Mapping economic drivers of China's NOx emissions due to energy consumption

Shutong He[a, b, c, 1]

Liangzhen Zhao[a, b, 1]

Shihao Ding[a, b]

Sai Liang[d]

Liang Dong[e] ("e" changes to "e,f")

Junfeng Wang[a, b, *]
jfwangnk@126.com

Yinchang Feng[f] ("f" changes to "g")

Lingxuan Liu[g] ("g" changes to "h")

[a]College of Environmental Science and Engineering, Nankai University, Tianjin, 300500, China

[b]Research Center for Resource, Energy and Environmental Policy, Nankai University, Tianjin, 300500, China

[c]Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, 1081 HV, Amsterdam, the Netherlands

[d]State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, 100875, China

[e]~~Institute of Environmental Sciences (CML), Leiden University, 2300 RA, Leiden, the Netherlands~~ Department of Public Policy, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong SAR, China (The author's affiliation has been changed. Please add another affiliation of this author (Liang Dong): f School of Energy and Environment, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kong SAR, China)

[~~f~~g]State Environmental Protection Key Laboratory of Urban Ambient Air Particulate Matter Pollution Prevention and Control, College of Environmental Science and Engineering, Nankai University, Tianjin, 300071, China

[~~g~~h]Management School, Lancaster University, LA1 4YX, Bailrigg, Lancashire, United Kingdom

*Corresponding author. College of Environmental Science and Engineering, Nankai University, Tianjin, 300500, China.

[1]These authors contributed equally.

Handling Editor: Zhifu Mi

Abstract

Emissions of NOx, a precursor to several atmospheric pollutants, are a crucial aspect of air pollution in China, which is closely related to its booming economy and high energy consumption. However, few studies explore the economic structure factors on NOx emissions from energy consumption, especially the spatial heterogeneity of economic drivers. To bridge the knowledge gap, this study adopts a structural decomposition analysis (SDA) to quantify and map the contributions of six drivers of China's NOx emissions from energy consumption (NEEC) between 2007 and 2012, which represent economic scale, economic structure, and energy consumption patterns. For China as a whole, the final demand scale and energy intensity factors increased NEEC, whereas economic structure factors showed an inhibiting effect. However, the change in provincial NEEC due to the production structure and product mix of the final demand varied in a large interval. A negative production structure accompanying a positive final demand product mix led to NEEC growth in metropolises like Beijing and Shanghai. Provincial disparities were dramatic within economic regions in eastern China, including the northwest, north coast, east coast, and south coast regions. These findings indicate that spatially differentiated economic structure and economic growth diversely featured the driving mechanism on provincial NOx emissions, which should be generally considered to make the different regional reduction policies in the future.

Keywords: NOx emissions; Spatial disparity; Economic drivers; Structural decomposition analysis

Nomenclature

Abbreviations

NOx

Nitrogen oxides

NEEC

NOx emissions from energy consumption

SDA

Structural decomposition analysis

IDA

Index decomposition analysis

LMDI

Logarithmic Mean Divisia Index

FYP

Five-Year Plan

MIOTs

Monetary input-output tables

ISC

Index of sectoral contribution

Symbols

Q

The calculated NEEC

N

NOx emissions coefficients by sector

S

Energy intensity, the energy consumption per unit of the total sectoral output

X

Total output

L

Leontief inverse matrix

Y

Final demand matrix by sector

M

Final demand structure

F

Final demand composition

G

Final demand scale

1 Introduction

In recent decades, China's booming economy has resulted in severe environmental pollutant emissions, particularly of nitrogen oxides (NOx), which cause direct damage to organism health and contribute to the formation of photochemical smog, acid rain, and fine particulates, including PM2.5 and PM10 (Lin et al., 2010; Hao et al., 2002). Thus, NOx is a key element of air pollution control. Moreover, NOx inventories have shown that the source of NOx emissions in China is complicated, mainly including multiple energy-intensive industries, e.g., electricity generation, industry, and transportation (Hao et al., 2002; Ohara et al., 2007; Fu et al., 2013; Zhao et al., 2013; Zheng et al., 2009; Qi et al., 2017), and its concentration correlates with socio-economic development (Hao et al., 2002; Fu et al., 2013; Zheng et al., 2009; Qi et al., 2017; Jiang et al., 2016). Hence, understanding NOx emissions from the perspective of economic activities, as a complement to the improvement of end-of-pipe treatment, is crucial.

It has been widely verified that both emissions and concentrations of NOx are correlated with or influenced by several aspects of socio-economic development by econometric methods and index decomposition analysis (IDA). Overall, economic growth is the most crucial factor for changes of NOx emissions (Diao et al., 2016, 2018; Ding et al., 2017; Lyu et al., 2016; Wang et al., 2018; Xu et al., 2019) and concentration (He and Wang, 2012; Luo et al., 2014). Moreover, a few studies take the economic structure and industrial sectors into account, the effect of which varies spatiotemporally and has become more important in recent years (Ding et al., 2017). Luo et al. (2014) verify the quadratic relationship between NO_2 concentration and the per capita output of secondary and tertiary industry with the stationary point showed at a rather high output level. Wei et al. (2018) regress NOx emissions on variables of China's energy production and consumption and conclude that the major socio-economic sources are coal consumption, coke production, power generation, and car ownership. He and Wang (2012) include capital-abundance ratio as an indicator of economic structure in the EKC model and indicate the factor could directly affect the relationship between pollutant emissions and the income. Within this strand of literature, other main influencing factors studied include urbanization (Ge et al., 2018; Xu et al., 2019), population scale (Xu et al., 2019; Lyu et al., 2016; Wang et al., 2018), spatial structure of population (Wang et al., 2018), sectoral outputs (Wei et al., 2018), production structure (Lyu et al., 2016), degree of economic openness (He and Wang, 2012), energy efficiency (Xu et al., 2019; Ding et al., 2017; Lyu et al., 2016), and technology improvement (Ding et al., 2017).

Structural Decomposition Analysis (SDA), with higher data requirements for the input–output table, performs more advanced and detailed decomposition of the economic structure; thus, it can capture both direct and indirect effects (Hoekstra and Van den Bergh, 2003). For China as a whole, studies have been conducted to understand the driving factors of NOx emissions by SDA, with studied periods lying between 1995 and 2012 (Chen et al., 2019; Liu and Liang, 2017; Xie et al., 2018; Xu et al., 2017; Zhang et al., 2015). Three of the studies decompose the total pollutant emissions (including NOx) (Chen et al., 2019; Xie et al., 2018) or the NOx emissions multiplier (Liu and Liang, 2017) other than NOx emissions. In general, economic scale effect contributes to the emissions growth (Chen et al., 2019; Xie et al., 2018; Xu et al., 2017; Zhang et al., 2015). Factors that inhibited China's NOx emissions previously are mainly related to technical progress, including the end-of-pipe facilities (Zhang et al., 2015), phasing out of backward capacity (Zhang et al., 2015), and energy intensity (Xu et al., 2017; Xie et al., 2018). However, economic structure, as measured by the change of Leontief inverse matrix, shows varied influences during different periods and among the models (Xu et al., 2017; Zhang et al., 2015; Xie et al., 2018).

Evidence from provincial analyses demonstrates potential regional differences in the driving mechanism of NOx emissions. Unlike other studies in which economic growth was predominant to NOx emissions, a case study in Beijing concluded that the population was the main driving factor (Zhang et al., 2015). Furthermore, economic structure, both production structure effect and final demand structure effects, shows opposite influence on NOx emissions of Beijing and Sichuan (Zhang et al., 2015; Liu et al., 2018).

Compared with most developed countries, regional heterogeneity is a novel feature of China (Meng et al., 2011), typified by vast spatial disparities in physical geography and socio-economic development (Dong et al., 2015;

Dong et al., 2015; Kanada et al., 2013). Taking China as a whole may lead to overlooking the internal difference and drawing a misleading conclusion (Wei et al., 2018). Therefore, to understand the specific problem in China, it is crucial to consider these spatial disparities.

Since the 12th Five-Year Plan (FYP) (2011–2015), NOx has been included in major indicators of environmental protection by the Chinese government. In China's current top-down target system for NOx emissions reduction, the national reduction target is directly broken into provincial targets based on provincial air quality goals (The State Council of the People's Republic of China, 2011, 2016). In this context, efforts to reduce NOx emissions should be addressed at both national and provincial scales. The lack of connection between reduction targets and local economic policymaking conditions may cause a discrepancy between the two parts and result in difficulties in achieving provincial and national reduction targets. To solve this issue, the relationship between NOx emissions and economic development, as well as energy consumption, must first be comprehensively understood.

Some first attempts to understand the spatial-temporal disparities of the driving forces behind energy consumption or emissions have been conducted by so-called multi-country temporal analysis, which compares independent decompositions of each country (Ang et al., 2016). This analysis has recently been applied to study changes in energy consumption (Yu et al., 2019), CO_2 emissions (e.g. Yan et al., 2016; Liu et al., 2012a; Liu et al., 2012b) and PM2.5 (Zhang et al., 2019). For NOx emissions, regional disparity analysis of driving forces remains limited, with the few first attempts performed only by Logarithmic Mean Divisia Index (LMDI) analysis (Diao et al., 2016; Ding et al., 2017), which cannot effectively evaluate the indirect influence of production structure and demand structure changes. To the best of our knowledge, the drivers of China's NOx emissions on a provincial scale have not been adequately quantified and compared, particularly regarding economic structural factors.

This study aims to address this knowledge gap by decomposing and comparing the drivers of NOx emissions from energy consumption (NEEC) in 30 provinces in China between 2007 and 2012 by adopting the SDA model. This includes the drivers of final demand scale, production structure, product structure of the final demand, final demand composition, energy intensity, and sectoral emissions coefficients. As a result, the driving mechanisms of NEEC in eight economic regions of China are identified, which can provide a reference for future regional NOx reduction. The main contribution of this research is twofold: (i) the contribution of production structure, final demand structure, final demand scale, and energy consumption patterns to NEEC changes in 30 Chinese provinces during the economic transition period is quantified and mapped; (ii) this research is unique in introducing a three-scope analysis to understand the drivers of China's NOx emissions; i.e., national, economic–regional, and provincial analysis, which can help improve the setting of top-down NOx reduction goals in China.

2 Methods and data

2.1 Structural decomposition analysis

The input–output model has been widely used in various empirical analyses. It can fully portray the relationship between economic sectors, the technological situation, and demand patterns in the economy. Therefore, the structural decomposition method, which is based on the input–output model, has become a powerful tool for identifying how various factors in the economic system are related to each other and how they affect important policy objectives (Miller and Blair, 1985). In this study, an SDA model was constructed to incorporate national and provincial analyses of China into a consistent framework. Six drivers of NEEC changes are identified and calculated. Table 1 shows a conceptual framework of the environmental–economic input–output model. NEEC can be described and calculated as:

$$Q = NSX, \tag{1}$$

Where Q is NEEC (10^4 t); N (1 × n column) indicates the NOx emissions coefficients by sector, whose element n_j represents the NOx emissions per unit energy consumption by sector j (10^4 t/tce); and S (n × n diagonal matrix) is the energy intensity of each sector, whose diagonal element s_j represents the energy consumption per unit of the total output by sector j (tce/10^4 CNY). Under the input–output model (Miller and Blair, 1985), the total output, X, can be described as:

$$X = (I - A)^{-1} Y. \tag{2}$$

Table 1 Conceptual framework of the environmental–economic input–output model used in this research.

alt-text: Table 1

	Intermediate output	Final demand	Total outputs
Intermediate input	*AX*	*Y*	*X*
Total inputs	*X*		
NEEC	*NSX*		

The n × 1 column vector X indicates each sector's total output (10^4 CNY). The n × n matrix $(I–A)^{-1}$ is the Leontief inverse matrix, which represents the total inducement from final unit demand or total output induced by the unit final demand. The n × 1 column vector Y indicates each sector's final demand (CNY) and can be further decomposed into the following form:

$$Y = MFG, \tag{3}$$

Where the n × 3 matrix M indicates the final demand structure, and elements of m_{kj} represent the share of the final domestic product used from sector j in final demand category k, including consumption, fixed capital formation, and net outflow. The 3 × 1 column F represents the final demand composition, and element f_k represents the ratio of the final demand category k to the total final demand for domestic products. G represents the final demand scale (10^4 CNY).

Using L to represent the Leontief inverted matrix and combining the sectoral emission coefficients, N, energy intensity, and S, and by incorporating Eq. (2) into Eq. (1), the NOx emissions from energy consumption, Q (in tons), can be described by Eq. (4):

$$Q = NSLMFG. \tag{4}$$

Changes in NEEC through the years can be represented by Eq. (5):

$$\Delta Q = Q_t - Q_0 = N_1 S_1 L_1 M_1 F_1 G_1 - N_0 S_0 L_0 M_0 F_0 G_0 \tag{5}$$

The notation ΔQ indicates the change in NEEC, and the subscripts t and 0 denote the years of 2012 and 2007, respectively. Follow the technique of two polar decomposition (Dietzenbacher and Los, 1998; Zhang, 2009), ΔQ is then decomposed as shown in Table 2.

Table 2 Decomposition equation of ΔQ.

alt-text: Table 2

ΔQ	Represented by
$= (\Delta N \times S_0 \times L_0 \times M_0 \times F_0 \times G_0 + \Delta N \times S_1 \times L_1 \times M_1 \times F_1 \times G_1)/2$	ΔQ_N
$+ (N_1 \times \Delta S \times L_0 \times M_0 \times F_0 \times G_0 + N_O \times \Delta S \times L_1 \times M_1 \times F_1 \times G_1)/2$	ΔQ_S
$+ (N_1 \times S_1 \times \Delta L \times M_0 \times F_0 \times G_0 + N_O \times S_O \times \Delta L \times M_1 \times F_1 \times G_1)/2$	ΔQ_L
$+ (N_1 \times S_1 \times L_1 \times \Delta M \times F_0 \times G_0 + N_0 \times S_0 \times L_0 \times \Delta M \times F_1 \times G_1)/2$	ΔQ_M
$+ (N_1 \times S_1 \times L_1 \times M_1 \times \Delta F \times G_0 + N_0 \times S_0 \times L_0 \times M_0 \times \Delta F \times G_1)/2$	ΔQ_F
$+ (N_1 \times S_1 \times L_1 \times M_1 \times F_1 \times \Delta \mathrm{G} + N_0 \times S_0 \times L_0 \times M_0 \times F_0 \times \Delta G)/2$	ΔQ_G

Finally, the total change in NEEC can be expressed as:

$$\Delta Q = \Delta Q_N + \Delta Q_S + \Delta Q_L + \Delta Q_M + \Delta Q_F + \Delta Q_G \tag{6}$$

Based on the results obtained by Eq. (5), we can quantify the impact of different factors on NOx emissions during the study period. ΔQ_N, ΔQ_S, ΔQ_L, ΔQ_M, ΔQ_F, and ΔQ_G indicate changes in NOx emissions due to the sectoral emissions coefficients factor, energy intensity factor, production structure factor, production mix of the final demand factor, final demand composition factor, and final demand scale factor, respectively.

The six factors are categorized into three effects: the economic scale effect, the economic structure effect, and the energy consumption pattern effect (Fig. 1). The economic scale effect only contains the final demand scale factor (ΔQ_G). In the economic structure effect, the production structure (ΔQ_L), product mix of the final demand (ΔQ_M), and final demand composition (ΔQ_F) factors are considered. The energy consumption pattern effect includes the energy intensity factor (ΔQ_S) and sectoral emissions coefficients factor (ΔQ_N). Additionally, according to the production side and demand side, the production structure factor captures the flow of intermediate products in various sectors of production. The final demand scale factor, production mix of the final demand factor, and final demand composition factor capture the economic drivers of NEEC from the demand side.

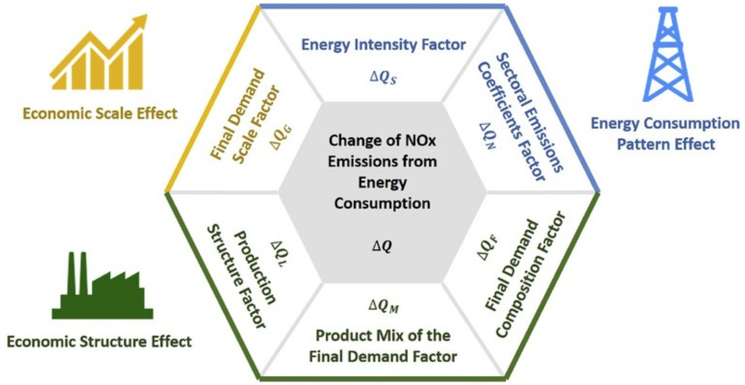


Fig. 1 Diagram of the structure decomposition model.

alt-text: Fig. 1

2.2 Data source

The monetary input-output tables (MIOTs) of the nation and 30 provinces for 2007 and 2012 were obtained from the National Bureau of Statistics of China. One mainland province, Tibet, as well as Taiwan, Hong Kong, and Macao are not included because of the lack of data. Also, due to the data availability, we rely on the 2007 and 2012 MIOTs, which have the most recent data that can be obtained. To match the sectoral energy consumption data, MIOTs with 42 sectors were consolidated into seven sectors; a summary of sector integration is shown in Table S1, Supplementary Material. Monetary data for 2007 and 2012 were converted into constant prices using the GDP index, assuming 2007 as the base year (Xu et al., 2017). The GDP index used in this study is a product of the GDP indices of 2008–2012 (PY = 100), which were obtained from the corresponding periods in the China Statistical Yearbook. The data in China's MIOTs include domestic and imported data. In order to avoid exaggerating the environmental impact, the imported goods and services in both the intermediate consumption and final consumption were separated from the MIOTs, which is consistent with the methods of previous studies (Zhang et al., 2015; Weber et al., 2008). This new IO table, with new intermediate demand matrices and final demand vectors, is termed noncompetitive MIOTs (Liu and Liang, 2017). Sectoral emissions coefficients (N in Eq. (3)) are calculated based on China's sectoral energy consumption data of 2007 and the NOx emission factors by energy type and industrial sector presented by Kato and Akimoto (1992). The energy intensity factor (S in Eq. (3)) is calculated from the energy consumption data and the total output of various sectors. The energy consumption data were collected from China Energy Statistical Yearbooks of 2008 and 2013.

3 Results

3.1 Overview of NEEC and decomposition results

Between 2007 and 2012, China's NEEC aggregated from the 30 provinces grew from 3050×10^4 t to 4296×10^4 t. An increase in NEEC was observed in all provinces except Beijing. However, the amount of NEEC and its growth varied significantly among the 30 provinces (Fig. 2). In 2007, the smallest and largest emitters were Hainan (9×10^4 t) and Shandong (314×10^4 t), respectively. In 2012, the smallest and largest emitters were Qinghai (16×10^4 t) and Shandong (411×10^4 t), revealing a larger gap between the two. Moreover, provinces with a growth rate over 80% included Xinjiang (109%), Hainan (100%), Ningxia (92%), Shaanxi (88%), and Inner Mongolia (86%). Inner Mongolia was one of the top emitters, Xinjiang and Shaanxi were moderate emitters, and Hainan and Ningxia were lesser emitters. Also, the top 10 emitters remained the same during all five years; these included Shandong, Hebei, Jiangsu, Guangdong, Henan, Inner Mongolia, Liaoning, Zhejiang, Shanxi, and Hubei, which are all eastern coastal provinces and their neighbors.

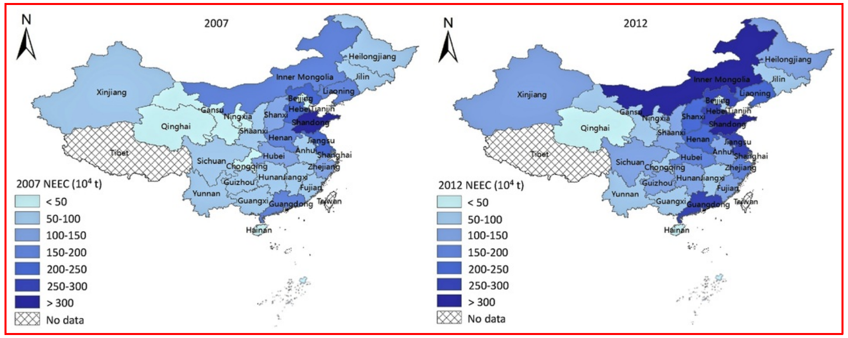


Fig. 2 Geographical distribution of China's NEEC in 2007 and 2012.

alt-text: Fig. 2

Decomposition results are shown in Table S2, Supplementary Material. From 2007 to 2012, China's NEEC increased by 30%. The main driver was the final demand scale, which led to an increase of 27% (Fig. 3). The energy consumption pattern effect, combining energy intensity and the sectoral emissions coefficients factor, was the second largest driver of NEEC increases, with a contribution of 23%. Moreover, all three components of economic structure factors partly offset NEEC growth. Holding other factors constant, the production structure factor, the product mix of the final demand factor, and final demand composition factor would lead to an NEEC decrease of 14%, 4%, and 2%, respectively.

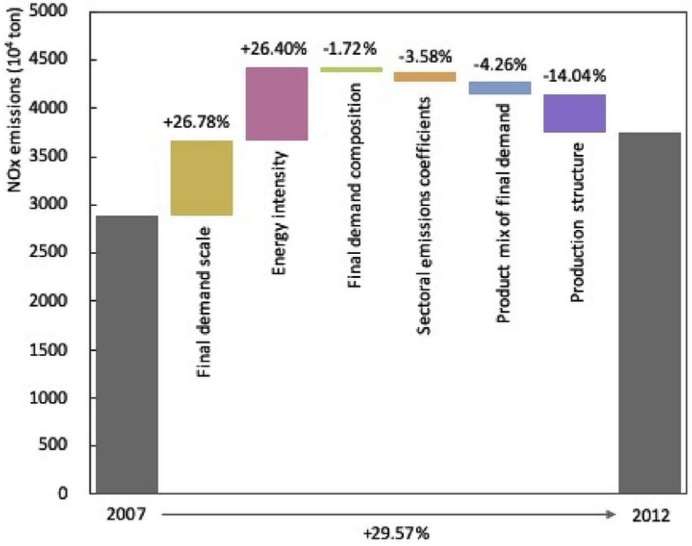


Fig. 3 Contributions of driving factors to national NEEC changes from 2007 to 2012.

alt-text: Fig. 3

Fig. 4 shows maps of the decomposition results of each province. Each map illustrates the contribution of each factor to the percentage change of provincial NEEC; i.e., the rate of NEEC change by specific factors compared to 2007. Shades of red represent a positive contribution of the factor to local NEEC increases, and shades of blue indicate a contribution to local NEEC decreases. The shades indicate the variation in the factor's contributing ability to local NEEC changes. Provinces in darker shades have higher contributions from that factor, and vice versa. At the provincial level, the final demand scale, energy intensity, and production structure factors were more prominent than the other three factors. From the perspective of geographical distribution, the final demand scale factor and energy intensity factor led to an NEEC increase in most provinces, whereas the performance of the other four factors was geographically heterogeneous, which is discussed in detail in the following subsections.

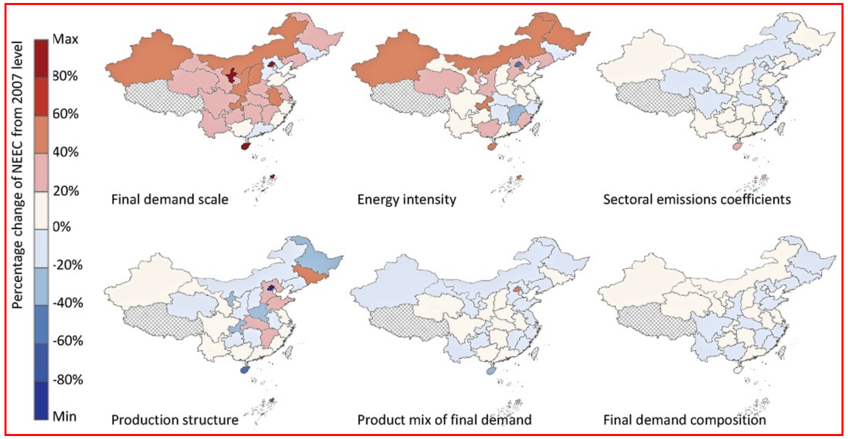


Fig. 4 Contributions of six factors to provincial NEEC changes from 2007 to 2012.

alt-text: Fig. 4

3.2 Contribution of the economic scale, economic structure, and energy consumption patterns to national and provincial NEEC changes

The economic scale effect is represented by the impact of the final demand scale on NEEC. The increase in the final demand scale is a major factor in China's NOx growth over 2007–2012, contributing to an increase in NEEC of 774×10^4 t. A similar impact of final demand has been found by Zhang et al. (2015) and Xu et al. (2017). At the provincial level, the economic scale effect promotes NEEC in most provinces (26 out of 30), except Tianjin, Hebei, Jilin, and Guangdong. However, regional disparities reveal a greater impact on NEEC in inland provinces than in coastal provinces (Fig. 4). In addition, the contribution to NEEC was significant in Ningxia, Beijing, and Hainan, which was mainly due to their low initial emissions.

The economic structure effect includes three factors: the production structure factor, the product mix of the final demand factor, and the final demand composition factor. For China as a whole, the production structure factor inhibited NEEC growth from 2007 to 2012, which is generally in line with the result of Xu et al. (2017). Sectoral changes behind this phenomenon are twofold: (1) to produce one unit of overall final demand, the requirements of three input sectors, electric and thermal power generation, agriculture, and industry, decrease; (2) the overall input requirements reduced to produce one unit of final demand of the construction sector and the sales and catering sector. According to provincial results, the inhibitory effect in Beijing (−138%) was most significant, followed by Hainan (−52%), Ningxia (−35%), Chongqing (−26%), and Shanghai (−26%). The promoting effect was most prominent in Jilin (46%), followed by Hebei (35%), Jiangxi (28%), Hubei (26%), and Shandong (25%). The production structure factor inhibited and promoted NEEC to a lesser extent in the other ten provinces.

The production structure factor represents the influence of Leontief inverse matrix changes, which reflect the efficiency and technological situation of the economy (Liang et al., 2016a,b Wang et al., 2014a, 2014b). As technology progresses, the production structure factor could lead to opposite changes. Technological improvement in one sector could conserve more input from upstream sectors (Liang et al., 2016a,b) but could also lead to product upgrades, requiring more input from other sectors (Zhang et al., 2015). Considering the comprehensive interaction between economic sectors in different economies, the reasons behind the diverse performance might be quite different (Plank et al., 2018). Taking Shanghai as an example, as one of the most industrialized cities in China, an economic transformation occurred as the economic focus shifted from industry to services. In contrast, production structure changes led to a dramatic increase of NEEC in Hebei and Shandong because the industry remains the leading economic sector during rapid development in these provinces.

The impact of product mix of final demand factor was complex and related to the product demand shift of each category of final demand (Zhang et al., 2015). This factor led to a national NEEC decrease of 4% from 2007 to 2012. In 16 provinces, this factor showed an inhibitory effect on NEEC, which varied from −25% to −2%, with an average of −10%. Geographically, five of the 16 provinces are in the north, seven are coastal provinces in the east and south, and four are southern inland provinces. The other 14 provinces are mainly in the central-inland area, where the product mix of final demand promoted NEEC, with the contribution ranging from 0.22% to 20%, except for an extremely high effect in Beijing (56%).

The final demand composition factor decreased national NEEC by 2%. Similarly, at the provincial scale, final demand composition played a less prominent role than the other two structure factors, with its contribution varying between −5% and 17%. This factor inhibited NEEC growth in 14 provinces and promoted NEEC growth in the other 16 provinces. Moreover, the geographical distribution of these two groups of provinces was more scattered than for the product mix of final demand factor (Fig. 4). The final demand composition indicates the contribution of all six components to the final demand, including the consumption expenditure of rural residents, urban residents, and the government and the investment including gross fixed capital formation, inventory, and export. As the six components relate to different types of goods and services, changing the combination could indirectly influence the NEEC through the supply chain (Zhang et al., 2015). During the study period, the share of the total final consumption expenditure decreased in 24 out of 30 provinces. In addition, the share of exports saw the most significant change, which was generally in the same direction as the final demand composition factor for the whole country as well as 26 out of 30 provinces, which may indicate the universal importance of external trade in NEEC changes in recent years.

From the perspective of the energy consumption pattern effect, the energy intensity factor represents the influence of the change in energy consumption per unit of total output. This factor increased the national NEEC by 26% during the study period. At the provincial scale, this factor inhibited provincial NEEC growth only in Beijing (−43%), Jiangxi (−27%), Hunan (−15%), Shanghai (−12%), Zhejiang (−7%), Hubei (−5%), and Jilin (−5%). In the other 23 provinces, the energy intensity factor promoted NEEC growth to different extents, from 2% to 49%. Similar results of the promoting emissions impact of the energy intensity factor have also been found in previous studies. Specifically, Shi et al. (2014) found that the energy intensity factor inhibited NOx emissions in China from 1990 to 2000; however, it increased emissions during 2000 and 2010 (Weber et al., 2008). Xu et al. (2017) reported that the energy intensity factor decreased NOx emissions from 2005 to 2010, but it has had almost zero impact from 2010 to 2012. The generally negative performance of the energy intensity factor observed in recent years could be related to the so-called rebound effect, whereby energy efficiency improvements may lead to increased consumption, offsetting the energy saving due to increased efficiency (Baiocchi and Minx, 2010).

The sectoral emissions coefficients factor is the other factor reflecting energy consumption patterns. The original NOx emissions coefficients are related to specific sectors and energy types, which are consistent among the provinces for all five years. In the SDA model we adopted, the coefficients matrix is a row vector, in which each element represents the weighted average coefficient of a specific sector. Thus, the performance of the sectoral emissions coefficients factor reflects the way an economy consumes energy. However, between 2007 and 2012, the impact of this factor was minimal, with a contribution of −4% to the national NEEC. For most provinces, contributions were between −4% and 12%, except for those of Beijing (−11%) and Hainan (24%).

4 Discussion

China is a large country with various resources, energy endowments, and economic characteristics (Meng et al., 2011), which directly influence NEEC. Additionally, spatial dependence exists in the economic development and pollutant emissions characteristics of China (Li and Hou, 2003); thus, the drivers of NEEC must be further studied within sub-regions. This study adopted the classification proposed by the Development Research Center of the State Council, which separates the 31 mainland provinces in China into eight economic regions (Fig. 5). Within each region, the provinces are geographically adjacent and share similarities in natural conditions, resource endowment, and socio-economic characteristics (Li and Hou, 2003).

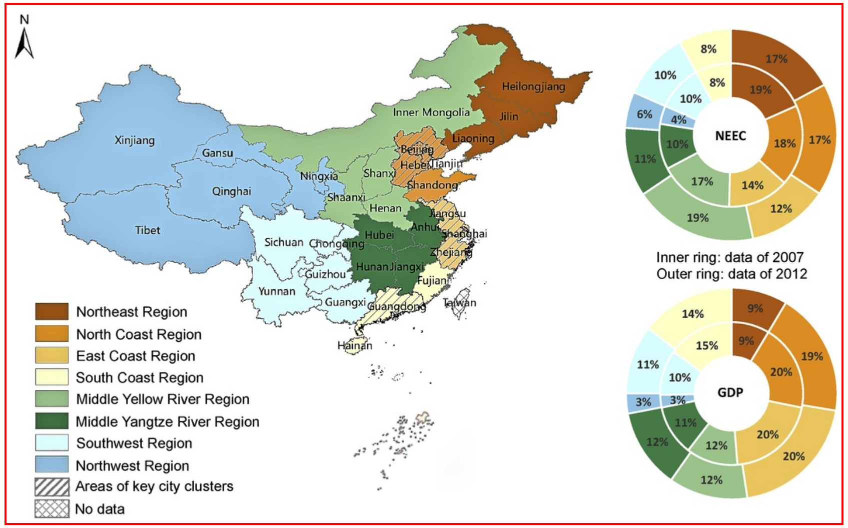


Fig. 5 Geographical distribution, the share of NEEC, and share of GDP for eight economic regions.

alt-text: Fig. 5

According to Fig. 5, inequalities appeared both in the regional distribution of NEEC and between the economic scale and NEEC in specific regions. As the upper doughnut chart in Fig. 5 shows, the NEEC contribution by each region was rather stable, with less than 2% variation. Interestingly, the three coastal regions, which emitted on average 39% of the national NEEC, contributed 54% to China's economy. The northeast region and middle Yellow River region contributed 21% to the economy and 36% of the national NEEC. The other three regions, located in middle and west China, contributed almost equally to the NEEC and GDP.

Fig. 6 shows the decomposition results of each province grouped by economic regions. Four of eight economic regions in the north and west of China belong to the G-S type, that the final demand scale and the energy intensity contributed to NEEC increase together. Overall, the impacts of these drivers were largely consistent among provinces within the middle Yellow River, southwest, and northwest regions, while Jilin performed differently than did the other two provinces in the northeast region. The major inhibitory factor to NEEC growth varied across regions. For the northeast, southwest, and northwest, the change in the product mix of the final demand featured the major inhibiting factor, whereas the production structure took the place of it in the middle Yellow River region.

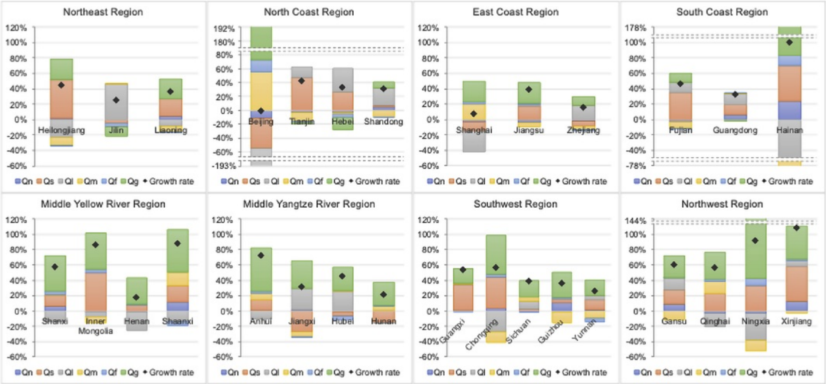


Fig. 6 Contributions of six factors to provincial NEEC changes grouped by region (Y-axis: percentage change of NEEC from 2007 level).

alt-text: Fig. 6

The exhibited driving mechanism could relate to regional feature with a relatively undeveloped economy at the base year and the growing energy-dependent industries during the studied period. Regions of this group have a relatively low combined efficiency of technology, resource, and environment (Tang et al., 2016). Specifically, the northeast region and the southwest region are the heavy industrial bases of China and the middle Yellow River region is the largest coal mining and processing area. Since 2003, a revitalization strategy was introduced in the northeast region. Due to the industrial reviving, a significant increase in both the manufacturing sector and energy consumption was observed between 2003 and 2012 (Li et al., 2016). Similarly, the great western development strategy has been initiated since 2000, in which most of the provinces of the southwest, northwest, and middle Yellow River regions are included.

The driving mechanism of NEEC in the east coast and middle Yangtze River regions is the G-other type; i.e., the final demand scale factor was dominant while other factors were variable. Specifically, in the east coast region, the driver performance in the core metropolis, Shanghai, was different from the surrounding provinces. The NEEC increase in Shanghai was predominantly promoted by the product mix of the final demand factor and inhibited by the production structure factor. However, the production structure factor showed a positive impact on NEEC growth in Zhejiang. The impacts of the production mix of the final demand factor in both Jiangsu and Zhejiang were opposite to those in Shanghai. The middle Yangtze River region includes four inland provinces with favorable natural resources for agriculture and industry (Tang et al., 2016). Production structure was the main factor driving NEEC in this region, mainly in Jiangxi and Hubei province. The possible reason behind this phenomenon is the growing intermediate input from the power sector and manufacture sector was required to provide the final demand.

The driving mechanism of NEEC growth in the north coast and south coast regions was the L-S type; i.e., the production structure factor and energy intensity factor jointly drove NEEC growth in these regions. The impact of the final demand scale was relatively low, and the factors indicating that the final demand structure were not significant. The north coast and south coast developed into China's high-tech and manufacturing centers during the studied period, while the manufacturing industry of consumer products developed rapidly in the South Coast region.

One province (or metropolis) in each of these two regions showed a different driving mechanism than the other provinces, i.e., Beijing in the North Coast region and Hainan in the South Coast region. Similarly, NEEC in Beijing and Hainan was rather small compared to that of the entire region; in 2012, the NEEC in Beijing was 39×10^4 t, representing 5% of North Coast emissions, and the NEEC in Hainan was 19×10^4 t, representing 5% of South Coast emissions. Unlike Hainan Province, where the scale of the population and economy is small, Beijing is the political and cultural center of China, much of its industrial production has moved elsewhere, and its development needs are supplied by other provinces, which could indirectly influence the industrial structure, energy consumption, and pollutant emissions in surrounding provinces.

Generally, the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta areas represent three city clusters of the greatest concern for economic development in China, which include not only three municipalities, i.e. Beijing, Tianjin, and Shanghai, but also some developed provinces, i.e. Jiangsu province, Zhejiang province, Anhui province, and Guangdong province. These areas as key areas for the prevention and control of air pollution (Ministry of Environmental Protection, 2012) used to exhibit high NOx concentrations. Here, a similar drivers' performance was observed from the central metropolises of these clusters, i.e., Beijing and Shanghai, which differed notably from their surrounding provinces. Specifically, the production structure in Beijing and Shanghai inhibited NEEC growth, whereas the product mix of final demand factors contributed significantly to emissions, in contrast to the other provinces in these two regions. We define an Index of Sectoral Contribution (ISC), indicated by the row-sum of Leontief inverse matrix (L_i), which can be interpreted as the increase in output of the ith sector to supply one-unit increase in the final demands of each sector (Jiang, 2011; Bekhet, 2010). As shown in Fig. 7, the ISC of most of the sectors reduced greatly in Beijing and Shanghai, probably due to the less dependence of domestic sectoral output. Additionally, disparity of the changes of key sectors within the economic area was more prominent in the Beijing-Tianjin-Hebei area than in the Yangtze River Delta area.

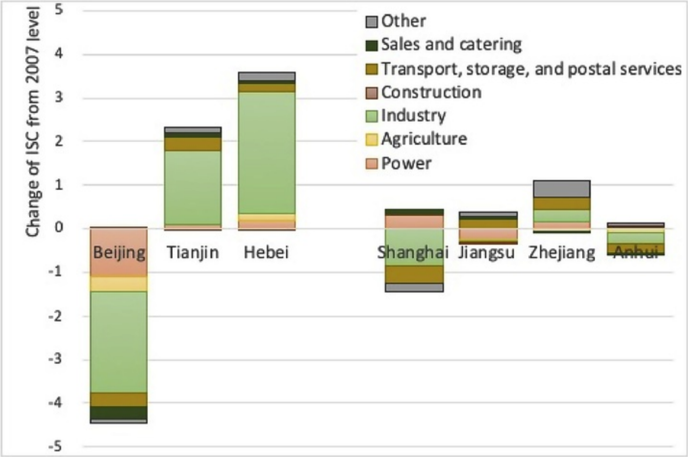


Fig. 7 Change of sectoral intermediate input for one unit of final demand.

alt-text: Fig. 7

This phenomenon could be related to the functional orientation of the development of the specific subnational region and regional cooperation in the national economic development. Taking the Beijing-Tianjin-Hebei area as an example, the major exporter of embodied NOx in this area was Hebei, exporting to both Beijing and Tianjin, and Tianjin was also an exporter to Beijing to a less extent (Wang et al., 2017). It is implied that in addition to the currently implemented national–provincial reduction targets, specific reduction targets for economic regions could be introduced in order to ensure the rational allocation of reduction obligations and improve inter-provincial cooperation towards overall NOx reductions.

5 Conclusion

The year of 2007 indicates a meaning shift process in China's economic development, at which the GDP growth rate reached its peak level. Furthermore, as China is a large national economy, economic production spatially varies among regions and provinces, as do the resulting environmental impacts. This study focused on the economic drivers of NEEC in China after 2007 using the latest available data. Compared to previous studies, the types and spatial disparities of NEEC driving mechanisms are emphasized. Based on the findings of our research, future NEEC reduction and regional cooperation in China can be better supported.

From the demand side, the impact of the final demand scale was typically dominant compared to the structural factors of final demand. The product mix of the final demand slightly influenced the NEEC in most provinces, which could have resulted from high sector aggregation (Plank et al., 2018). Interestingly, a change in the product mix of the final demand promoted NEEC growth by more than 20% in Beijing and Shanghai, the two most developed municipalities in China. This requires greater vigilance because NOx emissions could increase along with the rapid urban development and increased use of fine products. Meanwhile, further exploration and continuous tracking of the driving mechanism is needed for China's most developed metropolises.

From the production side, we confirm that the production structure was the main overall inhibiting factor to NEEC growth in China from 2007 to 2012. Regionally, the inhibiting impact only occurred in the northwest and middle Yellow River regions. Moreover, in the north coast, south coast, and middle Yangtze River regions, the production structure increased NEEC, requiring structural adjustments to economic development.

Differences in the performance of drivers among the eight economic regions are obvious, whereas provincial disparities and similarities were found within specific regions. A major driving mechanism of NEEC growth in China is the positive influence of the final demand scale accompanying the negative influence of energy intensity, which applied to the national results and most of the provinces in the northeast, middle Yellow River, northwest, and southwest regions. Considering that the economy is expected to grow steadily in the near future in China, promoting energy efficiency and optimizing economic structure could be the main path to NEEC reduction.

One major limitation of this study is the latest available IOT is of 2012, due to the long five-year term for compiling and publishing the official IOT, which is considered a common limitation in this field. With the data of 2007 and 2012, this study has shown the meaningful regional disparity of the economic drivers of NOx emissions, whereas it could not be enough to provide the concrete suggestions for real-time policies in the future. So, more studies with up-to-date dataset are needed to benefit public policy to a further extent. In addition, the estimated result of NEEC is an uncertainty. Data source of NOx emissions in previous studies includes Multi-resolution Emission Inventory for China (MEIC) developed by Tsinghua University (e.g. Lyu et al., 2016; Xu et al., 2017), national statistics on environment (e.g. Zhang et al., 2015; Ding et al., 2017), and the data estimated by emission factors (e.g. Wang et al., 2018). Due to the time mismatch of economic and emissions data as well as the scope of this study, an estimation method based on emission factors was adopted. Future study with emissions data of high spatiotemporal resolution would provide a deeper understanding of the driving mechanisms of NOx emissions.

Declarations of interest

None.

Acknowledgement

This work was supported by the Tianjin Natural Science Foundation [grant number 18JCZDJC39900], the National Natural Science Foundation of China [grant numbers 71373134], the Special Foundation to ~~b~~Build ~~u~~Universities of Tianjin [grant number C0291760], the China Scholarship Council [grant numbers 201806200003, 201809120014(Please add another grant number of this funding: 201809120014.)]~~, the Tianjin Natural Science Foundation [grant number 18JCZDJC39900]~~ and the Fundamental Research Funds for the Central Universities.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.118130.

References

Ang B.W., Su B. and Wang H., A spatial–temporal decomposition approach to performance assessment in energy and emissions, *Energy Econ.* **60**, 2016, 112–121.

Baiocchi G. and Minx J.C., Understanding changes in the UK's CO_2 emissions: a global perspective, *Environ. Sci. Technol.* **44** (4), 2010, 1177–1184.

Bekhet H.A., Ranking sectors changes of the Malaysian economy: input-output approach, *Int. Bus. Res.* **3** (1), 2010, 107.

Chen Y., Li Y. and Yan J., Tracing air pollutant emissions in China: structural decomposition and GVC accounting, *Sustainability* **11** (9), 2019, 2551.

Diao B., Zeng K., Su P., Ding L. and Liu C., Temporal-spatial distribution characteristics of provincial industrial NOx emissions and driving factors in China from 2006 to 2013, *Resour. Sci.* **38** (9), 2016, 1768–1779, (in Chinese).

Diao B., Ding L., Su P. and Cheng J., The spatial-temporal characteristics and influential factors of NOx emissions in China: a spatial econometric analysis, *Int. J. Environ. Res. Public Health* **15** (7), 2018, 1405.

Dietzenbacher E. and Los B., Structural decomposition techniques: sense and sensitivity, *Econ. Syst. Res.* **10** (4), 1998, 307–324.

Ding L., Liu C., Chen K., Huang Y. and Diao B., Atmospheric pollution reduction effect and regional predicament: an empirical analysis based on the Chinese provincial NOx emissions, *J. Environ. Manag.* **196**, 2017, 178–187.

Dong H., Dai H., Dong L., Fujita T., Geng Y., Klimont Z., Inoue T., Bunya S., Fujii M. and Masui T., Pursuing air pollutant co-benefits of CO_2 mitigation in China: a provincial leveled analysis, *Appl. Energy* **144**, 2015, 165–174.

Dong L., Dong H., Fujita T., Geng Y. and Fujii M., Cost-effectiveness analysis of China's sulfur dioxide control strategy at the regional level: regional disparity, inequity and future challenges, *J. Clean. Prod.* **90**, 2015, 345–359.

Fu X., Wang S., Zhao B., Xing J., Cheng Z., Liu H. and Hao J., Emission inventory of primary pollutants and chemical speciation in 2010 for the Yangtze River Delta region, China, *Atmos. Environ.* **70**, 2013, 39–50.

Ge X., Zhou Z., Zhou Y., Ye X. and Liu S., A spatial panel data analysis of economic growth, urbanization, and NOx emissions in China, *Int. J. Environ. Res. Public Health* **15** (4), 2018, 725.

Hao J., Tian H. and Lu Y., Emission inventories of NOx from commercial energy consumption in China, 1995-1998, *Environ. Sci. Technol.* **36** (4), 2002, 552–560.

He J. and Wang H., Economic structure, development policy and environmental quality: an empirical analysis of environmental Kuznets curves with Chinese municipal data, *Ecol. Econ.* **76** (1), 2012, 49–59.

Hoekstra R. and Van den Bergh J.C., Comparing structural decomposition analysis and index, *Energy Econ.* **25** (1), 2003, 39–64.

Jiang X., Statistical and Economic Applications of Chinese Regional Input-Output Tables, 2011, University of Groningen, SOM research school; Groningen.

Jiang J., Zhang J., Zhang Y., Zhang C. and Tian G., Estimating nitrogen oxides emissions at city scale in China with a nightlight remote sensing model, *Sci. Total Environ.* **544**, 2016, 1119–1127.

Kanada M., Dong L., Fujita T., Fujii M., Inoue T., Hirano Y., Togawa T. and Geng Y., Regional disparity and cost-effective SO_2 pollution control in China: a case study in 5 mega-cities, *Energy Policy* **61**, 2013, 1322–1331.

Kato N. and Akimoto H., Anthropogenic emissions of SO_2 and NOx in Asia: emission inventories, *Atmosp. Environ. Part A. Gen. Topics* **26** (16), 1992, 2997–3017.

Li S. and Hou Y., Analysis on regional socio-economic development characteristics of China (mainland), In: Ma H. and Wang M.K., (Eds.), *China Development Studies: Selected Research Reports of Development Research Center of the State Council (2003 Edition),* 2003, China Development Press; Beijing, 244, (In Chinese).

Li H., Lo K., Wang M., Zhang P. and Xue L., Industrial energy consumption in Northeast China under the revitalisation strategy: a decomposition and policy analysis, *Energies* **9** (7), 2016, 549.

Liang H., Dong L., Luo X., Ren J., Zhang N., Gao Z. and Dou Y., Balancing regional industrial development: analysis on regional disparity of China's industrial emissions and policy implications, *J. Clean. Prod.* **126**, 2016a, 223–235.

Liang S., Wang H., Qu S., Feng T., Guan D., Fang H. and Xu M., Socioeconomic drivers of greenhouse gas emissions in the United States, *Environ. Sci. Technol.* **50** (14), 2016b, 7535–7545.

Lin J.T., McElroy M.B. and Boersma K.F., Constraint of anthropogenic NOx emissions in China from different sectors: a new methodology using multiple satellite retrievals, *Atmos. Chem. Phys.* **10** (1), 2010, 63–78.

Liu L.J. and Liang Q.M., Changes to pollutants and carbon emission multipliers in China 2007–2012: an input-output structural decomposition analysis, *J. Environ. Manag.* **203**, 2017, 76–86.

Liu Z., Geng Y., Lindner S. and Guan D., Uncovering China's greenhouse gas emission from regional and sectoral perspectives, *Energy* **45** (1), 2012a, 1059–1068.

Liu Z., Liang S., Geng Y., Xue B., Xi F., Pan Y., Zhang T. and Fujita T., Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites: the case of Beijing, Tianjin, Shanghai and Chongqing, *Energy* **37** (1), 2012b, 245–254.

Liu L., Chen Y., Wu T. and Li H., The drivers of air pollution in the development of western China: the case of Sichuan province, *J. Clean. Prod.* **197**, 2018, 1169–1176.

Luo Y., Chen H., Peng C., Yang G., Yang Y. and Zhang Y., Relationship between air pollutants and economic development of the provincial capital cities in China during the past decade, *PLoS One* **9** (8), 2014, e104013.

Lyu W., Li Y., Guan D., Zhao H., Zhang Q. and Liu Z., Driving forces of Chinese primary air pollution emissions: an index decomposition analysis, *J. Clean. Prod.* **133**, 2016, 136–144.

Meng L., Guo J.E., Chai J. and Zhang Z., China's regional CO_2 emissions: characteristics, inter-regional transfer and emission reduction policies, *Energy Policy* **39** (10), 2011, 6136–6144.

Miller R.E. and Blair P.D., Input-output Analysis: Foundations and Extensions, 1985, Cambridge University Press.

Ministry of Environmental Protection of the People’s Republic of China, National Development and Reform Commission and Ministry of Finance People’s Republic of China, 12th Five-Year Plan for the Prevention and Control of Air Pollution in Key Areas, 2012, Ministry of Environmental Protection of the People’s Republic of China Publishing; China, (In Chinese).

Ohara T.A.H.K., Akimoto H., Kurokawa J.I., Horii N., Yamaji K., Yan X. and Hayasaka T., An Asian emission inventory of anthropogenic emission sources for the period 1980-2020, *Atmos. Chem. Phys.* **7** (16), 2007, 4419–4444.

Plank B., Eisenmenger N., Schaffartzik A. and Wiedenhofer D., International trade drives global resource use: a structural decomposition analysis of raw material consumption from 1990–2010, *Environ. Sci. Technol.* **52** (7), 2018, 4190–4198.

Qi J., Zheng B., Li M., Yu F., Chen C., Liu F., Zhou X., Yuan J., Zhang Q. and He K., A high-resolution air pollutants emission inventory in 2013 for the Beijing-Tianjin-Hebei region, China, *Atmos. Environ.* **170**, 2017, 156–168.

Shi Y., Xia Y., Lu B., Liu N., Zhang L., Li S. and Li W., Emission inventory and trends of NOx for China, 2000-2020, *J. Zhejiang Univ. - Sci.* **15** (6), 2014, 454–464, (in Chinese).

Tang K., Yang L. and Zhang J., Estimating the regional total factor efficiency and pollutants' marginal abatement costs in China: a parametric approach, *Appl. Energy* **184**, 2016, 230–240.

The State Council of the People’s Republic of China, Comprehensive Work Plan for Conserving Energy and Reducing Emissions for the Twelfth Five-Year Plan Period, 2011, The State Council of the People's Republic of China Publishing; China, (In Chinese).

The State Council of the People’s Republic of China, Comprehensive Work Plan for Conserving Energy and Reducing Emissions for the Thirteenth Five-Year Plan Period, 2016, The State Council of the People's Republic of China Publishing; China, (In Chinese).

Wang H., Small M.J. and Dzombak D.A., Factors governing change in water withdrawals for US industrial sectors from 1997 to 2002, *Environ. Sci. Technol.* **48** (6), 2014a, 3420–3429.

Wang H., Tian X., Tanikawa H., Chang M., Hashimoto S., Moriguchi Y. and Lu Z., Exploring China's materialization process with economic transition: analysis of raw material consumption and its socioeconomic drivers, *Environ. Sci. Technol.* **48** (9), 2014b, 5025–5032.

Wang J., Qiu Y., He S., Liu N., Xiao C. and Liu L., Investigating the driving forces of NOx generation from energy consumption in China, *J. Clean. Prod.* **184**, 2018, 836–846.

Wang Y., Liu H., Mao G., Zuo J. and Ma J., Inter-regional and sectoral linkage analysis of air pollution in Beijing–Tianjin–Hebei (Jing-Jin-Ji) urban agglomeration of China, *J. Clean. Prod.* **165**, 2017, 1436–1444.

Weber C.L., Peters G.P., Guan D. and Hubacek K., The contribution of Chinese exports to climate change, *Energy Policy* **36** (9), 2008, 3572–3577.

Wei Y., Gu J., Wang H., Yao T. and Wu Z., Uncovering the culprits of air pollution: evidence from China's economic sectors and regional heterogeneities, *J. Clean. Prod.* **171**, 2018, 1481–1493.

Xie R., Zhao G., Zhu B.Z. and Chevallier J., Examining the factors affecting air pollution emission growth in China, *Environ. Model. Assess.* **23** (4), 2018, 389–400.

Xu S., Zhang W., Li Q., Zhao B., Wang S. and Long R., Decomposition analysis of the factors that influence energy related air pollutant emission changes in China using the SDA method, *Sustainability* **9** (10), 2017, 1742.

Xu S.C., Miao Y.M., Gao C., Long R.Y., Chen H., Zhao B. and Wang S.X., Regional differences in impacts of economic growth and urbanization on air pollutants in China based on provincial panel estimation, *J. Clean. Prod.* **208**, 2019, 340–352.

Yan Q., Zhang Q. and Zou X., Decomposition analysis of carbon dioxide emissions in China's regional thermal electricity generation, 2000-2020, *Energy* **112**, 2016, 788–794.

Yu Y., Liang S., Zhou W., Ren H., Kharrazi A. and Zhu B., A two-tiered attribution structural decomposition analysis to reveal drivers at both sub-regional and sectoral levels: a case study of energy consumption in the Jing-Jin-Ji region, *J. Clean. Prod.* **213**, 2019, 165–175.

Zhang Y., Structural decomposition analysis of sources of decarbonizing economic development in China: 1992–2006, *Ecol. Econ.* **68** (8–9), 2009, 2399–2405.

Zhang W., Wang J., Zhang B., Bi J. and Jiang H., Can China comply with its 12th five-year plan on industrial emissions control: a structural decomposition analysis, *Environ. Sci. Technol.* **49** (8), 2015, 4816–4824.

Zhang Y., Wang H., Liang S., Xu M., Zhang Q., Zhao H. and Bi J., A dual strategy for controlling energy consumption and air pollution in China's metropolis of Beijing, *Energy* **81**, 2015, 294–303.

Zhang Y., Shuai C., Bian J., Chen X., Wu Y. and Shen L., Socioeconomic factors of PM2. 5 concentrations in 152 Chinese cities: decomposition analysis using LMDI, *J. Clean. Prod.* **218**, 2019, 96–107.

Zhao B., Wang S.X., Liu H., Xu J.Y., Fu K., Klimont Z., Hao J.M., He K.B., Cofala J. and Amann M., NOx emissions in China: historical trends and future perspectives, *Atmos. Chem. Phys.* **13** (19), 2013, 9869–9897.

Zheng J., Zhang L., Che W., Zheng Z. and Yin S., A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment, *Atmos. Environ.* **43** (32), 2009, 5112–5122.

Appendix A. Supplementary data

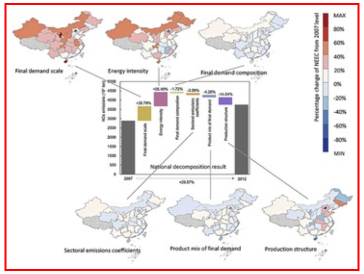
The following is the Supplementary data to this article:

Multimedia Component 1

Multimedia component 1

alt-text: Multimedia component 1

Graphical abstract



alt-text: Image 1

Queries and Answers

Query: Please confirm that the provided email “jfwangnk@126.com” is the correct address for official communication, else provide an alternate e-mail address to replace the existing one, because private e-mail addresses should not be used in articles as the address for communication.
Answer: I confirm that the provided email address is correct.

Query: Have we correctly interpreted the following funding source(s) and country names you cited in your article: China Scholarship Council, China; National Natural Science Foundation of China, China; Fundamental Research Funds for the Central Universities, China; Tianjin Natural Science Foundation, China; Special Foundation to build universities of Tianjin, China?
Answer: We make some changes in the Acknowledgement section. (1) The fundings are reordered. (2) Some initials are changed to capitals. (3) A second grant number of the China Scholarship Council is added.

Query: Please confirm that given names and surnames have been identified correctly and are presented in the desired order and please carefully verify the spelling of all authors’ names.
Answer: I confirm that the names of the authors are correct.

Query: Your article is registered as a regular item and is being processed for inclusion in a regular issue of the journal. If this is NOT correct and your article belongs to a Special Issue/Collection please contact k.kumar.1@elsevier.com immediately prior to returning your corrections.
Answer: Yes, this article belongs to a regular issue.

Query: For figure(s) 3,6,7, the resolution is too low to be used. Please provide better quality figure of 300 dpi.
Answer: High-resolution files of figures 3, 6, and 7 are attached.
Attachments: Fig 3.pdf, Fig 7.pdf, Fig 6.pdf