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Research article

# Atmospheric pollution reduction effect and regional predicament: An empirical analysis based on the Chinese provincial $NO_x$ emissions

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Atmospheric pollution emissions have become a matter of public concern in recent years. However, most of the existing researches on NOx pollution are from the natural science and technology perspective, few studies have been conducted from an economic point, and regional differences have not been given adequate attention. This paper adopts provincial panel data from 2006 to 2013 and the LMDI model to analyze the key driving factors and regional dilemmas of NOx emissions. The results show that significant regional disparities still exit on $NO_x$ emissions and its reduction effect 27 provinces didn't accomplish their corresponding reduction targets. Economic development factor is the dominating driving factor of $NO_x$ emissions during the study period, while energy efficiency and technology improvement factors offset total $NO_x$ emissions in the majority of provinces. In addition, the industrial structure factor plays a more significant role in reducing the $NO_x$ emissions after 2011. Therefore, the government should consider all these factors as well as regional heterogeneity in developing appropriate pollution mitigating policies. It's necessary to change NOx emissions control attitude from original key areas control to divided-zone control, not only attaches great importance to the reduction of the original key areas, but also emphasizes the new potential hotspots with high $NO_x$ emissions.



## 1. Introduction

Accompanying with the extensive economic development pattern of high pollution, high energy consumption and low efficiency, air pollution gradually becomes to be a critical issue to restrict China's sustainable development and ecological civilization construction (Wang et al., 2012; Chen et al., 2013). It has attracted a great attention by society and academic experts that many megacities frequently occurred in large range of serious haze pollution in recent years. How to effective control discharging of atmospheric pollutants and improve urban ambient air quality have proved to be important goals of social and economic transformation development in China (Wang et al., 2014).

Studies on $NO_x$ have been traditionally conducted from emission inventory (Ohara et al., 2007; Zhang et al., 2009), mass concentration and distribution of $NO_2$ (Hao et al., 1995–1998 Lin et al., 2010; Lamsal et al., 2013) and environmental influences. As a key pollutant of regional compound pollution in the atmosphere, $NO_x$ has a series of complicated influences on atmospheric chemical reactions in the troposphere. It could lead to adverse phenomena like photochemical smog in summer (Dimitriades, 1972; Rubio et al., 2002), the increasing of tropospheric ozone levels in urban (Volz and Kley, 1988; Melkonyan and Wagner, 2013), acid deposition (Galloway, 1995; Sickles and Shadwick, 2007; Matsumoto et al., 2011), formation of nitrate aerosol (Kim et al., 2012), and an important oxidant for sulfate formation (Cheng et al., 2016) etc. Furthermore, $NO_x$ has harmful impacts on ecological environment and human health (Weschler, 2006).

$NO_x$'s emission sources can be divided into two types: natural formation (Finney et al., 2016) and anthropogenic emissions. Anthropogenic emissions make the major contribution to the source of $NO_x$, which mainly include waste gases generating in burning of various fossil fuels and producing of explosives, dyes, nitric acid and nitrogenous fertilizer, etc. (Lee et al., 1977; Cui et al., 2013). And, it is a focus issue of academic circles and society that

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how to reduce anthropogenic emissions $NO_x$. In the previous researches, more scholars pay attention to engineering and technology in the field of $NO_x$ emissions reduction, such as the reduction of NOx emissions from biodiesel fueled engines (Agarwal et al., 2006; Palash et al., 2013; Li et al., 2016), NOx reduction in waste incinerators by selective catalytic reduction (Van Caneghem et al., 2016), decreasing NOx of two-stroke marine diesel engine (Raptotasios et al., 2015; Feng et al., 2016), etc. Although these studies help us understand the reduction of NOx emissions, they are based on a natural and technical science perspective, and lack of economic and social driving forces into account. Meanwhile, NOx emissions' regional differences had not been given appropriate attention, and few previous studies had sought to identify the antecedent factors of $NO_x$ emissions and how to solve its reduction dilemma in developing countries.

Due to the rapid growth of the economic development after 1978, China became the second largest economy in the world and experienced a rapid increase of energy consumption, which directly spurred the increase of $NO_x$ emissions (Shi et al., 2014). The growth rate of China's $NO_x$ emissions was the fastest comparing with other atmospheric pollutants (Ohara et al., 2007; Zhang et al., 2007, 2009). Therefore, urgent needs for $NO_x$ control in China have been addressed in recent studies and society (Zhao et al., 2009; Li et al., 2013). In China's 12th Five-Year Plan (2011–2015), nationwide control on $NO_x$ emissions would be implemented along with the control of $SO_2$ and other primary particles, and $NO_x$ emissions quantity first included in a binding index system. The Ministry of Environmental Protection (MEP) in China set a target to reduce the national $NO_x$ emissions in 2015 by 10% from the 2010 level (Wang et al., 2014). However, What was the effect of these measures in China's total $NO_x$ emission reduction when coming to the late Five-Year Plan period? According to the Mid-Term Assessment Report of 12th Five-Year Plan for reduction implementation by the National Development and Reform Commission (NDRC) at the end of 2013, the implementation of $NO_x$ emissions reduction was laggard, and only 2% $NO_x$ emissions reduction target were accomplished during 2011–2013. Currently, China is experiencing the most vital period of air quality management. At the beginning of the 13th Five-Year Plan, it is necessary to evaluate the effect of $NO_x$ emissions reduction over the past several years and the implementation conditions of emissions reduction among different provinces, and then to find out the main factors leading to the lag of emissions reduction, which would be significant to implement the target of $NO_x$ emissions reduction and re-clarify the shares of $NO_x$ emissions reduction quantity of different providences and areas in near future.

The main purpose of this paper are to (i) reveal the spatial distribution characteristic and key pollution control areas of provincial $NO_x$ emissions in China from 2006 to 2013; (ii) analyze and evaluate the provincial disparity of $NO_x$ emissions reduction effects combined with the National 12th Five Years Plan target. Furthermore, LMDI Model is adopted to identify the dominant driving factors on and the dilemmas of $NO_x$ emissions reduction at the analyzed areas. The results will assist the decision-makers to develop effective solutions and policies to break the regional dilemmas on atmospheric pollution reduction in the 13th Five Years Plan.

## 2. Research methods

### 2.1. Spatial distribution description

GIS technology is adept at forming a spatial database for provincial $NO_x$ emissions and identifying their current distribution characteristics, amounts, intensities, and historical (temporal) evolutions (Geng et al., 2014). It can serves as an efficient decision and policy-making tool to manage regional $NO_x$ emissions reduction. To reveal the spatial distribution characteristic of $NO_x$ emissions, a GIS-based database was established in ArcGIS 10.2 software (ESRI, Redlands, CA, USA). Then we analyzed the spatial distribution patterns and evolutions of $NO_x$ emissions based on the spatial data during 2006–2013, which seek out the hotspots with high emissions and high intensity and critical areas of reduction emissions.

### 2.2. Logarithmic mean divisa index (LMDI) approach

Decomposition analysis of pollutant emissions is a useful method to identify the key driving factors of sustainable development (Ang, 1994; Geng et al., 2011; Shao et al., 2014), energy-related greenhouse gas (Liu et al., 2012), industrial wastewater emissions (Geng et al., 2014), water footprint (Zhao and Chen, 2014) and atmospheric pollutants (mainly focused on $SO_2$) (He, 2010; Fujii et al., 2013; Liu et al., 2015), etc.

Actually, there are two typical decomposition analysis methods, namely, the index decomposition analysis (IDA) method and the structural decomposition analysis (SDA) method. IDA method uses index number concept in decomposition analysis and has advantages in temporal analysis due to its adaptability and simplicity (Liu et al., 2012), while SDA method has its advantages in analyzing detailed industrial sectoral emissions but requires the complete input-output table (Diakoulaki et al., 2006). Since it was first used by researchers to analyze industrial electricity consumption in the early 1980s, IDA has been widely adopted in energy and emission studies (Ang, 2015; Yang et al., 2016). Among various IDA approaches, the logarithmic mean divisa index (LMDI) approach has become the most popular one due to its path independency, consistency in aggregation, easily interpreted results and zero residual errors (Ang, 1994, 2004; Ang et al., 1998). In addition, LMDI approach can be applied in both a period-wise and a time series manner (Geng et al., 2014). Consequently, given these advantages, LMDI approach was selected in this study to identify the antecedent factors influencing China's $NO_x$ emissions.

Referring the previous LMDI approach (Ang, 2005; Liu et al., 2015; Geng et al., 2014), total $NO_x$ emissions can be expressed by the following Equation (1):

$$N^t = \sum_i^n N_i^t = \sum_i^n \left[ \left( \frac{N_i^t}{C_i^t} \right) \left( \frac{C_i^t}{V_i^t} \right) \left( \frac{V_i^t}{G_i^t} \right) \cdot G_i^t \right] \quad (1)$$

where $N^t$ denotes the total value of $NO_x$ emitted in year $t$ across the whole country; $N_i^t$ represents the total $NO_x$ emission value in province $i$. $C_i^t$ represents the consumption of coal in province $i$, $V_i^t$ represents the regional industrial added value, $G_i^t$ represents the gross domestic product (GDP) in province $i$. $n$ represents the total number of studied provinces ($n = 31$ in this study).

Then, four potential factors are identified as the driving forces of regional level of $NO_x$ emissions, which could be named as energy efficiency ($E$), technology improvement ($T$), industrial structure ($S$), and economic development ($G$). The formula is shown in Equation (2):

$$E_i^t = \frac{N_i^t}{C_i^t} \quad T_i^t = \frac{C_i^t}{V_i^t} \quad S_i^t = \frac{V_i^t}{G_i^t} \quad (2)$$

Substituting Equation (2) to the right of Equation (1), we obtain Equation (3) as follows:

$$N^t = \sum_i^n \left( E_i^t \cdot T_i^t \cdot S_i^t \cdot G_i^t \right) \quad (3)$$

According to LMDI approach, the change of $NO_x$ emissions between a base year $m$ and a target year $t$, denoting by $\Delta N_m^t$, can be