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

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Abstract: International negotiations of reducing CO₂ emissions address the question of how to meet commitments with more explicit engagement with subnational action and how to account annual CO₂ emissions of each sector of one city. This study is to establish the CO₂ inventories focused on four tiers of CO₂ emissions from 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 decision 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 CO₂ emissions to the atmosphere. From then on, the countries, policy makers enterprises, even consumers are interested in cutting back CO₂ emissions (Lash, J., Wellington, F., 2007). International negotiations of reducing CO₂ emissions address the question of how to meet commitments with more explicit engagement with subnational action. So a shift to subnational climate governances has emerged in the last few years, resulting in many campaigns 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 definitions 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 in 1936 (Leontief, 1986) to aid in manufacturing planning.

Matthews, et al. (2008) assessed 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 CO₂ inventories focused on four tiers of CO₂ emissions from 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 CO₂ emissions.

2. Model and Methodologies

2.1 Boundaries

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 production gate, also as known as cradle-to-gate emissions

Tier 4 besides the emissions of total supply chain, the CO₂ emissions from industrial process such as the cement production also are accounted.

2.2 models

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 1×28 matrix, 28 vector specifying CO₂ 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 CO₂ emission coefficients.

2.2.2 Tier 2 model

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

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

Where E_2 is the 1×28 matrix, 28 vector specifying CO₂ 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 CO₂ 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)

$$E_3 = F \cdot E^d (I-A)^{-1} Y \quad (3)$$

Where E_3 is the 1×28 matrix, 28 vector specifying CO₂ 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. $(I-A)^{-1}$ is the 28×28 Leontief inverse coefficient 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.

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

Where E_4 is the 1×28 matrix, 28 vector specifying CO₂ 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 Manufacturing 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 factors 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 behalf of Primary Industry and Tertiary Industry, are 81.64%, 55.26%, 93.24%, 31.92%, 17.16% of the 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 industrial 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 CO₂ emissions of four tiers in 28 sectors

1000 t CO ₂	tier1	% of total	Tier 2	% of total	Tier 3	% of total	Tier 4	Industrial 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 decision makers must acquire that the existing protocols have underestimated the emissions of each sector and tier 3 above is intended to aid effective management strategies and climate change policies.

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