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A multi-sectoral decomposition analysis of city-level greenhouse gas emissions: Case study of Tianjin, China

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ABSTRACT

To better understand how city-level greenhouse gas (GHG) emissions have evolved, we performed a multi-sectoral decomposition analysis to disentangle the GHG emissions in Tianjin from 2001 to 2009. Five sectors were considered, including the agricultural, industrial, transportation, commercial and other sectors. An industrial sub-sector decomposition analysis was further performed in the six high-emission industrial branches. The results show that, for all five sectors in Tianjin, economic growth was the most important factor driving the increase in emissions, while energy efficiency improvements were primarily responsible for the decrease in emissions. In comparison, the influences from energy mix shift and emission coefficient changes were relatively marginal. The disaggregated decomposition in the industry further revealed that energy efficiency improvement has been widely achieved in the industrial branches, which was especially true for the *Smelting and Pressing of Ferrous Metals* and *Chemical Raw Materials and Chemical Products* sub-sectors. However, the energy efficiency declined in a few branches, e.g., *Petroleum Processing and Coking Products*. Moreover, the increased emissions related to industrial structure shift were primarily due to the expansion of *Smelting and Pressing of Ferrous Metals*; its share in the total industry output increased from 5.62% to 16.1% during the examined period.

1. Introduction

The rapid increase in greenhouse gas (GHG) emissions to the atmosphere has resulted in a climate change with negative impacts on both natural and socio economic systems [1]. Since the Kyoto agreement in 1997, the issue of GHG emissions has aroused special attention throughout the world. Currently, China is one of the world's largest emitters. As one of the signatories to the United Nations Framework Convention on Climate Change, the Chinese government committed that by 2020, the CO_2 emission intensity of its gross domestic product (GDP) would be reduced by 40–45% compared to 2005 levels [2].

Cities are recognized as the major source of energy consumption and driver of greenhouse gas (GHG) emissions because they are the center of wealth and have the highest population density and largest economic scale [3]. The 35 largest cities in China, which contain 18% of the population, consume 40% of China's total energy use and CO_2 emissions [4]. Both the sources of GHGs and the opportunities for controlling emissions exist in cities [5]. Therefore, understanding the characteristics of city-level emissions is urgently required to help form effective policies for local climate change strategies and ultimately achieve the overall national targets.

Controlling and mitigating GHG emissions requires effective analysis of the factors that influence the emissions, e.g., economic and demographic development, technological changes, institutional frameworks, and energy structure [6]. The decomposition method, which mainly used to be applied in energy consumption related issue [7–10], has been widely used for the analysis of factors influencing emissions in recent years. A large number of researchers applied decomposition method to explore the underlying factors behind the changes of emissions in various countries, e.g., Portugal [11], Soviet Union [12], UK [13], Italy [14], Turkey [15], Latin American [16], European Union [17], Greece [18,19] and China [20–24].

However, most studies have only analyzed the emission driving forces at the national level; few studies have focused on city-level emissions. Among the few studies, Zhang et al. [25] explored the factors affecting energy-related carbon emissions in Beijing from 1995 to 2009 using the LMDI (logarithmic mean Divisa index) method. The study indicated that carbon emissions in Beijing have

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increased as a result of the rapid growth in the economy, population, and energy consumption per capita. Liu et al. [26] performed a time-serial LMDI decomposition analysis on the GHG emissions in four mega cities in China. They found that the increase in GHG emissions in these four cities during the period 1995–2009 was primarily due to the economic activity effect, partially offset by improvements in carbon intensity. Liu et al. [27] explored the underlying influencing factors of the GHG emissions in China's 30 provinces (including 4 cities) from 1997 to 2009 by using the index decomposition analysis. Their research indicated that large inequity of technology level exists among different regions, which has become a main barrier for China's CO_2 mitigation. The study conducted by Dhakal [4] also analyzed the carbon emissions of four mega cities in China using driving force analysis.

However, these city-level studies only considered the aggregate-level emissions when performing the decomposition analysis. These analyses seldom explored the economic sector or sub-sector dimensions. Because the sectors and sub-sectors differ significantly in terms of their technological infrastructure and have diverging intensity/scale/composition effects on the emission growth analysis, simply performing an aggregate-level analysis is not sufficient. A deeper analysis of the sector and sub-sector dimensions is further required to determine more detailed and specific explanations for the causes of urban emission changes.

In this paper, we analyzed the GHG emissions in Tianjin over the period 2001–2009 using a multi-sectoral LMDI method. Five economic sectors were distinguished, including the agricultural, industrial, transportation, commercial and other sectors. Due to the high concentration of emissions from industry, we further performed a more disaggregated decomposition analysis on six of the industrial sub-sectors that have the largest emission levels.

The remainder of this paper is organized as follows. Section 2 discusses methodology, including the estimation of GHG emissions in Tianjin and the decomposition technique used. Section 3 presents the data source. Section 4 introduces the case of Tianjin. In Section 5, the main results of the decomposition analysis are reported. Section 6 concludes the study and provides some policy implications.

2. Methodology

2.1. Estimation of city-level GHG emissions

In this study, carbon emissions are expressed in carbon dioxide equivalents (CO_2e). GHG emissions, including CO_2, CH_4 and N_2O, were all converted into CO_2e emissions by multiplying by the global warming potential (GWP) parameters, which are 1, 21 and 310 for CO_2, CH_4 and N_2O, respectively [1]. Following the IPCC 2007 guideline, the total CO_2 emissions in Tianjin can be estimated based on the energy consumption, emission factors and the fraction of oxidized carbon by fuel as follows:

$$C_{ij}^{t} = E_{ij}^{t} \times EF_j \times O_j \times 44/12 \tag{1}$$

and

$$C_{i}^{t} = \sum_{j} C_{ij}^{t}. \tag{2}$$

where C_{ij}^t denotes the direct CO_2 emissions based on fuel type j in sector i in year t (Mt); C_i^t denotes the total CO_2 emissions in sector i in year t; E_{ij}^t denotes the consumption of fuel j in sector i in year t (TJ); EF_j denotes the carbon emission factor of the fuel j (t-C/TJ); O_j denotes the fraction of the carbon oxidized based on fuel type j; 44/12 refers to the ratio of the molecular weight of CO_2 to the atomic weight of C.

The carbon emissions factors (EFs) and the fractions of carbon dioxide (O) of the 13 fuels are listed in Table 1. Because the current research focuses on the period from 2001 to 2009, which is relatively short, we assumed that the emissions factors of these 13 fuel types were constant. Although these coefficients have changed over time due to changes in the fuel grade, the changes were very small and could therefore be ignored when analyzing the macro changes in the emissions [2,25,30].

Both the CH_4 and N_2O emissions can be estimated based on equations similar to Eqs. (1) and (2) above using their respective emission factors, which are also listed in Table 1. All emissions types were ultimately converted into CO_2e emissions by multiplying their GWP parameters. They were added together to obtain the total GHG emissions (t CO_2e).

GHG emissions from heat and electricity were calculated from fuel combustion in power generators and then redistributed to each sector according to the amount of heat and electricity used in each sector. Unlike the constant emissions factors for fuel, the average emissions factors (efs) of heat and electricity varied significantly over time due to technology changes and fuel composition changes in heat and electricity generation in different years.

Because the only source of the heat consumed in Tianjin is the Tianjin local heat supply station, the average emission coefficient of heat can be calculated as follows:

Table 1
GHG emission factors of various energy types.

	Oxidation rate[a]	LVC (MJ/t or MJ/Mm^3)[b]	(CO_2) EF[c] (ton CO_2/TJ)	(CH_4) EF[c] (ton CH_4/TJ)	(N_2O) EF[c] (ton N_2O/TJ)	(GHG) EF (ton CO_2e/ton)
Raw coal	0.918	20.91	94.60	0.001	0.0015	1.83
Coke	0.928	28.44	107.07	0.001	0.0015	2.84
Coke Oven Gas	0.990	17.35	44.37	0.001	0.0001	7.71[d]
Other Gas	0.990	17.32	44.37	0.001	0.0001	7.71[d]
Crude Oil	0.979	41.82	73.33	0.003	0.0006	3.01
Gasoline	0.986	43.07	69.30	0.003	0.0006	2.95
Kerosene	0.980	43.01	71.87	0.003	0.0006	3.04
Diesel Oil	0.982	42.65	74.07	0.003	0.0006	3.11
Fuel Oil	0.985	41.82	77.73	0.003	0.0006	3.21
LPG	0.989	50.18	63.07	0.001	0.0001	3.13
Refinery Gas	0.989	46.06	66.73	0.001	0.0001	3.04
Natural Gas	0.990	38.93	56.10	0.001	0.0001	21.86[d]
Other Petroleum	0.979	40.20	77.33	0.003	0.0006	2.90

[a] Source: Chinese Energy Statistical Yearbook [28].
[b] Source: Cai et al. [29].
[c] Source: Liu et al. [26].
[d] The unit is ton- $CO_2e/10^4$ m^3.