Inventory of CO₂ emissions driven by energy consumption in Hubei Province: a time-series energy input-output analysis

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Abstract Based on an input-output analysis, this paper compiles inventories of fuel-related CO₂ emissions of Hubei economy in the years of 2002, 2005, and 2007. Results show that calculated total direct CO₂ emissions rose from 114,462.69 kt (2002) to 196,650.31 kt (2005), reaching 210,419.93 kt in 2007, with an average 22.50% rate of increase. Raw coal was the dominant source of the direct emissions throughout the three years. The sector of Electric Power, Heat Production, and Supply was the main direct emissions contributor, with the largest intensities observed from 2002 (1192.97 g/CNY) to 2007 (1739.15 g/CNY). From the industrial perspective, the secondary industry, which is characterized as manufacture of finished products, was still the pillar of the Hubei economy during this period concerned, contributing more than 80% of the total direct emissions. As a net exporter of embodied CO₂ emissions in 2002 and 2007, Hubei reported net-exported emissions of 4109.00 kt and 17,871.77 kt respectively; however, Hubei was once a net importer of CO₂ emissions in 2005 (2511.93 kt). The CO₂ emissions embodied in export and fixed capital formation had the two leading fractions of emissions embodied in the final use. The corresponding countermeasures, such as promoting renewable and clean energy and properly reducing the exports of low value added and carbon-intensive products are suggestions for reducing CO₂ emissions in Hubei.

Keywords input-output analysis, fuel-related CO₂ emissions, Hubei Province

1 Introduction

Out of numerous greenhouse gas (GHG) emissions sources, CO₂ from fossil fuel combustion is regarded as the major contributor (Liang and Zhang, 2011). CO₂ from energy was responsible for about 80% of global anthropogenic GHG emissions (Quadrelli and Peterson, 2007). The reduction of fuel-related CO₂ emissions therefore has become a focal point of the global community, attracting the attention of policy makers and scholars from all over the world. As the world’s largest energy consumer and CO₂ emitter (Minx et al., 2011), China is now under great pressure to mitigate CO₂ emissions from fuel combustion (Xia et al., 2014; Zhang et al., 2014a). China has 32 provincial regions and 2 special administrative regions. It has been shown that the provincial regions are major contributors of CO₂ emissions for the whole nation. Consequently, to draw a holistic picture of China’s fuel-related CO₂ emissions, it is vital to analyze CO₂ emissions from these regions.

A huge body of literature exists that evaluates carbon emissions at sub-national scale, especially in provincial regions (e.g., Guo et al., 2012a; Wang et al., 2013a; Ge and Lei, 2014; Zhang et al., 2014b). For instance, Guo et al. (2012b) compiled an inventory of CO₂ emissions induced by the fossil combustion of the Beijing economy in 2007 and found that total direct CO₂ emissions amounted to 9.45E+07 t, within which 56.81% were released from coal combustion. Taiwan, Jiangsu, and Liaoning are marked as hot regions in China’s provincial level of CO₂ emission studies (e.g., for Taiwan, see Lee et al., 2001; Lin et al., 2012; Liu et al., 2012; for Jiangsu, see Li and Zhang, 2011; Zhang and Huang, 2012; for Liaoning, see Xia, 2012; Geng et al., 2013; for arid-alpine regions in Gansu, Qinghai and Ningxia, see Qu et al., 2013). In addition, the literature has been written that highlights
energy and related CO₂ emissions in Macao, one of China’s two special administrative regions (Li and Chen, 2013; Li et al., 2013a, b). These studies shed light on China’s fuel and CO₂ emission research.

As one of the provinces with good economic performance in central China, Hubei Province has a strong, conventional industrial base (Li, 2007), and plays an important role in China. In 2013, Hubei’s per capita Gross Domestic Product (GDP) reached as high as 42,680.43 CNY with a total GDP of 2,466.85 billion CNY, ranking the top and second, respectively, among six central provinces in China. However, with the rapid pace of economic development, Hubei has simultaneously faced increasingly serious environmental problems and great pressure to mitigate carbon emissions. As observed by Li (2007), coal is the primary source for energy production and energy consumption in Hubei, resulting in high levels of carbon emissions and environmental contamination. To ensure a sustainable, low carbon, and energy saving environment in the development of Hubei’s economy, it is urgent that the characteristics and temporal structure of fuel-related CO₂ emissions are examined and that actions are implemented for their reduction. Since IO analysis has been globally proven an effective research instrument for identifying embodied (direct plus indirect) GHGs or CO₂ emissions (e.g., Munksgaard et al., 2005; Kok et al., 2006; Alcántara and Padilla, 2009; Chung and Tohno, 2009; Liu et al., 2009; Minx et al., 2009; Parikh et al., 2009; Acquaye and Duffy, 2010; Chen et al., 2010; Chen and Chen, 2010; Liu et al., 2010; Zhang and Chen, 2010; Liang et al., 2012; Su and Ang, 2013; Das and Paul, 2014; Meng et al., 2014; Zeng et al., 2014), this paper is utilizing input-output model analysis to clarify the embodiment of CO₂ emissions driven by fuel consumption in Hubei Province during the period of 2002–2007. The target of current work is to present inventories of fuel-related CO₂ emissions by 42 economic sectors of Hubei Province in the years of 2002, 2005, and 2007. In addition, the embodiment of CO₂ emissions in relevant economic activities will be calculated via the input-output analysis (IOA) approach.

The rest of this research is organized as follows: Section 2 articulates the methodological aspects of IOA employed in this paper and shows the data sources for this study, Section 3 describes the detailed results including the direct and indirect CO₂ emissions inventory, as well as corresponding embodiment analyses for Hubei in the years of 2002, 2005, and 2007, remarks are concluded in Section 4, and lastly, the policy implications for the mitigation of fuel-related CO₂ emissions in Hubei are discussed in Section 5.

2 Methodology and data sources

Each step of the construction of inventories of embodied CO₂ emissions driven by energy use in Hubei province in the years of 2002, 2005, and 2007 is presented in this section.

2.1 Economic sectors aggregation

The Hubei Input-Output Table (IOT, Table 1) 2002, issued by the Hubei Statistical Bureau, covers 42 sectors (including primary, secondary, and tertiary industries), and reflects the interaction between sectors within the Hubei economy as a whole. Each entry has been standardized by current producers’ prices. Since 24 industrial sectors of the Hubei IOT 2002 have been subdivided into 39 departments (with more meticulous definitions found in the Hubei Statistical Yearbook (HSY, 2003)), the 39 departments have been aggregated into the corresponding 24 sectors to ensure compliance with data homogeneity in the input-output analysis. The 42 sectors in the Hubei Input-Output Table 2002 are listed in Table 2. Departments of industry in HSY (2003) and the incorporation of sectors of industry are presented in Tables 3 and 4, respectively.

2.2 Algorithm

Through the aggregation of economic flows and carbon flows, a traditional economic input-output table has been transformed into an environmental input-output table. As shown in Table 1, Q₁ represents inter-industrial flows, Q₂ stands for final use (GDP with expenditure approach), Q₃ is half the value added (GDP with income approach), and Q₉ represents the fuel-related direct CO₂ emissions (Guo et al., 2012a).

According to previous input-output studies (Chen and Chen, 2010; Chen et al., 2010; Zhou et al., 2010; Li et al., 2015), it is assumed that imported commodities from other domestic and foreign regions have the same embodied emission intensities as those from local regions. Following these studies, the basic row balance of the input-output table for Hubei Province can be demonstrated as

\[
X = AX + F - X^m, \tag{1}
\]

where \(X\) denotes the total economic output; \(X^m\) and \(F\) represent imports and the final demand from rural and urban household consumption, government consumption, gross capital formation, export, and others, respectively; and \(A\) signifies the technology coefficients matrix whose element \(a_{ij} = Z_{ij}/X_i\), with \(Z_{ij}\) and \(X_i\) indicates the input from Sector \(i\) to Sector \(j\), and the total output of Sector \(j\) separately. Thereafter, with the introduction of the identity matrix \(I\), the form of Eq. (1) can be transformed as

\[
F - X^m = X - AX = (I - A)X. \tag{2}
\]

According to Zhou (2008), the emissions balance can be expressed as