Research Article

Energy-Dominated Local Carbon Emissions in Beijing 2007: Inventory and Input-Output Analysis

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For greenhouse gas (GHG) emissions by Beijing economy 2007, a concrete emission inventory covering carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) is presented and associated with an input-output analysis to reveal the local GHG embodiment in final demand and trade without regard to imported emissions. The total direct GHG emissions amount to $1.06 \times 10^{8}$ t CO₂-eq, of which energy-related CO₂ emissions comprise 90.49%, non-energy-related CO₂ emissions 6.35%, CH₄ emissions 2.33%, and N₂O emissions 0.83%, respectively. In terms of energy-related CO₂ emissions, the largest source is coal with a percentage of 53.08%, followed by coke with 10.75% and kerosene with 8.44%. Sector 26 (Construction Industry) holds the top local emissions embodied in final demand of $1.86 \times 10^{7}$ t CO₂-eq due to its considerable capital, followed by energy-intensive Sectors 27 (Transport and Storage) and 14 (Smelting and Pressing of Ferrous and Nonferrous Metals). The GHG emissions embodied in Beijing’s exports are $4.90 \times 10^{7}$ t CO₂-eq, accounting for 46.01% of the total emissions embodied in final demand. The sound scientific database totally based on local emissions is an important basis to make effective environment and energy policies for local decision makers.

1. Introduction

The success of reducing GHG emissions depends greatly on the policies making at urban, domestic and international scales [1]. The international and domestic governments have established general policies (e.g., United Nations Climate Change Conference and China’s 12th Five-Year Plan) [2, 3], but the policies enforced at the local level need to be improved by adding more detailed emission pictures within its own territory. Cities contribute 67% to the global GHG emissions from fossil energy use [4], so it is essential and urgent to implement reduction plans at the urban scale. As a result, this paper focuses on local energy inputs and GHG emissions in urban regions to guide environment and energy policies making at the substate level.

Many efforts have been made to calculate environmental emissions at the urban scale [1, 6–8], but most of them about urban carbon emissions just focus on the end-use emissions originated from industrial process, transportation, waste treatment, and so on [9–13], ignoring a deeper understanding of the total emissions in terms of both direct and indirect emissions caused by local commodities’ production processes. In fact, all of the commodities consumed in cities lead to GHG emissions during their production processes [8]. For example, the water supply must base on the construction and operation of water works, from which intermediate inputs of steel, concrete, electricity, and so forth are consumed and indirect GHG emissions are produced. As a result, urban planning should consider GHG emissions embodied in commodities used as intermediate inputs to produce products or commodities consumed in cities, not just these obvious direct GHG emissions [5, 14].

To track both direct and indirect effects on embodiments for economies as socioecological systems, input-output analysis (IOA) [15–18] has been applied to analyze embodied GHG emissions [5, 8, 14], energy [19, 20], water resources [21–23], and so forth at urban, domestic, and international scales. Previous input-output studies usually discuss the total emissions (including local and imported emissions) under the assumption that imported commodities have the same
embodied intensities as locally produced ones due to the lack of data, which blurs emission sources and responsibility allocation. However, this study highlights local emissions in view of local decision makers without regard to imported emissions. In doing this, based on local GHG emissions inventory, urban policymakers can make low-carbon plans to sustain the sustainable development of cities.

The rate of urbanization will increase from 40% in 2005 to 60% by 2030 in China along with the increasing living standard and the more energy-intensive lifestyle [6]. Taking Beijing as an example, its average annual economy growth rate exceeded 10% while energy consumption growth rate also overtook 6% over the period between 2000 and 2007 [24]. With the rapid development of economy and energy consumption in the near future, more emphasis should be laid on energy consumption and carbon emissions in Beijing.

With the latest available economic and environmental data, this paper calculates the local GHG emissions by 42 sectors of Beijing in 2007 and further analyzes the local emissions embodied in relevant economic activities based on systems IOA. The rest of this paper is organized as follows. In Section 2, methodological aspects of systems IOA based on the local ecological input-output table and data sources are described. Section 3 presents the direct GHG emissions inventory and corresponding embodiment analyses for Beijing 2007. Finally, we conclude this study in Section 4 by discussing the results and their implications.

### 2. Methodology and Data

#### 2.1. Local Ecological Input-Output Table

In an attempt to model the local embodiment of natural resources consumption and environmental emissions, a local ecological input-output table extended from the economic input-output table with local economic flows (including local intermediate use and final demand) is compiled as Table 1, integrating direct GHG (including CO₂, CH₄, and N₂O) emissions flows within and across the boundary of the urban economy.

Taking Beijing as a case, to account the local economic flows, local intermediate use and final demand need to be obtained based on Beijing’s competitive economy input-output table. Both intermediate use and final demand can be divided into three parts based on the proportion of local total output, domestic import, and foreign import [25–27]. Therefore, local intermediate input, $z^L_{ij}$, can be calculated as

$$z^L_{ij} = z_{ij} \left( \frac{x_i}{x_i + x^F_i + x^D_i} \right),$$

where $z_{ij}$ is the total intermediate input from Sector $i$ to Sector $j$, $x_i$ is the total output of Sector $i$, $x^F_i$ is the foreign imported economic flow of Sector $i$, and $x^D_i$ is the domestic imported economic flow of Sector $i$. While final demand of Sector $i$ from local output, $f^L_i$, is expressed as

$$f^L_i = f_i \left( \frac{x_i}{x_i + x^F_i + x^D_i} \right),$$

where $f_i$ is the total final demand of Sector $i$.

![Figure 1: Embodied GHG flows for a typical sector in an urban economy](image)

#### 2.2. Algorithm

From the perspective of local decision makers, this study focuses only on carbon flows coming from the urban system without taking into account carbon flows coming from the international and domestic systems. The embodied carbon flows for a typical sector in an urban economy based on local emissions can be described as Figure 1, including local and imported intra- and inter-sectoral carbon flows ($e^L_i$ is the local embodied intensity of products from Sector $i$, $z^L_{ij}$ is the monetary value of local intermediate inputs from Sector $i$ to Sector $j$, $e^M_{ij}$ is the imported embodied intensity of products from Sector $i$ to Sector $j$, $e^M_{ij}$ is the monetary value of imported intermediate inputs from Sector $i$ to Sector $j$, $e^L_j$ is the local embodied intensity of products from Sector $j$, and $z^M_{ij}$ is the monetary value of local intermediate inputs from Sector $j$ to Sector $i$, carbon flows embodied in final demand ($f^F_i$ denotes the final demand of Sector $j$ from local outputs), and net environmental inputs flows ($c_j$ is the amount of direct GHG emissions).

Based on Figure 1, the sectoral biophysical balance requires that

$$e^L_j x_j = \sum_{i=1}^{n} c^L_i x^D_i + \sum_{i=1}^{n} e^M_i x^M_i + c_j,$$

where $x_j$ is the monetary value of total outputs of Sector $j$.

To calculate local embodied emissions in this paper, emissions introduced by imported commodities from other domestic and foreign regions are not concerned. Then, rewrite the physical balance equation as

$$e^L_j x_j = \sum_{i=1}^{n} c^L_i x^D_i + c_j,$$

Then an aggregate matrix equation can be induced as:

$$E^L X = E^L Z^L + C,$$
Table 1: The local ecological input-output table (C is the direct GHG emissions matrix).

| Input             | Output            |
|-------------------|-------------------|
|                   | Input             | Intermediate use | Household consumption (rural) | Household consumption (urban) | Government consumption | Final demand | Export to foreign regions | Export to other domestic regions |
|                   | Sector 1          | Sector 2         | …                              | Sector n                      |                         | Fixed capital formation | Inventory increase |                           |
| Local intermediate inputs | Sector 1          | Sector 2         | …                              | Sector n                      |                         | Fixed capital formation | Inventory increase |                           |
|                   |                   | Z^L              |                                 |                               |                         | F^L                      |                           |                           |
| Net environmental inputs | CO₂               | CH₄              | N₂O                            | C                             |                           |                           |                           |                           |
in which \( E^L = [e_{ij}^L]_{1 \times n} \), \( Z^L = [z_{ij}]_{n \times n} \), \( C = [c_j]_{1 \times n} \), and \( X = [x_{ij}]_{n \times n} \), where \( i, j \in \{1, 2, \ldots, n\} \), \( x_{ij} = x_j (i = j) \), and \( x_{ij} = 0 \) \((i \neq j)\).

Therefore, with direct GHG emissions matrix \( C \), local intermediate input matrix \( Z^L \), and total outputs matrix \( X \) properly given, the embodied GHG emissions intensity matrix \( E^L \) can be calculated as

\[
E^L = C (X - Z^L)^{-1}.
\] (6)

Though very similar to the conventional formula based on the widely assumed equal embodiment intensity for both the local and import products, the above formal equation for local embodiment intensity has different implications. It reflects the embodied intensity induced by local direct emissions but ignores that induced by imported emissions. Therefore, local direct and indirect emissions can be clearly demonstrated.

Evidently, the GHG emissions embodied in final demand activities, denoted by EEFD [5, 27], can be calculated as the product of embodied intensity and corresponding final demand volume from Sector \( j \), as

\[
EEFD_j = \epsilon^L_j, f_j. \] (7)

Emission embodied in trade is a useful indicator to reveal transferring carbon emissions. Focusing on local emissions, emissions embodied in trade include emissions embodied in exports but exclude emissions embodied in imports. Combining GHG emissions from other domestic and foreign regions, GHG emissions embodied in exports (\( EEE^D \)), including emissions embodied in exports to other domestic regions (\( EEE^F \)) and exports to foreign regions (\( EEE^F \)), can be expressed as

\[
EEE^D_j = EEE^D_j + EEE^F_j = \epsilon^D_j, f^D_j + \epsilon^F_j, f^F_j,
\] (8)

where \( \epsilon^D_j \) and \( \epsilon^F_j \) denote the export to other domestic regions and export to foreign regions of Sector \( j \).

2.3. Data Sources. Most relevant environmental resources and economic data are adopted or derived from the recently issued official statistical yearbooks, such as Beijing Statistical Yearbook [28], China Agriculture Yearbook [29], China Energy Statistical Yearbook [30], China Environment Yearbook [31], China Industry Economics Statistical Yearbook [32], and China Statistical Yearbook for Regional Economy [33].

In this paper, all the three main GHG emissions of \( \text{CO}_2 \), \( \text{CH}_4 \), and \( \text{N}_2\text{O} \) are taken into consideration. The calculation of energy-related \( \text{CO}_2 \) emissions is based on a previous study [5], and the energy consumption data sources are from BSY and CESY by utilizing the default emission factors of IPCC [34]. For \( \text{CO}_2 \) emissions from industrial processes, the data of industrial products can be found in BSY, CIESY, and other sources. And corresponding emission factors are also adopted from IPCC combined with Chen and Zhang [14]. As to \( \text{CH}_4 \) and \( \text{N}_2\text{O} \), the data from different emission sources are derived from BSY, CAY, CESY, CEY, CIESY, and other.

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**Table 2: Sectors for Beijing’s economic input-output table 2007 [5].**

| Code | Sector |
|------|--------|
| 1    | Farming, Forestry, Animal Husbandry, Fishery, and Water Conservancy (Agriculture) |
| 2    | Coal Mining and Dressing |
| 3    | Petroleum and Natural Gas Extraction |
| 4    | Ferrous and Nonferrous Metals Mining and Dressing |
| 5    | Nonmetal and Other Minerals Mining and Dressing |
| 6    | Food Processing, Food Production, Beverage Production, and Tobacco Processing |
| 7    | Textile Industry |
| 8    | Garments and Other Fiber Products, Leather, Furs, and Down and Related Products |
| 9    | Timber Processing, Bamboo, Cane, Palm and Straw Products, and Furniture Manufacturing |
| 10   | Papermaking and Paper Products, Printing and Record Medium Reproduction, and Cultural, Educational, and Sports Articles |
| 11   | Petroleum Processing and Coking, Gas Production and Supply |
| 12   | Raw Chemical Materials and Chemical Products, Medical and Pharmaceutical Products, Chemical Fiber, Rubber Products, and Plastic Products (Chemical Products Related Industry) |
| 13   | Nonmetal Mineral Products |
| 14   | Smelting and Pressing of Ferrous and Nonferrous Metals |
| 15   | Metal Products |
| 16   | Ordinary Machinery, Equipment for Special Purpose |
| 17   | Transportation Equipment |
| 18   | Electric Equipment and Machinery |
| 19   | Electronic and Telecommunications Equipment |
| 20   | Instruments, Meters Cultural and Office Machinery |
| 21   | Manufacture of Artwork and Other Manufactures |
| 22   | Waste |
| 23   | Electric Power/Steam and Hot Water Production and Supply |
| 24   | Gas Production and Supply Industry |
| 25   | Water Production and Supply Industry |
| 26   | Construction Industry |
| 27   | Transport and Storage |
| 28   | Post |
| 29   | Information Transmission, Computer Services and Software |
| 30   | Wholesale, Retail Trade |
| 31   | Hotels, Catering Service |
| 32   | Financial Industry |
| 33   | Real Estate |
| 34   | Leasing and Commercial Services |
| 35   | Research and Experimental Development |
| 36   | Polytechnic Services |
| 37   | Water conservancy, Environment and Public Facilities Management |
3.1. Direct Emissions

3.1.1. Carbon Dioxide. The total direct CO2 emissions amount to 1.01E + 08 t. Guo et al. [5] provide a detailed inventory of energy-related direct CO2 emissions by fuel consumption in Beijing. As the largest emission source, fuel combustion contributes to 93.44% of total. Among the emissions from fuel combustion, the largest source is coal with a percentage of 53.08%, followed by coke with 10.75% and kerosene with 8.44% (see Figure 2).

Compared with fuel consumption, industrial processes are only responsible for 6.64E + 06 t CO2 emissions (6.56%), of which 4.44E + 02 t is contributed by manufacturing of cement (4.39%), 1.24E + 02 t is by smelting and pressing of steel (1.22%), 9.37E + 01 t is by smelting and pressing of pig iron (0.93%) and 2.35E + 00 t is by manufacturing of glass (0.02%).

3.1.2. Methane. The main sources of CH4 emission include agricultural activities (enteric fermentation, manure management, and field burning of plant residues), fugitive emissions (coal mining, oil and natural gas leakage), fossil fuel consumption, and waste (municipal solid waste, industrial wastewater, and domestic sewage) [14]. From the calculation, it is obtained that the total CH4 emissions amount to 1.18E + 01 t. As the most important source of methane emissions, the solid waste accounts for 45.48% of total, followed by enteric fermentation and coal mining with 17.79% and 13.81%, respectively. However, fossil fuel consumption only accounts for 1.43% of total, as shown in Table 3.

As the main source, agriculture activities cause 2.50E + 00 t CH4, of which emissions from enteric fermentation amount to 2.10E + 00 t as 17.79% of total, followed by manure management and field burning of agricultural residues with the fractions of 2.55% and 0.86%.

Fugitive CH4 emission sources in Beijing include coal mining with oil and natural gas systems, of which the CH4 emissions are 1.65E + 00 t and 1.14E + 00 t, respectively. The total fugitive CH4 emissions are 2.77E + 00 t, accounting for 23.46% of total.

With expansion of urban population, urban waste problems become increasingly severe. Among the CH4 emissions of waste, emissions from municipal solid waste (5.37E + 00 t, 45.48% of total) play a main role compared to industrial waste water (4.90E – 01 t, 4.15% of total) and domestic sewage (5.03E – 01 t, 4.26% of total).

3.1.3. Nitrous Oxide. Direct N2O emissions in Beijing from main sources like agricultural activities (manure management, cropland, and field burning of agricultural residues) and fuel combustion (see Table 4) are estimated in this paper. The total emissions of N2O from all sources amount to 2.84E – 01 t, which are far less than those of CO2 and CH4 by mass, but the global warming potential of N2O is the greatest among these three greenhouse gases (CO2 : CH4 : N2O = 1 : 21 : 310).

Considerable N2O emissions are caused by agricultural activities (58.09%) in Beijing. Cropland contributes the most to N2O emissions from annual synthetic fertilizer (29.23%), followed by manure management (28.20%) and field burning of agricultural residues (0.67%). Besides, the
3.1.4. Total Emissions. The total direct GHG emissions amount to 1.06E + 08 t CO2-eq in Beijing 2007 by the commonly referred IPCC global warming potentials, of which energy-related CO2 contributes to 9.45E + 07 t CO2-eq (90.49% of total), non-energy-related CO2 6.64E + 06 t CO2-eq (6.35% of total), CH4 2.48E + 06 t CO2-eq (2.33% of total), and N2O 8.81E + 05 t CO2-eq (0.83% of total) as shown in Figure 3.

With all the categories mentioned above, total direct GHG emissions are presented in Table 5, of which Sector 23 (Electric Power/Steam and Hot Water Production and Supply) contributes to the largest share of GHG emissions, which amount to 2.79E + 07 t CO2-eq (26.20% of total), followed by Sectors 14 (Smelting and Pressing of Ferrous and Nonferrous Metals), 27 (Transport and Storage), and 13 (Nonmetal Mining Products) with 2.08E + 07 t CO2-eq (19.54% of total), 1.43E + 07 t CO2-eq (13.40% of total), and 1.03E + 07 t CO2-eq (9.68% of total), respectively. Sector 23 is the energy conversion sector, while Sectors 14, 27, and 13 are all energy-intensive sectors. A host of GHG emissions are derived from aluminum production in Sector 14, and Sector 13 emits considerable GHG due to the production of nonmetallic mineral products including concrete and glass besides energy-related emissions.

With comparison of GHG emissions shown in Table 5, it is noted that CH4 and N2O emissions are tiny, excluding those in Sectors 1 (Agriculture) and 2 (Coal Mining and Dressing) attributed to agricultural activities and fugitive emissions. Direct CH4 emissions of Sectors 1 and 2 amount to 5.26E+05 and 3.42E+05 t CO2-eq, accounting for 21.22% and 13.80% of the total CH4 emissions. Sector 1 is the leading N2O emission sector with 5.18E+05 t CO2-eq, accounting for 81.27% of the total N2O emissions.

3.2. Embodied Emissions

3.2.1. Embodied Emission Intensity. As presented in Figure 4 for the local embodied GHG emission intensities of 42 sectors in Beijing 2007 based on (6) and Table 5, Sector 23 (Electric Power/Steam and Hot Water Production and Supply) has the largest intensity of 7.06E + 04 Yuan, followed by Sectors 5 (Nonmetal and Other Minerals Mining and Dressing), 14 (Smelting and Pressing of Ferrous and Nonferrous Metals), and 13 (Nonmetal Mining Products) with intensities of 6.67, 4.93, and 4.55 t CO2-eq/1E + 4 Yuan, respectively. More evidently, these high-intensity sectors are all characterized by remarkable direct emissions.

According to the emission type, embodied GHG emission intensities of most industries are dominated by the embodied CO2 emission industries, except for Sectors 2
The proportion of N₂O emissions intensities for most sectors activities are the main sources of N₂O emissions. Agriculture.

| Sector code | CO₂ (t) | CH₄ (t CO₂-eq) | N₂O (t CO₂-eq) | Total GHGs (t CO₂-eq) | Fraction |
|-------------|---------|----------------|----------------|------------------------|----------|
| 1           | 3.44E+06 | 5.26E+05 | 5.18E+05 | 4.48E+06 | 4.21% |
| 2           | 5.96E+04 | 3.42E+05 | 2.70E+02 | 4.02E+05 | 0.38% |
| 3           | 3.81E+04 | 2.39E+05 | 9.58E+01 | 2.78E+05 | 0.26% |
| 4           | 9.81E+04 | 4.19E+01 | 4.06E+02 | 9.86E+04 | 0.09% |
| 5           | 2.16E+05 | 8.11E+01 | 8.71E+02 | 2.17E+05 | 0.20% |
| 6           | 1.58E+06 | 4.69E+04 | 7.27E+03 | 1.64E+06 | 1.54% |
| 7           | 2.39E+05 | 1.94E+04 | 1.10E+03 | 2.60E+05 | 0.24% |
| 8           | 3.24E+05 | 9.54E+01 | 1.48E+03 | 3.25E+05 | 0.31% |
| 9           | 9.17E+04 | 3.90E+01 | 3.53E+02 | 9.21E+04 | 0.09% |
| 10          | 4.66E+05 | 2.97E+04 | 1.92E+03 | 4.97E+05 | 0.47% |
| 11          | 1.19E+06 | 4.89E+02 | 2.71E+03 | 1.19E+06 | 1.12% |
| 12          | 2.99E+06 | 1.01E+04 | 1.33E+04 | 3.02E+06 | 2.83% |
| 13          | 1.03E+07 | 1.68E+03 | 2.63E+04 | 1.03E+07 | 9.68% |
| 14          | 2.07E+07 | 3.96E+03 | 8.43E+04 | 2.08E+07 | 19.54% |
| 15          | 2.27E+05 | 9.59E+01 | 8.55E+02 | 2.28E+05 | 0.21% |
| 16          | 8.19E+05 | 2.63E+02 | 3.50E+03 | 8.23E+05 | 0.77% |
| 17          | 9.11E+05 | 2.88E+02 | 3.78E+03 | 9.15E+05 | 0.86% |
| 18          | 1.22E+05 | 5.17E+01 | 4.17E+02 | 1.23E+05 | 0.12% |
| 19          | 1.32E+05 | 6.12E+01 | 1.99E+02 | 1.32E+05 | 0.12% |
| 20          | 3.73E+04 | 2.02E+01 | 1.19E+02 | 3.74E+04 | 0.04% |
| 21          | 2.09E+05 | 5.54E+01 | 9.75E+02 | 2.10E+05 | 0.20% |
| 22          | 8.67E+03 | 4.47E+00 | 3.31E+01 | 8.71E+03 | 0.01% |
| 23          | 2.78E+07 | 6.74E+03 | 1.28E+05 | 2.79E+07 | 26.20% |
| 24          | 1.18E+05 | 6.06E+01 | 1.34E+02 | 1.18E+05 | 0.11% |
| 25          | 1.70E+04 | 8.34E+00 | 4.84E+01 | 1.71E+04 | 0.02% |
| 26          | 1.27E+06 | 3.04E+05 | 3.78E+03 | 1.57E+06 | 1.48% |
| 27          | 1.42E+07 | 8.00E+04 | 3.58E+04 | 1.43E+07 | 13.40% |
| 28          | 7.74E+05 | 6.91E+04 | 1.96E+03 | 8.45E+05 | 0.79% |
| 29          | 1.83E+05 | 6.85E+04 | 4.70E+02 | 2.52E+05 | 0.24% |
| 30          | 1.81E+06 | 1.07E+05 | 5.04E+03 | 1.93E+06 | 1.81% |
| 31          | 2.73E+06 | 1.06E+05 | 5.20E+03 | 2.84E+06 | 2.67% |
| 32          | 1.47E+05 | 4.68E+04 | 4.24E+02 | 1.94E+05 | 0.18% |
| 33          | 3.54E+06 | 4.78E+04 | 1.18E+04 | 3.60E+06 | 3.38% |
| 34          | 1.20E+06 | 4.73E+04 | 4.02E+03 | 1.25E+06 | 1.17% |
| 35          | 4.15E+05 | 4.69E+04 | 1.33E+03 | 4.63E+05 | 0.43% |
| 36          | 4.15E+05 | 4.69E+04 | 1.33E+03 | 4.63E+05 | 0.43% |
| 37          | 4.26E+05 | 4.69E+04 | 1.48E+03 | 4.74E+05 | 0.45% |
| 38          | 8.28E+05 | 4.70E+04 | 2.89E+03 | 8.78E+05 | 0.82% |
| 39          | 1.63E+06 | 4.73E+04 | 4.85E+03 | 1.69E+06 | 1.58% |
| 40          | 5.05E+05 | 4.69E+04 | 1.47E+03 | 5.53E+05 | 0.52% |
| 41          | 2.83E+05 | 4.69E+04 | 7.52E+02 | 3.30E+05 | 0.31% |
| 42          | 7.19E+05 | 4.71E+04 | 2.32E+03 | 7.68E+05 | 0.72% |
| Total       | 1.03E+08 | 2.48E+06 | 8.81E+05 | 1.06E+08 | 100.00% |

(Coal Mining and Dressing) and 3 (Petroleum and Natural Gas Extraction). The shares of CH₄ emission intensities of Sectors 1 (Agriculture), 2 (Coal Mining and Dressing), and 3 (Petroleum and Natural Gas Extraction) are especially high. The proportion of N₂O emissions intensities for most sectors is small except for Sector 1 (Agriculture) since agriculture activities are the main sources of N₂O emissions.

3.2.2. Emissions Embodied in Final Demand. As shown in Figure 5, the final demand activities of Beijing in terms of embodied GHG emissions are presented according to (7). The largest GHG-emission sector is Sector 26 (Construction Industry) with 1.86E + 07 t CO₂-eq due to its considerable fixed capital. With the strong growth of construction in Beijing, lots of direct and indirect inputs (e.g., cement,
metal, and energy) are produced during these construction activities, which lead to a great deal of carbon emissions. Sectors 27 (Transport and Storage) and 14 (Smelting and Pressing of Ferrous and Nonferrous Metals) provide the second and third largest emissions of $1.03E+07$ and $5.72E+06$ t CO$_2$-eq, mainly attributed to their substantial exports to foreign regions and other domestic regions, respectively. Besides, GHG emissions of Sector 27 are also introduced by massive government consumption and urban household consumption with rising traffic consumption level. Most sectors have prominent peaks on CO$_2$ emissions; Sectors 1 (Agriculture) and 6 (Food Processing, Food Production, Beverage Production, and Tobacco Processing) are also with massive CH$_4$ emissions due to agriculture activities, while Sector 26 (Construction Industry) are due to high energy usage. Especially for Sector 2 (Coal Mining and Dressing), CH$_4$ emissions contribute to 49.37% of the total due to this particular industrial process in Beijing.

Regarding the seven final demand categories (see Figure 6), emissions embodied in exports to other domestic regions excluding imports. The distribution of embodied emissions from the exports in 42 sectors is presented in Figure 7. The GHG emission embodied in Beijing’s exports is $4.90E+07$ t CO$_2$-eq, accounting for 46.01% of the total emissions in final use. The total EEE$^D$ ($3.52E+07$ t CO$_2$-eq) are 2.56 times larger than the total EEE$^F$ ($1.37E+07$ t CO$_2$-eq) for Beijing. The largest exporting sector is Sector 27 (Transport and Storage, 9.37E+06 t CO$_2$-eq, 19.12% of total), followed by Sectors 14 (Smelting and Pressing of Ferrous and Nonferrous Metals, 4.72E+06 t CO$_2$-eq, 9.64% of total), 36 (Polytechnic Service, 3.90E+06 t CO$_2$-eq, 7.96% of total), and 19 (Electronic and Telecommunications Equipment, 1.85E+06 t CO$_2$-eq, 5.82% of total). As a whole, most sectors have the larger EEE$^D$ except for some large foreign trade export sectors, for example, Sectors 1, 3, 7, 8, 19, 30, 34, and 42 with larger EEE$^D$.

3.2.3. Emissions Embodied in Exports. Since local emissions embodied in trade only focus on emissions induced by local direct emissions but do not take imports into account, this paper just studies the exports to foreign regions and other domestic regions excluding imports. The distribution of embodied emissions from the exports in 42 sectors is presented in Figure 7. The GHG emission embodied in Beijing’s exports is $4.90E+07$ t CO$_2$-eq, accounting for 46.01% of the total emissions in final use. The total EEE$^D$ ($3.52E+07$ t CO$_2$-eq) are 2.56 times larger than the total EEE$^F$ ($1.37E+07$ t CO$_2$-eq) for Beijing. The largest exporting sector is Sector 27 (Transport and Storage, 9.37E+06 t CO$_2$-eq, 19.12% of total), followed by Sectors 14 (Smelting and Pressing of Ferrous and Nonferrous Metals, 4.72E+06 t CO$_2$-eq, 9.64% of total), 36 (Polytechnic Service, 3.90E+06 t CO$_2$-eq, 7.96% of total), and 19 (Electronic and Telecommunications Equipment, 1.85E+06 t CO$_2$-eq, 5.82% of total). As a whole, most sectors have the larger EEE$^D$ except for some large foreign trade export sectors, for example, Sectors 1, 3, 7, 8, 19, 30, 34, and 42 with larger EEE$^D$.

4. Concluding Remarks

This paper provides a systematic and detailed calculation on the embodiment of local GHG emissions at urban scale through the extended economic input-output analysis with the case study of Beijing 2007. As a result, a local direct GHG emissions inventory and corresponding embodiment analyses are assessed.

The total direct GHG emissions amount to $1.06E+08$ t CO$_2$-eq in Beijing. For the total emissions structure, energy-related CO$_2$ emissions comprise 90.49%, non-energy-related CO$_2$ emissions 6.35%, CH$_4$ emissions 2.33%, and N$_2$O emissions 0.83%. Among the emissions from fuel combustion, the largest source is coal with a percentage of 53.08%, followed by coke with 10.75% and kerosene with 8.44%. Sector 23 (Electric Power/Steam and Hot Water Production and Supply) is the largest direct emissions sector for the Beijing economy in 2007, followed by energy-intensive
Sectors 14 (Smelting and Pressing of Ferrous and Nonferrous Metals), 27 (Transport and Storage), and 13 (Nonmetal Mineral Products).

For the final demand of Beijing in terms of embodied CO$_2$ emissions, Sector 26 (Construction Industry) provides the largest emissions of $1.86E+07$ t CO$_2$-eq due to its considerable capital during the concerned year. Sectors 27 (Transport and Storage) and 14 (Smelting and Pressing of Ferrous and Nonferrous Metals) provide the second and third largest emissions of $1.03E+07$ and $5.72E+06$ t CO$_2$-eq.

The GHG emissions embodied in Beijing's exports are $4.90E+07$ t CO$_2$-eq, accounting for 46.01% of the total emissions in final demand. The total EEE$^D$ ($3.52E+07$ t CO$_2$-eq) are 2.56 times larger than the total EEE$^E$ ($1.37E+07$ t CO$_2$-eq) for Beijing. The largest exporting sector is Sector 27 (Transport and Storage), followed by Sectors 14 (Smelting and Pressing of Ferrous and Nonferrous Metals), 36 (Polytechnic Service), and 19 (Electronic and Telecommunications Equipment).

Resulted embodied local GHG intensities for sectors indicate the average amount of local emissions embedded in one economic unit of local product, which provide sound scientific data for local policy makers to adjust industrial structure and energy consumption structure in order to relieve global climate change. From the perspective of local decision makers, this study is an important basis when local environment and energy policies are making.

Expansion of industrial scale has been the main driving factor of energy consumption and carbon emissions. While the change of industrial structure and maximize energy efficiency are effective measures to conserve energy and reduce emissions. Specific measures are as follows: (1) In terms of energy efficiency, local government continuously eliminates high-energy-consumption industries and backward production capacity. In the meantime, they should in favor of high and advanced production technology to maximize energy efficiency, especially for some high-energy-consumption or high-resource-consumption industries, such as Sectors 23 (Electric Power/Steam and Hot Water Production and Supply), 14 (Smelting and Pressing of Ferrous and Nonferrous Metals), etc. (2) Industrial structural change makes great impact on carbon emissions structure. Beijing has made great efforts for industrial structural change, for example, Beijing is greatly developing the tertiary industries and reducing the proportion of primary industries and secondary industries. However, detailed industrial structure should be adjusted based on the carbon consuming responsibilities.
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