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Demand-driven air pollutant emissions for a fast-developing region in China

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HIGHLIGHTS

- Consumption-based emissions for 7 air pollutants in Guangdong in 2007 and 2012 were estimated.
- Consumption-based emission patterns varied from production-based ones.
- Half of the air pollutant emissions were related to export.
- Production-end control, industrial structures and final demands explained emission trends.
- Guangdong was moving towards a cleaner production and consumption pathway.

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ABSTRACT

Guangdong is one of many fast-developing regions in China that are confronting the challenges of air pollution mitigation and sustainable economic development. Previous studies have focused on the characterization of production-based emissions to formulate control strategies, but the drivers of emission growth and pattern changes from the consumption side have rarely been explored. In this study, we used environmentally extended input-output analysis with well-established production-based emission inventories to develop a consumption-based emission inventory for seven pollutants in the years 2007 and 2012. The results showed that the demands of construction, transport and other services dominated the emissions from the consumption perspective, followed by electric power and some machinery and light industries. The varying trends of air pollutants from 2007 to 2012 were associated with production-based control measures and changes in economic structure and trading patterns. From the consumption perspective, due to the stringent control of SO_2 in power plants and key industries, the SO_2 emissions underwent substantial declines, while the less controlled PM_{10}, $PM_{2.5}$, VOC and CO emissions continued to grow. The contributions of the cleaner (that is, with lower emission intensity) service sectors (third-sector industries, excluding transport, storage and post) to all seven pollutants increased. This increase could be a consequence of the expansion of the service sector in Guangdong; in this five-year period, the service sector grew by 41% in terms of its contributions to Guangdong's gross domestic product. Meanwhile, exports accounted for more than half of the emissions, but their share had started to decrease for most pollutants except VOC and CO. The results suggest that Guangdong moved towards a cleaner production and consumption pathway. The transformation of the industrial structure and increase in of urban demand should help to further reduce emissions while maintaining economic development.

1. Introduction

The air pollution problem in China, characterized by a high concentration of $PM_{2.5}$ (particulate matter with an aerodynamic

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diameter of less than 2.5 μm) and persistent haze, has raised extensive concerns domestically and internationally. The origins of air pollution are closely related to the rapid urbanization and industrialization processes in China, especially in the fast-developing regions along the coastline [1]. The economic growth in these regions has been accompanied by severe air pollution, and these areas are now confronting the challenge of pollution mitigation and earnestly exploring new approaches to sustainable development.

Guangdong province is a microcosm of China's fast-developing regions. Located on the coast of southern China, the province occupies approximately 1.9% of China's land coverage but contributed 6.6% and 10.6% of the national population and gross domestic product (GDP), respectively, in 2015 [2]. From 2007 to 2015, the GDP of Guangdong grew at an annual rate of 11% [2]. The highly dense population and intensive industrial activities have led to notable air pollution and deteriorating air quality in recent decades.

To address the air pollution problem, Guangdong, along with adjacent Hong Kong, is taking a lead role in China in emission reduction and air quality improvement measures [3]. Dating back to 2003, the governments of Guangdong and Hong Kong signed the Pearl River Delta Regional Air Quality Management Plan to pursue regional reductions in sulphur dioxide (SO_2), nitrogen oxide (NOx), PM_{10} (particulate matter with an aerodynamic diameter of less than 10 μm) and volatile organic compound (VOC) emissions [4]. By 2010, the reduction targets for SO_2, NOx and PM_{10} had been fulfilled compared to the reference level of 1997, but reductions in VOC emissions failed to meet the goal. Nevertheless, the air quality in Guangdong was under control, largely due to these efforts. Compared with the levels in 2007, the SO_2, NO_2 and PM_{10} concentrations in 2015 decreased by 63%, 16% and 29%, respectively, while ozone (O_3) increased by 6% [5]. In 2012, the two governments endorsed a succeeding emission reduction plan that would further reduce the air pollutant emissions up to 2020 [4]. Determining how to meet the emission reduction target and improve regional air quality while maintaining economic growth and the local living standard is a challenge for Guangdong and a key task of policymakers.

In the past few decades, many studies conducted in Guangdong have endeavoured to clarify the causes of air pollution. In terms of bottom-up emission accounting, following the localization of emission factors [6–8], chemical source profiles [7,9,10], the spatial allocation method [6,11–13] and an emission processing system [7], a series of highly temporal and spatially resolved emission inventories for SO_2, NOx, carbon monoxide (CO), PM_{10}, $PM_{2.5}$, VOC, black carbon (BC), organic carbon (OC), ammonia (NH_3), mercury and others have been developed [6,8,10,14–18]. These inventories serve as fundamental data to understand the emission contributors from the production end and to support air quality simulations and forecasts [19–22]. In addition, ambient concentrations of multipollutants were monitored, and a top-down receptor model was applied to characterize the emission sources [23–27]. These studies laid the groundwork for emission reduction and air pollution control in Guangdong province and contributed to air quality improvement in recent years [3]. However, such efforts generally focused on production-based emissions, while the causes from the consumption perspective and the economic and social drivers remain largely unknown. Because Guangdong is an important exporting province in China, further reduction of air pollutants will require not only production-based measures but also consumption-end measures and stimulations. These measures should be built on a thorough understanding of air pollutant emissions from the consumption perspective.

Consumption-based accounting allows the tracking of emissions along production supply chains and associates the emissions with different final demands [28–33], yet the advantages and benefits of this method are not fully manifested in the understanding of air pollution causes, especially at the regional- and city-level scales. There is a wealth of literature on the consumption-based accounting of greenhouse gas emissions [34–38]. For example, Feng et al. (2013) [39] studied the carbon emissions embodied in products in Chinese cities, and Mi et al. (2016) [40] calculated the consumption-based CO_2 emissions for 13 cities in China and examined the relationship between trading patterns and carbon emissions. In terms of air pollutants, the body of literature is much thinner, and most studies are focused on the broader global or national scales. Concerning international trade, Zhang et al. (2017) [41] linked global air pollution and related mortality to the production and consumption of goods and services in different world regions, combining input-output (IO) analysis and other models. At the national scale, Huo et al. (2014) [42] examined production- and consumption-based air pollution in China and found substantial differences between the two accounting approaches. Guan et al. (2014) [43] decomposed the socioeconomic drivers of China's primary $PM_{2.5}$ emissions based on environmentally extended input-output (EEIO) analysis and found that exports was the only final demand category that drove China's emission growth between 1997 and 2010. Zhao et al. (2015) [44] assessed the air pollution embodied in interprovincial trade in China, providing a valuable understanding of how the pollutants were triggered and transferred through economic and trade activities. These studies demonstrated the advantages and effectiveness of consumption-based accounting in understanding the socioeconomic causes and impacts of air pollutions. To support bottom-up air pollution regulation and control from a local perspective, however, more regional- and city-level investigations are required. This is especially true for fast-developing regions such as Guangdong province, where the emission reduction potentials of end-of-pipe treatments and other production-end measures are becoming exhausted due to the stringent control measures in recent years [18,45].

Therefore, this study examines the air pollutant emissions in Guangdong province in 2007 and 2012 from the consumption perspective to obtain a proper understanding of the demand-driven emissions in this province and to determine how they evolved over half a decade, with the aim of supporting further air pollution controls.

2. Methods and data

In this study, consumption-based emissions driven by different final demands for seven air pollutants (SO_2, NOx, CO, PM_{10}, $PM_{2.5}$, VOC and NH_3) in Guangdong province in 2007 and 2012 were calculated and compared to the production perspective. The methods and data sources are described below.

2.1. Environmentally extended input-output model for consumption-based accounting

EEIO analysis has increasingly been used to study the drivers and causes of regional and global environmental changes associated with air pollutant emissions [41–44]. This method was used to calculate the consumption-based emissions in this study.

The methodological framework of IO is built upon the delineation of sectoral outputs with interindustry flows and final demands. The total outputs of sectors in a given economy can be defined as

$$\boldsymbol{X} = \boldsymbol{Z} + \boldsymbol{F} = \boldsymbol{AX} + \boldsymbol{F} \tag{1}$$

where $\boldsymbol{X}$ is the total output of n sectors; $\boldsymbol{Z}$ is the direct requirement matrix between sectors; $\boldsymbol{F}$ represents the matrix of final demands;