, et al., 2008).

Economic input-output models were first proposed by Leontief in1936 (Leontief, 1986) to aid in manufacturing planning.

Matthews, et al. (2008) assested the variety scopes of carbon footprint from 3 tiers, including direct emissions, emissions from purchased energy and supply chain emissions, in two case studies, book publishers and power generation. Results showed that direct emissions from an industry are, on average, only 14% of the total supply chain carbon emissions and direct emissions plus industry energy inputs are only 26%. Larsen and Hertwich (2009) developed a greenhouse gas emissions inventory related to the provision of municipal services in the city of Trondheim. The analysis showed that approximately 93% of the total carbon footprint of municipal services was indirect emissions.

The aim of this study is to establish the CO_2 inventories focused on four tiers of CO_2 emissions form each sector, e.g. agriculture, industry, transportation and tertiary industry. Carbon footprint is chosen to evaluate 28 sectors of Chongqing, from four tiers, including direct emissions, emissions from purchased energy, the total supply chain, supply chain plus industrial process. That identifies the main productive linkages among the industry branches in terms of CO_2 emissions.

2.Model and Methodologies

2.1Bounderies

We develop estimation equations for six tiers of carbon footprint estimates for all economic sectors in Chongqing from the perspective of 4 energy types,including coal, oil, natural gas and electricity.

Tier 1 includes direct emissions of energy final combustion in each sector, including emissions from coal,oil and natural gas.This is similar to the "producer perspective" used for emissions inventories of countries, states, etc.

Tier 2 includes emissions due to electricity and steam purchases for a sector.

Tier 3 analysis the embodied carbon emissions based on produce from the total supply chain up to the productiongate, also as known as cradle-to-gate emissions

Tier4 besides the emissions of total supplu chain, the CO2 emissions from industrial process such as the cement production also are accounted.

2.2models

2.2.1 Tier 1 model

The tier 1 account model is specified in Eq.(1)

$$E_1 = F \cdot E^d \quad (1)$$

Where E_1 is the 1×28matrix, 28 vector specifying CO_2 emissions from 28 production sectors. E^d is the 3×29 matrix specifying use of 3 energy types, including coal, oil and natural gas. F is the 1×3 matrix of CO_2 emission coefficients.

2.2.2Tier 2 model

The tier 2 account model is shown in Eq.(2)

$$E_2 = F' \cdot E^f \qquad (2)$$

Where E_2 is the 1×28matrix, 28 vector specifying CO_2 emissions from 28 production sectors. $E^{f'}$ is the 4×28 matrix specifying use of 4 energy types, including coal, oil, natural gas and electricity. F' is the 1×4 matrix of CO_2 emission coefficients.

2.2.3 Tier 3 model

An input-output model is used to account the direct and indirect emissions of each sector ,that is embodied carbon and the model is shown in Eq.(3)

$$E_3 = F \cdot E^d \left(\text{I-A}\right)^{-1} Y \qquad (3)$$

Where E_3 is the 1×28matrix, 28 vector specifying CO_2 emissions from 28 production sectors. E^d is the 3×28 matrix specifying use of 3 energy types per unit for 28 production sectors, including coal, oil and natural gas. $\left(\text{I-A}\right)^{-1}$ is the 28×28 Leontief inverse cofficient matrix. Y is the 28×1 vector specifying Gross Domestic Product of 28 sectors.

2.2.4 Tier 4 model

Based on the tier 3 model, including industrial process.

$$E_4 = F \cdot E^d \left(\text{I-A}\right)^{-1} Y + E^i \left(\text{I-A}\right)^{-1} Y \qquad (4)$$

Where E_4 is the 1×28matrix, 28 vector specifying CO_2 emissions from the energy consumption and industrial process of 28 production sectors. E^i is the 1×28 matrix specifying the CO2 emissions from industrial process per unit for 28 production sectors.

3.Data

Chongqing input-output tables for the year 2002 from 2002 Input-output table in China(2002). The tables encompass 42 sectors. Energy-flow matrixes for the year 2002 from Chongqing Statistical Year book 2003, containing energy consumption for 40 sector. In this paper, the economic of Chongqing is divided into 28 sectors, as Table 1 showed. And the final consumption of energy is specified in 4 types of energy, including coal, oil natural gas and electricity.

Table 1 Sectors Classification

NO.	Sector	NO.	Sector
1	Farming,Forestry,Animal Husbandry and Fishery	16	Ordinary and Special Equipment
2	Coal Mining and Dressing	17	Transportation Equipment
3	Petroleum and Natural Gas Extraction	18	Electric Equipment and Machinery
4	Metals Minerals Mining and Dressing	19	Communication Equipment, Computers and Other Electronic Equipment
5	Nonmetal Minerals Mining and Dressing	20	Instruments, Meters, Cultural and Office Machinery
6	Food Production and Tobacco Processing	21	Other Manufcturing Industry
7	Textile Industry	22	Electricity,Steam Production and Supply
8	Garmenta, Leather Furs Down and Related Products	23	Gas Production and Supply
9	Timber Processing and Furniture Manufacturing	24	Water Production and Supply
10	Paper making, Printing and Cultural Educational and Sports Goods	25	Construction
11	Petroleum, Coking and Nuclear Fuel Processing	26	Transportation, Storage,Postal and Telecommunication Services
12	Chemical Industry	27	Wholesale, Retail Sale Trade and Catering Trade
13	Nonmetal Mineral Products	28	Others
14	Smelting and Pressing of Metals	29	Residential Consumption
15	Metal Products		

The factors are based on the carbon content of the fuels and the type of energy. CO2 emissions fators for renewable energy are considered to be zero. In the paper, considering no CO2 emissions from the consumption of electricity and heating, energy inputs for the production of secondary energy of electricity and heating are estimated as one commodity among others.

Table 2 The CO2 emissions of factors of energy

NO.	1	2	3	4
Energy	Coal （$KgCO_2/GJ$）	Oil（ $KgCO_2/GJ$）	Natural gas （$KgCO_2/GJ$）	Electricity （$KgCO_2/kwh$）
CO_2 emission coefficients	90.90	72.93	51.19	0.7077

4.Results

Based on Chongqing 2002 data, we estimate the accounting models for 28 economic sectors in tier1, 2, 3, 4.And the results of tier 4 are seen as the total emissions of sectors.

As seen in Table 3, direct emissions (tier 1)of sector 1, 25, 26, 27, 28, which on behave of Primary Industry and Tertiary Industry,are 81.64%, 55.26%, 93.24%, 31.92%, 17.16% of rthe total emissions of the supply chain, respectively, and direct emissions plus electricity (tier 2) are 81.64%, 55.26%, 93.24%, 32.00%, 17.16%, respectively. As for industrr sectors, from sector 2 to sector 24, direct emissions cover only 0.23% on average, and the emissions of tier 2 capture 10.53%. In total, cement process are, on average, only 0.53% of the total emissions.

Table 3 The CO_2 emissions of four tiers in 28 sectors

1000 t CO_2	tier1	% of total	Tier 2	% of total	Tier 3	% of total	Tier 4	Indutrial process	% of total
1	4.49E+02	81.64%	4.49E+02	81.64%	5.50E+02	100.000%	5.50E+02	2.21E-03	0.0004%
2	4.16E+02	1.15%	4.61E+02	1.27%	3.61E+04	99.724%	3.62E+04	2.55E+00	0.0070%
3	3.40E+00	0.14%	5.69E+00	0.24%	2.42E+03	100.000%	2.42E+03	1.15E-01	0.0048%
4	2.38E+01	0.09%	3.93E+01	0.14%	2.79E+04	100.000%	2.79E+04	7.44E-01	0.0027%
5	3.72E+01	0.25%	5.36E+01	0.35%	1.51E+04	100.000%	1.51E+04	5.13E+01	0.3397%
6	3.23E+01	0.00%	1.73E+02	0.02%	7.03E+05	100.000%	7.03E+05	1.28E+01	0.0018%
7	4.38E+01	0.02%	1.01E+02	0.05%	2.24E+05	100.000%	2.24E+05	2.83E+00	0.0013%
8	1.04E+00	0.00%	1.53E+01	0.04%	4.27E+04	100.000%	4.27E+04	1.00E+00	0.0023%
9	4.89E+00	0.04%	1.51E+01	0.13%	1.18E+04	100.000%	1.18E+04	8.72E-01	0.0074%
10	2.80E+01	0.10%	5.00E+01	0.17%	2.92E+04	100.000%	2.92E+04	1.41E+00	0.0048%
11	2.10E-01	0.00%	8.83E+00	0.16%	5.68E+03	100.000%	5.68E+03	6.18E-01	0.0109%
12	5.58E+02	0.11%	9.97E+02	0.20%	5.06E+05	100.000%	5.06E+05	9.36E+01	0.0185%
13	6.44E+02	0.40%	9.13E+02	0.57%	1.60E+05	100.000%	1.60E+05	8.53E+01	0.0533%
14	3.75E+02	0.15%	8.26E+02	0.32%	2.58E+05	100.000%	2.58E+05	1.26E+01	0.0049%
15	9.47E+00	0.02%	8.02E+01	0.16%	4.99E+04	100.000%	4.99E+04	3.08E+00	0.0062%
16	1.26E+01	0.09%	2.77E+01	0.21%	1.34E+04	100.000%	1.34E+04	7.17E-01	0.0054%
17	5.83E+00	0.00%	9.03E+02	0.08%	1.11E+06	100.000%	1.11E+06	5.46E+01	0.0049%
18	5.07E+01	0.02%	3.07E+02	0.12%	2.46E+05	100.000%	2.46E+05	1.79E+01	0.0073%
19	1.33E-01	0.00%	2.11E+01	0.07%	2.91E+04	100.000%	2.91E+04	1.42E+00	0.0049%
20	1.76E+00	0.00%	5.18E+01	0.08%	6.86E+04	99.854%	6.87E+04	3.25E+00	0.0047%
21	1.42E+01	0.01%	1.10E+02	0.06%	1.81E+05	100.000%	1.81E+05	9.65E+00	0.0053%
22	1.23E+03	2.61%	2.56E+03	5.42%	4.72E+04	100.000%	4.72E+04	2.79E+00	0.0059%
23	1.74E+00	0.03%	9.22E+00	0.17%	5.43E+03	100.000%	5.43E+03	1.65E-01	0.0030%
24	7.58E-02	0.00%	3.40E+01	0.50%	6.74E+03	100.000%	6.74E+03	3.17E-01	0.0047%
25	5.52E+01	55.26%	5.52E+01	55.26%	9.99E+01	100.000%	9.99E+01	1.34E-02	0.0134%
26	2.62E+02	93.24%	2.62E+02	93.24%	2.81E+02	100.000%	2.81E+02	1.09E-03	0.0004%
27	3.99E+01	31.92%	4.00E+01	32.00%	1.25E+02	100.000%	1.25E+02	1.78E-03	0.0014%
28	2.30E+01	17.16%	2.30E+01	17.16%	1.34E+02	100.000%	1.34E+02	6.28E-03	0.0047%

5.Conclusions

We find that the first 2 tiers, popular in most protocols, only cover a small fraction of the total supply chain, especially for industrial sectors. It is clear that, as for any complicated product, all different players in the whole supply chain could be responsibility for the emissions associated with supplying raw materials.

Without quantitative indicators of the total supply chain of each sector, these decisions on the part of policy makers would be less effective, because they would not be told the whole story. So desion makers must acquire that the existing protocols have underestimate the emissions of each setor and tier 3 above is intended to aid effective management strategies and climate change policies.

6.References

Alcántara, V., Padilla, E., 2009. Input－output subsystems and pollution: an application to the service sector and CO_2 emissions in Spain. Ecological Economics, 68 (3), 905-914.

Betsill, M.M., Bulkeley, H.,2006. Cities and the multievel governance of global climate change. Global Governance, 12 (2), 141-159.

Chongqing Statistical Year book, 2003. http://www.cqtj.gov.cn/tjnj/2003/yearbook/index.htm.

China Climate Change Country Study Group, 2000. China Climate Change Country Study. Tsinghua University Press:Beijing, 36 pp.

Lash, J.; Wellington, F., 2007. Competitive advantage on a warming planet. Harvard Business Review, 85 (3), 94-104.

Leontief, W. W, 1986. Input-Output Economics, 2nd ed. Oxford University Press: New York, 436 pp.

ICLEI, 2008. Local Government Operation Protocol: For the quantification and reporting of greenhouse gas emissions inventories. ICLEI-Local Governments for Sustainability.

Machado, D., Schaeffer, R., Worrell, E., 2001. Energy and carbon embodied in the international trade of Brazil: an input-output approach. Ecological Economics, 39, 409-424.

Munksgaard, J. and Pedersen K.A., 2001. CO_2 accounts for open economies: producer or consumer responsibility? Energy Policy, 29, 327-334.

Matthews, H.S., Hendrickson, C.T., Weber, C.L., 2008. The importance of carbon footprint eatimation boundaries. Environmental Science&Technology, 42, 5839-5842.

Pan, J., Phillips, J., Chen, Y., 2008. China's balance of emissions embodied in trade: approaches to measurement and allocating international responsibility. Oxford Reviewof Economic Policy, 24 (2), 354-376.

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecological Economics, 65, 13-23.

Wheeler,S., 2008. State and municipal climate change plans: the first generation. Journal of the American Planning Association, 74(4), 481-496

Wiedmann, T., Minx, J.A., 2007. Definition of Carbon Footprint. Integrated Sustainability Analysis UK: Durham UK, 1-11 pp.

World Resources Institute, 2004. The greenhouse gas protocol. World Business Council for Sustainable Development.

World Resources Institute, 2009. Greenhouse gas protocol initiative: new guidelines for product and supply chain accounting and reporting. World Business Council for Sustainable Development.

2002 input-output tables in China, 2008.Year Book Press: Beijing, 264-275 pp.