Advancing Emission Reduction Pathways: A Multi-Perspective Policy Analysis Based on Spatial and Social Factors

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論 文 名：Advancing Emission Reduction Pathways: A Multi-Perspective Policy Analysis Based on Spatial and Social Factors
（空間的・社会的要因に基づく多面的政策分析による排出削減経路の高度化）

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論　文　内　容　の　要　旨

Rapid economic growth and widespread energy consumption have propelled human progress but also intensified global air pollution, particularly in urban areas. As economic hubs, cities consume vast amounts of energy and rely heavily on fossil fuels across industry, transportation, and housing. This dependence has led to increased emissions of harmful pollutants, significantly degrading urban environments.

In response, governments around the world have implemented clean air policies to reduce emissions and safeguard public health. The United Kingdom led the way with the Clean Air Act of 1956, followed by countries such as Japan, the United States, Germany, and members of the European Union, each establishing their own regulatory standards. In 2013, China introduced its first national-level strategy—the Air Pollution Prevention and Control Action Plan (APPCAP)—marking a major step in its environmental policy. Collectively, these initiatives reflect a global commitment to combating air pollution and laying the groundwork for sustainable development.

In the context of China, the sources of air pollution can be categorized into six primary sectors: the integrated sector, transportation, industry, residential, agriculture, and other sectors. Among these, the industrial sector accounts for the largest share of emissions. Its primary sources—centralized, high-emission units such as coal-fired power plants—are subject to well-established policy tools and assessment systems, resulting in a substantial body of research and effective control measures.

By contrast, emissions from the transportation and residential sectors are more decentralized and behavior-driven, with significant spatial variability. These characteristics introduce considerable uncertainty and regional disparities in the effectiveness of emission control policies. As a result, these sectors have increasingly become focal points for regulatory efforts in recent years, with a notable rise in the frequency and scope of policy implementation.

This study quantitatively evaluates the effectiveness of three major emission reduction policies in China: heating regulations, residential energy use, and transportation initiatives. It aims to identify regional differences influenced by social and spatial factors, thereby enabling the development of tailored strategies for the coordinated reduction of air pollutants and carbon emissions.

To achieve this, the study employs econometric and energy economics models to assess both the impact of these policies and their optimal implementation order. By analyzing the spatial effects of each policy, the

research investigates the underlying causes of regional disparities and identifies key factors driving these differences. Using data from the China Air Quality Online Monitoring and Analysis Platform and the Multi-resolution Emission Inventory for China (MEIC), the study proposes emission reduction strategies that integrate both spatial and social dimensions.

The thesis is organized into five chapters. Chapter 1 introduces the research context, objectives, and structure of the thesis, along with the scientific rationale and theoretical framework guiding the study.

Chapter 2 evaluates the policy impacts of the autumn and winter air pollution control action plans using panel data and the regression discontinuity design (RDD) method. The analysis reveals that PM2.5 and PM10 are the primary pollutants driving the observed reduction in air pollution. Additionally, a panel threshold model estimates the critical GDP per capita value influencing the Air Quality Index, classifying the 28 cities as either “affluent” or “less affluent.” The chapter highlights the need for the government to strengthen economic and technical support for less affluent cities while maintaining the current policy framework. This approach aims to reduce regional disparities in emission reductions and enhance the overall effectiveness of pollution control efforts.

Chapter 3 investigates the role of social factors in coordinated emission reduction within China’s residential sector and proposes an optimized reduction pathway. Using the LMDI (Logarithmic Mean Divisia Index), CCD (Coupling Coordination Degree), and GTWR (Geographically and Temporally Weighted Regression) models, the study analyzes air pollutant emissions across 30 provinces from 2001 to 2020. Findings show that residential emissions are primarily driven by coal consumption, with 12 provinces accounting for over 50% of coal-related emissions. Key drivers include energy emission factors and population size. The study introduces a new regional classification to better capture local differences and recommends targeted policies such as efficient urbanization and energy optimization. Coordination is strongest in the north, while the southeast is influenced by hydropower and urbanization, the west by R&D and governance, and the northeast by industrial structure and energy use. This spatial heterogeneity underscores the importance of region-specific governance strategies. Notably, since 2015, population-driven emissions in southern cities have surpassed those in the north for the first time, due to rapid urbanization and economic growth. This shift signals the urgent need for a revised regional policy approach.

Chapter 4 examines the synergistic effects of carbon dioxide and air pollutants within China's transportation sector. It systematically explores the drivers of pollutant emissions, the roles of various contributing factors, and regional disparities. The analysis reveals that while air pollutant emissions are generally declining, carbon dioxide emissions continue to rise, particularly from off-road vehicles. This trend underscores the growing significance of off-road sources in overall emissions. The decline in emission intensity reflects improvements in vehicle management, fuel quality, and technological advancements. Among the various drivers, population growth emerges as the most significant contributor to transportation emissions, surpassing the influence of per capita GDP growth. Notably, the synergies between carbon dioxide and air pollutants increased between 2013 and 2020. Regional differences in these synergies are primarily linked to gasoline consumption patterns. In southern regions, particulate matter emissions are largely attributed to off-road and diesel vehicles, whereas in other regions, off-road vehicles account for more than 50% of total emissions.

Chapter 5 summarizes the study and its key findings. The research systematically investigates the effects, synergies, and drivers of emission reduction policy implementation across three primary domains: urban fall and winter heating, residential, and transportation. It also analyzes the spatial and social factors that influence

the effectiveness of emissions policies. The study introduced a new regional classification to capture local differences and recommends targeted policies such as efficient urbanization and energy optimization. These findings provide valuable insights for urban planners and policymakers, offering a foundation for the development and implementation of more effective emission reduction strategies.